Brady Heywood.

Technical and Organisational Investigation of the Callide Unit C4 Incident

July 2024

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Brady Heywood.

Executive Summary

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EXECUTIVE SUMMARY

Introduction

Between 1:33 pm and 2:07 pm on 25 May 2021, an incident occurred at Unit C4 of Callide C power station resulting in the catastrophic failure of the unit. There were no fatalities, but the incident destroyed Unit C4's turbine generator and destabilised the Queensland power grid.

The Brady Heywood investigation into the causes of the incident was undertaken in two parts: a technical investigation and an organisational investigation. The technical investigation examined the technical causes of the incident, and the organisational investigation examined the organisational factors related to the incident.

Technical Investigation

Unit C4 Overview

Unit C4 is a coal-fired turbine generator unit. Coal is burned in a boiler, which heats water and turns it into high pressure steam. This steam expands through a turbine and drives a rotor at 3,000 revolutions per minute (rpm). The rotor components are attached to a shaft, see Figure 1.

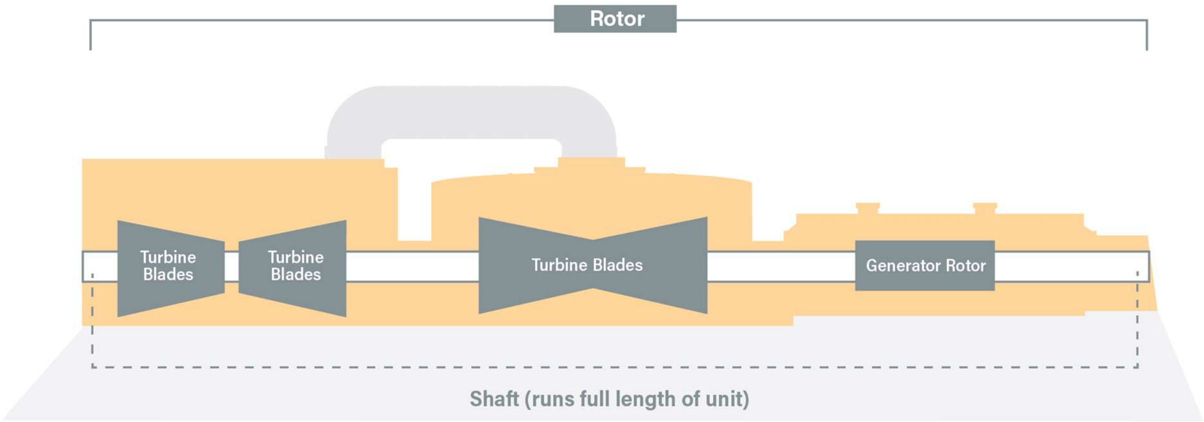

Figure 1 Shaft running through the turbine generator

As the rotor spins inside the generator, it produces electricity that is exported to Calvale substation, which forms part of the Queensland power grid.

The rotor shaft is held in position by bearings situated at eight locations along its length, as illustrated in Figure 2.

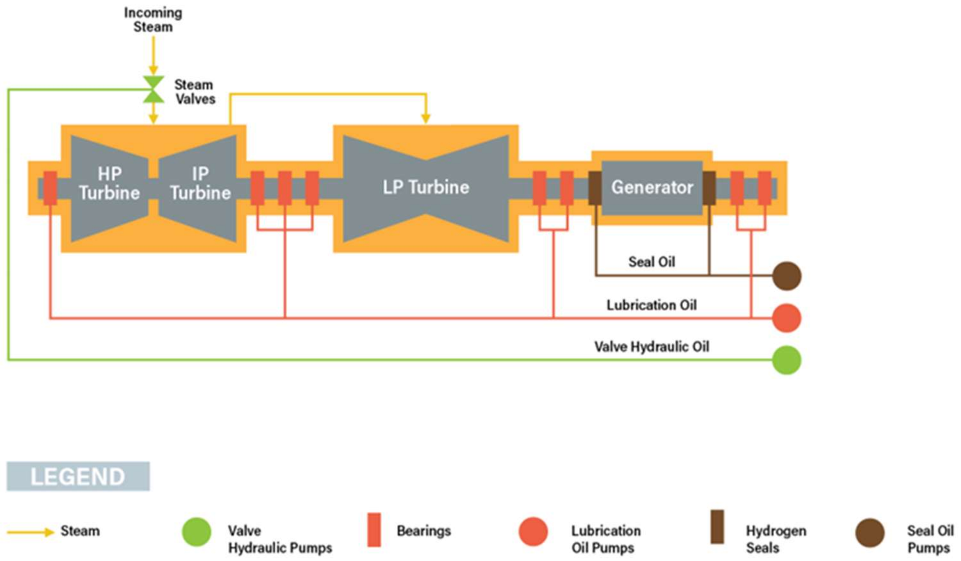

Figure 2 Unit C4 rotor shaft and the location of eight bearings

The bearings consist of cylindrical sleeves that are pumped with pressurised oil to provide a thin film of lubrication oil between the rotor shaft and bearings. This allows the rotor to spin freely without metal-on-metal contact.

Inside the generator, the rotor is cooled by pressurised hydrogen gas. To prevent hydrogen escaping, a seal is created by pumping pressurised oil into the small gap between the rotor shaft and generator casing at each end of the generator.

Unit C4 relies on two electrical systems: an AC system and a DC system. These systems provide electrical supply to the unit:

- The AC system supplies most of the equipment required for the unit to operate. This includes equipment that provides lubrication oil to the bearings, equipment that provides cooling for the unit, and equipment that opens and closes valves.
- The DC system supplies the unit's protection, control, and monitoring systems. It also supplies backup equipment, such as the emergency lubrication oil pumps. The protection, control, and monitoring systems detect and respond to faults in the unit. For example, if AC supply is lost, they can disconnect the unit from the grid and shut it down safely.

The Unit C4 DC system is supplied by a battery charger and a battery. The battery charger is the primary source of supply to the DC system, with the battery providing redundancy should the battery charger cease to operate. The battery charger receives its supply from the Unit C4 AC system.

Unit C4 DC Supply Status Prior to the Incident

In February 2021, a project was underway to replace the battery charger in Unit C4. To facilitate this replacement, the Unit C4 battery charger and battery were disconnected from the Unit C4 DC system. With these supplies disconnected, the unit received its DC supply from an alternate source, referred to in this report as the 'Station DC supply'.

Loss of DC and AC Supply to Unit C4

On 25 May 2021, the Unit C4 battery charger had been replaced and was ready to be brought into service. This involved connecting the battery charger and battery to the Unit C4 DC system using a pre-planned, formal sequence of steps called a 'switching sequence'. This switching sequence was conducted with Unit C4 online (i.e., connected to the Queensland power grid) and exporting electricity.

Prior to the switching sequence commencing:

- All DC supply to Unit C4 was being provided by the Station DC supply (the alternate supply).
- The Unit C4 battery charger and battery were yet to be connected to the unit.

During the switching sequence, the following took place:

- The replacement battery charger was first connected to the Unit C4 DC system.
- Then, in accordance with the switching sequence, the Station DC supply (the alternate supply) was disconnected from Unit C4. At this step in the switching sequence, the Unit C4 battery had not yet been connected to the unit. This was due to occur in the next step of the switching sequence.
- With no battery connected, the disconnection of the Station DC supply resulted in the Unit C4 battery charger being the sole source of DC supply to Unit C4.
- As the sole source of supply, the battery charger was required to respond instantly to maintain the voltage in the Unit C4 DC system. The battery charger, however, did not respond instantly, which caused the Unit C4 DC system voltage to collapse from ~243 V to ~120 V.
- The voltage collapse in the DC system caused one of the unit's protection systems, known as 'arc flap protection', to respond as if a fault had occurred on the unit's AC system. Despite no such fault actually occurring, the arc flap protection activated and disconnected the AC supply to Unit C4.
- With no AC supply, the Unit C4 battery charger shut down and, with no battery to provide redundancy, this resulted in a complete loss of DC supply to Unit C4 (from ~120 V to ~0 V).

The loss of AC and DC supplies to Unit C4 occurred in less than two seconds, leaving the unit without the two electrical systems it needed to operate properly, disconnect from the grid, or shut down safely.

A Failure to Restore DC and AC Supply

There is a switch on the Unit C4 DC system, known as the 'automatic changeover switch'. If DC supply is lost, this switch should operate automatically and restore supply to part of the unit. The Unit C4 automatic changeover switch had, however, been damaged in a previous incident, and it was inoperable in automatic mode on 25 May 2021. This meant DC supply to Unit C4 was not restored.

There is an emergency diesel generator in Callide C power station. If AC supply is lost, this generator should start automatically and restore supply to part of the unit. On 25 May 2021, the emergency diesel generator started, but it could not restore AC supply to Unit C4. This was because of the loss of DC supply to the unit. DC supply is needed to power the switches required to reconfigure the AC system so that it can receive supply from the emergency diesel generator. With no DC supply to the unit, the AC system could not be reconfigured, and AC supply to Unit C4 was not restored.

Motoring of Unit C4

As there was no AC supply, the turbine's steam valves closed, resulting in no steam entering the turbine to drive the rotor. As there was no DC supply, the unit's protection systems could not operate, resulting in Unit C4 remaining connected to the grid.

With no steam driving the rotor, but with Unit C4 still connected to the grid, the unit went from exporting power to the grid, to importing power from the grid. This imported power caused the rotor to continue to spin. This is called ‘motoring’.

Therefore, despite the loss of both the AC and DC systems, Unit C4’s rotor continued to spin at approximately 3,000 rpm.

Callide Control Room

In the Callide control room, the Unit C4 display screens went black because of the loss of both AC and DC supply. The operators in the control room were without access to the data they needed to assess Unit C4’s status and take informed action.

Loss of Key Systems

The key consequences of the loss of AC and DC supply were as follows:

- No seal oil being pumped to the generator hydrogen seals, which resulted in hydrogen escaping, likely causing hydrogen fires. This loss of hydrogen, in combination with the loss of other cooling systems, caused the generator to overheat.
- No lubrication oil being pumped to the bearings, which resulted in the thin film of oil between the rotor shaft and the bearings being lost. The rotor shaft and bearings began grinding metal-on-metal, which created friction and heat. This led to the bearings melting and the rotor shaft softening and deforming. The deformations caused the rotor to wobble out of its finely tuned and balanced alignment.
- No protection, control, and monitoring systems being available for the unit to operate properly, disconnect from the grid, or shut down safely, due to the loss of DC supply.

The motoring of Unit C4 continued for approximately 34 minutes and, with the loss of key systems, led to the catastrophic failure of Unit C4.

Catastrophic Failure of Unit C4

At 2:06 pm, the wobbling of the rotor likely caused part of the rotor to snag on the metal turbine casing. With the rotor still spinning at approximately 3,000 rpm, this sudden impact transferred tremendous force to the rotor shaft. This caused the rotor shaft to tear apart at nine locations.

A piece of rotor shaft weighing more than two tonnes was thrown five metres across the floor of the turbine hall. A piece of equipment weighing 300 kg, known as the ‘barring gear’, was thrown 20 metres into the air, punching through the turbine hall roof. The force from the impact also ejected remnants of coupling covers, bearings and rotor shaft sections from the turbine generator, resulting in widespread damage to the surrounding environment, including the turbine hall's wall and roof. The catastrophic failure of the turbine generator is referred to as the ‘turbine missile event’.

After the turbine missile event, the generator remained connected to the grid for approximately 40 seconds. During this time, an electrical fault developed in the generator, causing it to arc and draw high current from the grid – more than twice the unit’s rated export power. The protection systems in the Queensland power grid responded by disconnecting Calvale substation from the grid.

The disconnection of the substation also disconnected Unit C4, concluding the incident. By 2:07 pm, the turbine generator, along with other equipment, had been destroyed, and the incident had destabilised the Queensland power grid.

Technical Summary

Technical Causes of the Incident

The technical causes of the incident are summarised as follows:

(a) **Switching with Unit C4 online without battery redundancy**: The switching sequence was carried out with the unit online, and it included steps with no redundancy to the DC system. The redundancy provided by the Unit C4 battery was unavailable because it was not connected – the switching sequence did not allow its connection until the Station DC supply had been disconnected.

Thus, the switching sequence created a situation whereby when the Station DC supply was disconnected, the battery charger became the sole source of DC supply to Unit C4. The switching sequence, therefore, created the requirement that when the Station DC supply was disconnected, the Unit C4 battery charger needed to respond instantly to maintain the voltage in the Unit C4 DC system.

(b) **The Unit C4 battery charger**: The replacement Unit C4 battery charger did not respond instantly and did not maintain the voltage in the Unit C4 DC system. This caused the voltage to collapse from ~243 V to ~120 V.

The battery charger, however, had not been specified or tested for the requirements of the switching sequence being carried out at the time of the incident (i.e., to maintain the voltage in the Unit C4 DC system after the Station DC supply was disconnected), nor was it capable of doing so under the operating conditions at the time.

(c) **The loss of AC and DC**: The DC voltage collapse in Unit C4 directly led to the loss of AC supply to the unit. This occurred because Unit C4's arc flap protection responded to the DC voltage collapse as if a fault had occurred in the AC system. Despite no fault actually occurring, the arc flap protection activated and disconnected Unit C4's AC supply.

The loss of AC supply then caused the battery charger, which was the sole source of supply to the DC system, to shut down, leading to the complete loss of DC supply to Unit C4.

(d) **The Unit C4 automatic changeover switch**: The Unit C4 automatic changeover switch, which should operate and restore DC supply to parts of the unit as a backup supply in the event of a loss of DC, was inoperable in automatic mode on the day of the incident. Therefore, DC supply was not restored to Unit C4.

These causes combined to result in the incident. The switching sequence was carried out with Unit C4 online, and included steps where the only source of supply to the unit's DC system was the replacement battery charger. There was no redundancy or backup available to the DC system in the form of a battery or the automatic changeover switch. When the battery charger did not respond as required by the switching sequence, both DC and AC supply to Unit C4 were lost. The loss of these supplies, combined with the unit being online, led to it motoring for 34 minutes and resulted in its catastrophic failure.

Role of the Key Technical Causes

The catastrophic failure of Unit C4 would have been unlikely, or would have been mitigated, if any one of these technical causes had been absent:

(a) **Switching with Unit C4 online without battery redundancy**: The incident would have been avoided if the unit had been offline, with the rotor stationary. In this situation, the turbine generator would not have been damaged despite the loss of AC and DC supplies.

The incident would also have been avoided if the Unit C4 battery had been connected to the Unit C4 DC system. In this situation, the battery would have provided redundancy and removed the requirement for the battery charger, as the sole source of supply, to respond instantly to maintain the DC voltage.

(b) **The Unit C4 battery charger**: The incident would have been avoided if the replacement battery charger had maintained the voltage in the DC system.

(c) **The loss of AC and DC**: The incident would have been avoided if the AC supply had not been lost due to the DC voltage collapse.

If AC supply had not been lost, the Unit C4 battery charger would have likely responded to the collapse in DC voltage and recovered the voltage in the Unit C4 DC system.

(d) **The Unit C4 automatic changeover switch**: The incident could have been mitigated if the Unit C4 automatic changeover switch was operable and had successfully restored DC supply.

Upon restoration of DC supply, the unit's protection systems would likely have responded and disconnected the unit from the grid. While the unit would likely have sustained significant damage, the turbine missile event would likely have been avoided.

No evidence was found that mechanical or metallurgical failures were likely to have contributed to the incident.

No evidence was found that an IT systems fault or cyberattack (internal or external) were likely to have contributed to the incident.

Organisational Investigation – Control Room Response

On the day of the incident, after AC and DC supply were lost, the Unit C4 display screens in the control room went black. The control room operators were then without access to the data they needed to assess Unit C4's status and take informed actions. Throughout the incident, including when the display screens had been restored (after approximately 20 minutes), the information available to the operators from site personnel, AEMO, Powerlink and the display screens was inconclusive and contradictory.

The loss of DC supply also meant that the only way for the control room operators to disconnect Unit C4 from the grid was to request Powerlink to open a circuit breaker at Calvale substation. This would have stopped Unit C4 from motoring.

Before making this request, however, the operators needed to be certain that Unit C4 was not being driven by steam and exporting power to the grid. If Unit C4 was being driven by steam and was then disconnected from the grid, this likely would result in an 'overspeed' event and the complete destruction of the unit.

Due to the inconclusive and contradictory information available to them during the incident, the operators were unable to reach this certainty before the turbine missile event occurred.

Organisational Investigation – Direct Factors

Switching With Unit C4 Online and Without Battery Redundancy

On the day of the incident, there was no redundancy to the Unit C4 DC supply between two steps in the switching sequence. The Unit C4 DC system is typically supplied by a battery charger and a battery, with the battery providing redundancy. The redundancy provided by the Unit C4 battery was unavailable because it was not connected.

No evidence has been sighted that CS Energy understood or formally considered the risks posed by this lack of redundancy, particularly combined with carrying out the switching sequence with the unit online and exporting power. If the incident had occurred with the unit offline (i.e., with the unit shut down and rotor not spinning), the damage to the turbine generator could have been avoided.

CS Energy's processes, however, did not require any form of formal risk assessment when planning or executing switching sequences. Its processes only required consideration of the personal safety risk posed to those personnel undertaking the work, not of any risks posed to the wider plant. While formal risk assessments would not necessarily have led to avoidance of the incident, they could have increased the likelihood of identifying the risks associated with proceeding with the switching sequence with the unit online and without DC redundancy.

This lack of redundancy in the Unit C4 DC system, therefore, placed a requirement on the Unit C4 battery charger to respond instantly to maintain the Unit C4 DC system voltage when the Station DC supply was disconnected. No evidence has been sighted that CS Energy understood this requirement, considered the risk of the battery charger not performing as required, nor considered the consequences that could result from the battery charger not performing as required with the unit online.

While the design, execution and decision-making regarding the switching sequence were all in accordance with CS Energy's processes, these processes were deficient because they did not require consideration of the risks posed by the switching sequence to the wider plant.

The Battery Charger Project

The replacement Unit C4 battery charger was neither specified nor tested for the requirements of the switching sequence being carried out at the time of the incident, nor was it capable of maintaining the voltage in the Unit C4 DC system under the operating conditions at the time.

The battery charger replacement project should have followed CS Energy's management of change process, but this process was not effective nor was it effectively applied to the project.

While following an effective management of change process would not have necessarily led to the avoidance of the incident, it could have increased the likelihood of identifying the performance requirements for the battery charger. It could also have increased the likelihood of identifying the risks and consequences of the battery charger failing to perform in accordance with these requirements.

Risk of the Loss of AC and DC Systems

No evidence has been sighted to suggest CS Energy considered the risk of the loss of AC supply during the switching sequence. It is highly unlikely, however, that CS Energy could have anticipated that a DC system voltage collapse could result in arc flap protection operating and leading to the loss of AC supply to Unit C4. This is due to the highly unusual manner of the DC voltage collapse.

No evidence has been sighted that the risks and impact of the loss of DC supply were considered with respect to carrying out the switching sequence with the unit online.

The Inoperable Automatic Changeover Switch

The Unit C4 automatic changeover switch, which should operate and restore DC supply to parts of the unit in the event of a loss of DC, was inoperable in automatic mode on the day of the incident. Therefore, DC supply was not restored to Unit C4.

It is likely that CS Energy intentionally left the Unit C4 ACS inoperable after it was found to be inoperable following a previous event in January 2021.

Despite an acknowledgement by CS Energy that an inoperable automatic changeover switch was a removal of redundancy from the DC system, no evidence has been sighted of any formal risk assessments or management of change undertaken with respect to the Unit C4 automatic changeover switch being in an inoperable state.

No evidence has been sighted that indicates the inoperable state of the Unit C4 automatic changeover switch was considered in preparing for or deciding to proceed with the switching sequence with Unit C4 online, nor has any evidence been sighted that the inoperable state of the Unit C4 automatic changeover switch was widely communicated within CS Energy.

Organisational Investigation – Wider Factors

Process Safety

Within high hazard industries, there is a widely accepted and well-established approach to managing the risk of catastrophic failure known as ‘process safety’.

Process safety consists of practices that companies adopt in order to understand and control the catastrophic risks associated with their operations. From an organisational perspective, the catastrophic failure of Unit C4 should be examined through the lens of process safety.

The Brady Heywood investigation examined the following process safety aspects at CS Energy:

- CS Energy’s organisational context.
- CS Energy’s Critical Risk Program.
- The effectiveness of CS Energy’s systems, such as management of change.

Organisational Context

CS Energy has two significant structural influences: it is a government owned corporation, and it shares ownership of Callide C power station. As a government owned corporation, CS Energy is obliged to meet Shareholder Mandates, as well as meet agreed annual key performance indicators. In the years leading up to the incident, these mandates focused on cost savings, and performance indicators were dominated by financial and production metrics, as well as personal safety-related metrics. Shared ownership of Callide C power station led to increased complexity in its management, including competing asset investment priorities.

From 2015 onwards, there was a period of significant organisational reform. Multiple initiatives to improve performance were delivered across the organisation – six of which had direct impact on operations at the Callide site. This reform overlapped with a period of high turnover of Callide site management.

In this context, special effort was required to foster and maintain a focus on process safety.

The Critical Risk Program

CS Energy's Critical Risk Program was piloted in 2017, and then launched in 2018. This program aimed to develop a better understanding and management of risk across all CS Energy's sites.

The program started well, and was consistent with emerging best practice regarding process safety in the industry. But in the two years that followed, the program lost key resources and funding. By the time of the incident, the Critical Risk Program had not materially impacted the understanding or management of process safety risk on the Callide site.

Despite this, internal and external messaging presented a confident view that an effective process safety program had been established within CS Energy.

Effectiveness of CS Energy's Systems

In the years leading up to the incident, CS Energy conducted reviews into how it managed change, how it conducted maintenance work, how it responded and learned from incidents, and the effectiveness of its Permit to Work system. These are all key systems needed for the effective management of process safety.

Substantive issues were identified with each of these systems. CS Energy's agreed actions in response to these issues tended to address the symptoms and rarely addressed underlying causes.

In particular, the reviews into how CS Energy conducted management of change (i.e., its Plant Modifications Procedure) identified longstanding issues with the effectiveness of how CS Energy applied management of change. These issues are consistent with those identified in both the procurement of the battery charger and the decision-making surrounding the Unit C4 automatic changeover switch being inoperable.

Organisational Investigation – Summary

The key organisational factor related to the incident can be summarised as a failure to implement effective process safety practices.

These practices could have increased the likelihood of identifying and managing the risks associated with undertaking the switching sequence to bring the replacement battery charger into service, with no redundancy or backup to the DC system, and with the unit online.

CS Energy had substantive and longstanding issues with systems that are critical for process safety, and its project to embed process safety within the organisation lost key resources and funding, and did not materially impact the management of process safety risk.

The failure to implement effective process safety practices was not unique to the incident on 25 May 2021. Rather, it was consistent with an organisation that did not value or practise effective process safety.

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1 THE BRADY HEYWOOD INVESTIGATION

1.1 Incident

Between 1:33 pm and 2:07 pm on 25 May 2021, Unit C4 at Callide C power station suffered a catastrophic failure, hereafter referred to as the incident. There were no fatalities, but the incident destroyed the turbine and generator of Unit C4 and had a major impact on the Queensland power grid.

1.2 Engagement

On 1 June 2021, Dr Sean Brady of Brady Heywood was engaged by the law firm Norton Rose Fulbright on behalf of CS Energy Ltd, the operator of Callide C power station. This engagement was to conduct an independent investigation into the causes of the incident, hereafter referred to as the Brady Heywood investigation.

1.3 The Brady Heywood Investigation

Dr Brady assembled a multidisciplinary team to conduct the investigation in two parts: technical and organisational. He supervised the work conducted by the team, and the opinions expressed in this report are his own.

The investigation involved the collection and examination of physical evidence, testing, data analysis, interviews, and a review of CS Energy's records, systems and processes.

1.4 Report

The main body of this report is written for a non-technically trained reader. It is divided into two parts. The technical causes of the incident are discussed in Part A: Technical Investigation. The organisational factors relating to the incident are discussed in Part B: Organisational Investigation.

Further technical discussion is provided in appendices, which are intended for a technically trained reader. There are no organisational investigation appendices.

Documents are cross-referenced to the document database provided by Norton Rose Fulbright for the purpose of the Brady Heywood investigation. Names of individuals, and other personal identifiers, have been removed or redacted in the text and in the images of this report.

1.5 Animation

The Brady Heywood investigation has created an animation to aid in the understanding of this report's technical findings, but it is not intended to replace this report. A link to the animation has been provided to Norton Rose Fulbright.

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Part A: Technical Investigation

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2 OVERVIEW OF PART A: TECHNICAL INVESTIGATION

2.1 Introduction

This chapter provides a brief overview of the operation of Unit C4 and summarises the key causative and consequential technical events of the incident. It also provides an overview of the approach taken in the technical investigation, introduces the technical investigation team, and explains the layout of Part A of this report.

2.2 Overview of Operation of Unit C4

In simple terms, Unit C4 operates as follows:

- Coal is burned in a boiler, which heats water to create steam. The steam drives a turbine.
- The turbine spins a generator rotor at 3,000 revolutions per minute (rpm) to generate electricity.
- The electricity is passed through a generator transformer, which steps up the electrical voltage from 19.5 kV to 275 kV.[1]
- The electricity is then exported to Calvale substation, which is operated by Powerlink.

The operation of Unit C4 relies on two electrical systems: the Unit C4 AC (alternating current) system and the Unit C4 DC (direct current) system:

- The Unit C4 AC system supplies equipment required for the operation of the turbine and the generator (together referred to as the 'turbine generator').
- The Unit C4 DC system supplies equipment required for the monitoring, control and protection of Unit C4. It also supplies backup equipment if AC supply is lost.

The Unit C4 DC system is supplied by a battery charger and a battery. The battery charger is the primary source of supply to the DC system, with the battery providing redundancy should the battery charger cease to operate. The battery charger receives its supply from the Unit C4 AC system.

2.3 Technical Causes of the Incident

The technical causes of the incident are summarised as follows:

(a) **Switching with Unit C4 online without battery redundancy**: The switching sequence was carried out with the unit online, and it included steps with no redundancy to the DC system. The redundancy provided by the Unit C4 battery was unavailable because it was not connected – the switching sequence did not allow its connection until the Station DC supply had been disconnected.

Thus, the switching sequence created a situation whereby when the Station DC supply was disconnected, the battery charger became the sole source of DC supply to Unit C4. The switching sequence, therefore, created the requirement that when the Station DC supply was

[1] 'kV' denotes kilovolts, which equals 1,000 volts.

disconnected, the Unit C4 battery charger needed to respond instantly to maintain the voltage in the Unit C4 DC system.

(b) **The Unit C4 battery charger**: The replacement Unit C4 battery charger did not respond instantly and did not maintain the voltage in the Unit C4 DC system. This caused the voltage to collapse from ~243 V to ~120 V.

The battery charger, however, had not been specified or tested for the requirements of the switching sequence being carried out at the time of the incident (i.e., to maintain the voltage in the Unit C4 DC system after the Station DC supply was disconnected), nor was it capable of doing so under the operating conditions at the time.

(c) **The loss of AC and DC**: The DC voltage collapse in Unit C4 directly led to the loss of AC supply to the unit. This occurred because Unit C4's arc flap protection responded to the DC voltage collapse as if a fault had occurred in the AC system. Despite no fault actually occurring, the arc flap protection activated and disconnected Unit C4's AC supply.

The loss of AC supply then caused the battery charger, which was the sole source of supply to the DC system, to shut down, leading to the complete loss of DC supply to Unit C4.

(d) **The Unit C4 automatic changeover switch**: The Unit C4 automatic changeover switch, which should operate and restore DC supply to parts of the unit as a backup supply in the event of a loss of DC, was inoperable in automatic mode on the day of the incident. Therefore, DC supply was not restored to Unit C4.

These causes combined to result in the incident. The switching sequence was carried out with Unit C4 online, and included steps where the only source of supply to the unit's DC system was the replacement battery charger. There was no redundancy or backup available to the DC system in the form of a battery or the automatic changeover switch. When the battery charger did not respond as required by the switching sequence, both DC and AC supply to Unit C4 were lost. The loss of these supplies, combined with the unit being online, led to it motoring for 34 minutes and resulted in its catastrophic failure.

2.4 Role of the Key Technical Causes

The catastrophic failure of Unit C4 would have been unlikely, or would have been mitigated, if any one of these technical causes had been absent:

(a) **Switching with Unit C4 online without battery redundancy**: The incident would have been avoided if the unit had been offline, with the rotor stationary. In this situation, the turbine generator would not have been damaged despite the loss of AC and DC supplies.

The incident would also have been avoided if the Unit C4 battery had been connected to the Unit C4 DC system. In this situation, the battery would have provided redundancy and removed the requirement for the battery charger, as the sole source of supply, to respond instantly to maintain the DC voltage.

(b) **The Unit C4 battery charger**: The incident would have been avoided if the replacement battery charger had maintained the voltage in the DC system.

(c) **The loss of AC and DC**: The incident would have been avoided if the AC supply had not been lost due to the DC voltage collapse.

If AC supply had not been lost, the Unit C4 battery charger would have likely responded to the collapse in DC voltage and recovered the voltage in the Unit C4 DC system.

(d) **The Unit C4 automatic changeover switch**: The incident could have been mitigated if the Unit C4 automatic changeover switch was operable and had successfully restored DC supply.

Upon restoration of DC supply, the unit's protection systems would likely have responded and disconnected the unit from the grid. While the unit would likely have sustained significant damage, the turbine missile event would likely have been avoided.

No evidence was found that mechanical or metallurgical failures were likely to have contributed to the incident.

No evidence was found that an IT systems fault or cyberattack (internal or external) were likely to have contributed to the incident.

2.5 Approach to the Technical Investigation

The approach to the technical investigation was as follows:

- Physical evidence: A large quantity of physical evidence was collected after the destruction of the turbine generator. Components and debris of Unit C4 were strewn around the turbine hall, and some had been ejected through the roof and were located outside the building. The collection of this physical evidence continued over several months.
- Metallurgical testing: Metallurgical testing of various components was undertaken.
- Electrical testing: On-site testing of Unit C4's AC and DC systems was undertaken to determine how these systems operated on the day of the incident.
- Data analysis: Unit C4 is monitored by the integrated control and monitoring system (ICMS), which provides control and monitoring functionality for the unit.[2] Data from this system, along with data from other systems, was analysed. This data played a key role in determining the operation of the unit prior to and during the incident.[3]
- Interviews: Interviews with CS Energy personnel and others were conducted. This investigation also relied on interview transcripts and witness statements provided by Norton Rose Fulbright.
- Documentation: Considerable documentary evidence on the history and operation of Unit C4, as well as reports prepared by others, were examined.

2.6 Technical Investigation Team

The technical investigation team was primarily as follows.

[2] The term 'ICMS' has been used for consistency throughout this report. The ICMS is the term to describe the overall control and monitoring system for the whole of Callide C power station.

[3] Although multiple signals were lost during the incident, the data that was available was retrieved and analysed by the Brady Heywood investigation.

2.6.1 Sean Brady (Lead Investigator)

Dr Sean Brady CPEng, FIEAust, RPEQ is a forensic engineer, and the lead investigator of this incident. He supervised the work conducted by the team, and the opinions expressed in this report are his own.

2.6.2 Mechanical Investigation

Martin Boettcher CPEng, RPEQ, RPEV is a mechanical engineer with over 30 years experience in power stations. This includes experience at Tarong North power station.

Mr Boettcher conducted the mechanical investigation, focusing on establishing the sequence of events that led to the catastrophic failure of the turbine generator and other associated equipment.

2.6.3 Metallurgical Investigation

Dr David Tawfik CPEng has 18 years of specialist experience in engineering failure analysis, including material failures, mechanical failures, damage analysis, metallurgy and corrosion across various sectors.

Dr Tawfik conducted the metallurgical investigation. He observed and supervised the recovery and dismantling phase of the failed turbine generator, ensuring this process was performed in a forensically sound manner for the identification, collection and preservation of the relevant evidence. He also performed inspections on components and debris recovered from the incident, and planned and supervised the metallurgical investigation and mechanical testing programs undertaken by third-party laboratories.

2.6.4 Electrical Investigation

Fiona Wingate BSc Eng, CEng, MIET is a chartered electrical engineer. She has over 25 years experience with an emphasis on electrical power and high-voltage power generation. She has led teams investigating control system and generation failures. She has experience in the specification, installation, commissioning and recommissioning of generators and turbines.

Ms Wingate conducted the electrical investigation. She investigated the loss of the Unit C4 AC system and Unit C4 DC system and conducted tests on site. Ms Wingate was assisted in her investigation by Alan Kinson and Dr Friedhelm Bonn in relation to the generator and generator transformer, respectively.

2.6.5 Battery Charger Investigation

Daniel Jessen BEng Mechatronics Engineering specialises in electronics design and product development. He has over 20 years experience in electronics design and practical trade experience. He has led teams and carried out design and development work on a range of power converters, including inverters and battery chargers.

Mr Jessen conducted the Unit C4 battery charger investigation and conducted on-site tests on the Callide C battery chargers and the AC and DC systems.

2.6.6 Cybersecurity Investigation

Chris Watson is a cybersecurity expert, specialising in forensic investigations. He was a Detective in the Computer Forensic Investigations Team with the London Police Force prior to working in private practice. He brings over 30 years experience in forensic investigations, cybersecurity and financial crime.

Mr Watson conducted the investigation of CS Energy's cybersecurity systems and processes.

2.7 Layout of Part A: Technical Investigation

Part A is written for the non-technically trained reader.[4] Technical terms and jargon have been avoided, and many aspects of the incident have been simplified by only focusing on equipment and events that relate directly to the incident.

Chapter 3 presents an overview of Unit C4, and Chapter 4 provides a summary of the incident. Chapters 5 to 7 explain how the Callide C electrical systems work, how the switching sequence initiated the incident, and discusses the loss of, and failure to restore, AC and DC supply to Unit C4. Chapters 8 and 9 discuss in more detail how the loss of AC and DC supply occurred. Chapter 10 provides the technical investigation conclusions.

Technical Investigation Appendices A1–A7 provide further detail on the technical investigation process, the incident and its causes, and the evidence that supports the opinions in Part A of this report. These appendices are intended for the technically trained reader.

[4] Footnotes have, however, been included to provide further technical information for the technically trained reader.

3 INTRODUCTION TO UNIT C4

3.1 Introduction

This chapter introduces the operation and key equipment of Unit C4 at Callide C power station, primarily focusing on the components that played a role in the incident on 25 May 2021.[5]

3.2 Overview of Unit C4 at Callide C Power Station

Callide C and Callide B power stations are located near Biloela, Queensland, Australia.[6] Callide C power station is comprised of two units: Unit C4 and Unit C3. Callide B power station also has two units: Unit B2 and Unit B1.

Each of the four units has its own turbine generator, which are located in a single building referred to as the 'turbine hall'. Figure 3 shows the arrangement of the four units.[7]

Figure 3 Site layout of Callide C and B power stations showing position of turbine generators

The incident resulted in the catastrophic failure of Unit C4. The other units on the site played no significant role in the incident and are discussed only where relevant.

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[5] This chapter, and Chapter 4 *Summary of the Incident*, present a set of simplified illustrations to assist the non-technically trained reader in understanding the key components of Unit C4 and the role these components played in the incident. These illustrations should not be considered an accurate representation of the unit.

[6] While the term 'Callide power station' is often used to describe the site, the site is comprised of two power stations: Callide B and Callide C. In this report, the site is referred to as 'Callide'.

[7] Photograph sourced from: Google (2024) *CNES/Airbus*. https://intelligence.airbus.com/imagery

3.3 Overall Operation of Unit C4

Unit C4 is a coal-fired power generator.[8] Coal is burned in a boiler, which heats water and turns it into high pressure steam. This steam expands through a turbine and applies force to blades that drive the rotor at 3,000 revolutions per minute (rpm). The expanded steam is then condensed into water (in the condenser) and returned to the boiler for the cycle to repeat.

Inside the generator, the spinning of the rotor at 3,000 rpm converts rotational energy into electrical energy. This electricity is exported to Calvale substation, which forms part of the Queensland power grid. Figure 4 illustrates the general arrangement of the Unit C4 turbine generator.

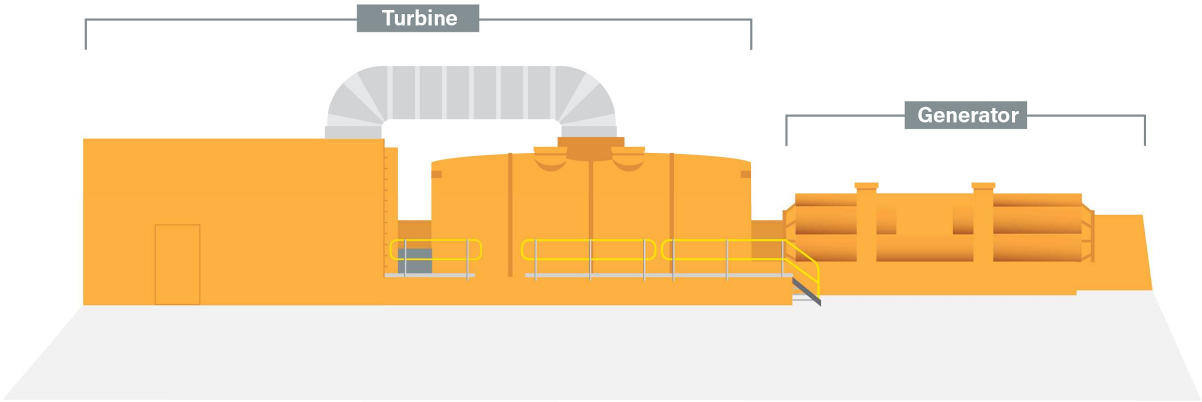

Figure 4 Unit C4 – general arrangement of the turbine generator

The turbine generator contains a rotor, which is comprised of several component rotors bolted together, as depicted in Figure 5.[9]

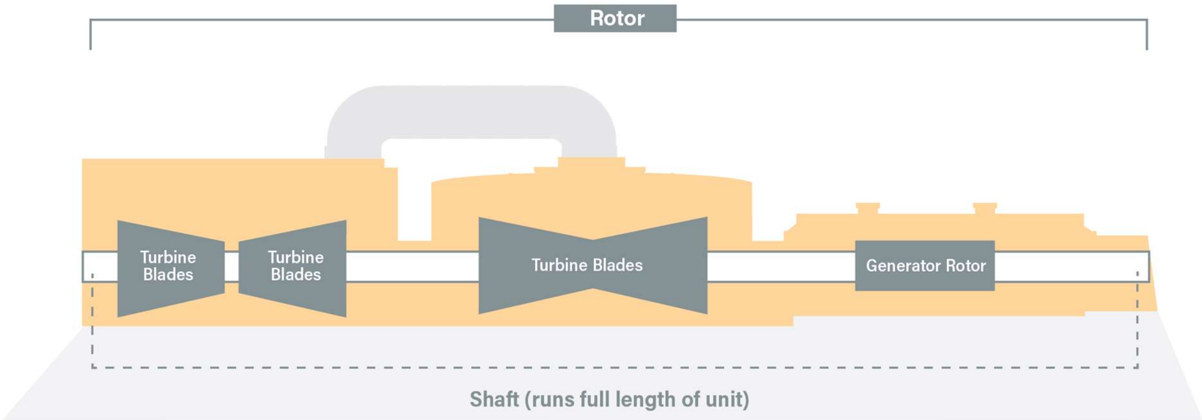

Figure 5 Rotor running through the turbine generator

[8] Unit C4 is a black coal-fired unit of supercritical pressure and single reheat design, with a capacity of 424 MW.

[9] The shaft is coupled in the following locations: between the turbine stub shaft and the HIP shaft, between the HIP shaft and the LP shafts, between the LP shaft and the generator shafts, and between the generator shaft and the generator stub shaft. The couplings of the rotors have been omitted from this diagram for simplicity.

The turbine blades and generator rotor components are attached to a central 'shaft'. As discussed below, the shaft is held in place inside the turbine generator by bearings. The entire assembly is referred to as a 'rotor'.

3.4 Mechanical Overview

3.4.1 Turbine

The 'turbine' is made up of three turbines: the high pressure (HP) turbine, the intermediate pressure (IP) turbine, and the low pressure (LP) turbine. The HP and IP turbines are located inside a common casing and are referred to as the 'HIP turbine'. The arrangement of the turbines is shown in Figure 6.

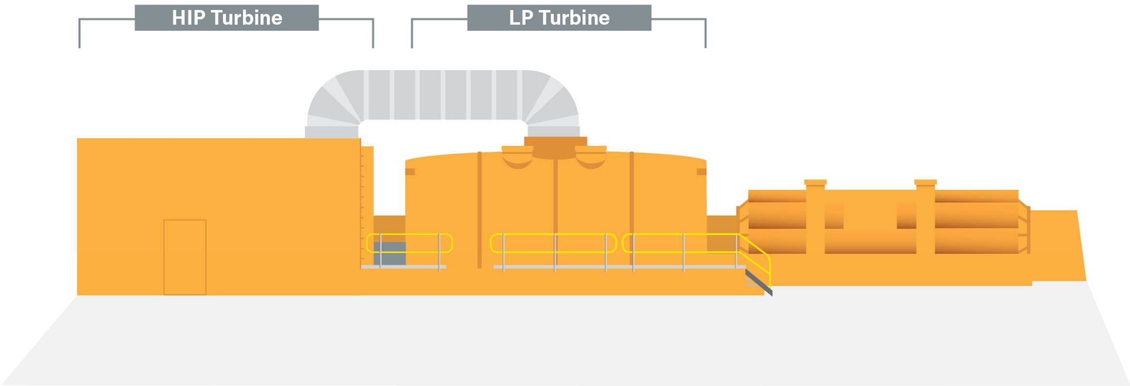

Figure 6 Arrangement of the turbines

Steam from the boiler flows through the HP turbine, then returns to the boiler for reheating. It then flows through the IP turbine and into the LP turbine. Each turbine is comprised of a series of blades that run along the rotor. The steam applies force to these blades, spinning the rotor at 3,000 rpm. The three turbines are shown schematically in Figure 7.

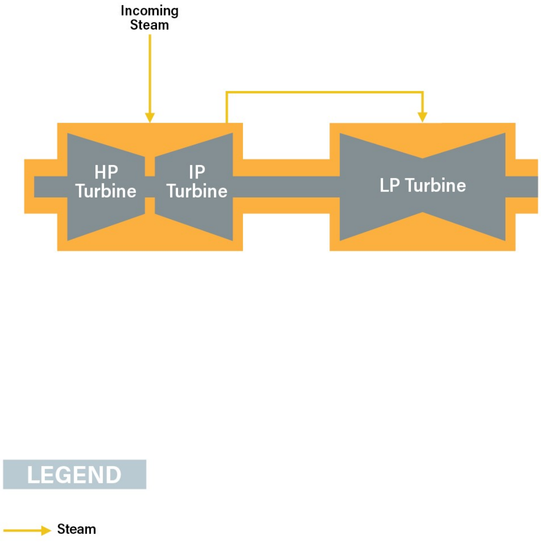

Figure 7 HP, IP and LP turbines

3.4.2 Steam Valves

Steam from the boiler enters the turbine via the isolation steam valves and control steam valves, which are collectively referred to as 'steam valves' in this report. The steam valves are operated by a hydraulic oil system.[10] The steam valves and valve hydraulics system are illustrated in green in Figure 8.

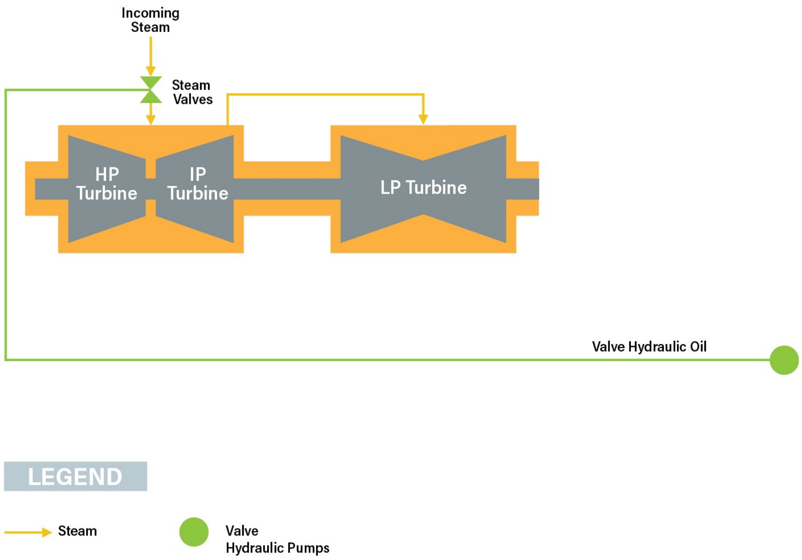

Figure 8 Steam valves and valve hydraulics

These valves are of a fail-safe design, meaning that hydraulic oil pressure is required to keep them open. In the event of a loss of hydraulic oil supply, large mechanical springs force the valves closed, which immediately shuts off the flow of steam to the turbines.

3.4.3 Generator

The generator is comprised of a rotor and a stator, as illustrated in Figure 9.

[10] While this report uses the term 'steam valves' and illustrates a single steam supply, the physical arrangement is more complex. Steam to the HP turbine goes through the main stop valves (MSVs) and turbine control valves (TCVs). The exhaust of the HP turbine goes back to the boiler and gets reheated. It returns to the IP turbine via the reheat stop valves (RSVs) and intercept control valves (ICVs).

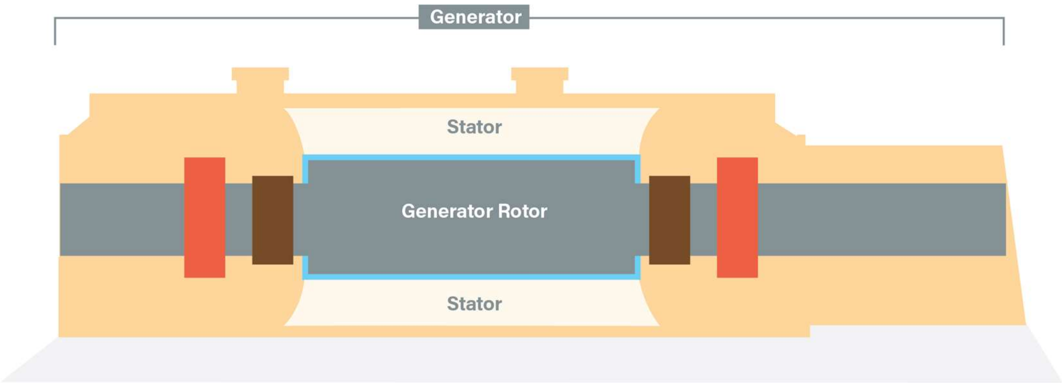

Figure 9 Generator rotor and stator

As their names suggest, the generator rotor rotates, while the stator remains stationary.[11] The rotation of the generator rotor inside the stator, driven by the turbine, generates electricity.[12]

When operating, the generator also produces heat, which is removed by two cooling systems. The generator stator is cooled by water, and the generator rotor is cooled using pressurised hydrogen gas, as illustrated by the blue line in Figure 9.[13]

3.4.4 Bearings

Bearings hold the shaft in place at eight locations along its length, as indicated in red in Figure 10.[14]

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[11] The generator rotor consists of the following components: a central shaft (single forging), slip rings and connections, the rotor electrical coils and their insulation, the cooling fans, the coil retaining rings, and balance weights.

[12] In simple terms, an electric current is passed through the rotor winding coils, which creates a magnetic field around the rotor. The movement of this magnetic field (due to the turbine spinning the generator rotor) results in an electric current flowing through the conductors of the stator. In other words, the generator operates on the principle that moving a conductor in a magnetic field generates electricity in the conductor. In this case, however, it is the magnetic field that is moving (due to the generator rotor spinning) and the conductor (the stator) that is remaining still.

[13] The stationary part of the generator is cooled by ultra-pure water, called 'stator coolant', which is pumped through hollow stator conductor bars to absorb and remove heat. The hydrogen gas is cooled in the hydrogen coolers using treated cooling water. The treated cooling water (that flows in a closed circuit) is cooled by the auxiliary cooling water system, which rejects its heat in the cooling towers. The main cooling water circuit is separate to, but uses the same cooling towers as, the auxiliary cooling water system.

[14] There are seven radial bearings along the shaft, and one thrust bearing located between the HIP and LP turbines.

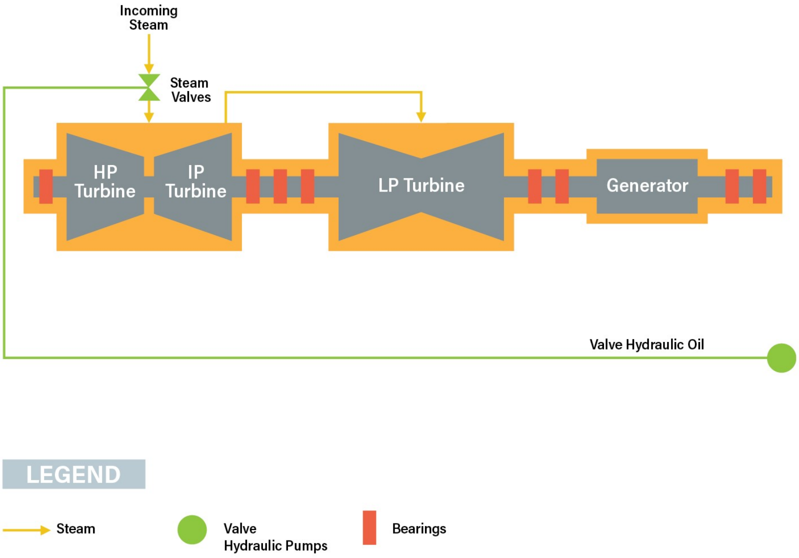

Figure 10 Bearing locations

The bearings are made of steel and are lined with a soft white metal lining.[15] Each bearing is made up of two semicircular 'collars', which form a ring around the shaft to hold it in place. An exploded view of the shaft and a bearing is illustrated in Figure 11.

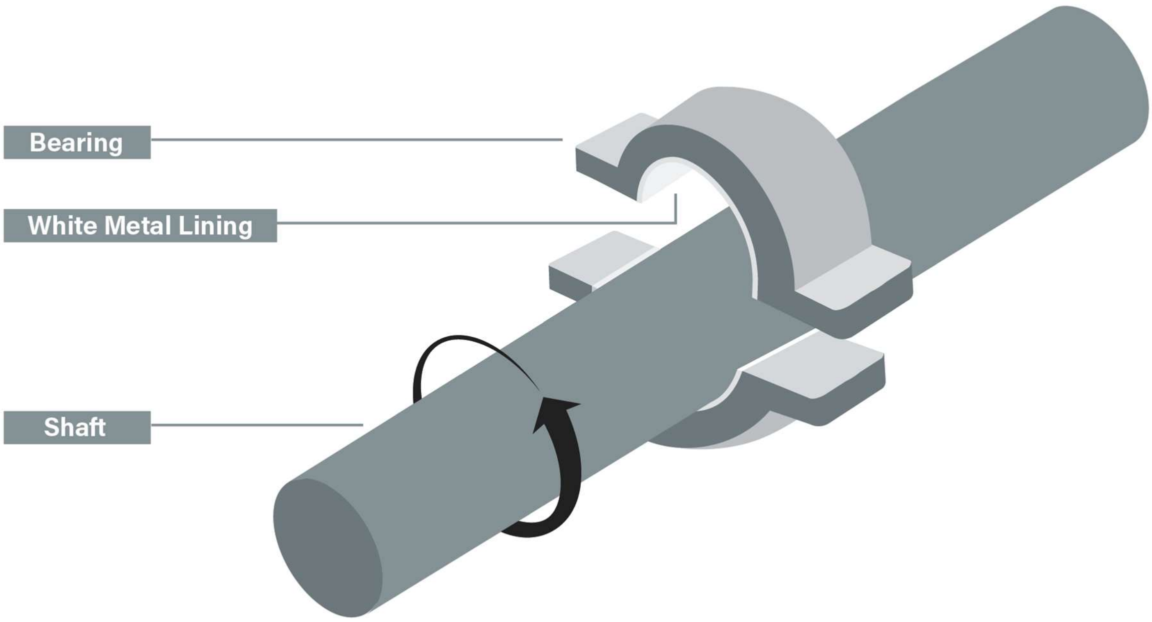

Figure 11 Illustration of shaft and bearing

[15] The white metal lining is a soft metal layer on the inside of the bearing. If the bearing loses lubrication oil, this layer will wear first, minimising damage to the rotor, which is made from 'harder' steel.

Lubrication oil is pumped into the gap between the shaft and the bearings to form a thin film of oil. The shaft spins on this thin film of oil, ensuring no metal-on-metal contact.[16] Figure 12 illustrates the lubrication oil pumps, with the lubrication oil supply shown in red.[17]

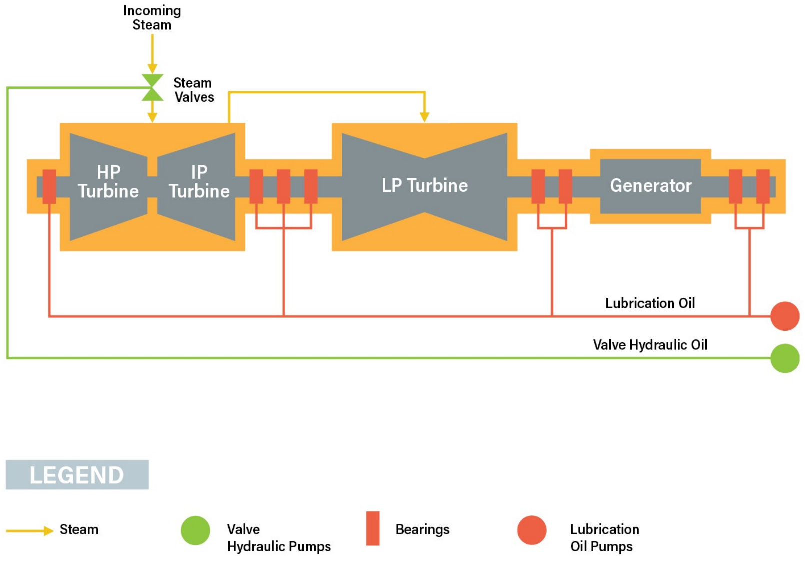

Figure 12 Bearings and lubrication oil pumps

A loss of lubrication oil pressure (e.g., due to the loss of the lubrication oil pumps) will result in the shaft directly touching the bearings. This can result in physical damage to the shaft and the bearings, and can generate significant heat.

3.4.5 Generator Seal Oil

Pressurised hydrogen gas is contained inside the generator to keep the rotor cool as it spins.[18] To ensure hydrogen does not escape, a seal is created by pumping pressurised oil into the small gap between the shaft and generator casing at each end of the generator.[19] This oil is referred to as 'seal oil', and its pressure is maintained by a seal oil pump, as shown in Figure 13.[20]

[16] The lubrication oil also removes heat generated from the rotation of the shaft. Heat is removed from the lubrication oil system in the lubrication oil coolers, with the heat taken away by the auxiliary cooling water system.

[17] The unit has two AC lubrication oil pumps and one emergency DC lubrication oil pump.

[18] The hydrogen transfers the heat to the treated cooling water system in the hydrogen coolers. It also assists in the removal of heat from the stator.

[19] Where the shaft enters the generator, tight clearances are maintained between the shaft and generator casing. The tight clearances in combination with the oil creates the oil seal.

[20] Unit C4 has one AC seal oil pump, one emergency DC seal oil pump and a small AC recirculating pump.

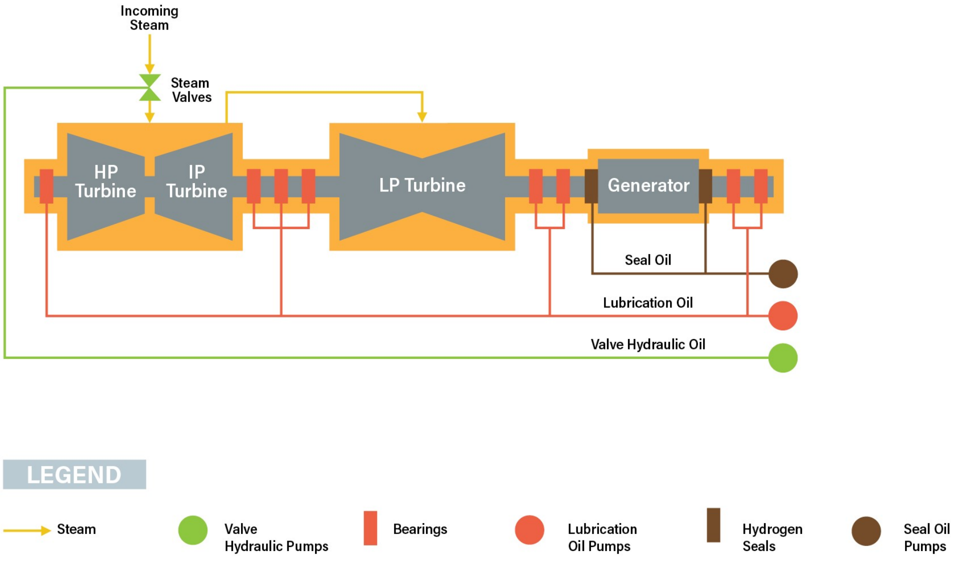

Figure 13 Generator hydrogen seals and seal oil pumps

3.4.6 Generator Circuit Breaker

Electricity generated by the generator is exported to the Queensland power grid, via a switch called the generator circuit breaker, as illustrated in Figure 14.

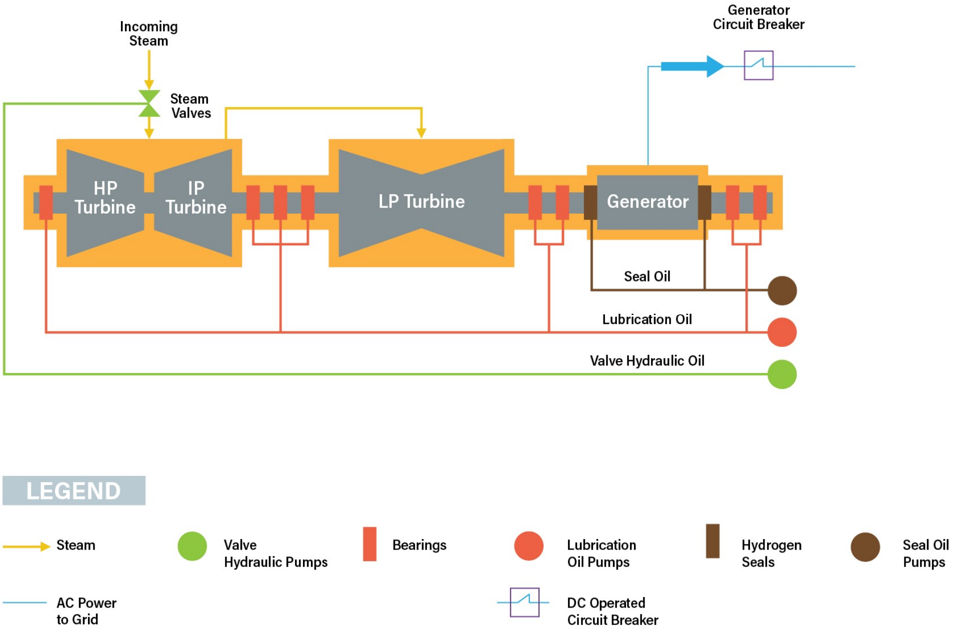

Figure 14 Generator circuit breaker

The generator circuit breaker both connects and disconnects Unit C4 from the grid. It is a critical safety device because disconnecting from the grid is a key requirement when shutting down a unit safely.[21]

[21] At Calvale substation there are also transmission system circuit breakers. Unit C4 does not have a generator transformer HV circuit breaker.

The generator circuit breaker is located in the turbine hall, one level below the turbine generator.

3.4.7 Generator Transformer

Generated electricity then passes through the generator transformer, as illustrated in Figure 15.

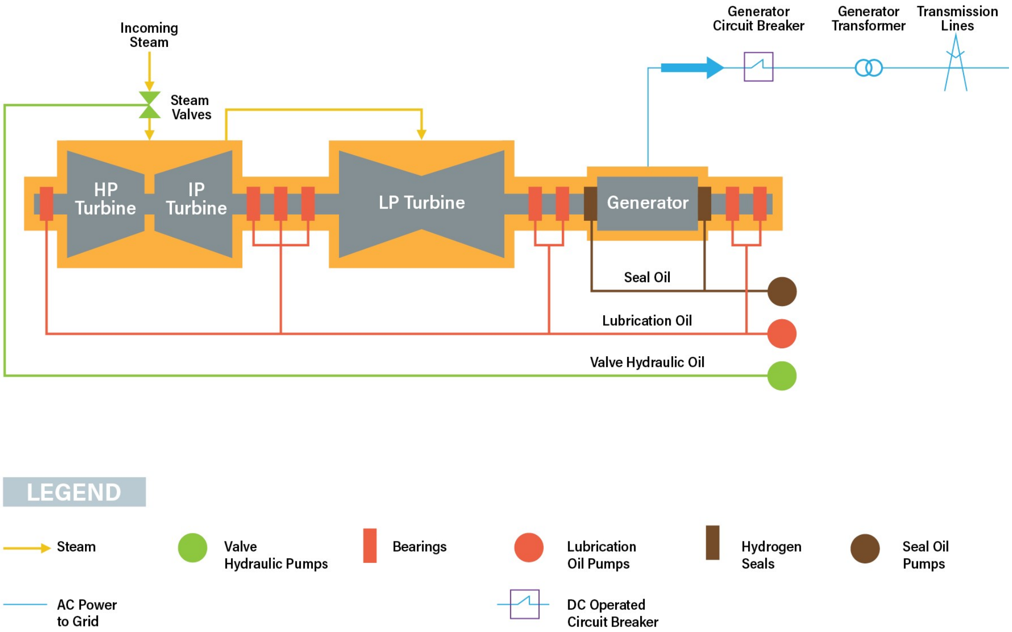

Figure 15 Generator transformer

The role of the generator transformer is to convert the generated electricity from 19.5 kV to the transmission grid voltage of 275 kV. During operation, the generator transformer produces heat, which is removed by its own cooling system.

3.4.8 Calvale Substation

The electricity generated from Unit C4 is exported to Calvale substation, as depicted in Figure 16.

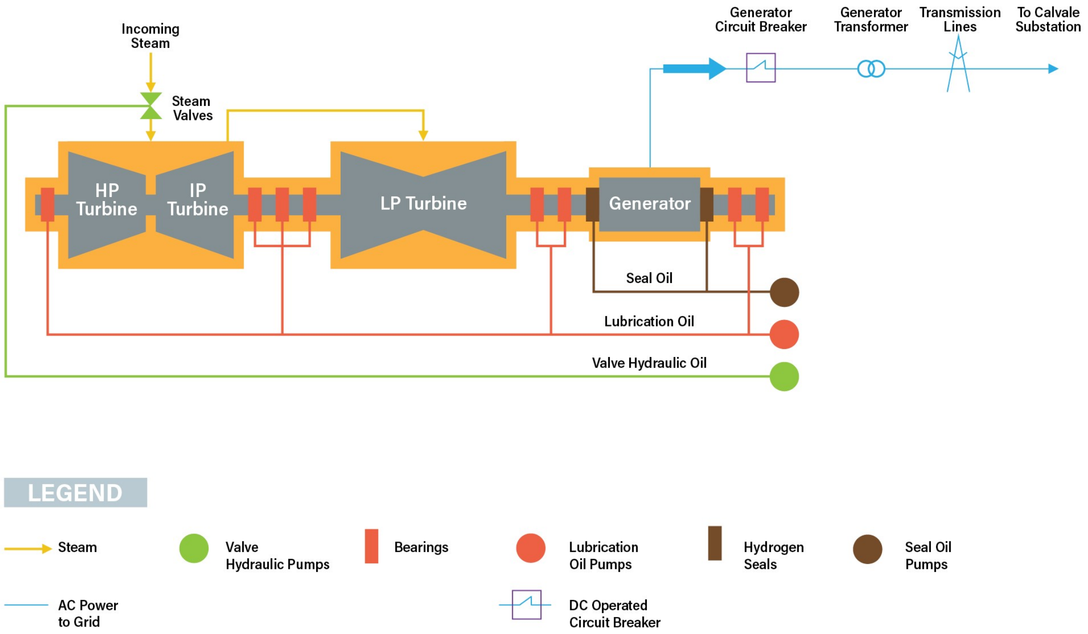

Figure 16 Calvale substation

Calvale substation is operated by Powerlink, and it forms part of the Queensland power grid.

3.5 Electrical Overview

3.5.1 Callide C Electrical System

The Callide C electrical system supplies equipment at Callide C power station. It is comprised of two electrical systems: the Callide C AC system and the Callide C DC system. They are separate systems, but have some interdependencies.

The two electrical systems perform different roles within Callide C power station:

- The Callide C AC system connects to the grid and, in simple terms, supplies the equipment necessary for the Unit C3 and Unit C4 turbine generators to generate electricity.[22]
- The Callide C DC system is supplied from battery chargers and batteries, which work together to supply a range of control, monitoring, and protection systems, as well as emergency backup systems. These systems are critical for the safe operation of Unit C3 and Unit C4, and they can be thought of as the 'brain and life support' of the units.

3.5.2 Callide C AC System

The Callide C AC system is divided into three subsystems:

- Unit C3 AC system, which supplies the AC equipment associated with Unit C3.

[22] In typical operating conditions, the unit generators and the AC system are connected to the grid, and the AC system receives its AC supply from the unit generator. If a unit generator is disconnected from the grid, its AC system receives supply directly from the grid.

- Unit C4 AC system, which supplies the AC equipment associated with Unit C4.
- Station AC system, which supplies AC equipment common to both Unit C3 and Unit C4.

3.5.3 Callide C DC System

The Callide C DC system is also divided into three subsystems:

- Unit C3 DC system, which supplies the DC equipment associated with Unit C3.
- Unit C4 DC system, which supplies the DC equipment associated with Unit C4.
- Station DC system, which supplies DC equipment associated with Station, and can also provide backup DC supply to parts of Unit C3 and Unit C4.

3.5.4 Configurability in the AC and DC Systems

Each of these three AC systems and DC systems can be configured to suit the operational needs of Callide C power station.

This configurability affords a high level of robustness within the Callide C electrical system. For example, if scheduled maintenance is being performed on equipment in the Unit C4 DC system, supply to other equipment can be routed from the Station DC system.

Changes to the configuration of the Callide C electrical system is carried out in accordance with a formal, pre-planned sequence of steps, referred to as a 'switching sequence'.

3.5.5 Unit C4 AC System

The Unit C4 AC system supplies most of the equipment necessary for Unit C4 to generate electricity.[23] It also supplies the steam valve hydraulics, the main lubrication oil pumps and the main seal oil pump, see Figure 17.[24]

[23] This includes large equipment such as fans, mills and conveyors.

[24] There are multiple transformers in the AC system, which are omitted from this diagram.

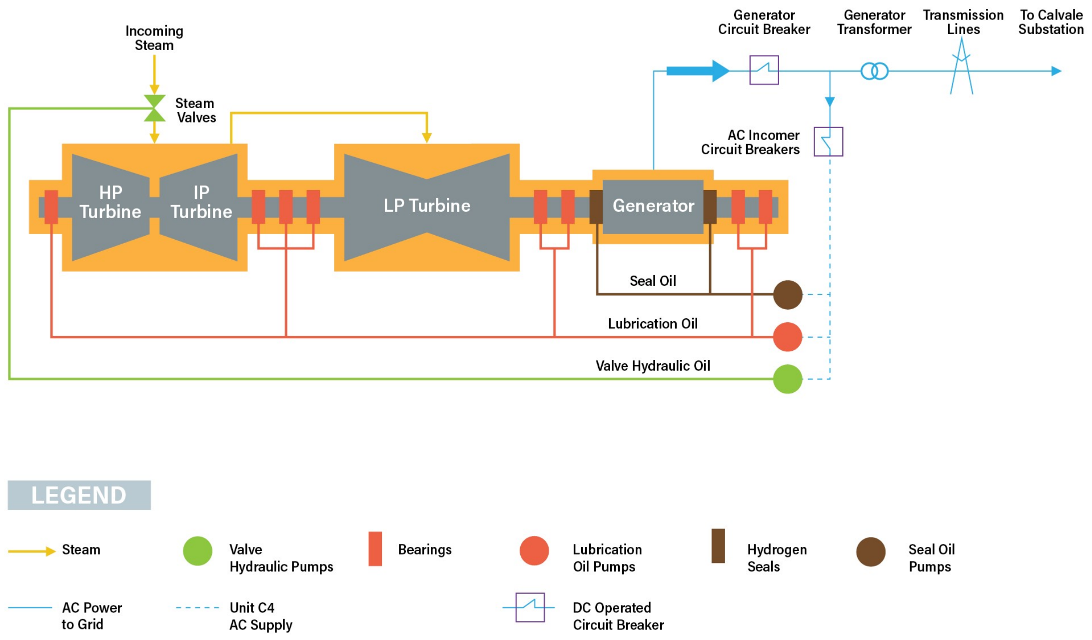

Figure 17 Simplified Unit C4 AC system

Figure 15 also illustrates how AC supply passes through AC circuit breakers (known as the AC 'incomer circuit breakers'). If a fault develops in the AC system, these AC incomer circuit breakers can open automatically, tripping the AC supply to Unit C4's equipment.[25]

3.5.6 Unit C4 DC System

The Unit C4 DC system is supplied by a battery charger and a battery, illustrated in Figure 18.

[25] There are multiple circuit breakers in the AC system, which are omitted from this diagram. All major electrical equipment will have its own circuit breakers that can trip that piece of equipment if a fault is detected.

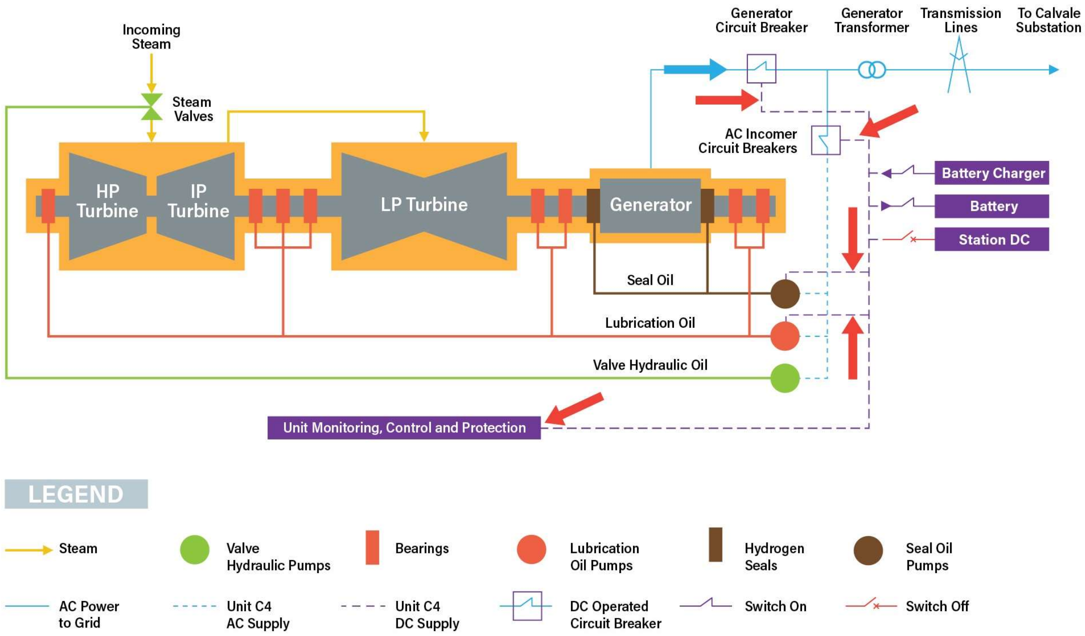

Figure 18 Simplified Unit C4 DC system

As indicated in Figure 16, the Unit C4 DC system supplies:

- The generator circuit breaker, which connects and disconnects the Unit C4 generator from the grid. (The generator circuit breaker requires DC supply to operate.)
- The AC incomer circuit breakers, which connect and disconnect AC supply from the Unit C4 AC system. (The AC incomer circuit breakers require DC supply to operate.)
- The emergency seal oil pump, which operates in the event of a loss of AC supply to the main seal oil pump.
- The emergency lubrication oil pump, which operates in the event of a loss of AC supply to the main lubrication oil pumps.
- Unit monitoring, control and protection systems, including the X protection and the Y protection systems, which are discussed further in Chapter 5 *How the Callide C Electrical System Works*.

3.5.7 Battery Charger and Battery

Unit C3, Unit C4 and Station each have two separate DC supplies: a battery charger and a battery. Figure 19 shows the Unit C4 battery charger and battery.

(a) Unit C4 battery charger

(b) Unit C4 battery

Figure 19 Unit C4 battery charger and battery

The Unit C4 battery charger is supplied by the AC system, and, in simple terms, converts AC supply into DC supply. Although the term 'battery charger' suggests its role is to simply charge the battery, its function is more nuanced. Despite its name, it is the battery charger that primarily provides DC supply to all the equipment in the DC system, while also maintaining the battery at a full state of charge.[26]

The battery charger, therefore, should be considered the primary source of supply to the DC system.

A primary role of the battery is to provide important redundancy should the battery charger cease to operate. For example, if the battery charger loses its AC supply, it will shut down, and if this occurs, the battery takes over the role of providing supply to the DC system.

3.5.8 Automatic Changeover Switch

Unit C4 has a switch known as the 'automatic changeover switch'. If DC supply is lost to the unit, this switch can operate (i.e., change over) automatically to supply part of Unit C4 from the Station DC system.[27]

The automatic changeover switch has control circuitry that detects the loss of DC supply, and a motorised switch that operates to reroute Station DC supply to Unit C4.[28] Figure 20 shows the Unit C4 automatic changeover switch.

[26] As well as providing redundancy, the battery also supplies some current during dynamic changes in load. In this situation, the battery charger adjusts its output to provide for this additional load and restore the battery back to its full state of charge. This behaviour is explored in detail in Appendix A4 *Battery Charger Investigation*.

[27] Station and Unit C3 also have automatic changeover switches.

[28] The automatic changeover switch is also capable of being operated manually.

Figure 20 Unit C4 automatic changeover switch

On the day of the incident, the Unit C4 automatic changeover switch was inoperable in automatic mode.[29]

3.5.9 Emergency Diesel Generator

If AC supply is lost to Unit C3, Unit C4 or Station, an emergency diesel generator can operate to restore AC supply to critical equipment.[30] The emergency diesel generator is shown in Figure 21.

[29] In this report, 'inoperable' means 'inoperable in automatic mode', unless otherwise stated. While the Unit C4 automatic changeover switch was operable in manual mode on the day of the incident, manual operation of the switch was not a practical response to the collapse and loss of DC supply in Unit C4.

[30] The emergency diesel generator operates in response to a loss of AC supply to Station. Restoration of AC supply to Unit C3 or Unit C4 is achieved by configuring the AC system to supply each unit from the Station AC system.

Figure 21 Callide C emergency diesel generator

3.6 Chapter Summary

This chapter summarised the operation and key equipment of Unit C4 relevant to the incident, presenting them in a simplified diagram, see Figure 22.

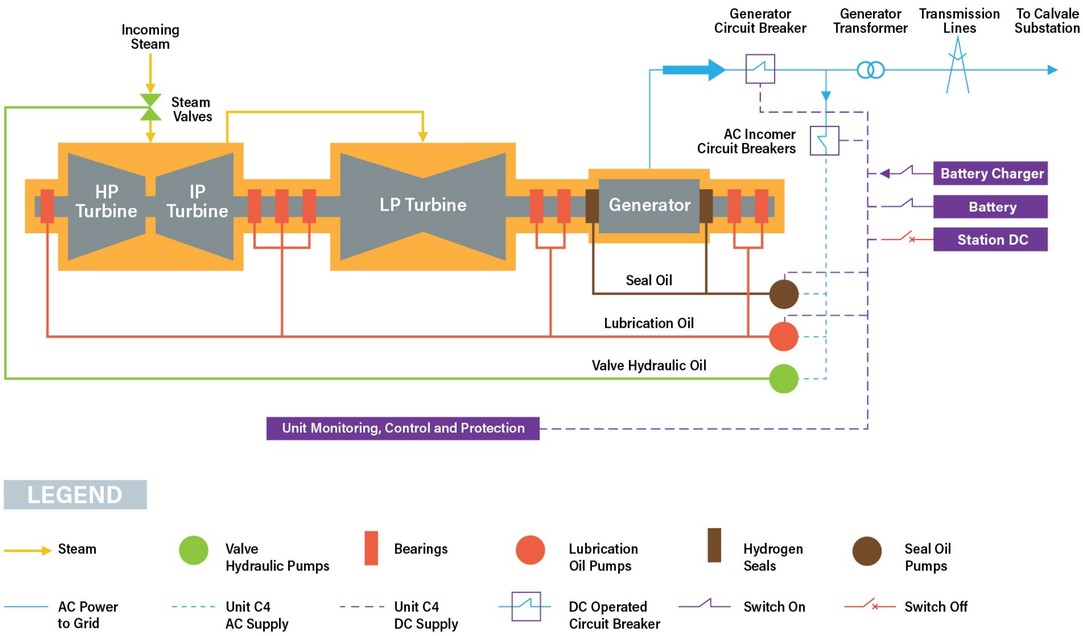

Figure 22 Simplified diagram of Unit C4

In the next chapter, Figure 20 is used to explain the key events that occurred during the incident.

4 SUMMARY OF THE INCIDENT

4.1 Introduction

This chapter summarises the key events that occurred during the incident, as well as the technical causes of the incident. Subsequent chapters discuss these events further, and a more detailed explanation of the events is provided in appendices for the technically trained reader.

This chapter examines the following:

- Collapse and loss of DC supply.[31]
- Loss of AC supply.
- Motoring of Unit C4.
- Catastrophic failure of Unit C4.

4.2 The Collapse and Loss of Unit C4 DC Supply

4.2.1 Background to 25 May 2021

In the 18 months leading up to the incident, an upgrade program had been initiated to replace the battery chargers at Unit C3, Unit C4 and Station. Prior to the incident, the Unit C3 and Station battery chargers had been replaced and successfully brought back into service.

In February 2021, the Unit C4 battery charger and battery were taken out of service to facilitate the battery charger's replacement. With the Unit C4 battery charger and battery out of service, Unit C4 was supplied from Station DC, as depicted in Figure 23.

[31] In the incident, the Unit C4 DC voltage collapsed from ~243 V to ~120 V. It then decayed rapidly to ~0 V.

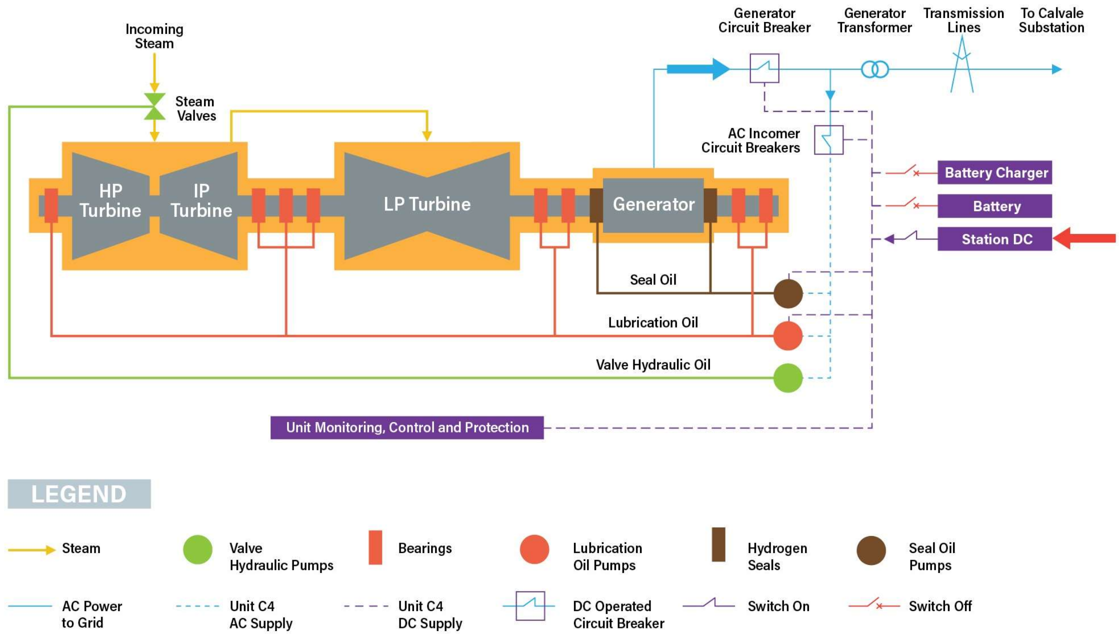

Figure 23 Unit C4 DC system supplied from Station DC system

On the day of the incident, the replacement Unit C4 battery charger and existing battery were being reconnected to the unit.

4.2.2 The Switching Sequence

The reconnection of the battery charger and battery was undertaken using a process called ‘switching’. Switching is the formal process of making changes to a unit's electrical configuration, and is carried out in accordance with a series of prescriptive sequential steps, which is referred to in this report as a ‘switching sequence’. While this switching sequence was being executed, Unit C4 was operational and exporting power to the grid.

By 1:32 pm on the day of the incident, the switching sequence was in progress.[32] The next step in the sequence was to connect the replacement Unit C4 battery charger to Unit C4, see Figure 24.

[32] In this report, all time is expressed in Australian Eastern Standard Time (AEST).

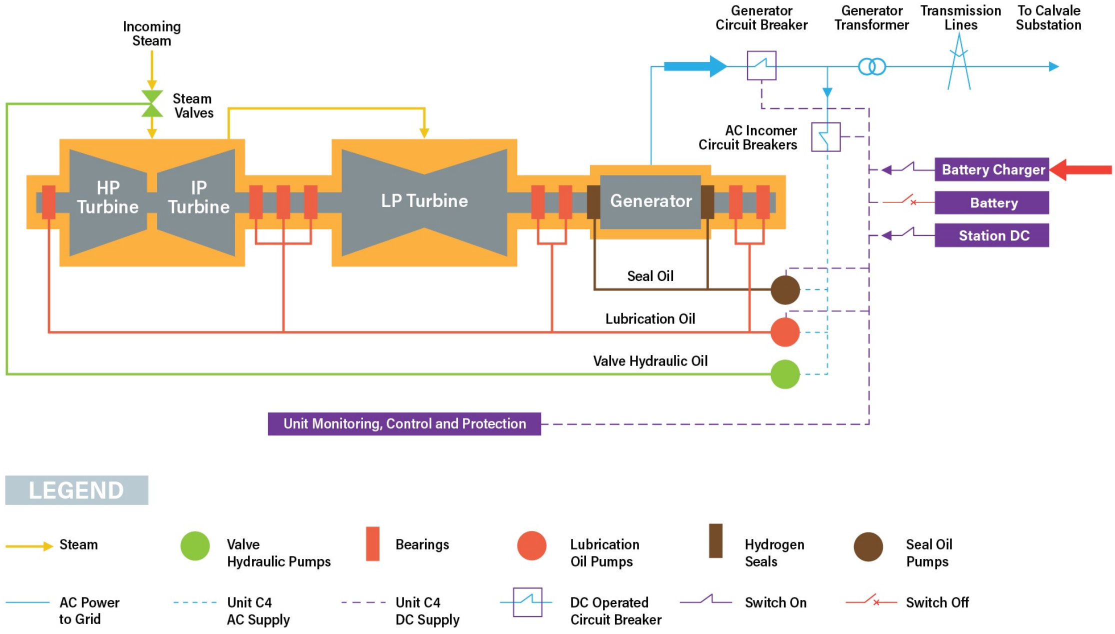

Figure 24 Unit C4 battery charger connected to Unit C4 DC system

This step was completed successfully, resulting in Unit C4 now having two potential DC supplies: supply from the Station DC system and supply from the Unit C4 battery charger.[33] The next step was to disconnect the Station DC system from Unit C4, see Figure 25.

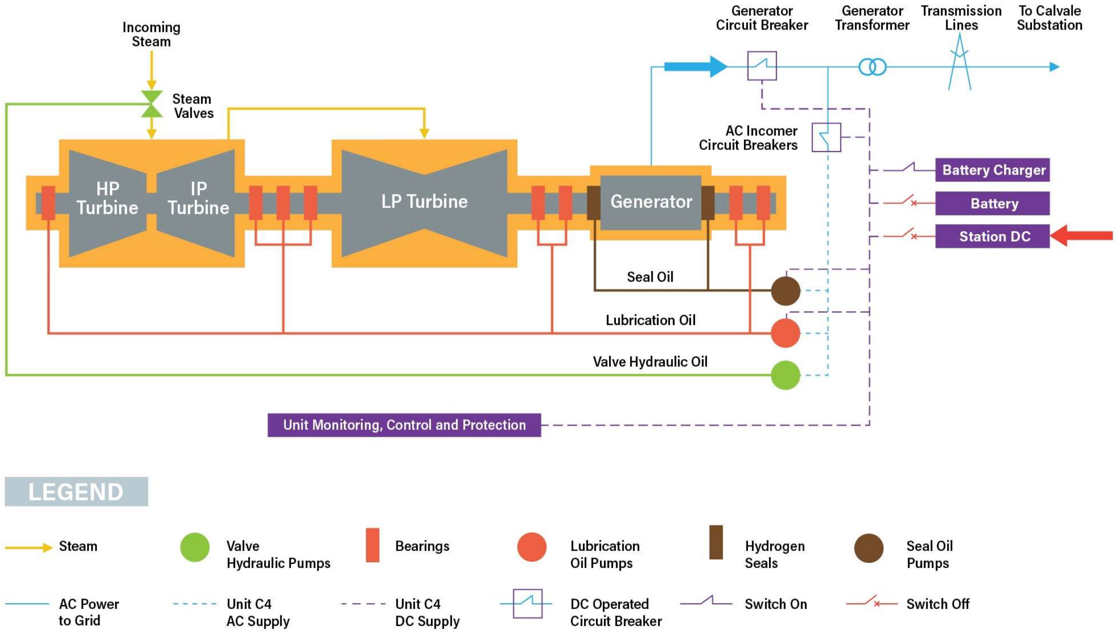

Figure 25 Station DC supply disconnected from Unit C4 DC system

[33] The Station DC system supply is comprised of the Station battery charger and battery.

Disconnecting the Station DC supply resulted in the Unit C4 battery charger becoming the sole source of DC supply to Unit C4. This step placed a requirement on the battery charger to respond instantly to maintain the voltage in the Unit C4 DC system. Despite this being a requirement of the switching sequence, the ability of the battery charger to meet this requirement had not been specified or tested by CS Energy.[34]

4.2.3 Collapse and Loss of DC Supply

When Station DC was disconnected from Unit C4, the voltage in the Unit C4 DC system instantly collapsed from ~243 V to ~120 V. This collapse occurred because the Unit C4 battery charger failed to maintain the voltage in the Unit C4 DC system. The voltage in the Unit C4 DC system then decayed rapidly over a period of two seconds to ~0 V, leading to a complete loss of DC supply to Unit C4.[35] This loss of DC supply is indicated by the dotted grey line in Figure 26.

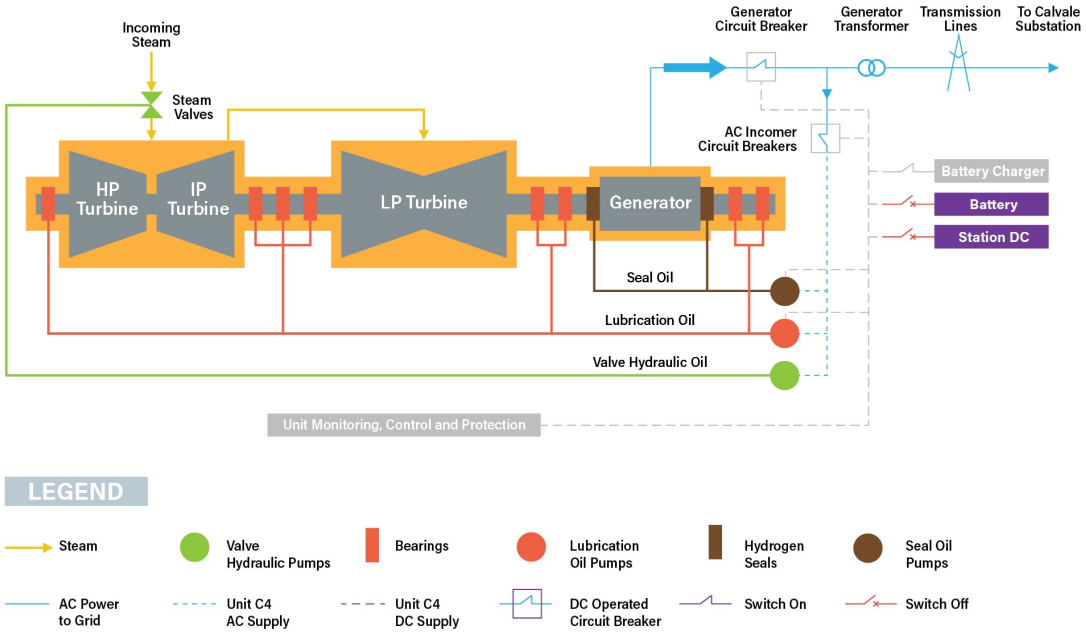

Figure 26 Loss of Unit C4 DC supply

4.2.4 Consequences of Collapse and Loss of DC Supply

The collapse and subsequent loss of DC supply to Unit C4 resulted in an immediate loss of several critical systems, as indicated by the red arrows in Figure 27.

34 The Brady Heywood investigation concluded that, under the specific conditions on the day of the incident, the battery charger was not capable of responding instantly and maintaining the voltage in the Unit C4 DC system.

35 As discussed later in this report, the collapse of the Unit C4 DC system voltage to ~120 V directly led to the loss of the Unit C4 AC supply (~0 V), which in turn led to the loss of the Unit C4 DC supply (i.e., the voltage rapidly decayed to ~0 V).

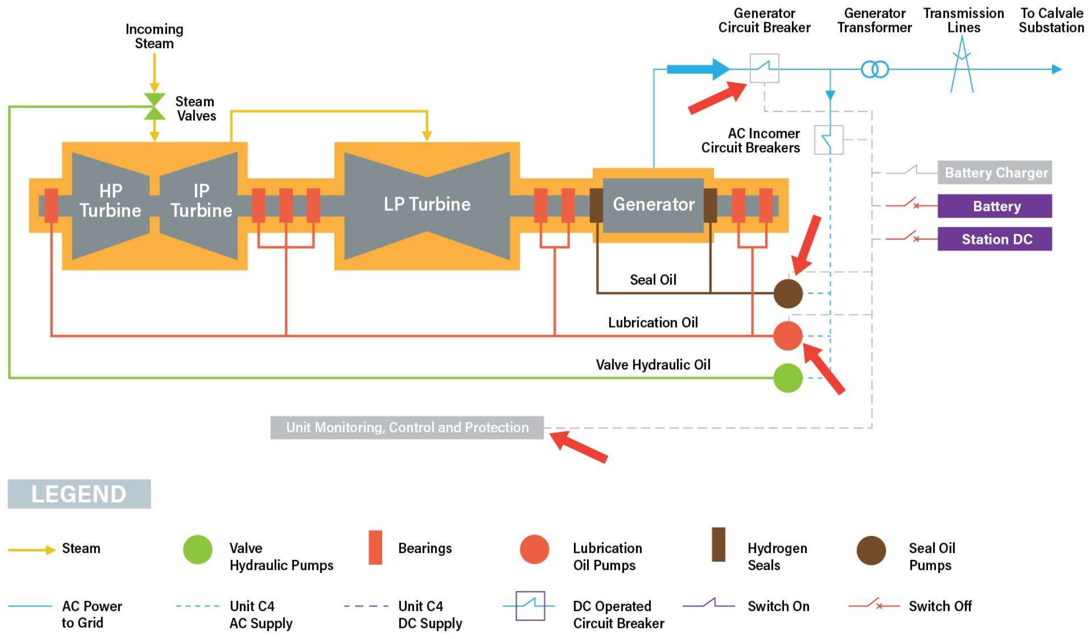

Figure 27 Loss of critical DC systems

These critical Unit C4 systems included:

- The generator circuit breaker: The loss of the generator circuit breaker meant the unit could not be disconnected from the grid by the Callide operators.[36]
- The emergency oil pumps for seal oil and lubrication oil: The loss of these backup pumps was not an immediate issue because the lubrication and seal oil pressures were still being maintained by the AC pumps.
- The protection systems that detect faults or issues with the turbine generator and respond accordingly: The loss of the protection systems meant the unit could no longer be monitored, shut down safely, or automatically disconnected from the grid.

4.3 Unit C4 Automatic Changeover Switch Failed to Restore Unit C4 DC Supply

As discussed in Chapter 3 *Introduction to Unit C4*, Unit C4 has an automatic changeover switch. But this switch was inoperable in automatic mode.[37] Therefore, it did not operate, and Unit C4 DC supply was not restored.

[36] Technically, the DC supply to the generator circuit breaker is called the ‘generator circuit breaker control’. The term ‘generator circuit breaker’ is used for simplicity.

[37] The Brady Heywood investigation concluded that prior to the incident, the Unit C4 automatic changeover switch's control circuitry was damaged, its fuses were blown, and the blown fuses were potentially removed. Any one of these three conditions alone would result in the automatic changeover switch being inoperable in automatic mode. (Evidence was

Had the automatic changeover switch been operational, it may have responded to the loss of DC voltage and automatically 'changed over' to supply part of the Unit C4 DC system from the Station DC system.[38] While the unit would likely have sustained significant damage, the turbine missile event would likely have been avoided.

4.4 Loss of Unit C4 AC Supply

4.4.1 Cause of Loss of AC Supply

The voltage collapse in the Unit C4 DC system directly led to the loss of Unit C4 AC supply. In simple terms, the voltage collapse in the DC system caused one of the unit's protection systems, known as arc flap protection, to respond as if a fault had occurred on the unit's AC system. Despite no such fault actually occurring, the arc flap protection activated and disconnected the AC supply to Unit C4. Chapter 8 *How Arc Flap Protection Led to the Loss of AC Supply* discusses how this occurred in more detail. The loss of AC supply to the unit is illustrated in Figure 28.

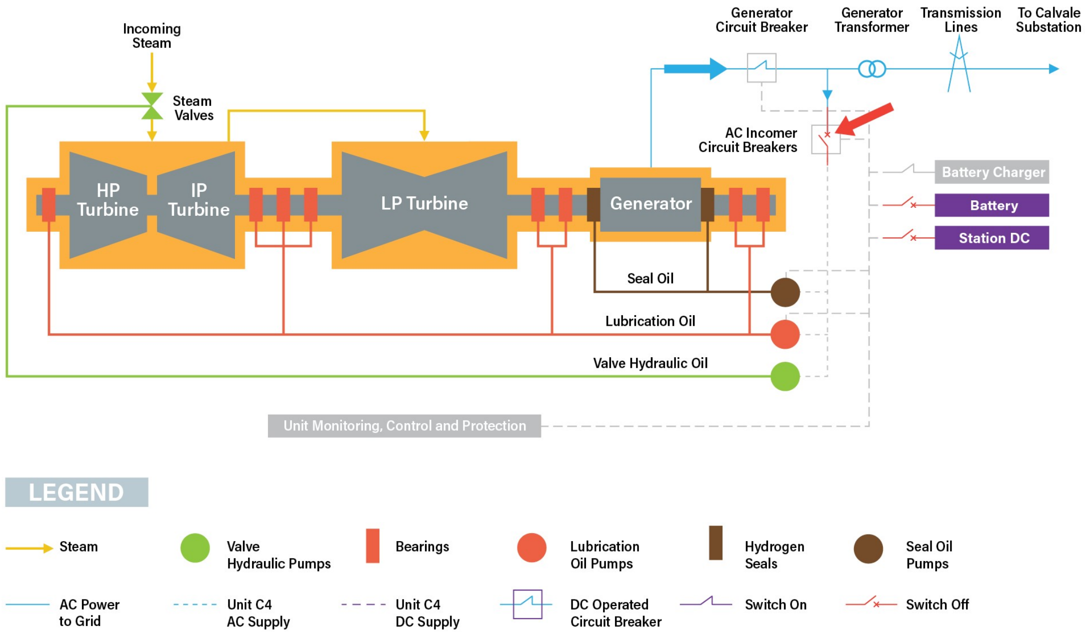

Figure 28 AC incomer circuit breakers trip and disconnect AC supply to the unit

4.4.2 Consequences of Loss of AC Supply

The loss of AC supply to Unit C4 had five key consequences.[39]

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sighted that confirms CS Energy became aware in January 2021 that the fuses to the Unit C4 automatic changeover switch were blown.) As such, the Unit C4 automatic changeover switch was not operable on the day of the incident.

The inoperable status of the Unit C4 automatic changeover switch is discussed in detail in Chapter 21 *The Inoperable Automatic Changeover Switch*.

38 The Brady Heywood investigation concluded that the automatic changeover switches in Callide C were prone to reliability issues, and therefore did not always operate successfully to restore supply as expected.

39 These consequences did not necessarily occur sequentially as represented in this chapter, but they are, for simplicity, discussed and illustrated sequentially. Note that the loss of AC supply also led to the boiler tripping.

First, it led to the failure of the hydraulic oil system that operates the steam valves, causing the valves to close (due to their fail-safe design). This meant steam was no longer entering and driving the turbine, see Figure 29.

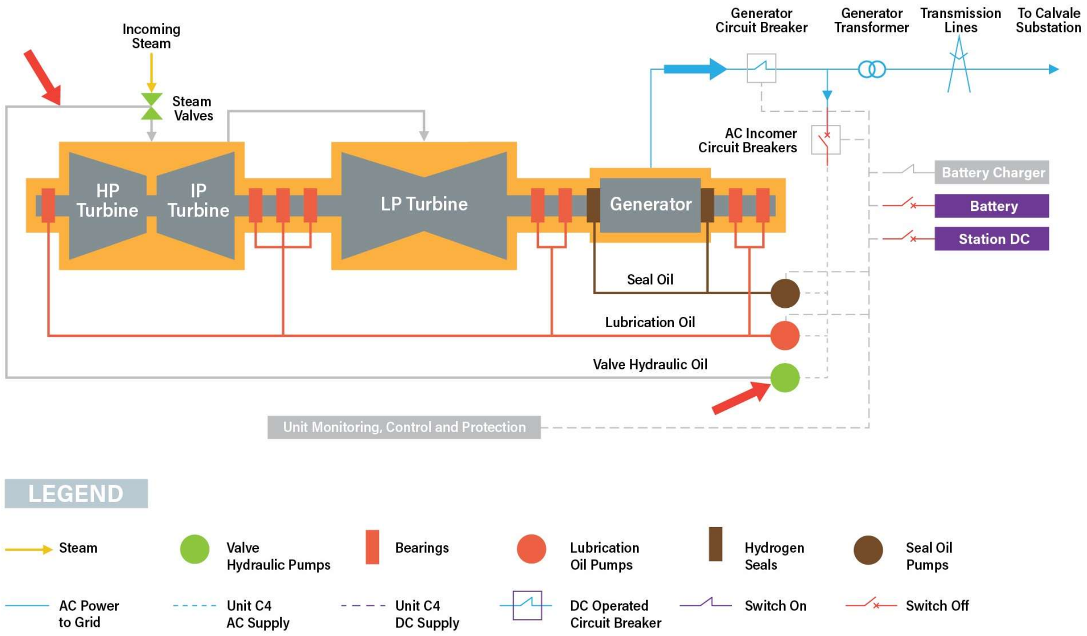

Figure 29 Loss of AC supply to steam valve hydraulics

Second, the loss of AC supply led to the loss of the AC lubrication oil pumps, see Figure 30.

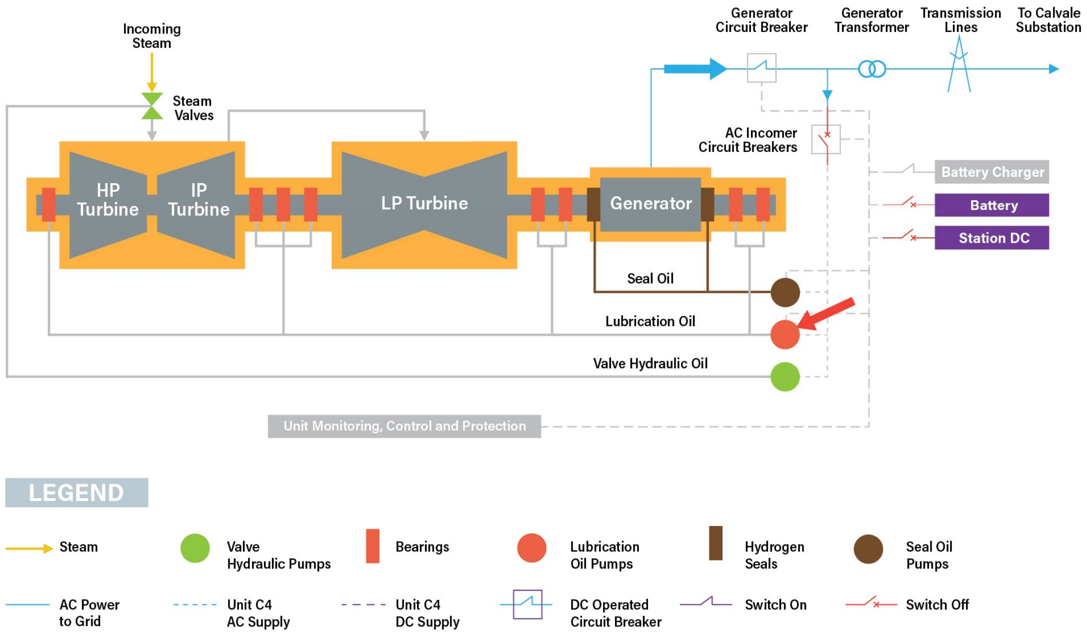

Figure 30 Loss of AC lubrication oil pumps

The loss of AC lubrication oil pumps resulted in a loss of oil supply to the bearings. Ordinarily, the DC emergency lubrication oil pump would start automatically and restore lubrication oil, but it did not operate because of the loss of its DC supply. This resulted in the shaft and bearings grinding metal-on-metal.

Third, the loss of AC supply resulted in the loss of the AC seal oil pump, see Figure 31.

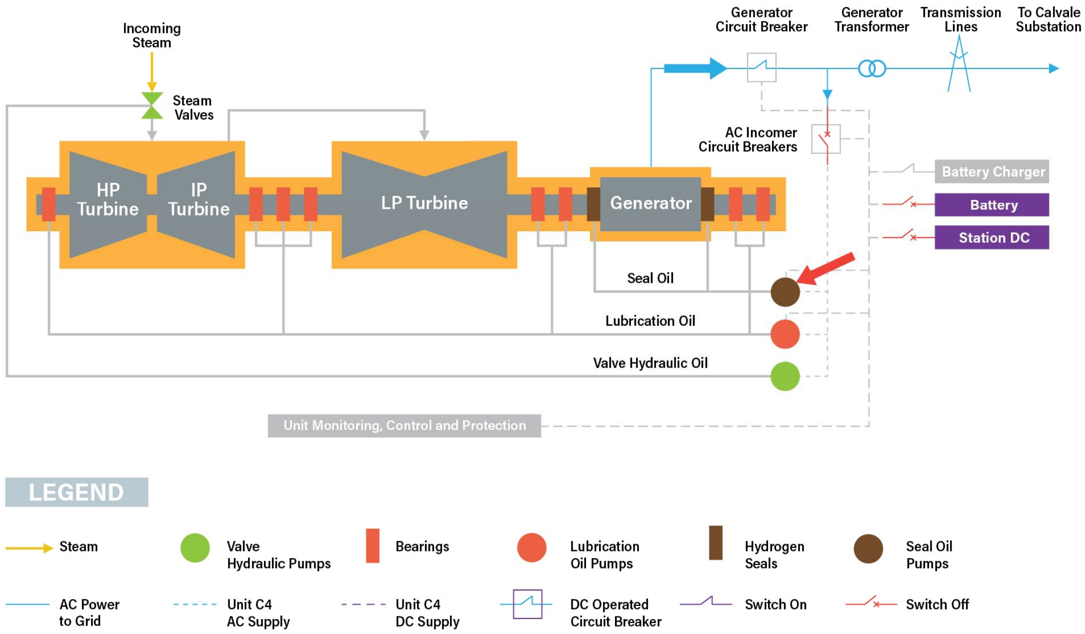

Figure 31 Loss of AC seal oil pump

The loss of this pump resulted in the loss of oil supply to the generator hydrogen seals. Ordinarily, the DC emergency seal oil pump would automatically start and restore seal oil, but it did not operate because of the loss of its DC supply. This resulted in hydrogen escaping from the generator into the surrounding air.

Fourth, the loss of AC supply meant that none of the cooling systems critical for the safe operation of the turbine generator and generator transformer were available (not shown in the figure above).

Fifth, the loss of AC supply directly led to the loss of the Unit C4 DC supply. While the DC system had already collapsed to ~120 V, it was the loss of AC that turned this DC collapse into a complete loss (~0 V). The Unit C4 battery charger requires AC supply to operate, and when AC supply was lost, the battery charger shut down. Because the battery charger was the sole source of DC supply to Unit C4, this led to the DC system voltage decaying (from ~120 V to ~0 V).

If the AC supply to the Unit C4 battery charger had not been lost, then it is likely that the battery charger would have responded to the DC voltage collapse and restored it to ~243 V in the order of ~2 seconds.

4.5 Emergency Diesel Generator Failed to Restore Unit C4 AC Supply

When AC supply is lost, the emergency diesel generator should operate automatically and restore it.

On the day of the incident, the emergency diesel generator did operate, but AC supply was not restored to Unit C4. It was not restored because the AC system needed to be configured to receive this supply (i.e., specific switches in the AC system needed to be opened or closed). These switches in the AC system are operated by the Unit C4 DC system. But because the DC system was lost, the switches could not be operated, and the necessary configuration of the Unit C4 AC system could not occur. As a consequence, AC supply from the emergency diesel generator was not routed to the Unit C4 AC system.[40]

4.6 Motoring Commenced

4.6.1 Introduction

The loss of AC and DC supply to Unit C4 created a situation where the unit commenced motoring. Two conditions were necessary for this to occur: the steam valves needed to close, and the unit needed to remain connected to the grid.[41]

4.6.2 Steam Valves Close

The loss of AC supply led to the failure of the hydraulic pumps, which provide hydraulic pressure to keep the steam valves open. As a result, the steam valves closed (due to their fail-safe design), thus preventing steam from entering the turbine, see Figure 32.

[40] The Brady Heywood investigation concluded that there was a possibility that, even if the DC supply had been available to operate the AC switches, the AC supply to the Unit C4 emergency switchboard may not have been restored. This is because, even though the AC switches may have operated and restored AC supply to the Unit C4 emergency switchboard, the AC switches may then have tripped again (due to low load on the circuits), disconnecting AC supply to the Unit C4 emergency switchboard. If this had occurred, AC supply would have been momentarily restored to Unit C4 before being lost again.

This momentary restoration occurred with the Unit C3 AC switches when Calvale substation was disconnected from the grid at the conclusion of the incident. This scenario with respect to Unit C4 was not explored in depth because it is hypothetical.

[41] Technically, it is a lack of steam driving the turbine that is the necessary condition. In the incident, the steam valves closing resulted in this condition.

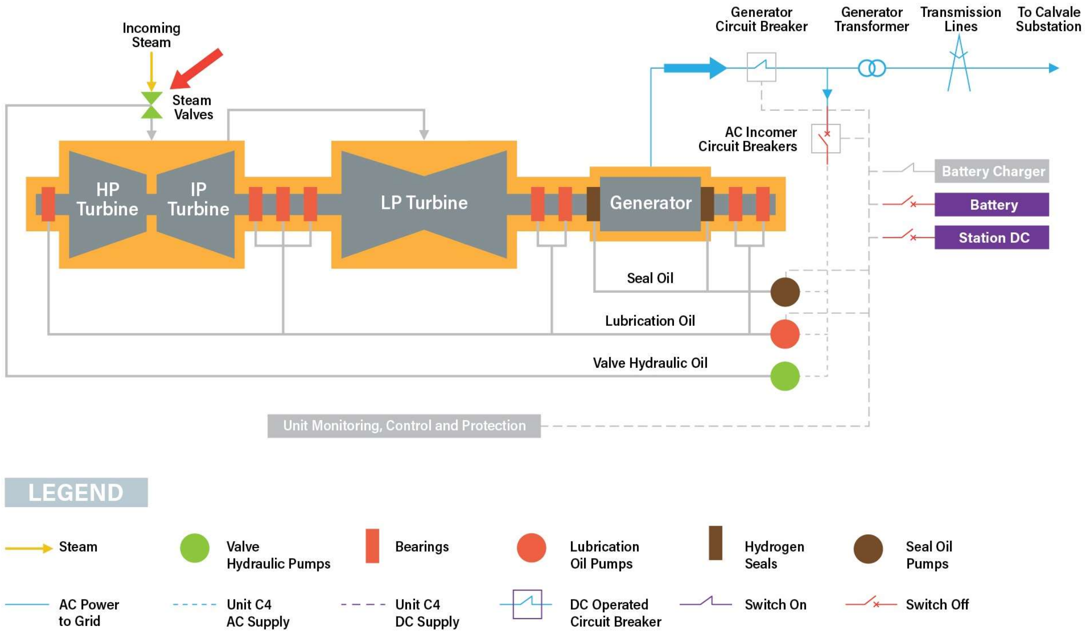

Figure 32 Steam valves close and prevent steam entering turbine

4.6.3 Generator Circuit Breaker did not Disconnect Unit C4 From the Grid

A loss of AC supply would typically be detected by the Unit C4 protection systems, which would automatically trip the generator circuit breaker, disconnecting the unit from the grid. However, the loss of DC supply meant that Unit C4's protection systems were no longer functioning, and there was no DC supply available to open the generator circuit breaker, see Figure 33.

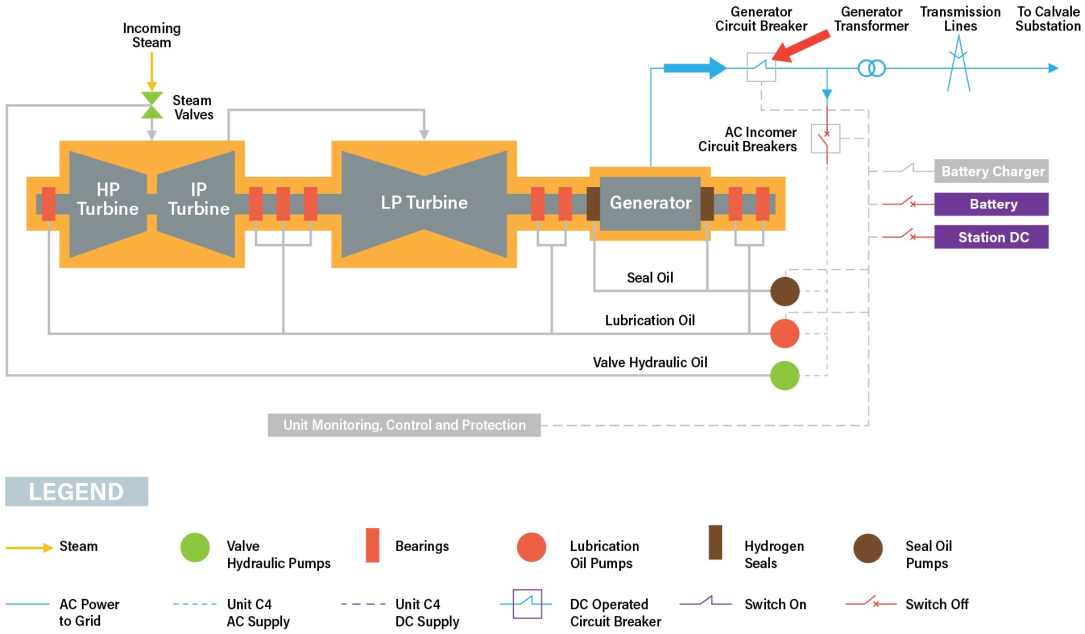

Figure 33 Generator circuit breaker did not disconnect Unit C4 from the grid

Because the generator circuit breaker did not operate, Unit C4 remained connected to the grid for the duration of the incident.

4.6.4 Unit C4 Commenced Motoring

With no steam driving the unit, but with it still connected to the grid, Unit C4 began 'motoring'. Motoring occurs in a turbine generator when it stops exporting power to the grid, and instead imports power from the grid, becoming an electric motor. Motoring results in the rotor continuing to spin in the same direction at approximately 3,000 rpm.[42] Unit C4 importing power from the grid is illustrated in Figure 34.

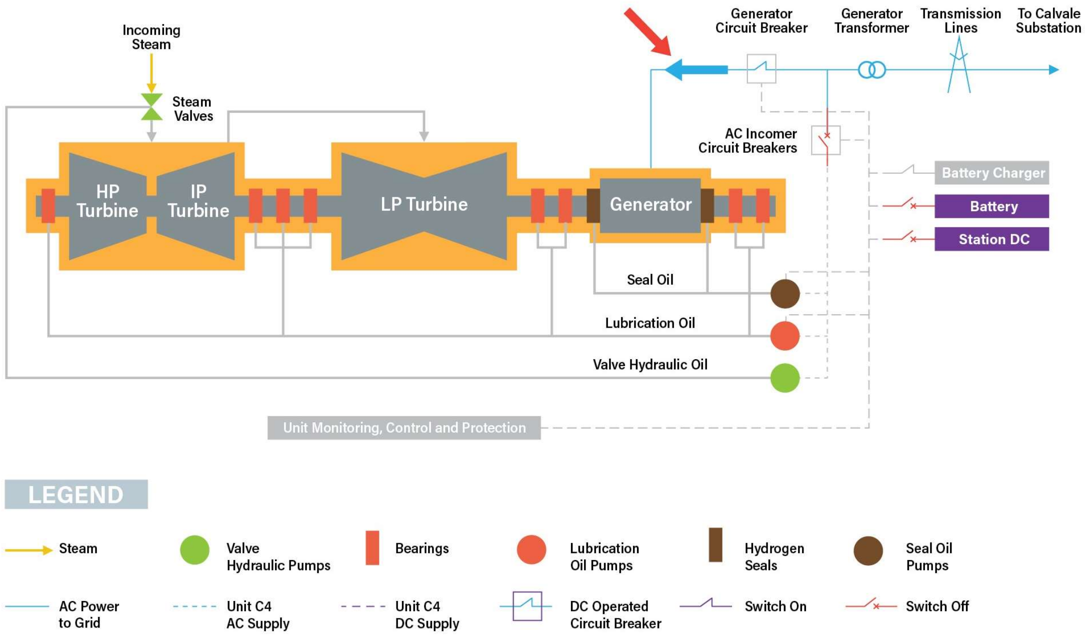

Figure 34 Motoring commences

4.7 Calvale Substation Circuit Breaker did not Open Automatically

If the generator circuit breaker on Unit C4 is unable to open for any reason, the unit's protection systems typically send a signal to Calvale substation. On receipt of the signal, the Calvale substation circuit breaker associated with Unit C4 opens and disconnects the unit from the grid.

This did not occur in the incident. When the generator circuit breaker did not open, the Unit C4 protection systems had no ability to communicate with Calvale substation for it to open its circuit breaker because of the loss of Unit C4's DC supply. There was no automatic disconnection of Unit C4 from the grid and the unit continued to motor.[43]

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[42] There was no excitation available due to the field switch being open, hence the generator motored as an induction motor (i.e., asynchronously) at ~ 2,940 to 2,980 rpm. If the field switch had remained closed, the rotor likely would have operated at the synchronous speed of 3,000 rpm.

[43] While Calvale substation did detect an abnormal condition in its protection systems, it would not have been apparent that Callide Unit C4 was the issue. Further, the loss of Unit C4's X and Y protection systems meant that Calvale substation did not receive a positive 'request to open Unit C4 breaker' instruction. This did not occur because the loss of DC supply meant that Unit C4's protection systems could not send the instruction. Powerlink did, however, receive 26 alarms within the first minute

In this state, the only remaining mechanism available to disconnect Unit C4 from the grid (and stop the motoring) was for the circuit breaker at Calvale substation to be operated by Powerlink. This would have required the Unit C4 operators to understand the rapidly unfolding situation at Unit C4, and then communicate such a request to Powerlink.

4.8 Loss of Supply to Unit C4 Operator Screens in Control Room

All four units at Callide are operated from a single control room located in the turbine hall building.[44] The operators in the control room rely on display screens to monitor the status of the units and control equipment.[45]

When the incident began, the loss of both AC and DC supply resulted in the display screens for Unit C4 going black (i.e., powering off).[46] Supply to these screens was restored by the operators approximately 20 minutes into the incident.

4.9 34 Minutes of Sustained Motoring

Unit C4 had lost its protection systems (due to the loss of DC supply), it had lost its main and emergency lubrication oil and seal oil pumps (due to the loss of AC supply and DC supply, respectively), and its steam valves were closed (due to the loss of AC supply).[47]

With no steam driving the turbine, but with it still connected to the grid, the Unit C4 generator acted like an electric motor. The rotor continued to spin, importing power from the grid.

With no lubrication oil to the bearings, the white metal lining of the bearings melted in a few minutes and led to metal-on-metal contact between the shaft and bearings.[48] Heat caused by friction caused the bearings to melt, and the shaft to soften and deform. This deformation caused the turbine generator rotor to wobble out of its finely tuned and balanced alignment.

With no seal oil to keep the pressurised hydrogen inside the generator, the hydrogen escaped through the seals, likely causing hydrogen fires.[49]

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of the incident. Excel Spreadsheet *Alarm log*, CSE.001.054.0327. These included a protection circuit abnormal alarm and indications that the all-grid supply transformers and automatic voltage regulators at Calvale had to adjust their tap position to regulate the grid voltage.

[44] There is a single control room for all four units (B1, B2, C3 and C4) of Callide B and Callide C power stations. The control room is located some distance away from Unit C4.

[45] There are up to 100 display screens in the control room for Callide B and Callide C power stations.

[46] The control room was designed so that the display screens are powered via an uninterruptible power supply (UPS) with both an AC supply and a DC supply to provide redundancy in the event of one supply being lost. If only one supply had failed, it is unlikely that the loss of screens would have occurred.

[47] Unit C4 has two AC lubrication oil pumps and one emergency DC lubrication oil pump, and one AC seal oil pump and one emergency DC seal oil pump.

[48] The load on the Unit C4 turbine gradually increased from ~5 MW, reaching a peak of 80 MW after about seven minutes. It then settled at 50 MW until the turbine missile event occurred. Bearing temperatures rapidly increased (such as No. 2 bearing reaching melting point in ~100 seconds). It is hypothesised by the Brady Heywood investigation that after seven minutes, all white metal was likely melted away on the bearings, and this molten metal likely provided 'lubrication' until the turbine missile event occurred, hence the reduction to ~50 MW until the turbine missile event. See Appendix A2 *Mechanical Investigation* for further details.

[49] It is also likely to have caused a small explosion in the main oil tank of Unit C4.

This motoring continued for 34 minutes without any operational cooling systems for the turbine generator or the generator transformer.[50]

4.10 Catastrophic Failure

At 2:06 pm, the wobbling of the rotor likely caused part of the rotor to snag on the metal turbine casing. With the rotor still spinning at approximately 3,000 rpm, this sudden impact transferred tremendous force to the rotor shaft. This caused the rotor shaft to tear apart at nine locations.

A piece of shaft weighing more than two tonnes was thrown five metres across the floor of the turbine hall. A piece of equipment weighing 300 kg, called the barring gear, was thrown metres into the air, punching through the turbine hall roof. The force from the impact also ejected remnants of coupling covers, bearings, and sections of the shaft from the turbine generator, resulting in widespread damage to the surrounding environment, including the floor, walls and roof of the turbine hall. This is referred to as the 'turbine missile event'. The damage to Unit C4 is shown in Figure 35.

Figure 35 Post-incident damage to Unit C4

4.11 Unit C4 Disconnection from the Grid

After the turbine missile event, the generator remained connected to the grid for approximately 40 seconds. During this time, an electrical fault developed in the generator, causing it to arc and draw

[50] The turbine generator was motoring at ~50 MW and 300 MVAR without cooling systems – including main cooling water, treated and auxiliary cooling water, stator cooling and transformer cooling – all of which are usually supplied by the Unit C4 AC system.

high current from the grid – more than twice the unit's rated export power.[51] The protection systems in the Queensland power grid responded by disconnecting Calvale substation from the grid. This initiated the destabilisation of the Queensland power grid.[52]

The disconnection of Calvale substation also disconnected Unit C4, concluding the incident. By 2:07 pm, the turbine generator and other associated equipment had been destroyed.

4.12 Overview of Damage

The following series of photographs show the extent of the damage that occurred during the incident. Figure 36 shows the overall damage to the turbine generator from the eastern side of the turbine hall.

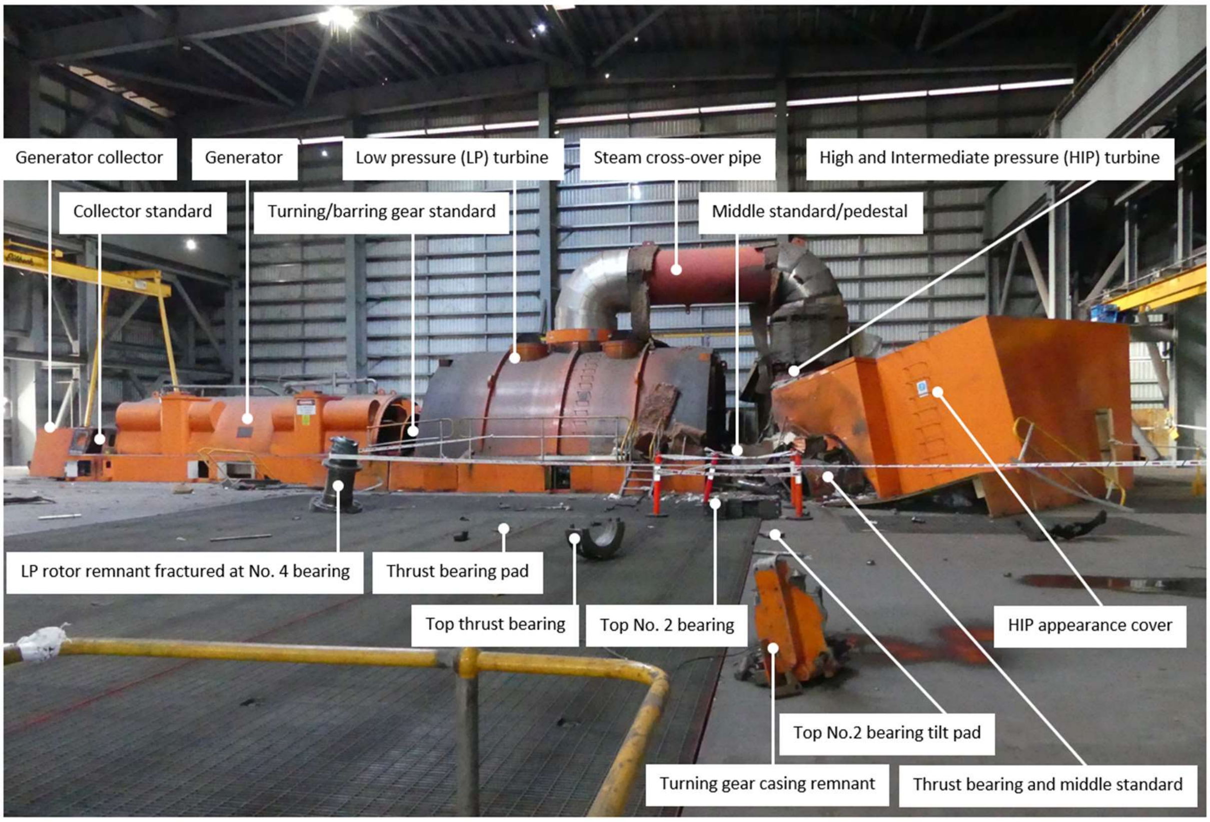

Figure 36 Damage to Unit C4 (eastern side view)

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[51] The imported power from the grid peaked at 300 MW and over 1,400 MVAR.

[52] AEMO (2021) *Trip of multiple generators and lines in Central Queensland and associated under-frequency load shedding on 25 May 2021*. https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2021/trip-of-multiple-generators-and-lines-in-qld-and-associated-under-frequency-load-shedding.pdf, Section 4.1: '*The Callide C4 fault which occurred at 14:06 hrs was picked up by protection on circuits connecting Calvale to the wider network in protection zone 2, this was detected as a phase A – B – ground fault. … The protection operation opened all remote end circuit breakers connecting Calvale 275 kV substation to the wider system, disconnecting Callide C4 from the power system. The overall time from fault inception to clearance was approximately 600 ms.*'

Figure 37 shows an aerial view of damage to the Unit C4 turbine generator.

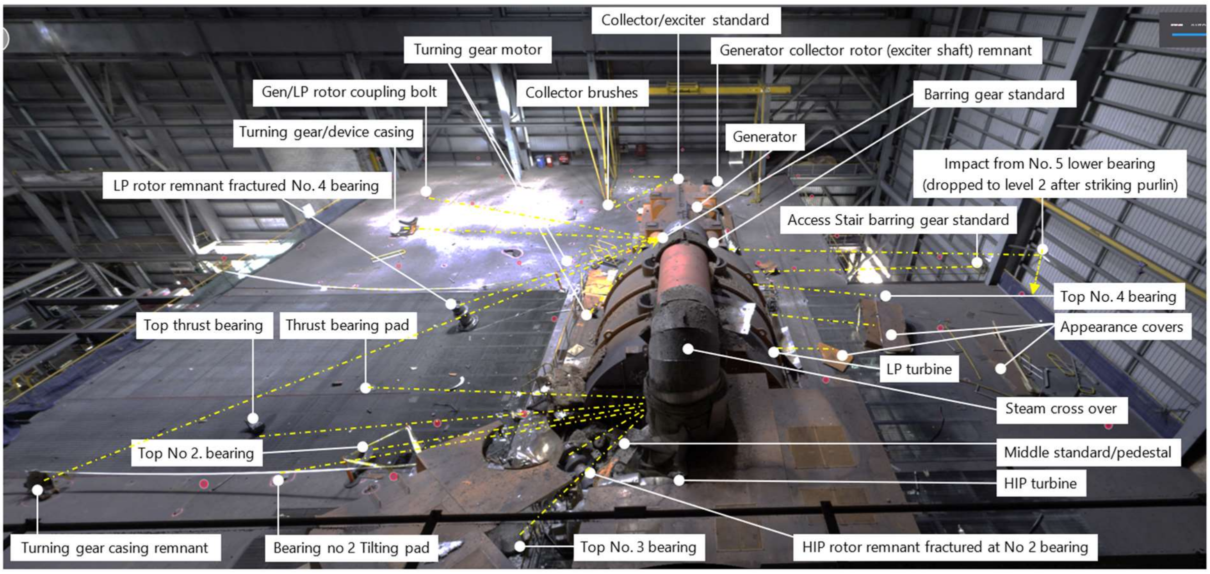


Figure 37 Damage to Unit C4 (aerial view)

Figure 38 shows the damage between the generator and the LP turbine.

Figure 38 Damage between the generator and the LP turbine

Figure 39 shows the damage in the area between the LP and HIP turbines.

Figure 39 Damage between LP and HIP turbines

Figure 40 is a selection of photographs showing damage to the HP turbine, LP turbine and generator shaft.

Figure 40 HP turbine, LP turbine and generator shaft damage

Figure 41 shows the heat damage to the orange casing of the LP turbine.

Figure 41 Heat damage to LP turbine casing

Figure 42 shows the damage to the generator stator.

(a) Generator stator internal condition *(b) Damage to stator*

Figure 42 Damage to the generator stator

4.13 Cause of the Incident

The damage to Unit C4 was the result of the loss of both DC and AC supply to the unit.

4.14 Causes of Incident Ruled Out

Causes of failure ruled out as part of the Brady Heywood investigation are briefly discussed below, with further discussion provided in Appendix A2 *Mechanical Investigation,* Appendix A5 *Metallurgical Investigation* and Appendix A7 *Cybersecurity Investigation*.

4.14.1 Overspeed Event

A well understood catastrophic failure mechanism in turbine generators is an 'overspeed event'. In typical operating conditions, when the turbine generator is connected to the grid and generating electricity, the grid provides resistance to the rotation of the generator rotor.

If the generator is disconnected from the grid (e.g., by opening the generator circuit breaker), this resistance is removed. If this resistance is removed while the turbine is still being driven by steam, the turbine generator rapidly speeds up – due to the removal of resistance – and can tear itself apart in the order of 10–20 seconds.

The damage to Unit C4 was highly unlikely to have been caused by an overspeed event because:

- There was no steam driving the turbine throughout the 34 minutes of motoring.
- The turbine generator remained connected to the grid throughout the duration of the incident, limiting the speed of rotation to approximately 3,000 rpm.

4.14.2 Mechanical or Metallurgical Causes

Mechanical or metallurgical failures are highly unlikely to have contributed to the incident.[53]

[53] See Appendix A2 *Mechanical Investigation* and Appendix A5 *Metallurgical Investigation.*

4.14.3 Cybersecurity Causes

An IT systems fault or cyberattack (internal or external) is highly unlikely to have contributed to the incident.[54]

4.15 Chapter Summary

The collapse, loss, and failure to recover the Unit C4 AC and DC systems resulted in the catastrophic failure of the unit.

The following chapters of Part A examine in more detail how the collapse, loss, and failure to recover the Unit C4 AC and DC systems occurred:

- Chapter 5 *How the Callide C Electrical System Works*: provides a more detailed overview of the Unit C4 AC system and DC system (within the Callide C electrical system).
- Chapter 6 *How the Switching Sequence Initiated the Incident*: examines the switching sequence that was taking place on the Callide C electrical systems on the day of the incident.
- Chapter 7 *The Loss of AC and DC Supply*: discusses the loss of the Unit C4 AC and DC supply.
- Chapter 8 *How Arc Flap Protection Led to the Loss of AC*: explains how the loss of DC supply led to the loss of AC supply.
- Chapter 9 *How the Battery Charger Led to the DC Voltage Collapse*: examines how the Unit C4 battery charger contributed to the loss of DC supply to Unit C4.

[54] See Appendix A7 *Cybersecurity Investigation*.

5 HOW THE CALLIDE C ELECTRICAL SYSTEM WORKS

5.1 Introduction

This chapter provides a detailed discussion of how the Callide C electrical system operates. It explains the components and typical configuration of Callide C's AC and DC systems, then shows how these systems integrate within the wider Callide C electrical system. Some repetition of material previously presented is necessary.

5.2 Callide C Electrical System

Figure 43 shows a simplified representation of the Callide C electrical system in its typical configuration with both units online.

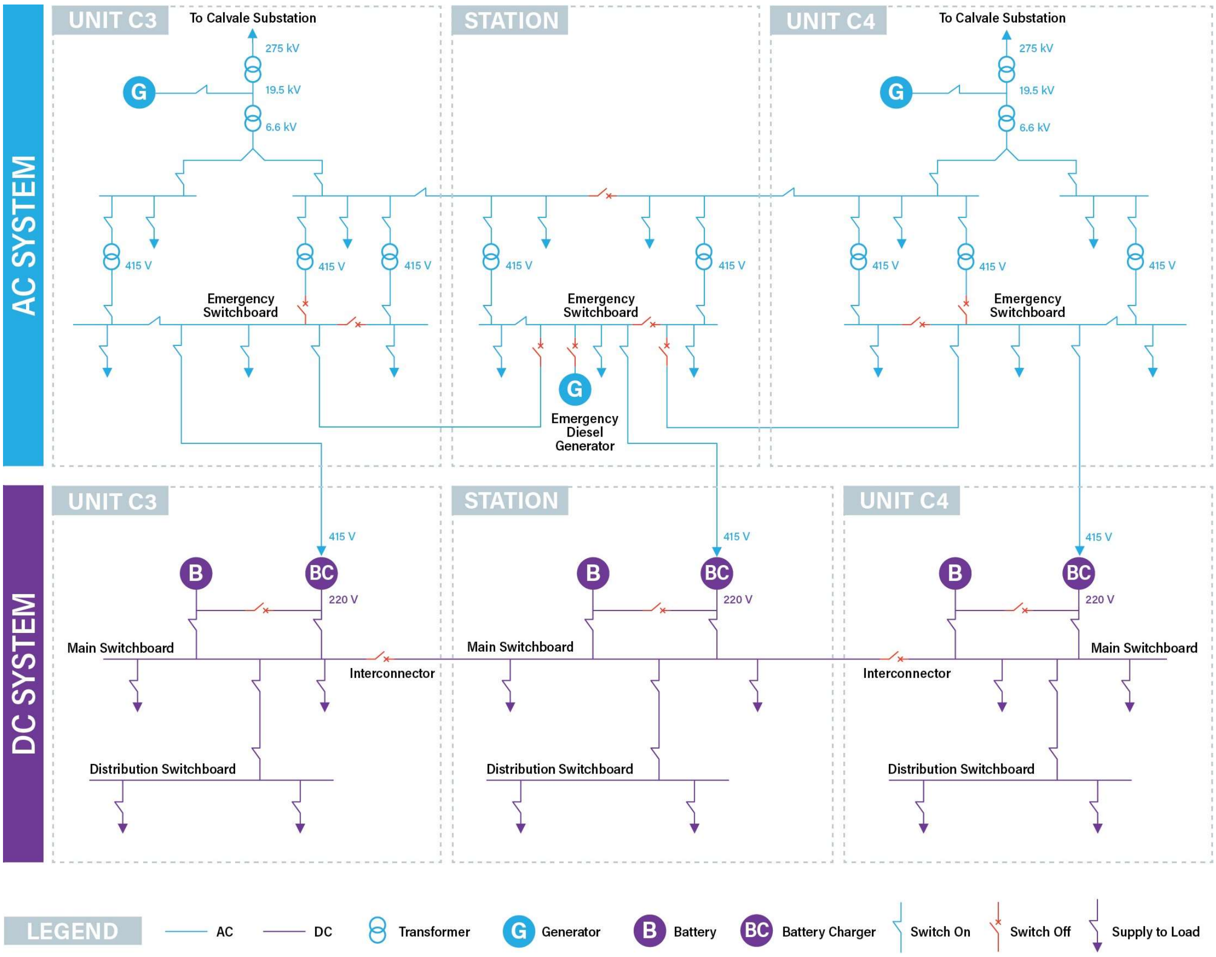


Figure 43 Callide C AC and DC systems

The AC system is shown at the top of the figure, with the DC system shown at the bottom. Both systems are explained in the sections that follow.

5.3 Introduction to the Unit C4 AC System

The Unit C4 AC system is shown in red in Figure 44.

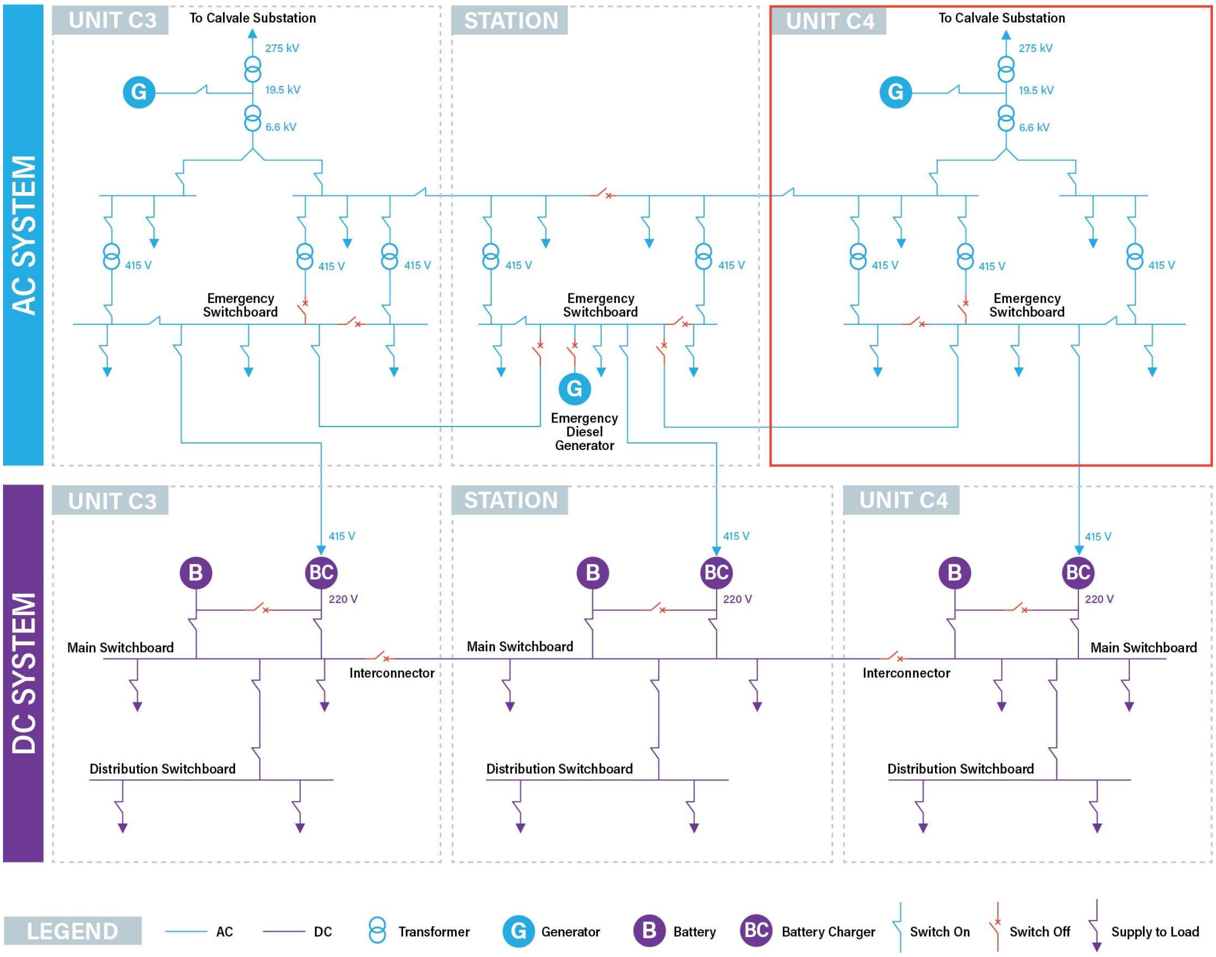


Figure 44 Unit C4 AC system (indicated in red)

The sections that follow explain the various components of the Unit C4 AC system.

5.3.1 Generator

Figure 45 shows the Unit C3 generator (which is identical to the Unit C4 generator).[55]

[55] At a number of locations in this report, various Unit C3 equipment is used to illustrate Unit C4 in an undamaged state.

Figure 45 Unit C3 generator

5.3.2 Generator Circuit Breaker and Generator Transformer

Unit C4 generates AC electricity at 19.5 kV, which is exported to the grid via the generator circuit breaker and the generator transformer. The role of the generator circuit breaker is to connect and disconnect the generator to and from the grid. Figure 46 shows the Unit C3 generator circuit breaker, which is identical to Unit C4.

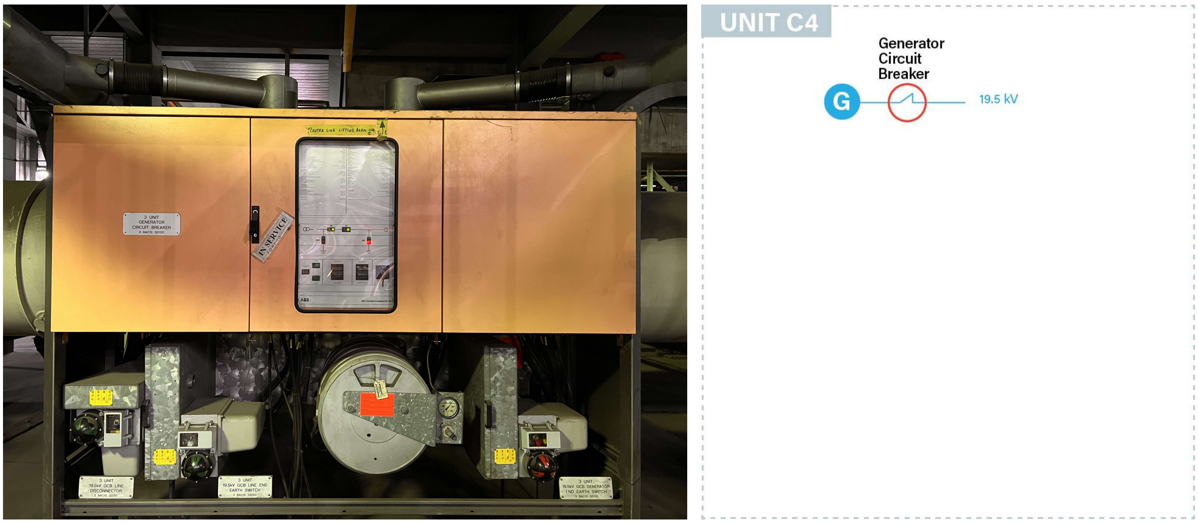


Figure 46 Unit C3 generator circuit breaker

Figure 47 shows the Unit C3 generator transformer (which is identical to the Unit C4 generator transformer), located outside the turbine hall.

Figure 47 Unit C3 generator transformer

The generator transformer converts electricity produced by the generator from 19.5 kV to 275 kV, which is the transmission grid voltage. The generator transformer's cooling fans are evident in the foreground of the figure.

5.3.3 Calvale Substation

The electricity supply generated from Unit C4 passes through overhead cables to Calvale substation, which is operated by Powerlink, see Figure 48.

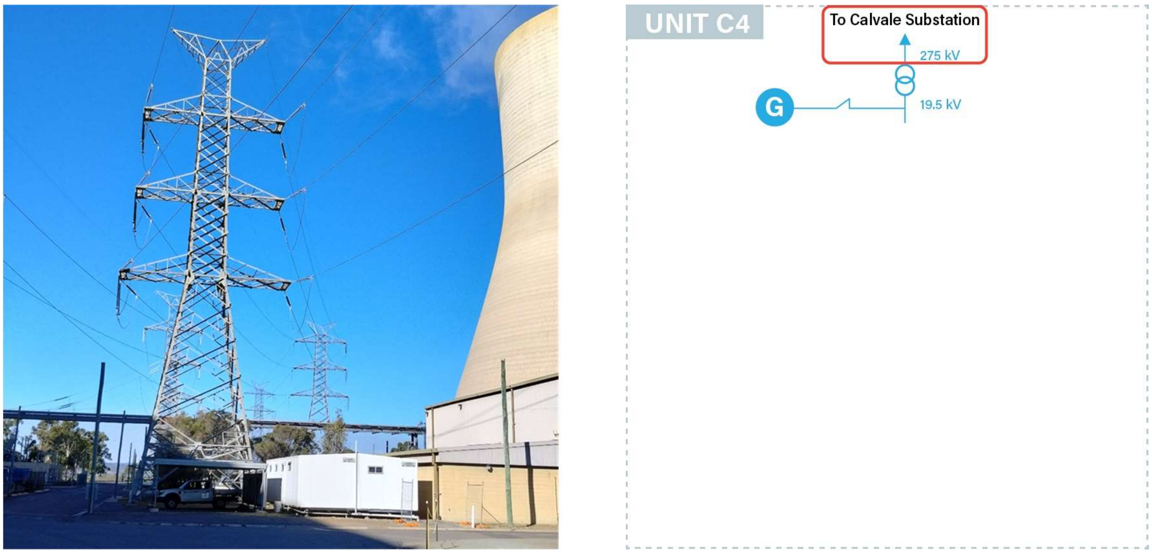


Figure 48 Transmission lines from Unit C4 to Calvale substation (circled in red)

5.3.4 Step-Down Transformer

The 19.5 kV supply from the generator passes through another transformer that steps down the voltage to 6.6 kV. This 6.6 kV voltage supplies the Unit C4 AC system. Figure 49 shows the Unit C3 step-down transformer, which is identical to that in Unit C4.

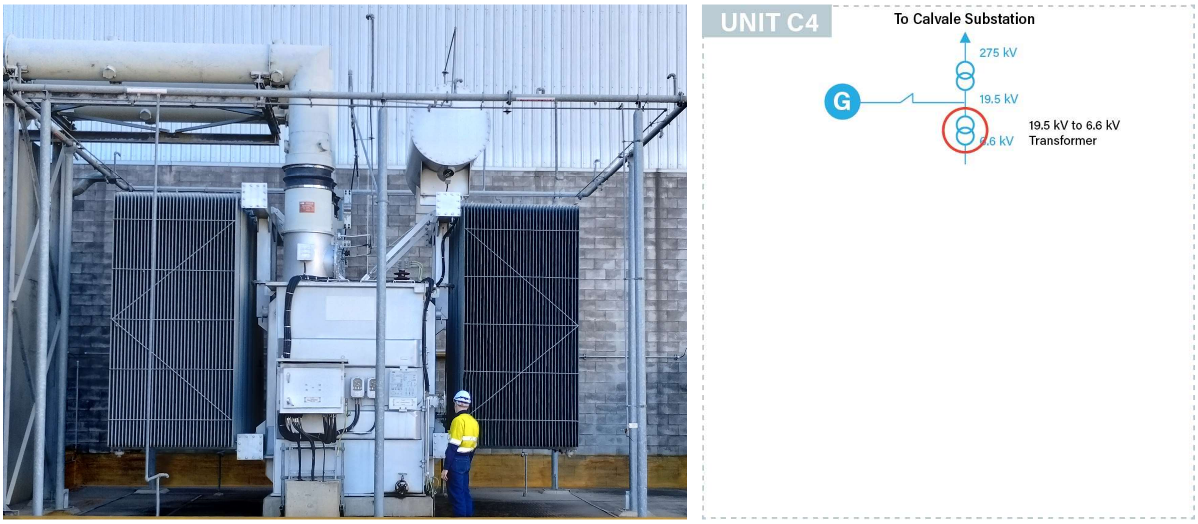
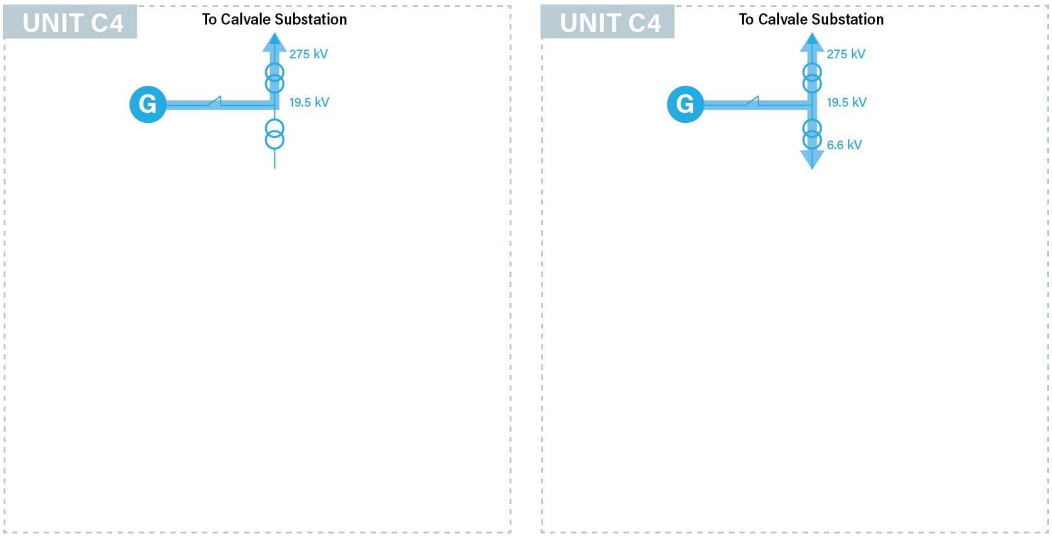


Figure 49 Unit C3 step-down transformer (circled in red)

5.3.5 Importing and Exporting AC Power

When the generator is operating normally, electricity is both exported to Calvale substation and used to supply the Unit C4 electrical system, see Figure 50.



(a) Generator exports to Calvale substation   *(b) Generator also supplies Unit C4*

Figure 50 Unit C4 generator exporting to Calvale substation and supplying Unit C4 AC system

5.3.6 6.6 kV Incomer Circuit Breakers

The 6.6 kV AC supply to Unit C4 passes through two 6.6 kV incomer circuit breakers (housed in cabinets), see Figure 51.[56]

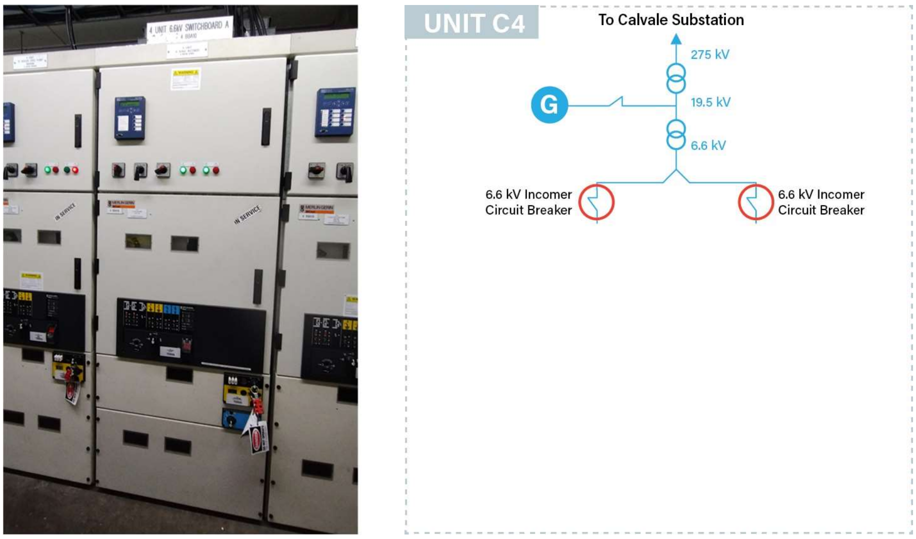


Figure 51 6.6 kV incomer circuit breakers (circled in red)

The purpose of the 6.6 kV incomer circuit breakers is to connect and disconnect the AC supply to the unit.

5.3.7 Switchboards

The AC supply is distributed to two 6.6 kV switchboards, which supply large equipment. Figure 52 illustrates the 6.6 kV switchboards.[57]

[56] The previous chapters referred to these breakers as 'AC incomer circuit breakers'. From this point onwards in this report, they are referred to as '6.6 kV incomer circuit breakers'.

[57] For simplicity, in this report, various circuit breakers and switchgear have been referred to as 'switches'. Electrical equipment connected to a switchboard is referred to as a 'load'.

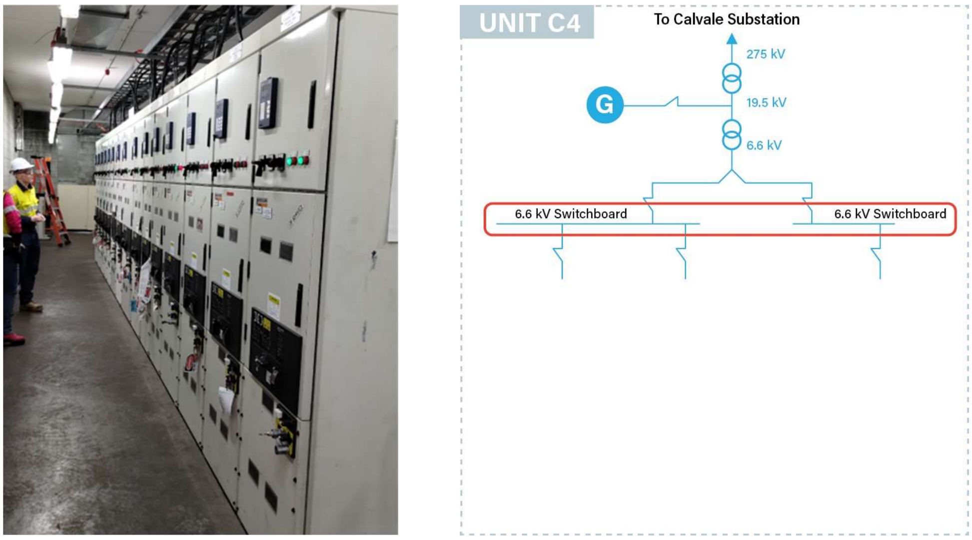


Figure 52 6.6 kV AC switchboards (circled in red)

5.3.8 Transformers

The 6.6 kV supply connects to a number of transformers, which step the voltage down to 415 V, see Figure 53.

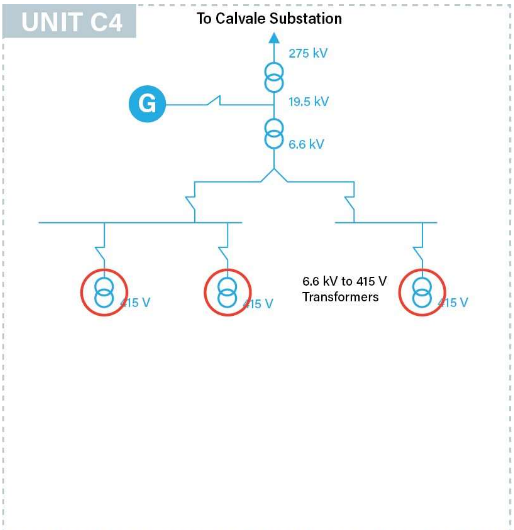


Figure 53 Transformers (circled in red)

The 415 V AC supplies various small loads, such as motors, fans, valves, pumps, lighting, power outlets, and air conditioning.

5.3.9 415 V Emergency Switchboard

The 415 V AC supply connects to an emergency switchboard, which supplies equipment critical for the safe operation of Unit C4, see Figure 54.[58]

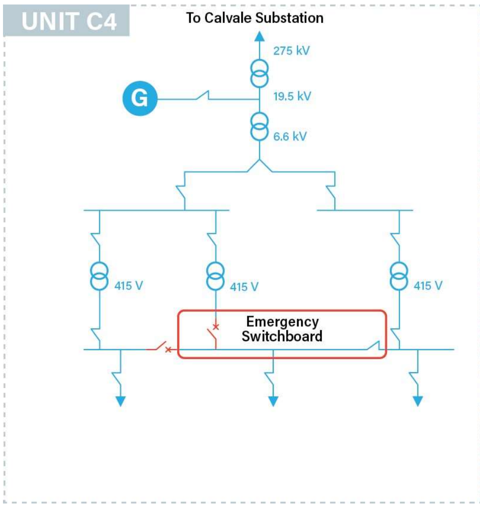


Figure 54 Unit C4 415 V AC switchboards (emergency switchboard location in red)

The emergency switchboard – which, despite its name, provides supply in typical operation as well as in an emergency – supplies critical equipment, such as the main lubrication oil pumps and the battery charger.

5.4 Introduction to the Wider Callide C AC System

This section explains the wider AC system at Callide C power station.

5.4.1 Unit C3 and Station AC Systems

In addition to the Unit C4 AC system, there is a Unit C3 AC system and a Station AC system. The Unit C3 AC system is identical to Unit C4, see Figure 55.

[58] While the emergency switchboard is the primary 415 V switchboard discussed in this report, there are multiple 415 V AC switchboards, including a single phase (240 V AC) switchboard provided via a UPS/inverter.

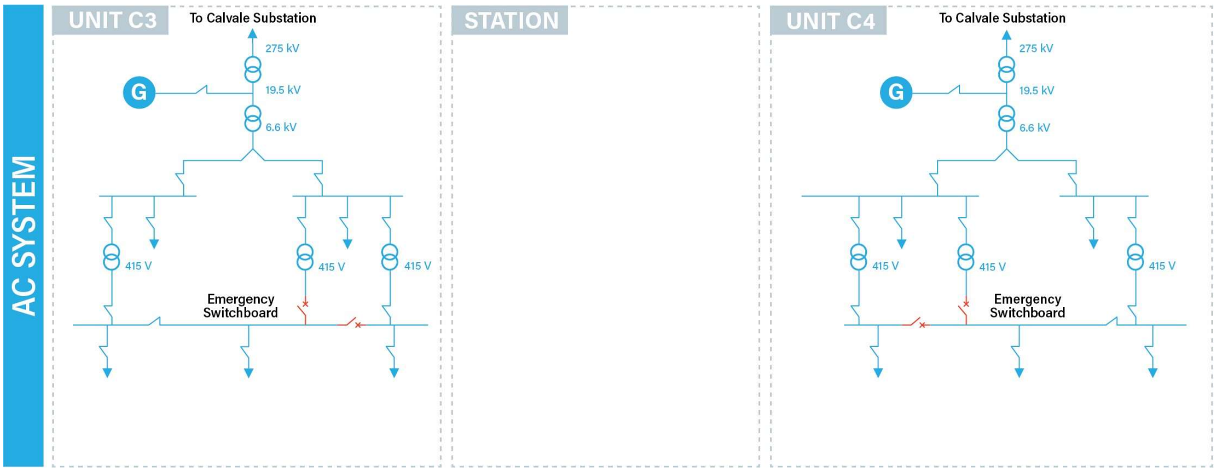


Figure 55 Unit C3 and Unit C4 AC systems

The Station AC system is located between the Unit C3 and Unit C4 AC systems. It has its own 6.6 kV to 415 V transformers, and its own 415 V emergency switchboard, see Figure 56.

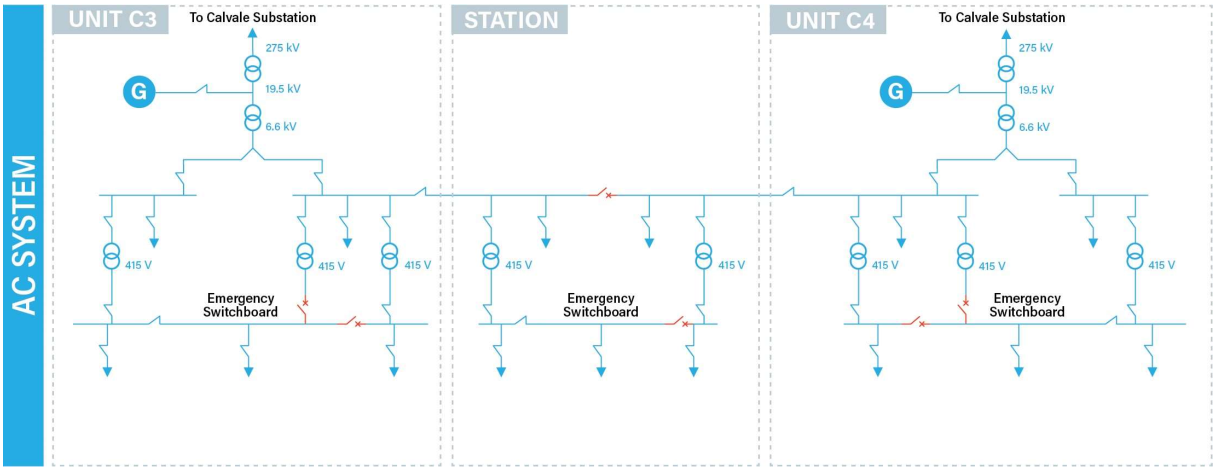


Figure 56 Unit C3, Station and Unit C4 AC systems

Station does not have a turbine generator, but instead receives AC supply from Unit C3 and Unit C4. Figure 57 illustrates the Station AC system being partially supplied from Unit C3 (the partial supply from Unit C4 is not illustrated).

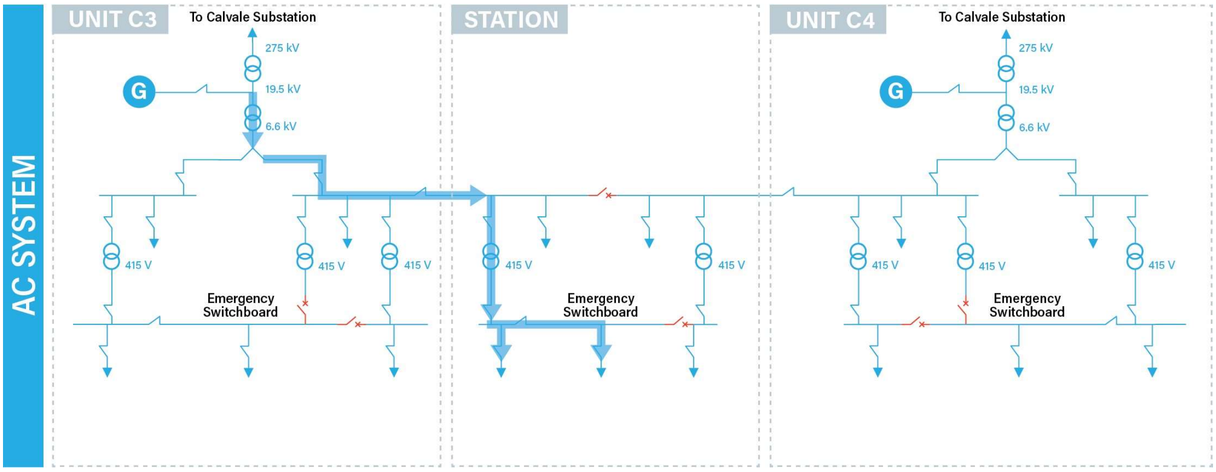


Figure 57 Unit C3 supplying parts of the Station AC system

The 415 V emergency switchboards supply key AC equipment and systems. These switchboards are connected via switches, which means that the Callide C AC system can, under certain circumstances, be configured to allow distribution of AC supply to other specific switchboards. Figure 58 shows the connection between the Unit C3, Station and Unit C4 emergency switchboards.

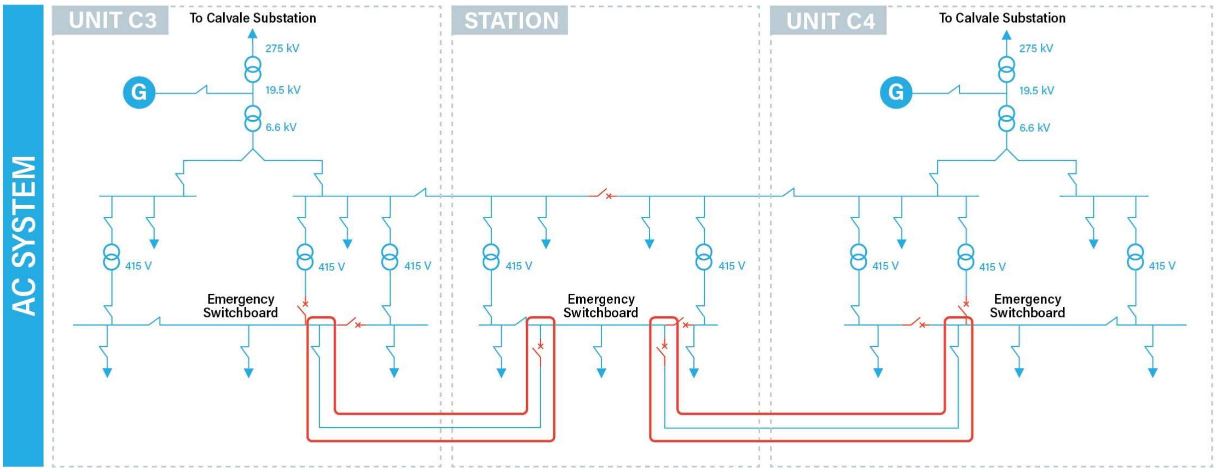


Figure 58 Connection between the Unit C3, Station and Unit C4 emergency switchboards

5.4.2 Callide C Emergency Diesel Generator

Figure 59 shows the emergency diesel generator at Callide C.

Figure 59 Emergency diesel generator

If a loss of AC supply occurs, the emergency diesel generator will start automatically and connect to the Station emergency switchboard. The Station emergency switchboard can then supply the Unit C3 and Unit C4 emergency switchboards, via switches. Figure 60 illustrates the Unit C4 emergency switchboard receiving AC supply directly from the Station emergency switchboard.

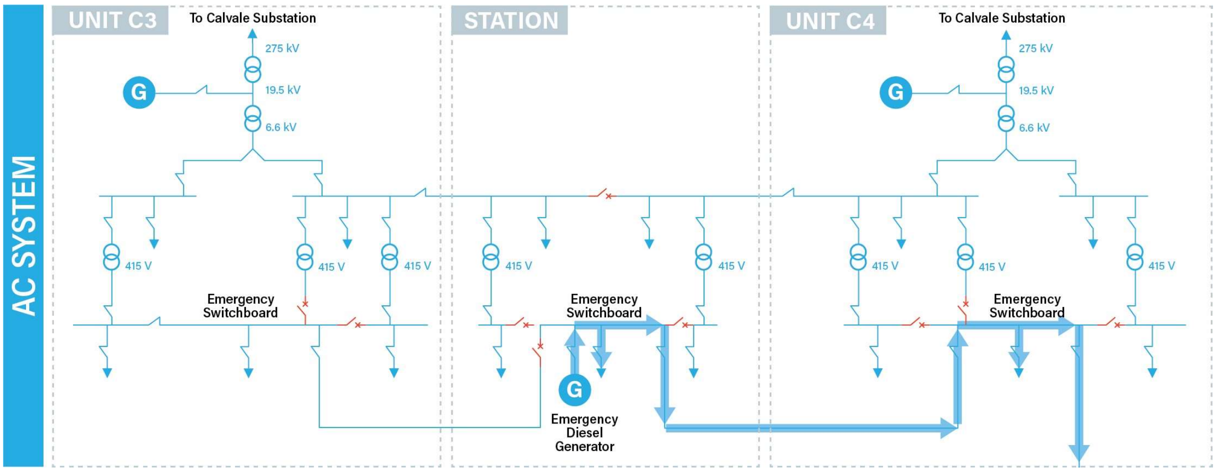


Figure 60 AC supply from emergency diesel generator to Station emergency switchboard and Unit C4 emergency switchboard

5.5 Introduction to the Unit C4 DC System

The Unit C4 DC system is shown in red in Figure 61.[59]

[59] The DC system operates at a nominal voltage of 220 V. This nominal voltage is depicted in the figures. When relevant, the actual (or approximate) voltage of the DC system is used in the text.

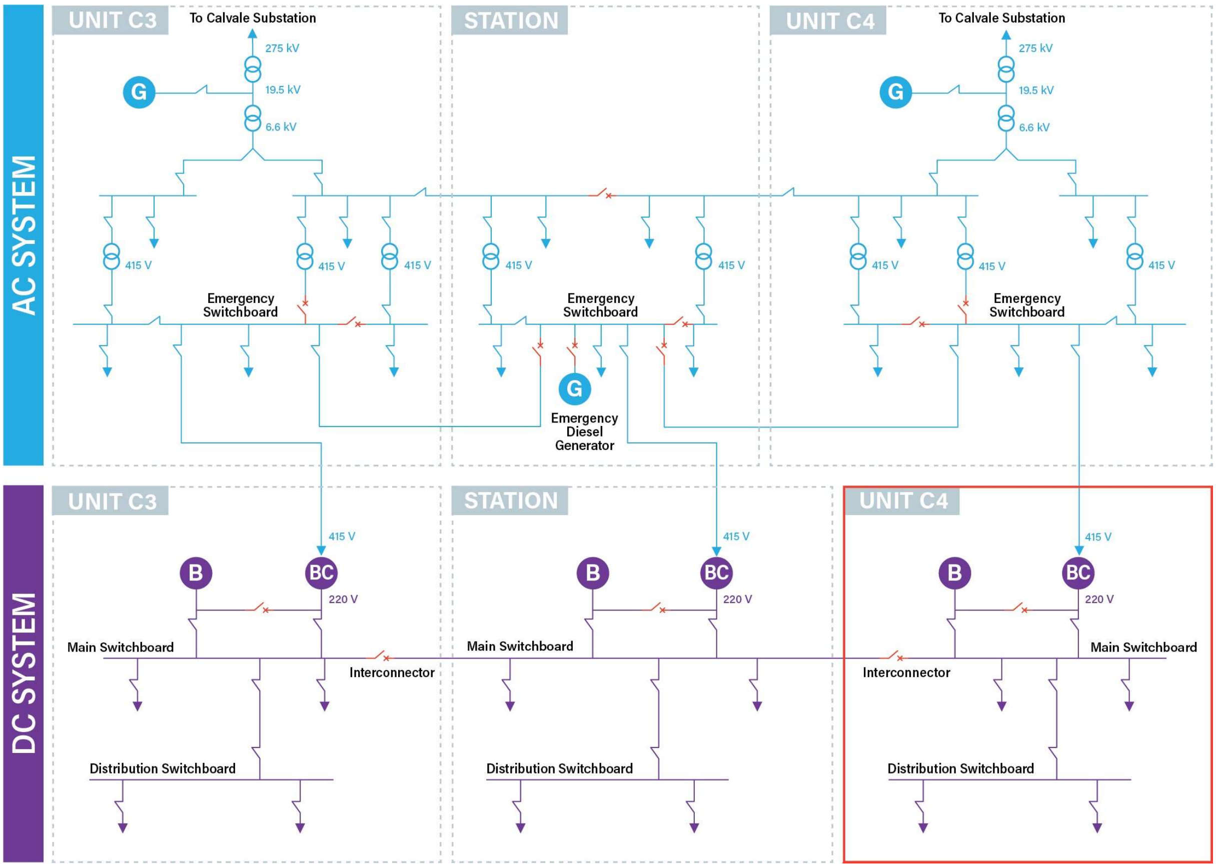


Figure 61 Unit C4 DC system (indicated in red)

5.5.1 Battery Charger and Battery

The Unit C4 DC system has two sources of supply: a battery charger and a battery. Figure 62 shows the Unit C4 battery charger.

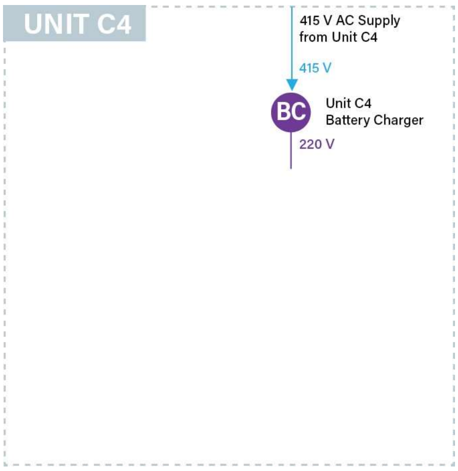


Figure 62 Unit C4 battery charger

Figure 63 shows the Unit C4 battery.[60]

Figure 63 Unit C4 battery

5.5.2 Main Switchboard

As shown in Figure 64, the Unit C4 battery charger and battery both connect to the Unit C4 main switchboard.[61]

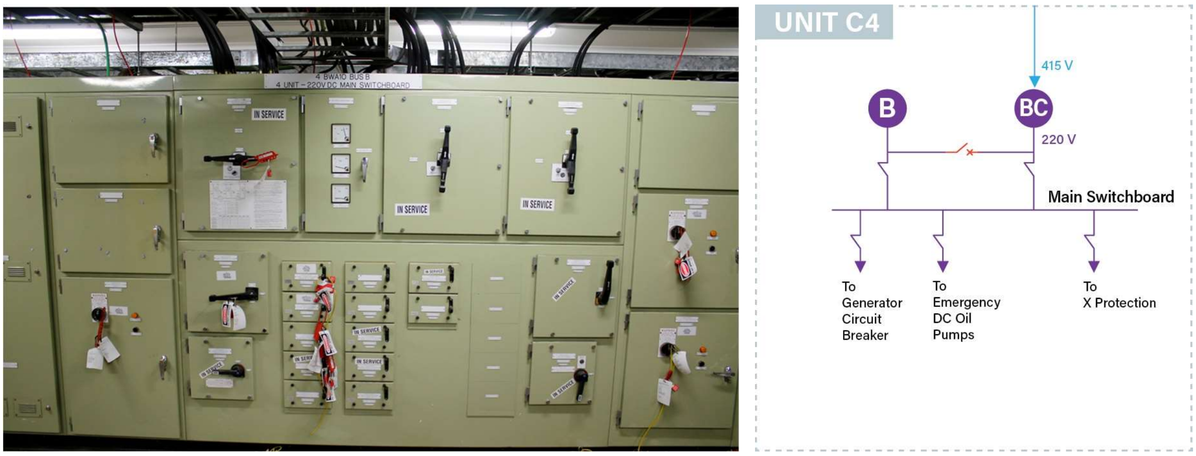


Figure 64 Unit C4 main switchboard

The main switchboard distributes DC supply to a range of systems. It supplies the emergency DC lubrication oil and seal oil pumps. It also supplies power to the Unit C4 generator circuit breaker, which can operate automatically or be operated remotely from the control room.[62]

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[60] The Unit C4 battery consists of a string of 108 individual cells connected in series, which are collectively referred to as the 'Unit C4 battery'.

[61] There is also a switch that connects the battery charger and battery directly to one another, without the battery charger or battery being connected to the main switchboard. This switch allows the battery charger to charge the battery directly, without supplying any of the Unit C4 loads. This configuration is referred to as 'offline charging mode'.

[62] The Unit C4 main switchboard also supplies the Unit C4 uninterruptable power supply (UPS).

The main switchboard also supplies the unit's 'X protection' system, which monitors and protects the turbine generator.[63] When the X protection system detects a fault or issue, it takes appropriate action, such as safely shutting down the unit and disconnecting it from the grid.

5.5.3 Relationship Between Battery Charger and Battery

The relationship between the Unit C4 battery charger and battery is as follows. The primary role of the battery charger is to provide DC supply to the equipment in the DC system, while also keeping the battery at a full state of charge.[64] Therefore, the battery charger should be considered the primary source of supply to the DC system, as illustrated in Figure 65.

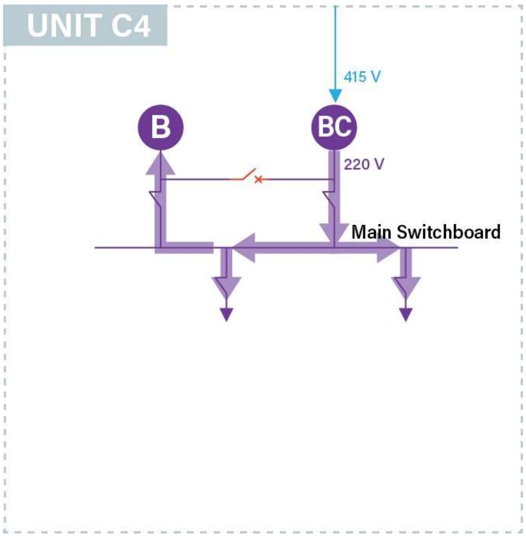

Figure 65 Battery charger as primary source of DC supply to Unit C4

The primary role of the battery is to provide important redundancy should the battery charger cease operating. For example, if the battery charger loses its AC supply, it will shut down. If this occurs, the battery takes over the role of providing supply to the DC system.[65] The battery therefore provides redundancy, as illustrated in Figure 66.

---

[63] The X protection and Y protection (discussed in Section 5.5.4) monitor the generator, generator transformer, unit transformer and excitation system for electrical faults. The X and Y protection responds to trip signals from the turbine protection system and Calvale substation (which are separate from the X and Y protection systems). The X and Y protection can also send trip signals to the turbine and boiler in the event of an electrical fault on the generator, generator transformer, unit transformer and excitation system. Depending on the nature of the fault, the X and Y protection can trip the generator circuit breaker and, in certain conditions, send intertrip signals to Calvale substation and trip the 6.6 kV incomer circuit breakers.

[64] The battery also supplies some current during dynamic changes in load because the battery charger may not be able to respond quickly enough to these changes. In this situation, the battery charger then adjusts its output to provide for this additional load, and restores the battery back to its full state of charge. This behaviour is explored in detail in Appendix A4 *Battery Charger Investigation*.

[65] As well as providing redundancy, the battery also supplies some current during dynamic changes in load. In this situation, the battery charger adjusts its output to provide for this additional load and restore the battery back to its full state of charge. This behaviour is explored in detail in Appendix A4 *Battery Charger Investigation*.

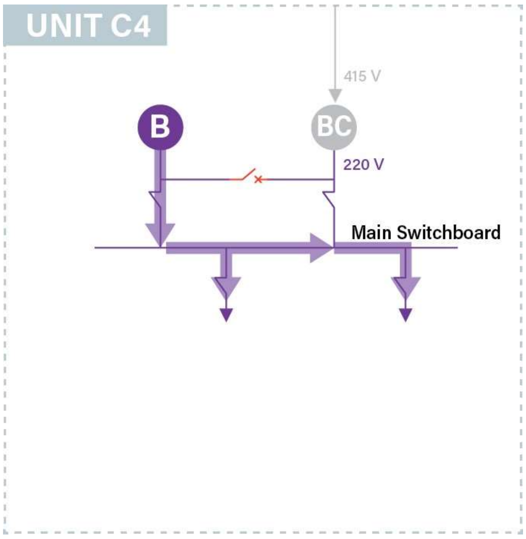

Figure 66 Battery providing DC supply to Unit C4

The Unit C4 battery can supply the DC system for several hours. This gives sufficient time for operators to respond and restore the battery charger output, or safely shut down the turbine generator.

5.5.4 Distribution Switchboard

The DC supply is routed from the main switchboard to the Unit C4 distribution switchboard, see Figure 67.

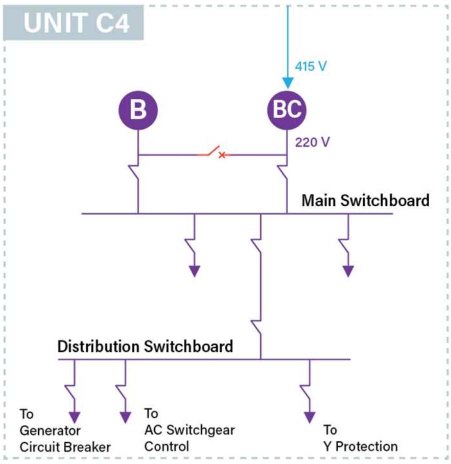

Figure 67 Unit C4 DC distribution switchboard

The Unit C4 distribution switchboard also distributes DC supply to a range of systems. It provides supply to the unit's 'Y protection' system. Similar to the X protection system discussed above, the Y protection system also takes appropriate action when it detects an issue with the unit's operation.

The distribution switchboard also provides an additional supply to the Unit C4 generator circuit breaker.

It also provides DC supply to what is referred to as the 'AC switchgear control'. The AC switchgear control allows AC switches and AC circuit breakers to be operated remotely from the control room and to operate automatically.

5.6 Introduction to the Wider Callide C DC System

This section explains the wider DC system at Callide C power station.

5.6.1 Unit C3 and Station DC Systems

The Unit C3 and Station DC systems are identical to Unit C4, see Figure 68.

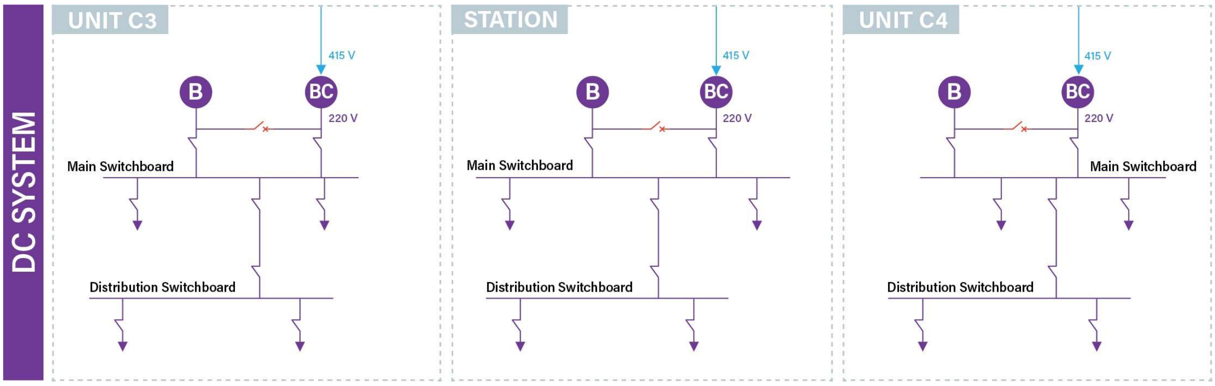

Figure 68 Callide C DC system

Unlike the Station AC system, which receives supply from Unit C3 and Unit C4, the Station DC system receives supply from its own battery charger and battery.

The Station, Unit C3, and Unit C4 DC systems can be configured to interconnect with one another via switches called 'interconnectors', see Figure 69.

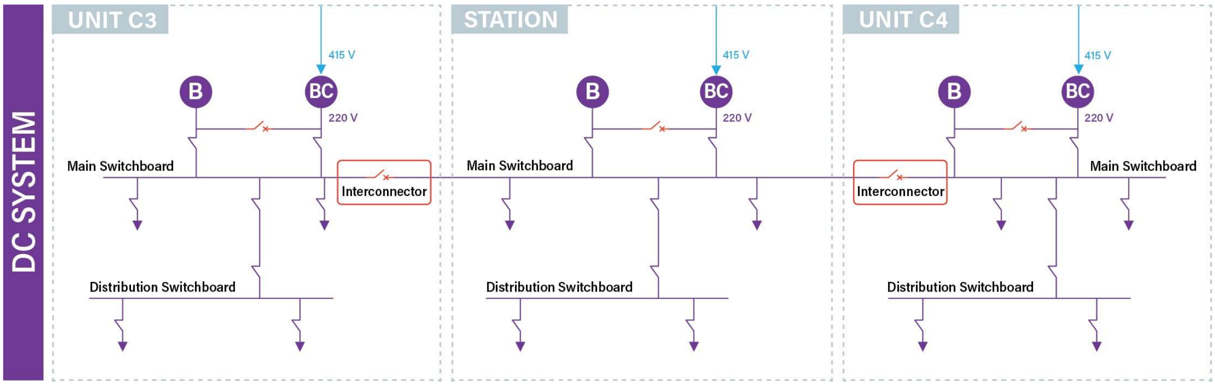

Figure 69 Callide C DC system interconnectors (indicated in red)

5.6.2 Automatic Changeover Switches

The Station, Unit C3 and Unit C4 DC systems each have a switch called the automatic changeover switch. Each switch can automatically respond and operate in the event of a loss of supply to its DC system. The Unit C4 automatic changeover switch is shown in Figure 70.

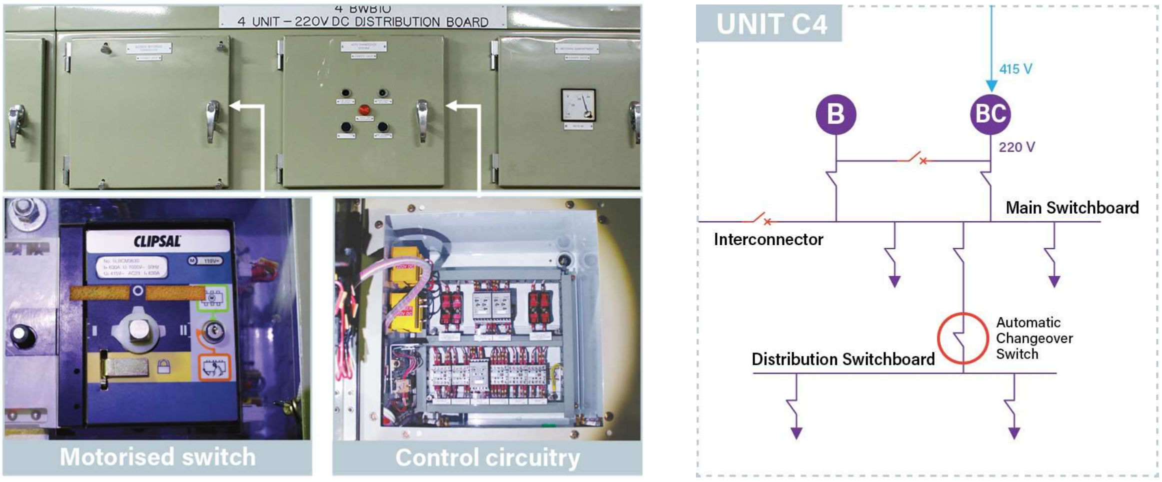

Figure 70 Unit C4 automatic changeover switch

As discussed above, the Unit C4 distribution switchboard supply is usually supplied from the Unit C4 main switchboard, and this occurs via the automatic changeover switch, as illustrated in Figure 71.

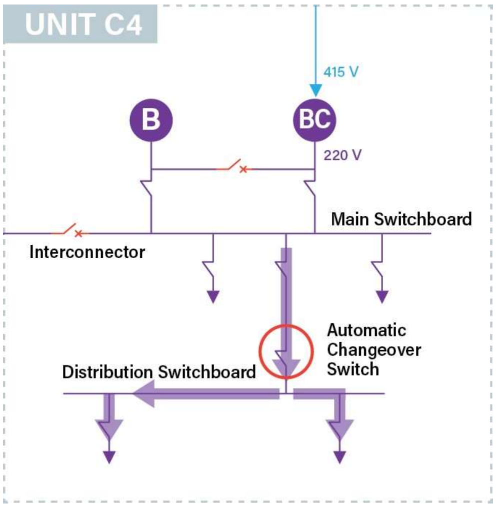

Figure 71 Unit C4 distribution switchboard supplied through automatic changeover switch

The Unit C4 automatic changeover switch also has a connection from the Station main switchboard, see Figure 72.

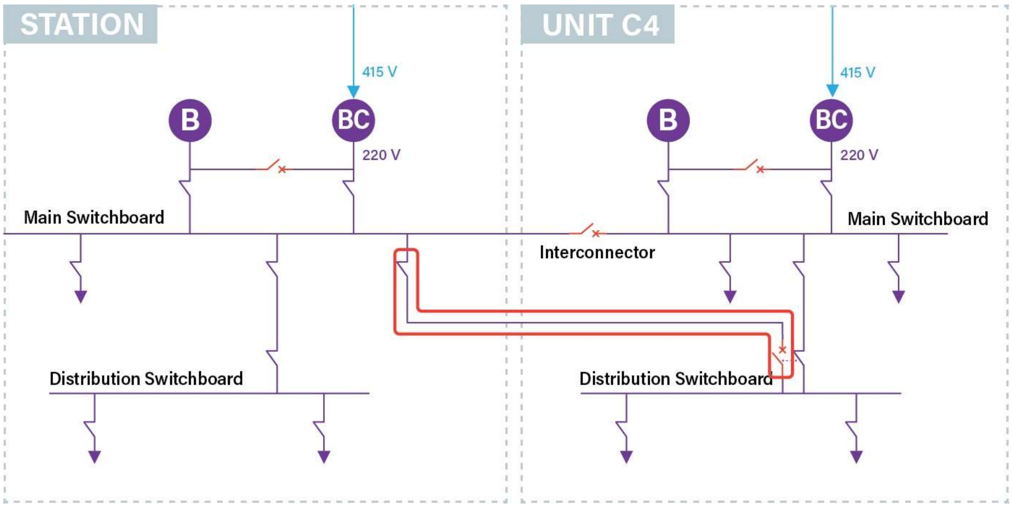

Figure 72 Automatic changeover switch connects to Station main switchboard

If a loss of DC supply occurs in Unit C4, the automatic changeover switch can automatically operate and disconnect the unit distribution switchboard from the unit main switchboard. This switch then 'changes over' to supply the Unit C4 distribution switchboard from the Station main switchboard, see Figure 73.[66]

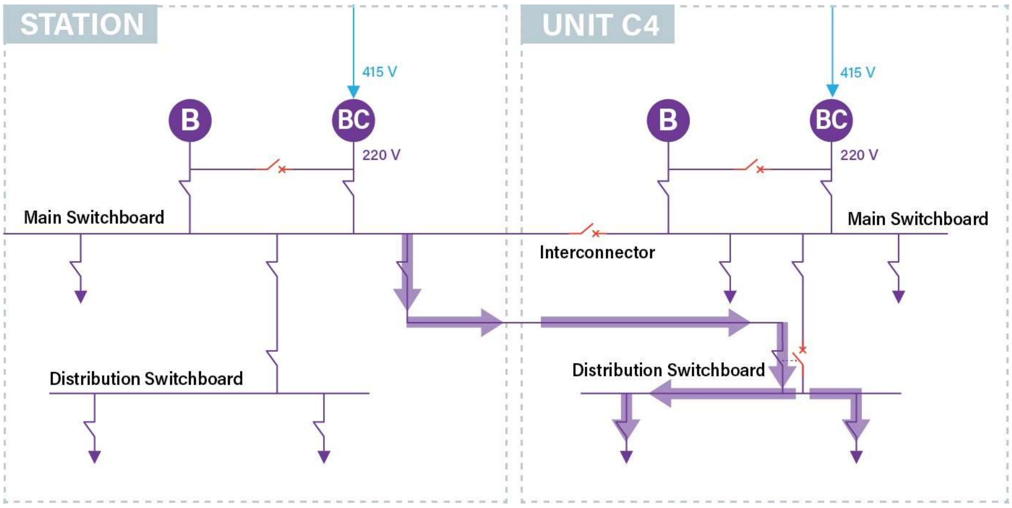

Figure 73 Unit C4 distribution switchboard supplied from the Station main switchboard

5.7 Relationship Between the Callide C AC and DC Systems

Although the Callide C AC and DC systems are separate systems, there are relationships between them.

[66] The Unit C4 automatic changeover switch operates by first disconnecting the supply from the Unit C4 main switchboard, then connecting the supply from the Station main switchboard. This is known as 'break before make'. The changeover takes up to two seconds.

5.7.1 AC System to DC System Relationship

Within each DC system, the battery charger receives its AC supply from the corresponding AC system, as shown in Figure 74.

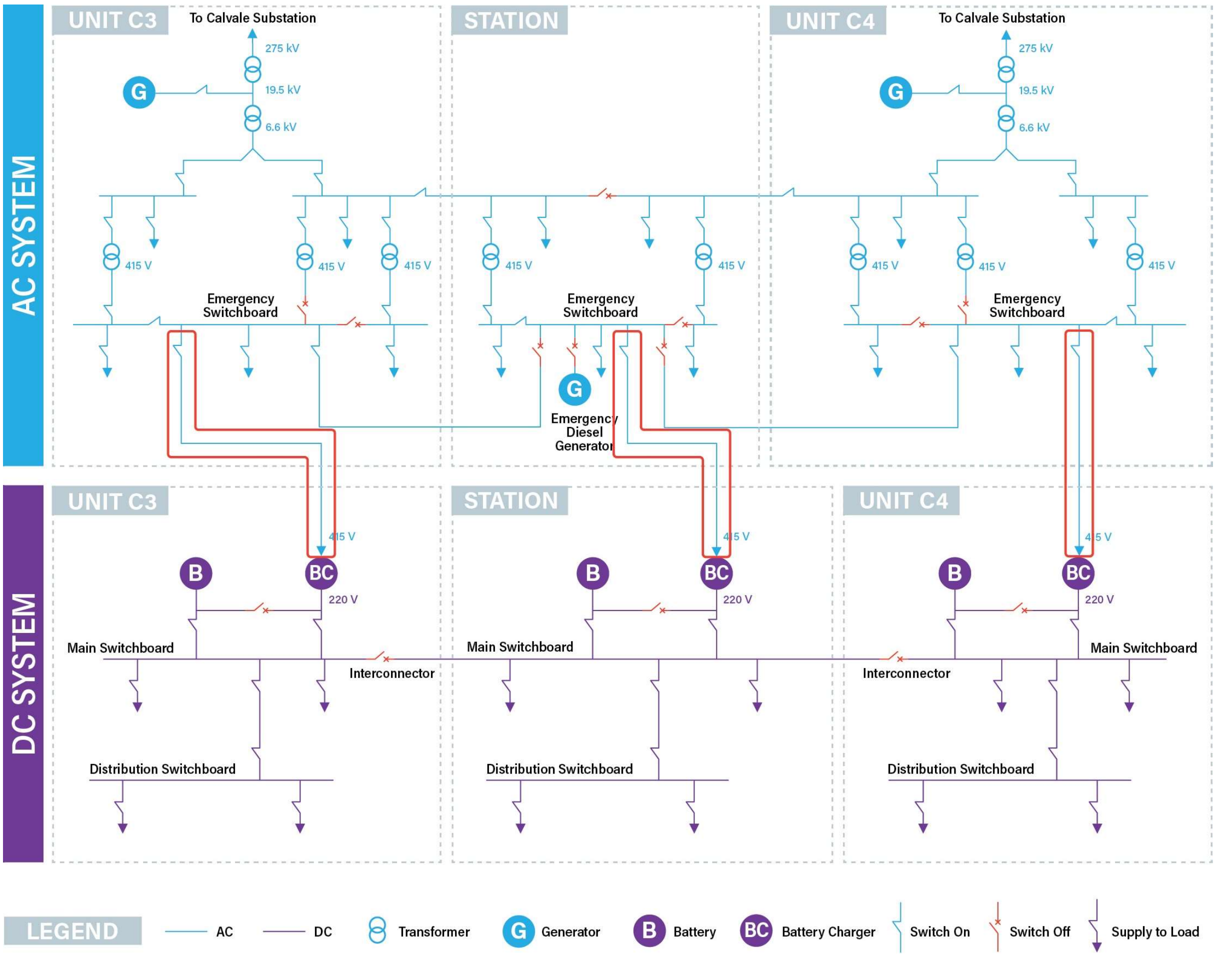

Figure 74 AC supply to each DC battery charger (indicated in red)

5.7.2 DC System to AC System Relationship

The AC system contains switches that require DC supply to operate automatically (or be operated remotely from the control room).[67] The DC supply to the AC switches is called the AC switchgear control. The Unit C3, Station and Unit C4 AC switchgear control receive their DC supply from their own DC system's distribution board. For example, the Unit C4 AC switchgear control receives its DC supply from the Unit C4 distribution board, see Figure 75.

[67] This includes the generator circuit breakers of Unit C3 and Unit C4, all the 6.6 kV circuit breakers, and a number of the 415 V circuit breakers.

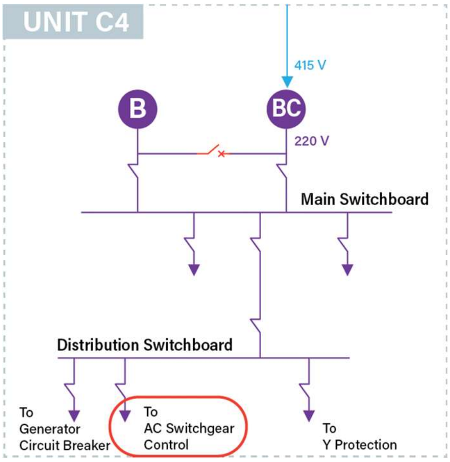

Figure 75 Unit C4 AC switchgear control is supplied by the Unit C4 distribution board

5.8 Chapter Summary

This chapter provided a more detailed discussion of how the Callide C electrical system operates. The next chapter examines the switching sequence taking place on Unit C4 at the time of the incident.

6 HOW THE SWITCHING SEQUENCE INITIATED THE INCIDENT

6.1 Introduction

This chapter discusses how the switching sequence taking place on 25 May 2021 initiated the incident. It provides a background to the switching sequence, examines the typical configurations of the AC and DC systems, and discusses how the steps in the sequence were consistent with the physical design of the DC system.

6.2 Background to the Switching Sequence

Prior to the switching sequence commencing to bring the replacement Unit C4 battery charger into service, neither the Callide C AC system nor the Callide C DC system were in their typical electrical configuration. The AC system was in a different configuration to facilitate maintenance, and the DC system was in a different configuration to facilitate the replacement of the Unit C4 battery charger.

6.2.1 Callide C AC Configuration Prior to the Switching Sequence

The Callide C AC system's typical configuration is for the Station AC system to receive supply from both the Unit C3 and Unit C4 AC systems. Figure 76 illustrates the typical Callide C AC system configuration, highlighting the parts of the Station AC system typically supplied by Unit C4.

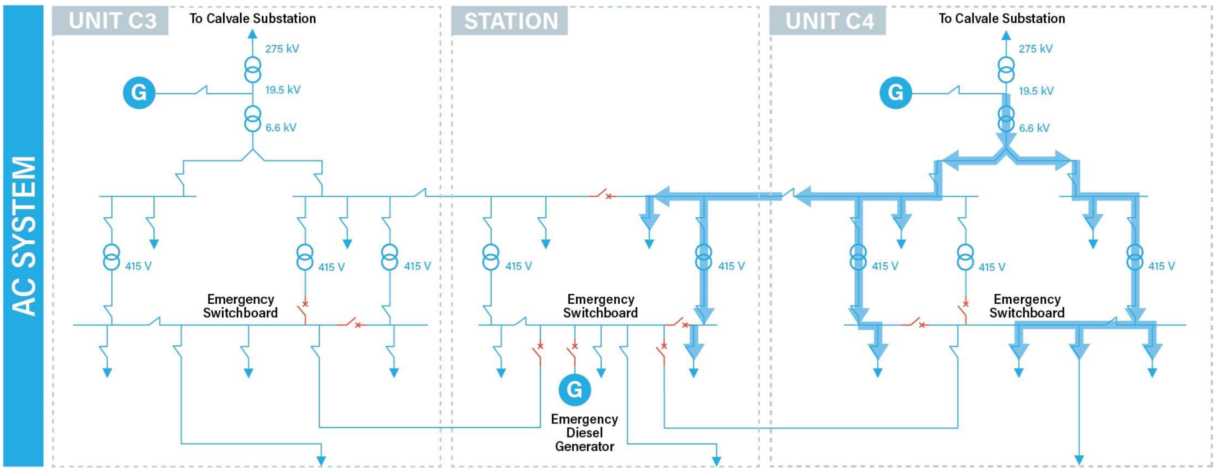

Figure 76 Typical Callide C AC system configuration (arrows highlight parts of the Station AC system supplied by Unit C4)

On the day of the incident, the Callide C AC system was not in its typical configuration. Instead of the Station AC system receiving its supply from each of the units, it was receiving its supply entirely from Unit C4. Figure 77 illustrates this different configuration, with the key differences indicated in red.

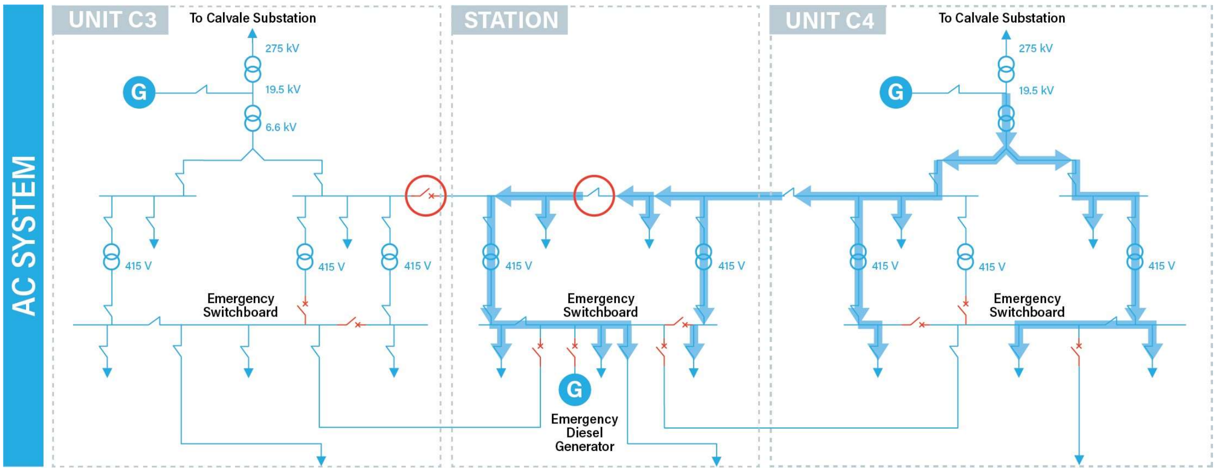

Figure 77 Callide C AC system configuration on the day of the incident

The key differences were:

- The 6.6 kV switch between Unit C3 and Station was open.
- The 6.6 kV switch on Station was closed.

This configuration on the day of the incident was in accordance with the design of the Callide C AC system and was in place to facilitate maintenance of the 6.6 kV switch between Unit C3 and Station.

6.2.2 Callide C DC System Configuration Prior to the Switching Sequence

The Callide C DC system's typical configuration is for each DC system to be supplied by its own battery charger and battery. Figure 78 illustrates this typical configuration.

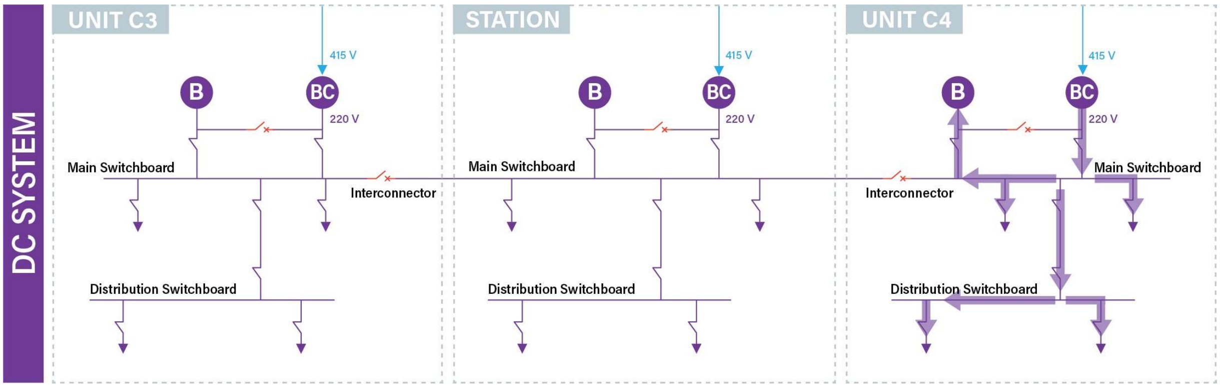

Figure 78 Typical Callide C DC system configuration (Unit C4 battery charger supplies the Unit C4 DC system)

On the day before the incident, when the switching sequence to bring the replacement Unit C4 battery charger into service commenced, the Unit C4 DC system was not in its typical configuration. Instead of the Unit C4 DC system receiving supply from its own battery charger and battery, the Unit C4 DC system was receiving its supply from the Station DC system. In this configuration, the Unit C4 battery charger and battery were not connected to Unit C4. Figure 79 illustrates this different configuration, with the key differences indicated in red.

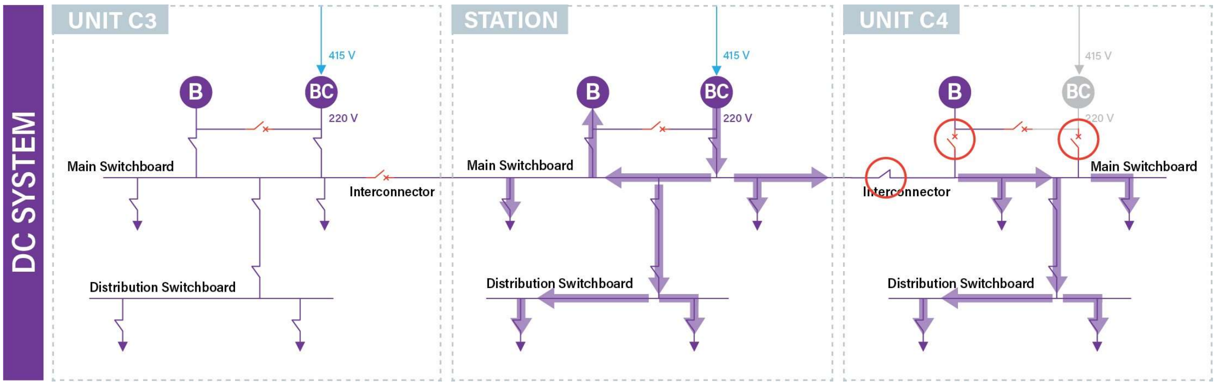

Figure 79 Callide C DC system configuration on the day before the incident (Station battery charger supplies the Unit C4 DC system)

The key differences were:

- The Unit C4 battery charger and battery were not connected to the Unit C4 main switchboard, and were not providing supply.
- The interconnector between Station and Unit C4 was closed.

This configuration was in accordance with the design of the Callide C DC system, and it was in place to facilitate the replacement of the Unit C4 battery charger, which had been underway since February 2021.

6.3 The Switching Sequence

6.3.1 Planned Switching Sequence

On 24 May 2021, the day before the incident, the switching sequence commenced to restore the Unit C4 DC system to its typical configuration.

This planned switching sequence was to:

(a) Connect the replacement battery charger to the existing Unit C4 battery (to bring it to a full state of charge overnight).

(b) The following day (25 May 2021), disconnect the replacement battery charger from the existing battery.

(c) Connect the replacement battery charger to the Unit C4 DC system.

(d) Disconnect the Station DC supply from the Unit C4 DC system.

(e) Connect the existing battery to the Unit C4 DC system.

The replacement Unit C4 battery charger and existing battery would then be supplying the Unit C4 DC system. This would be the first time the replacement Unit C4 battery charger would be connected to the Unit C4 DC system.

The sections that follow discuss the planned switching sequence.

6.3.2 Charging the Unit C4 Battery

The first step in the planned switching sequence was to connect the replacement Unit C4 battery charger to the battery to charge it overnight. This step was completed on 24 May 2021, and the battery was restored to a full state of charge, see Figure 80.[68]

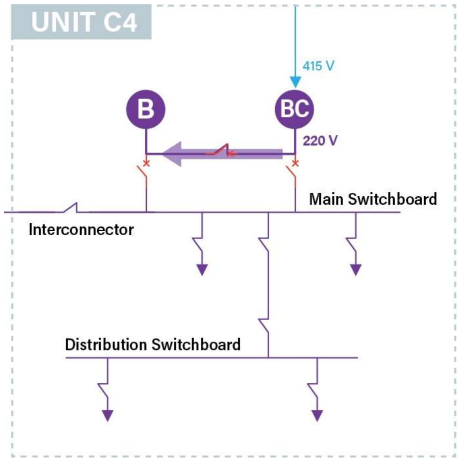

Figure 80 Charging on the day before and morning of the incident

In this configuration, neither the battery charger nor battery were connected to the Unit C4 DC system main switchboard.

6.3.3 Disconnecting the Battery Charger

With the battery restored to a full stage of charge, the next step in the planned switching sequence was to disconnect the replacement Unit C4 battery charger from the battery. This step was completed just before 1:30 pm on 25 May 2021, the day of the incident, see Figure 81.

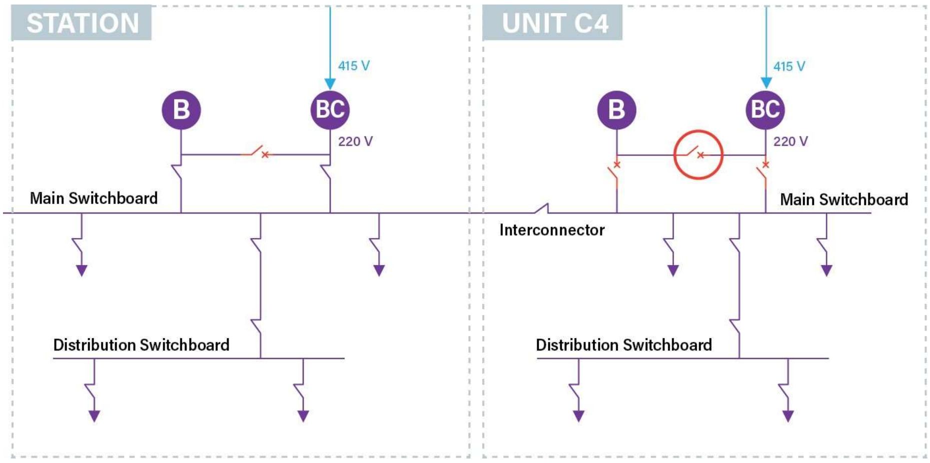

Figure 81 Disconnection of the Unit C4 battery from the Unit C4 battery charger

68 This configuration is referred to as 'offline charging'. The Unit C4 battery had been disconnected for three months, and it was no longer at full charge.

6.3.4 Connecting the Battery Charger to Unit C4

The next step in the planned switching sequence was to connect the replacement Unit C4 battery charger to the Unit C4 DC system main switchboard. This step was completed at 1:32 pm on 25 May 2021, see Figure 82.

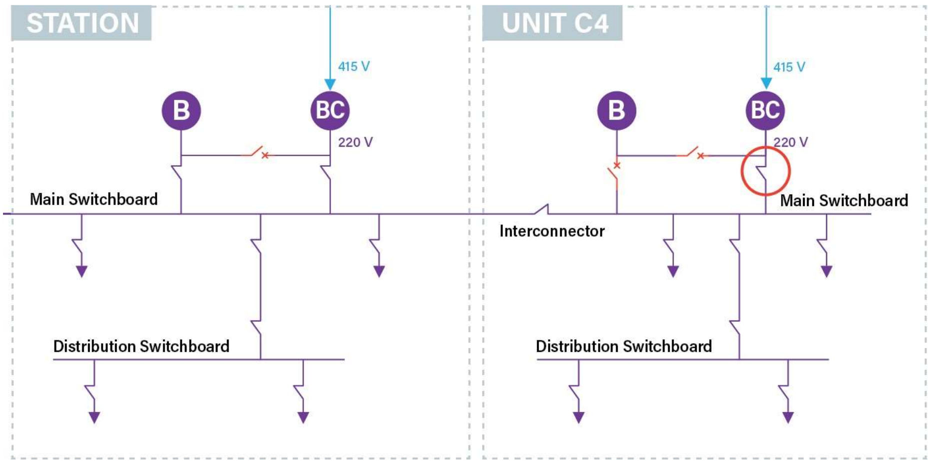

Figure 82 Connection of the Unit C4 battery charger to the Unit C4 DC system main switchboard

At this point in the switching sequence, the Station and Unit C4 DC systems were still connected (via the interconnector) and had three independent sources of supply available: the Station battery, the Station battery charger and the Unit C4 battery charger.[69]

As discussed further in Chapter 9 *How the Battery Charger Led to the DC Voltage Collapse*, the Brady Heywood investigation concluded that even though the Unit C4 battery charger was connected to the Unit C4 DC system – and had the potential to supply the Unit C4 DC system – it was the *Station battery charger* that continued to provide all supply (including maintaining the Station battery at a full state of charge), see Figure 83.

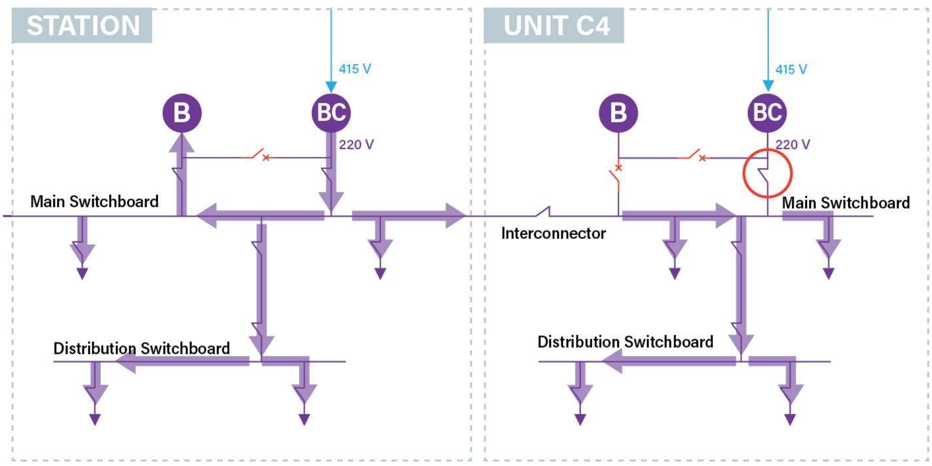

Figure 83 Station battery charger continues to provide all DC supply

[69] Note that while there were three sources of supply available, this does not necessarily mean all three sources were supplying the loads in the (connected) Station and Unit C4 DC system.

The Brady Heywood investigation concluded that, at this step in the switching sequence, the replacement Unit C4 battery charger was not providing any supply (i.e., not outputting power).

6.3.5 Disconnecting Station DC Supply

The next step in the planned switching sequence was to disconnect the Station DC supply from the Unit C4 DC system by opening the interconnector between the Station and Unit C4 DC systems. This step was completed at 1:33 pm on 25 May 2021, see Figure 84.

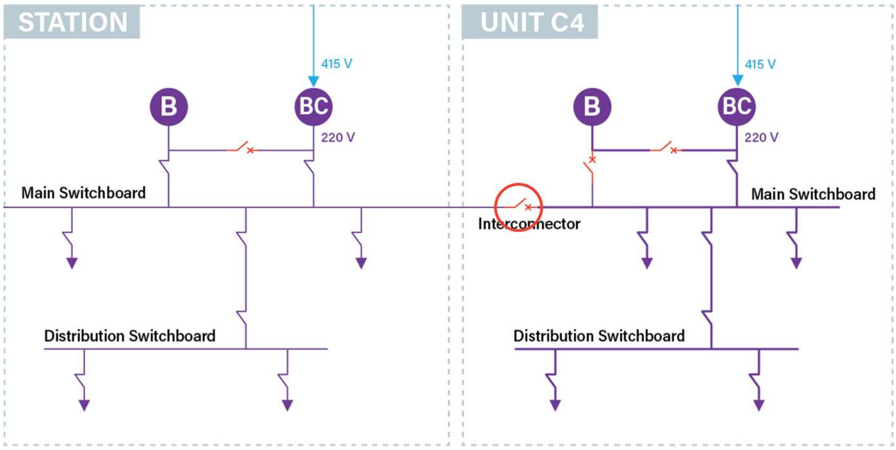

Figure 84 Disconnection of Station DC supply from the Unit C4 DC system

The disconnection of the Station DC supply (by opening the interconnector) initiated the voltage collapse in the Unit C4 DC system.

6.3.6 DC System Voltage Collapse

The DC system voltage collapse occurred in the following manner. When the Station DC supply was disconnected, the Unit C4 battery charger became the sole source of DC supply to Unit C4. The switching sequence, therefore, placed a requirement on the replacement Unit C4 battery charger to respond instantly to maintain the voltage in the Unit C4 DC system, as illustrated in Figure 85.

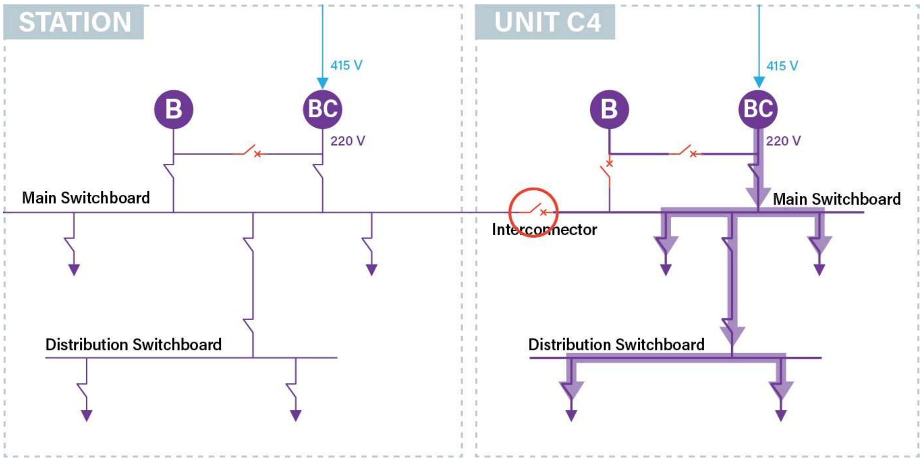

Figure 85 Requirement for the Unit C4 battery charger to maintain Unit C4 DC system voltage

However, on the day of the incident, when the Station DC supply was disconnected, the replacement Unit C4 battery charger was unable to respond instantly to maintain the DC system voltage. At this point in the switching sequence, there was an almost instantaneous collapse of voltage in the Unit C4 DC system, as illustrated in Figure 86.

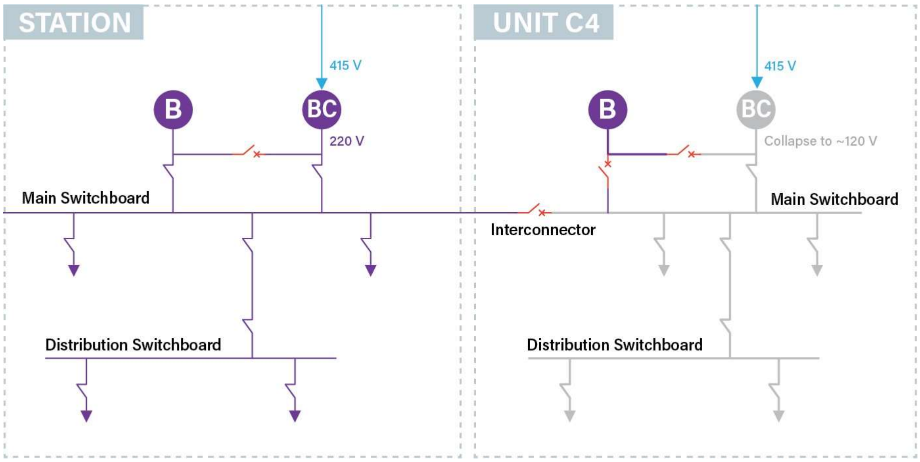

Figure 86 Collapse of DC supply to Unit C4 DC system (indicated in grey)

This reasons for this voltage collapse are discussed in detail in Chapter 9 *How the Battery Charger Led to the DC Voltage Collapse*.

6.3.7 Connecting the Unit C4 Battery (Did Not Occur)

The final step in the planned switching sequence was to connect the Unit C4 battery to the Unit C4 DC system main switchboard, see Figure 87.

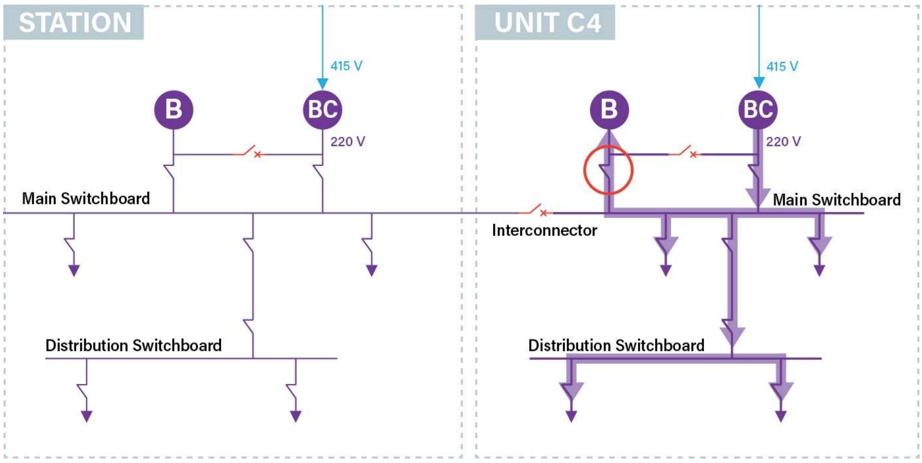

Figure 87 Planned connection of the Unit C4 battery to the Unit C4 DC system (did not occur)

This step, however, was not attempted or completed because the switching sequence was abandoned due to the commencement of the incident. If it had been completed, it would have restored the Callide C DC system to its typical configuration.

6.4 The Order of Steps in the Switching Sequence

6.4.1 DC System Physical Design

A step in the switching sequence required the Unit C4 battery charger to be the sole source of DC supply to Unit C4, without the redundancy provided by the Unit C4 battery (the battery was not connected). The order of the steps in the switching sequence meant that this redundancy could only be restored (by connecting the Unit C4 battery) *after* the Station DC supply was disconnected. Had the Unit C4 battery been connected *before* the Station DC supply was disconnected, it is highly likely that the battery would have maintained the voltage in the Unit C4 DC system when the Station DC supply was disconnected.

Although it may appear more logical to connect the Unit C4 battery *prior* to disconnecting the Station DC supply (providing redundancy to the Unit C4 DC system), the physical design of the DC system itself did not permit such a step.

The DC system's physical design prevents more than one battery being connected to the same DC system.[70] With the interconnector closed, the Station and Unit C4 DC systems were combined into a single electrical system (with the Station battery connected). The DC system's physical design, therefore, physically prevented the connection of the Unit C4 battery to this system, as this would have resulted in both the Unit C4 and Station battery being connected to the same DC system. The physical design, therefore, prevented the Unit C4 battery being connected to the DC system prior to the disconnection of the Station DC supply.

Once the interconnector was opened, however, the Station and Unit C4 DC systems were no longer connected as a single system, and the DC system's physical design no longer prevented the connection of the Unit C4 battery (because the Station battery was no longer connected).

Therefore, the order of steps in the switching sequence was consistent with the physical design of the DC system.

6.4.2 Trapped Key Interlock System

The physical system that prevents two batteries being connected to the same DC system is called a 'trapped key interlock system'.[71] This system works by requiring a key to operate certain switches. The operation of these switches results in keys being either 'trapped' or 'released'.

Figure 88 shows the order of the four switches that needed to be operated during the switching sequence on the day of the incident.[72]

[70] One reason for this physical design is that the Callide C batteries are rated at 2,000 Ah and connecting two 2,000 Ah batteries to the same DC system places them in parallel, which would exceed the DC switchgear short circuit rating. British Electricity International (1992) *Modern Power Station Practice Volume D – Electrical Systems and Equipment*, 3rd edition, 65.

[71] This system prevents certain switches from being operated unless other switches are in a known and proven state.

[72] In the diagram, letters are used to represent the steps in the switching sequence. 'Step A' is Step 190, 'Step B' is Step 200, 'Step C' is Step 210 and 'Step D' is Step 220.

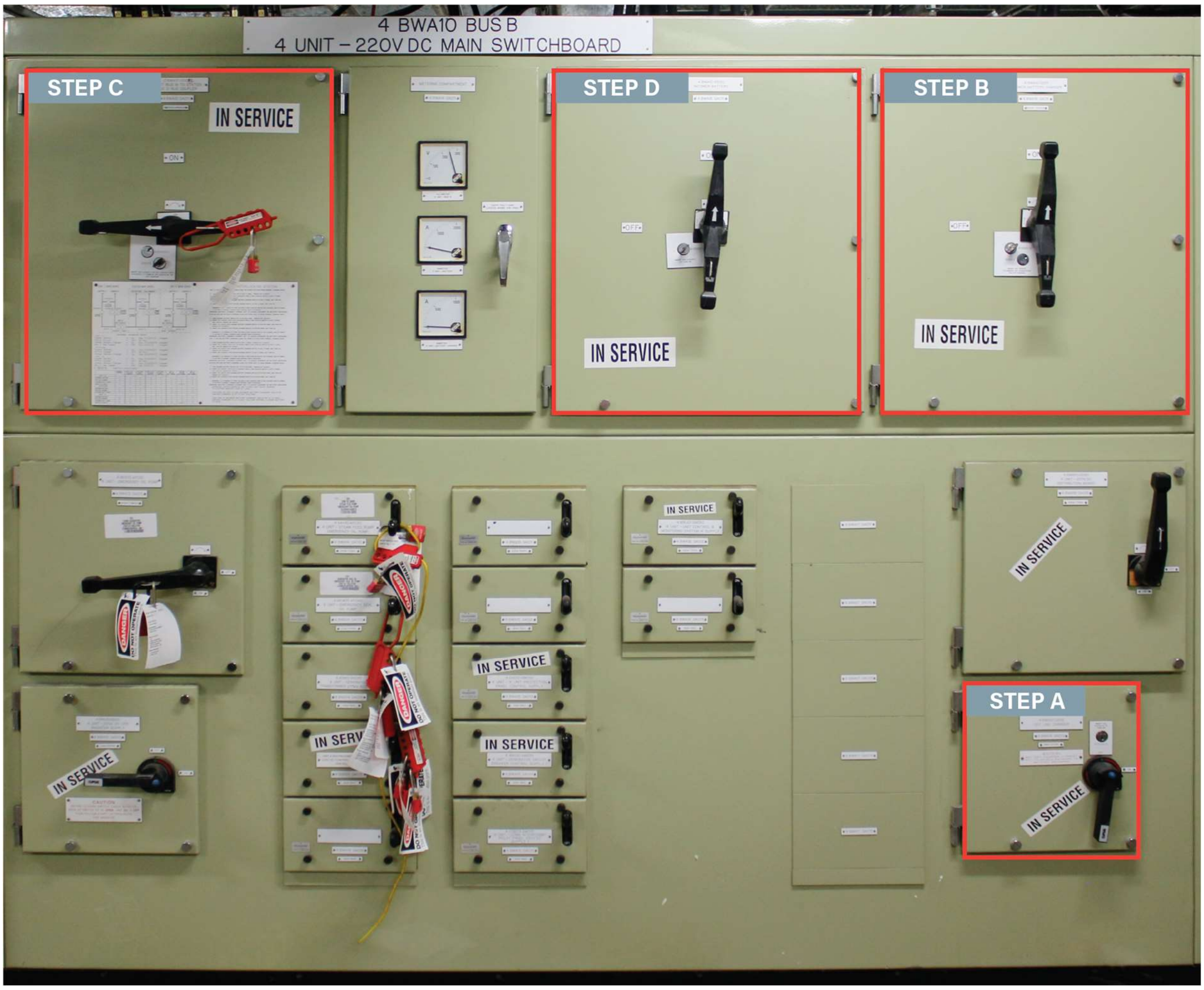

Figure 88 Unit C4 main switchboard (with the switches to be operated as part of the planned switching sequence indicated in red)

During the switching sequence on the day of the incident, the key required to operate the switch to connect the Unit C4 battery to the Unit C4 DC system first had to be 'released' by opening the interconnector.

Figure 89 illustrates how the blue key required in Step D (to connect the Unit C4 battery to the Unit C4 DC system) first had to be released in Step C (by opening the interconnector and disconnecting Station DC supply).

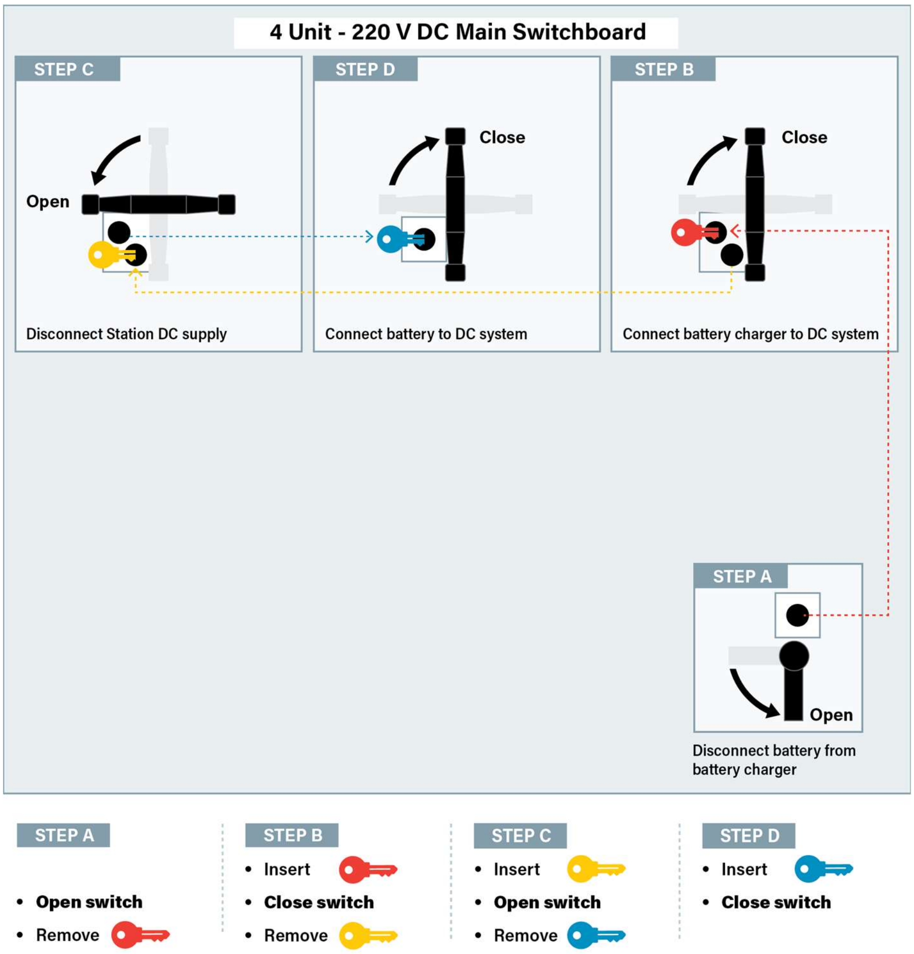

Figure 89 The actions in the planned switching sequence required to return the replacement Unit C4 battery charger to service

6.5 Chapter Summary

The switching sequence to bring the replacement battery charger into service was carried out with the unit online, and included steps that removed redundancy provided by the battery. The replacement battery charger, as the only source of supply to the unit at that time, was required to respond instantly to the disconnection of the Station DC supply and maintain the voltage in the Unit C4 DC system. The next chapter examines the loss of AC and DC supply to Unit C4.

7 THE LOSS OF AC AND DC SUPPLY

7.1 Introduction

This chapter discusses the loss of and failure to restore the Unit C4 AC and DC supply. Chapters 8 and 9 examine in more detail how these supplies were lost.

7.2 Loss of AC and DC Supply

In the planned switching sequence, the Station DC supply to the Unit C4 DC system was disconnected by opening the interconnector. This required the Unit C4 battery charger, as the sole source of supply to Unit C4, to respond instantly to maintain the voltage in the DC system. This did not occur.

The opening of the interconnector led to the following sequence of events:

- The voltage in the Unit C4 DC system collapsed from ~243 V to ~120 V.
- This collapse in DC voltage led to the loss of AC supply to Unit C4 and Station (to ~0 V).
- The loss of AC supply led to the complete loss of DC supply to Unit C4 (to ~0 V).

This sequence is discussed further in the sections below.

7.2.1 The Collapse of DC Voltage in Unit C4

The disconnection of the Station DC supply from Unit C4 initiated the incident. Immediately prior to this point in the switching sequence, there were three sources of supply available to maintain the voltage in the interconnected Station and Unit C4 DC systems: the Station battery, the Station battery charger and the Unit C4 battery charger.

Despite these three available sources, it was only the Station battery charger that was actually supplying the Unit C4 DC system at this time.[73] When the interconnector was opened, the Unit C4 battery charger became the sole source of DC supply to Unit C4. This placed a requirement on the Unit C4 battery charger to respond instantly to maintain supply to the Unit C4 DC system. The battery charger did not respond in this manner.

When the interconnector was opened, the voltage in Unit C4 DC system collapsed to ~120 V, see Figure 90.

[73] This behaviour was confirmed by the Brady Heywood investigation and is discussed further in Chapter 9 *How the Battery Charger Led to the DC Voltage Collapse*. No evidence has been sighted that indicates CS Energy planned the switching sequence with respect to how the Station and Unit C4 battery chargers would behave when connected to the same DC system.

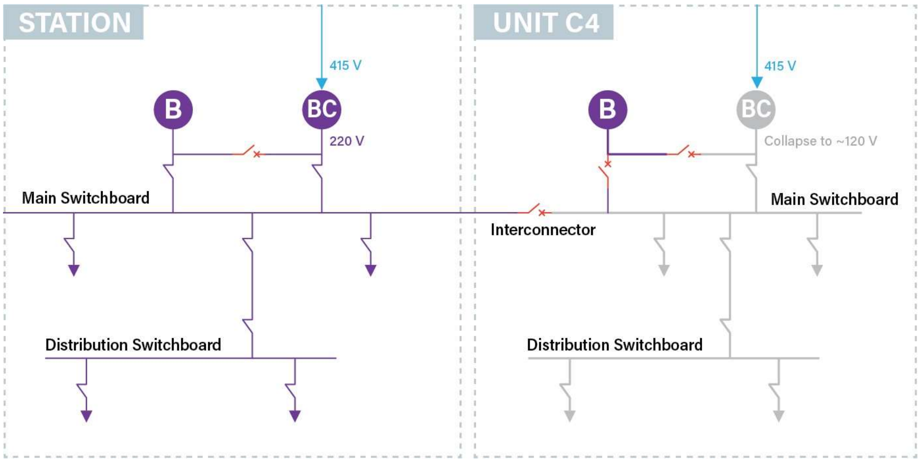

Figure 90 Collapse of DC supply to Unit C4 DC system (indicated in grey)

A detailed discussion of why the battery charger behaved in this manner is provided in Chapter 9 *How the Battery Charger Led to the DC Voltage Collapse*. The remainder of this chapter focuses on the consequences of the loss of AC and DC supply to Unit C4.

7.2.2 The Loss of AC Supply to Unit C4 and Station

The collapse in voltage in the Unit C4 DC system directly led to the loss of AC supply to the Unit C4 and Station AC systems. The precise manner in which this loss occurred is discussed in detail in Chapter 8 *How Arc Flap Protection Led to the Loss of AC Supply*. In simple terms, the collapse in DC voltage caused both of the 6.6 kV incomer circuit breakers in the Unit C4 AC system to trip (open automatically), as indicated in red in Figure 91.

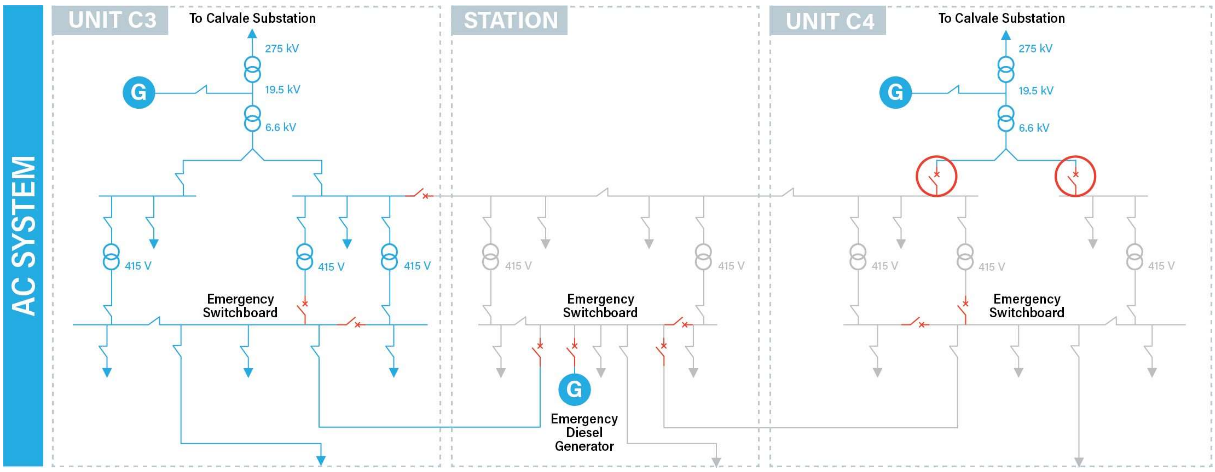

Figure 91 Unit C4 6.6 kV incomer circuit breakers trip (indicated in red)

The opening of the 6.6 kV incomer circuit breakers resulted in a complete loss of AC supply to the Station and Unit C4 AC systems, as indicated in grey in Figure 91 above.

7.2.3 The Loss of DC Supply to Unit C4

While it was the disconnection of Station DC supply from the Unit C4 DC system that led to the Unit C4 DC system voltage collapse (to ~120 V), it was the subsequent loss of AC supply to Unit C4 that led to the complete loss of DC supply to Unit C4 (~0 V).

The loss of AC supply to the Unit C4 AC system emergency switchboard resulted in a loss of AC supply to the Unit C4 battery charger, which resulted in the battery charger shutting down, see Figure 92.

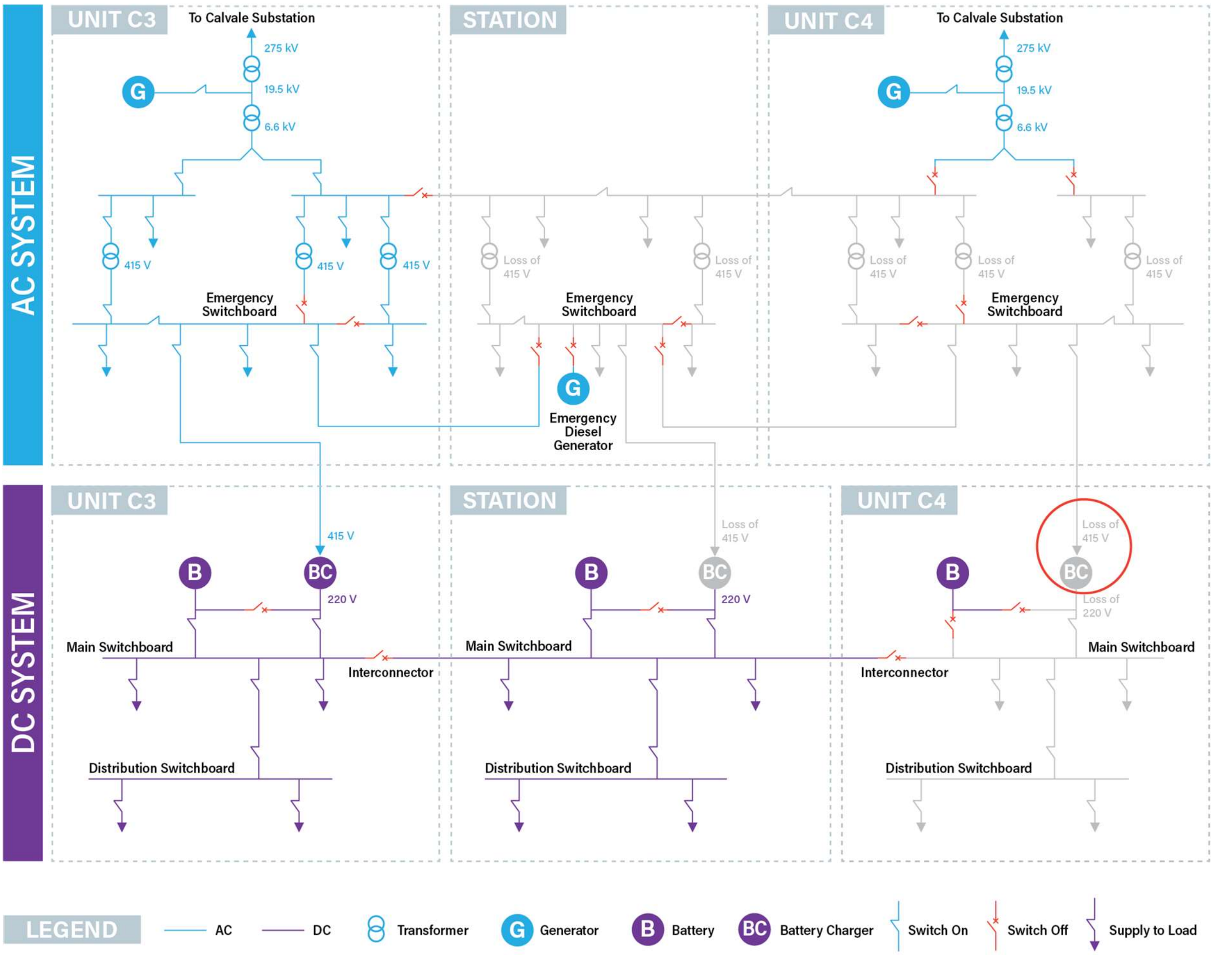

Figure 92 Loss of AC supply to Unit C4 battery charger (circled)

Had the Unit C4 battery charger's AC supply been maintained, it is likely that the battery charger would have restored the DC system voltage to its usual level within 2 seconds. However, the loss of AC supply resulted in the Unit C4 battery charger shutting down before it could restore the DC system voltage.[74]

7.2.4 Summary

The opening of the interconnector led to a voltage collapse in the Unit C4 DC system. This voltage collapse led to the loss of AC supply to Station and Unit C4. This loss of AC supply led to the Unit C4 battery charger shutting down, so it could not recover the voltage in the Unit C4 DC system. This led to a complete loss of supply in the Unit C4 DC system.

[74] The figure also illustrates that the loss of Station AC supply resulted in the loss of AC supply to the Station battery charger. DC supply to Station was not lost because the Station battery was still connected and able to maintain supply.

7.3 Consequences of the Loss of AC and DC Supply

The following sections discuss the consequences of the Unit C4 DC system voltage collapse, the loss of AC supply to the Unit C4 and Station, and the loss of DC supply to Unit C4.

7.3.1 Consequences of the Collapse of DC Voltage in Unit C4

Multiple items of equipment became unavailable at the time of the voltage collapse in the Unit C4 DC system. However, the key consequence of the collapse was the loss of AC supply to the Unit C4 and Station AC systems.

7.3.2 Consequences of the Loss of AC Supply to Unit C4 and Station

The loss of 6.6 kV and 415 kV AC supply led to the loss of multiple pieces of equipment, including:[75]

- The loss of the AC steam valve hydraulic pumps, resulting in a loss of hydraulic oil pressure, causing the turbine's steam valves to shut. (The loss of steam was a necessary step for motoring to occur).
- The loss of the AC lubrication oil pumps, resulting in a loss of lubrication oil pressure to supply oil to the bearings.
- The loss of the AC seal oil pump, resulting in a loss of seal oil pressure to the seals that prevent hydrogen escaping from the generator.
- The loss of all cooling systems (main and auxiliary cooling water, treated cooling water, stator coolant, transformer cooling fans and oil pumps, etc.), resulting in a build-up of heat.
- The loss of 415 V AC supply to the Unit C4 battery charger, resulting in the inability of the battery charger to recover the voltage in the DC system. This led to the loss of DC supply to Unit C4.

7.3.3 Consequences of the Loss of DC Supply to Unit C4

The loss of DC supply (~0 V) resulted in the loss of both the Unit C4 main switchboard and the Unit C4 distribution switchboard, as shown in grey in Figure 93.

[75] In the 6.6 kV AC system, this includes the loss of the boiler (which tripped, placing the boiler in a safe state), the loss of the main cooling water pump (which resulted in the loss of cooling for the condenser), the loss of water flow through the units (condensate/feedwater, etc.), and the loss of two of the three control air compressors (which led to the eventual trip of Unit C3). It also led to the loss of the unit extract pumps. The equipment listed in bullet points were all supplied by 415 V AC.

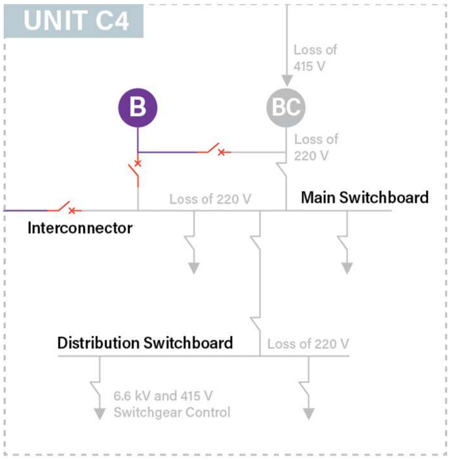

Figure 93 DC supply lost to Unit C4 main switchboard and distribution switchboard

The loss of DC supply to the Unit C4 main switchboard led to several key consequences:[76]

- The loss of the DC emergency lubrication oil pump. This, combined with the loss of the AC lubrication oil pumps, meant that no lubrication oil was provided to the bearings. Without lubrication oil, the bearings began grinding metal-on-metal.
- The loss of the DC emergency seal oil pump. This, combined with the loss of the AC seal oil pump, meant that no seal oil was provided to the hydrogen seals in the generator. Without seal oil, the hydrogen began escaping to the surrounding air.
- The loss of the unit's X protection system. This resulted in the partial loss of ability to detect issues in Unit C4 and shut it down safely.
- The loss of the first of two DC supplies to the Unit C4 generator circuit breaker.
- The loss of supply to the Unit C4 distribution switchboard, which was being supplied by the Unit C4 main switchboard.

The loss of DC supply to the Unit C4 DC distribution switchboard led to several key consequences:

- The loss of the unit's Y protection system. This resulted in the complete loss of ability to detect issues in Unit C4 and shut it down safely.
- The loss of the ability for the Unit C4 protection systems to disconnect Unit C4 from the grid by initiating a trip of the 275 kV circuit breakers at Calvale substation. This meant Unit C4 remained connected to the grid.[77]
- The loss of the second of two DC supplies to the Unit C4 generator circuit breaker. This resulted in the inability to open the Unit C4 generator circuit breaker and disconnect Unit C4 from the grid.

[76] The loss of the DC supply to the Unit C4 main switchboard also led to the loss of the uninterruptable power supply (UPS), which, along with the loss of AC supply to Unit C4, led to the loss of the Unit C4 screens in the control room.

[77] Both the X and Y protection systems can initiate a trip of the 275 kV circuit breakers at Calvale substation. This is known as an intertrip signal. The loss of the unit's Y protection system (in combination with the loss of the unit's X protection system) resulted in the loss of the ability of these protection systems to send an intertrip signal. The 275 kV circuit breakers at Calvale substation could, however, still automatically trip or be remotely tripped by Powerlink.

- The loss of the AC switchgear control. This resulted in a failure to restore AC supply to the Unit C4 emergency switchboard from the emergency diesel generator.

7.4 Station DC Supply Was Not Lost

The loss of Station AC supply led to the Station battery charger shutting down. Station DC, however, was not lost during the incident because the Station battery remained connected to the Station DC system, see Figure 94.

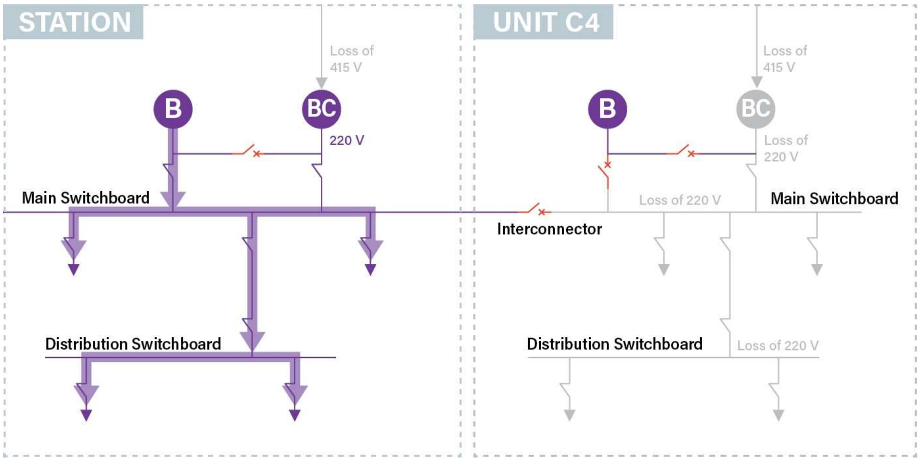

Figure 94 Station DC supply maintained by the Station battery while Station AC was lost (shown in grey)

Maintaining supply to the Station DC system had important ramifications for the operation of the emergency diesel generator, as discussed in the next section.

7.5 The Role of the Emergency Diesel Generator in the Incident

7.5.1 Introduction

Callide C has an emergency diesel generator that forms part of the Station AC system. In the event of a loss of AC supply, the emergency diesel generator is supposed to operate and restore 415 V AC to the affected system’s emergency switchboard.

On the day of the incident, supply to the Station AC system was restored, but supply to the Unit C4 AC system was not.

7.5.2 The Restoration of Station AC Supply

When the AC supply was lost to Unit C4, this led to a loss of AC supply to Station, see Figure 95.

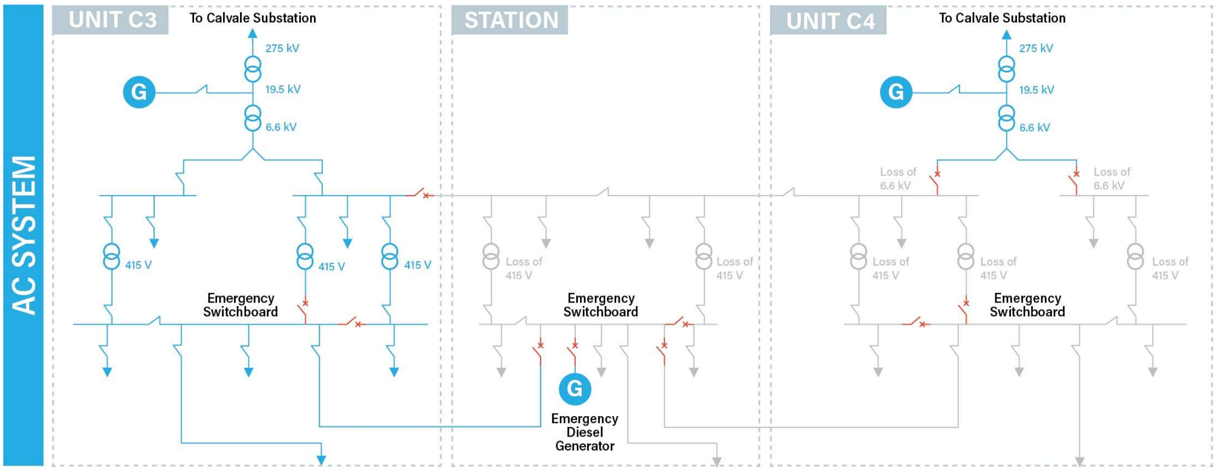

Figure 95 Loss of AC supply to Unit C4 and Station (shown in grey)

This loss resulted in the emergency diesel generator operating and generating AC supply. The emergency diesel generator, however, still needed to connect to the Station emergency switchboard. For this to occur, it was necessary to configure switches in the Station AC system so that the AC supply from the emergency diesel generator could be received by the emergency switchboard.[78] This configuration of the Station AC system is carried out by switches that are powered by the Station DC system, see Figure 96.[79]

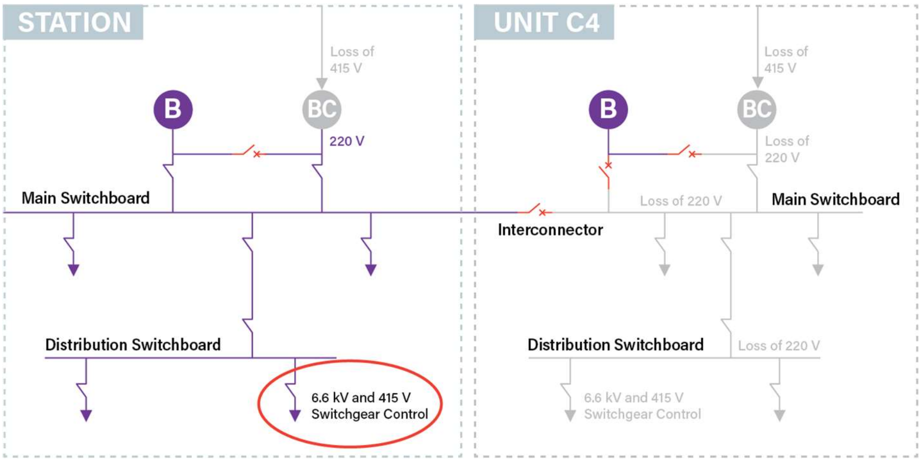

Figure 96 Availability of DC supply to Station AC switchgear control (indicated in red)

While AC supply to Station was lost in the incident, DC supply was not. The DC supply for the AC switchgear control was therefore available to allow the Station 415 V switches to operate.[80] Within 25

[78] In order to configure the Station emergency switchboard to receive supply from the emergency diesel generator, it is necessary to ensure all other switches from alternate sources of supply (to the emergency switchboard) are open. This is to avoid, for example, the overloading of the diesel generator or the Station emergency switchboard back-feeding onto the Station 6.6 kV switchboard (through the 6.6 kV to 415 V transformers).

[79] There are separate switches on the Station distribution board for the 6.6 kV AC switchgear control and 415 V AC switchgear control. For simplicity, these have been combined into a single switch in this diagram.

[80] While the loss of Station AC supply led to a loss of the Station battery charger, the Station battery continued to supply the Station DC system.

seconds, the Station 415 V switches had operated and reconfigured the Station emergency switchboard to receive supply from the emergency diesel generator. AC supply was therefore successfully restored to the Station emergency switchboard, see Figure 97.

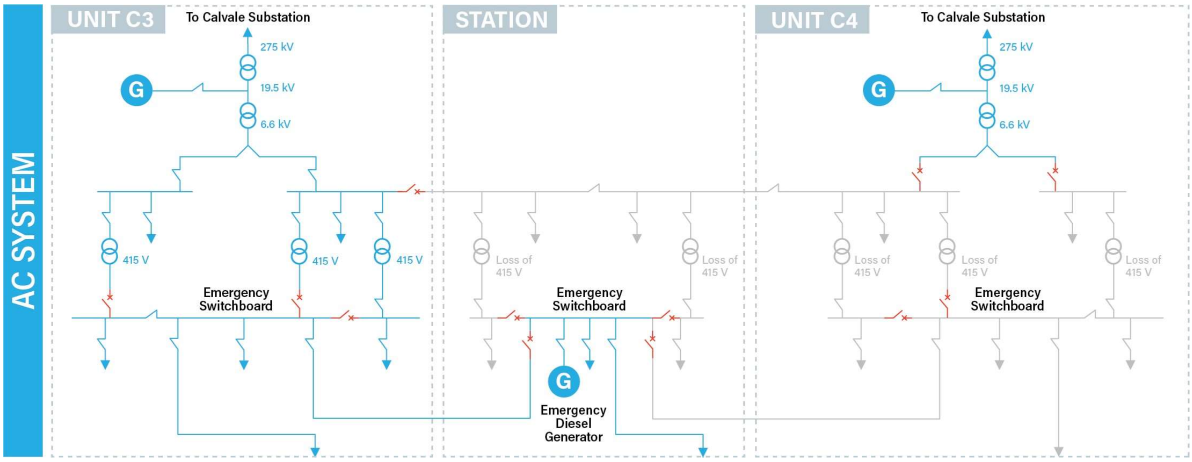

Figure 97 Emergency diesel generator restores AC supply to Station 415 V emergency switchboard

The restoration of AC supply to the Station emergency switchboard restored supply to the Station battery charger. The Station battery charger then resumed supplying Station DC loads and restored charge to the Station battery. This meant that, in the first ~50 seconds of the incident, AC was partially restored to Station, and the Station battery charger's functionality was restored.

7.5.3 The Failure to Restore Unit C4 AC Supply

With DC supply lost to Unit C4, there was no supply available to the Unit C4 AC switchgear control, see Figure 98.[81]

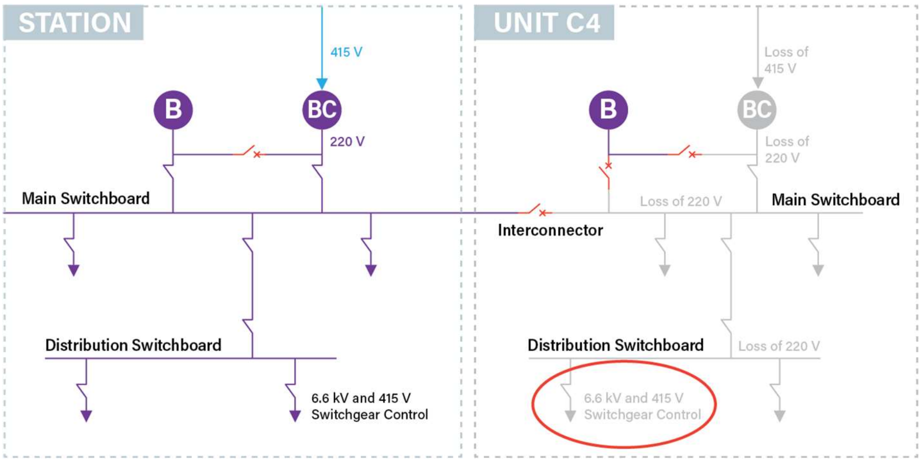

Figure 98 Loss of DC supply to Unit C4 AC switchgear control (indicated in red)

[81] As with Station, there are separate switches on the Unit C4 distribution board for the 6.6 kV AC switchgear control and 415 V AC switchgear control. For simplicity, these have been combined into a single switch in this diagram.

Without DC supply available for the Unit C4 AC switchgear control, the Unit C4 switches could not operate.

Figure 99 illustrates AC switches that could not be configured as a result, indicated in red.

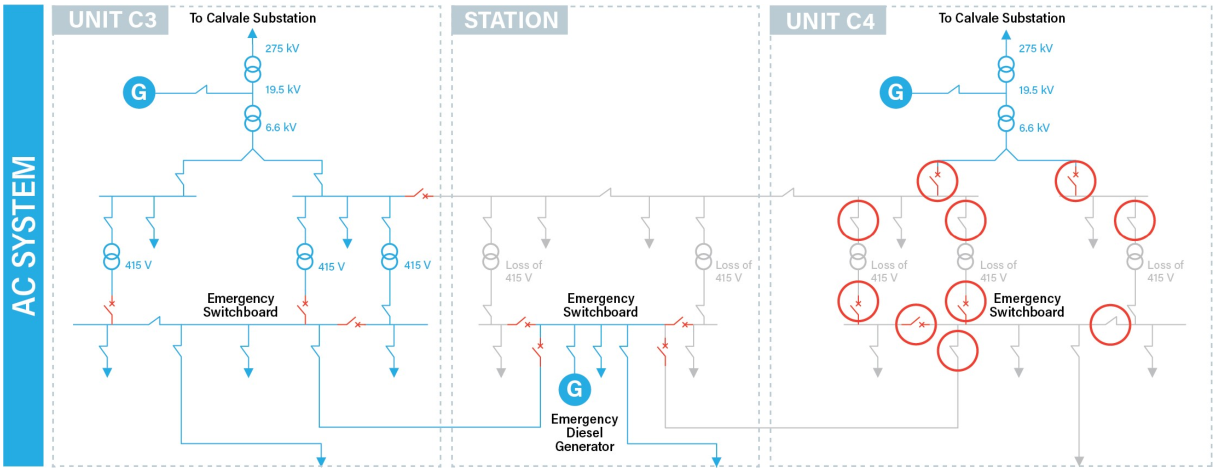

Figure 99 Switches in the Unit C4 AC system could not be configured due to loss of DC supply (indicated in red circles)

Without the ability to reconfigure the necessary Unit C4 AC switches, AC supply from the emergency diesel generator (via the Station emergency switchboard) could not be restored to the Unit C4 emergency switchboard.

7.6 The Role of the Automatic Changeover Switch in the Incident

7.6.1 Introduction

If DC supply to Unit C4 is lost, then the automatic changeover switch can automatically operate and 'change over' to supply the Unit C4 distribution switchboard from the Station main switchboard, see Figure 100.

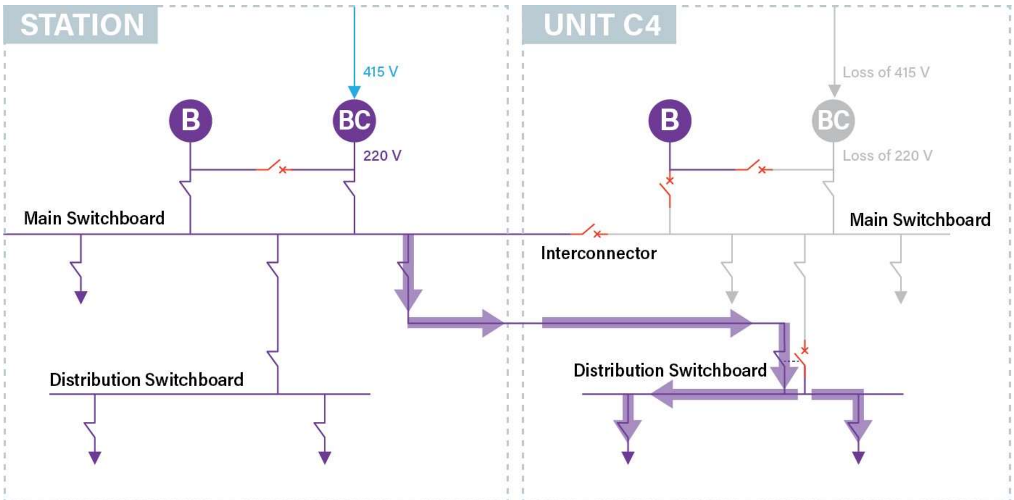

Figure 100 Unit C4 automatic changeover switch supplies Unit C4 distribution switchboard from the Station main switchboard

7.6.2 Status of the Automatic Changeover Switch on the Day of the Incident

The automatic changeover switch was inoperable in automatic mode on the day of the incident.

7.6.3 Potential Consequences of Lack of Functionality of Automatic Changeover Switch

Had the automatic changeover switch been operational in automatic mode, and had it successfully changed over to supply the Unit C4 distribution switchboard from Station, the consequences of the incident likely would have been mitigated.[82] The scenario presented below is generally speculative and is highly dependent on an exact set of assumptions. It is explored in more detail in Appendix A3 *Electrical Investigation*.

The following sequence of events is likely to have occurred if the Unit C4 automatic changeover switch had successfully operated on the day of the incident:

- The voltage collapse in the DC system would likely still have resulted in a loss of AC supply to Unit C4 and Station, in the same manner as it did on the day of the incident.
- The loss of AC supply would likely still have resulted in a loss of DC supply to Unit C4.
- Unit C4 would likely still have remained connected to the grid and would have begun to motor (without lubrication oil and seal oil).[83]

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[82] Even if the Unit C4 automatic changeover switch had been repaired and operational in automatic mode on the day of the incident, it is not clear if it would have successfully operated and restored DC supply to the Unit C4 distribution switchboard.

The Brady Heywood investigation concluded that the automatic changeover switches in Callide C were prone to reliability issues. These reliability issues are inherent in the design of the automatic changeover switches' control circuitry, and can result in the motor of the automatic changeover switch being supplied with a voltage higher than its rated voltage. It was demonstrated that this higher voltage could cause the fuses (that provide power to the automatic changeover switches' control circuitry and motor) to blow mid-way through a changeover operation. This results in the automatic changeover switch stopping mid-way. Because the automatic changeover switch operates by *first* disconnecting the current supply *then* connecting the other supply, this leaves its associated distribution switchboard without supply from either its preferred or standby supply.

The conclusion that automatic changeover switches were prone to reliability issues is based on the following physical tests that were conducted:

- The Unit C3 automatic changeover switch was tested by CS Energy after the incident, and it informed the Brady Heywood investigation that it had failed mid-way through the first operation, leaving the Unit C3 distribution switchboard without supply.
- The Station automatic changeover switch was tested as part of the Brady Heywood investigation, and successfully changed over once, but failed mid-way through the second operation, leaving the Station distribution switchboard without supply.
- The Unit C4 automatic changeover switch was tested as part of the Brady Heywood investigation. It failed to change over due to the control circuitry being damaged (likely as result of a dual trip event in January 2021).

  To facilitate further testing as part of the Brady Heywood investigation, CS Energy repaired the Unit C4 automatic changeover switch (using parts from the Station automatic changeover switch's control circuitry). The subsequent tests performed as part of the Brady Heywood investigation were inconclusive. The Brady Heywood investigation discovered that the control circuitry had still failed, but it had failed in such a manner that the voltage supplied to the motor of the Unit C4 automatic changeover switch was *lower* than its rated voltage, rather than *higher*. This caused the Unit C4 automatic changeover switch to operate slower than normal, and did not result in blown fuses. It could not be determined if the failure that led to the under-voltage of the motor (and the reliable, but slower, operation of the Unit C4 automatic changeover switch) occurred prior to the 25 May 2021 incident, during the repair, or during the first operation conducted as part of the Brady Heywood investigation testing.

[83] Unit C4's rotor would have needed to slow down slightly for the unit to transition from generating to asynchronous motoring.

- If the Unit C4 automatic changeover switch had then operated successfully, DC supply likely would have been restored to the Unit C4 distribution switchboard within ~2 seconds.[84]
- The restoration of supply to the Unit C4 DC distribution switchboard likely would have restored supply to the Y protection system. After the Y protection system powered up, it would have had several mechanisms to detect that Unit C4 was motoring, and likely would have responded by attempting to open the generator circuit breaker and disconnect Unit C4 from the grid.
- In order to successfully open, the generator circuit breaker requires a source of DC supply. The restoration of supply to the Unit C4 DC distribution switchboard should have restored DC supply to the generator circuit breaker. However, it is likely that the fuses were blown between the Unit C4 DC distribution switchboard and the generator circuit breaker.[85] These blown fuses therefore would have prevented the DC supply from being restored to the generator circuit breaker, preventing it from operating. Unit C4 likely would have remained connected to the grid.
- The Y protection system, however, likely would have detected that the generator circuit breaker had not operated, and likely would have sent an intertrip signal to Calvale substation. The protection system at Calvale substation likely would have operated and disconnected Unit C4 from the substation, therefore disconnecting it from the grid.
- It is unlikely that the Unit C4 AC lubrication oil pumps would have been restored because AC supply would not have been restored to the unit.[86]
- From this point, Unit C4 would have run (spun) down over a period of time, with no lubrication oil (leading to the shaft and bearings grinding metal-on-metal) and with no seal oil (leading to the hydrogen escaping from the generator).[87]

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[84] DC supply would not have been restored to the main switchboard, and the emergency lubrication oil and seal oil pumps, supplied from the main switchboard, would not have operated.

[85] In March 2024, CS Energy became aware that the fuses supplying the Unit C4 generator circuit breaker from the Unit C4 distribution switchboard were blown. It is likely that these fuses were blown during the incident. Note, these fuses are not to be confused with the fuses in the automatic changeover switch.

[86] AC supply to the AC lubrication oil pumps likely would have been momentarily restored by the following mechanism:

- The DC supply for the Unit C4 AC switchgear control is located on the Unit C4 distribution switchboard, and this likely would be restored if the automatic changeover switch had successfully functioned.
- This means that when the emergency diesel generator activated and supplied the Station AC emergency switchboard, the Unit C4 AC switches could have been configured to route this AC supply to the Unit C4 emergency switchboard.

However, the Unit C4 AC switches would then likely have disconnected the AC supply to the Unit C4 distribution switchboard because of a design issue inherent in the switches.

This is discussed in detail in Appendix A3 *Electrical Investigation* and based on the following:

- When Calvale substation disconnected Callide C from the grid, Unit C3 lost AC supply.
- The Unit C3 AC switches were configured to route the supply from the Station emergency switchboard (which was supplied from the emergency diesel generator) to the Unit C3 emergency switchboard.
- The Unit C3 AC switches then disconnected this AC supply.

It is likely that the Unit C4 AC switches would have responded in a similar manner in this scenario.

[87] The run-down time would depend on many factors – such as the level of friction produced from the shaft and bearings – but would possibly be in the order of ~10 minutes.

- Running down without lubrication oil likely would have caused significant damage to the shaft and rotor, but the turbine missile event likely would have been avoided.
- The generator rotor may have sustained significant damage, but the stator damage likely would have been much less than that sustained in the incident. Damage to the generator transformer would be highly unlikely.

The final outage duration after such a scenario would depend on the level of damage to the shaft at the bearing locations, whether the HP and IP turbine rotor deformed permanently, and whether there was mechanical damage to the generator rotor.

7.7 Chapter Summary

This chapter discussed the loss of AC and DC supply to Unit C4.

Chapter 8 *How Arc Flap Protection Led to the Loss of AC Supply* explores how the specific manner of the voltage collapse in the Unit C4 DC system led to the loss of AC supply to Unit C4.

8 HOW ARC FLAP PROTECTION LED TO THE LOSS OF AC SUPPLY

8.1 Introduction

This chapter examines how the voltage collapse in the Unit C4 DC system led to the loss of the Unit C4 AC supply. It explains how the specific manner of the DC voltage collapse caused one of the Unit C4 protection systems – the arc flap protection – to operate and disconnect AC supply from Unit C4.

8.2 The Manner of the Voltage Collapse in the Unit C4 DC System

Prior to the disconnection of the Station DC supply from Unit C4 (by opening the interconnector), the voltage in the Unit C4 DC system was being maintained by the Station DC system. When the interconnector was opened, the Unit C4 battery charger became the unit's sole source of DC supply. The Unit C4 battery charger was, therefore, required to respond instantly to maintain the voltage level in the Unit C4 DC system, as illustrated by the dashed line in Figure 101.

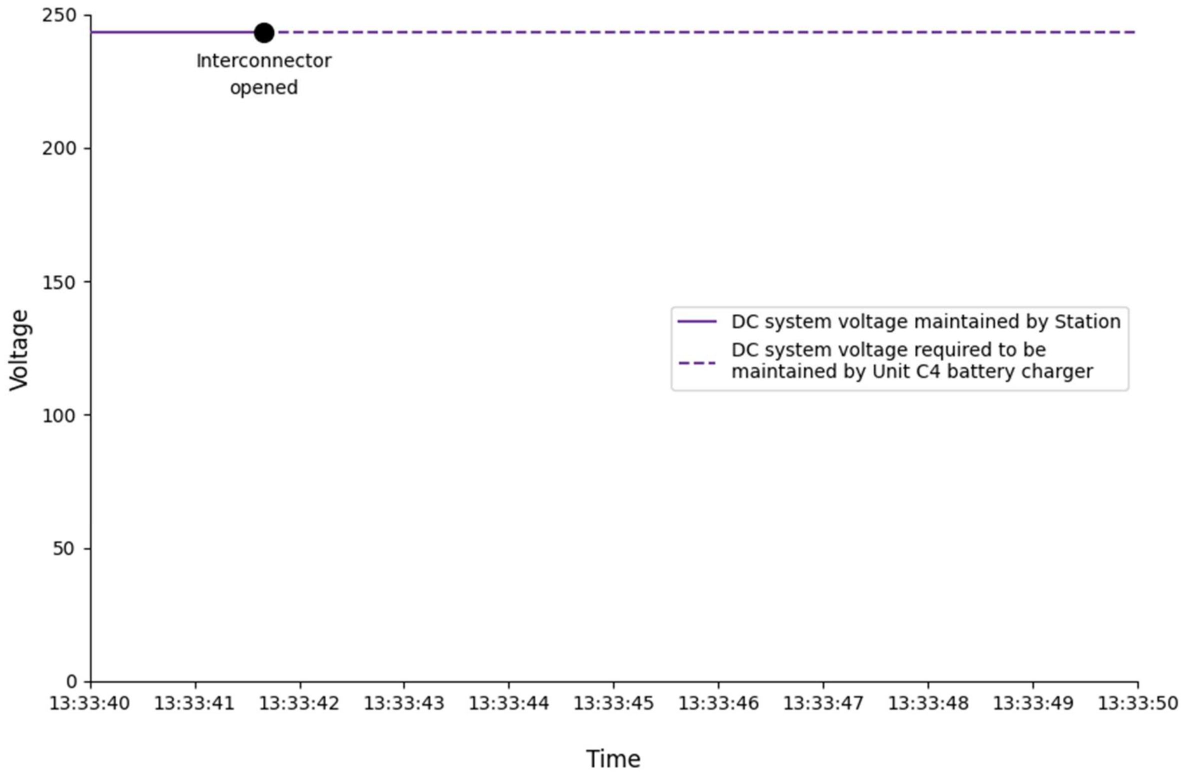

Figure 101 Voltage level required to be maintained by Unit C4 battery charger (indicated by dashed line)

The Unit C4 battery charger did not maintain the voltage when the Station DC supply was disconnected, leading to a voltage collapse in the Unit C4 DC system. Figure 102 shows the voltage in the Unit C4 DC system prior to and after the Station DC system being disconnected.[88]

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[88] Excel Spreadsheet (20 January 2022) *C4 Data.xlsx*, Worksheet: 4BWB10, CSE.001.284.0041.

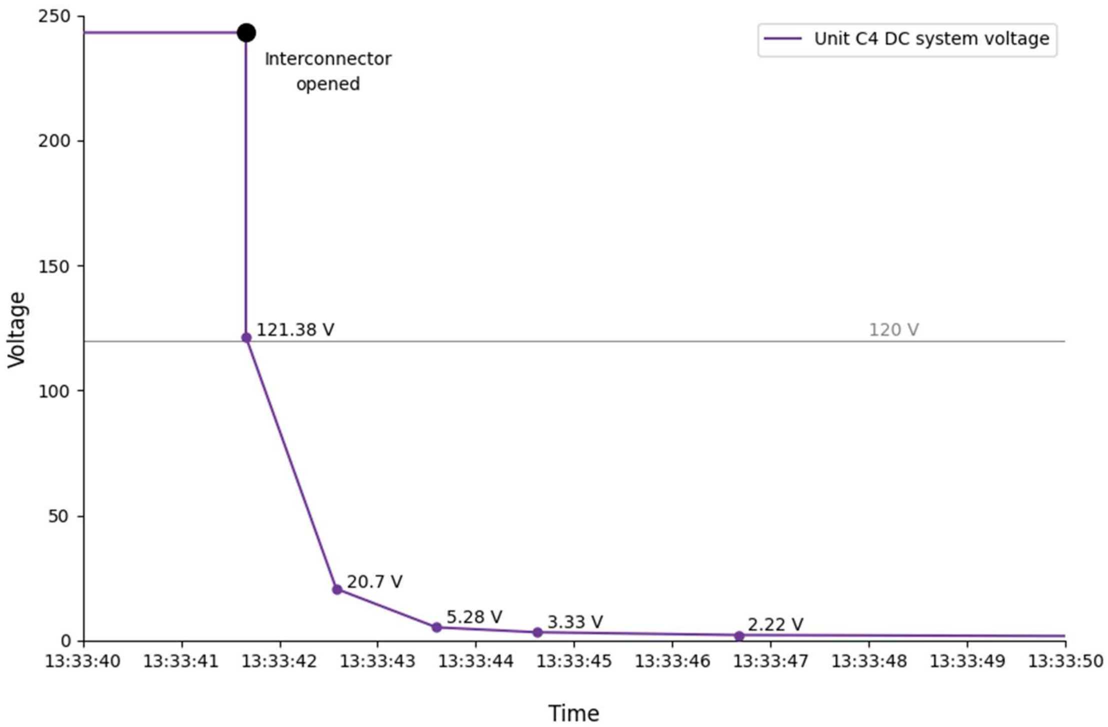

Figure 102 DC voltage in Unit C4 distribution switchboard

Prior to the interconnector being opened, the voltage in the DC system was ~243 V. When the interconnector was opened, the voltage collapsed to ~120 V, then rapidly decayed to ~0 V.[89] This voltage collapse was a result of the behaviour of the Unit C4 battery charger, which is discussed in detail in Chapter 9 *How the Battery Charger Led to the DC Voltage Collapse*.

The remainder of this chapter discusses how the manner of the DC voltage collapse led to the loss of AC supply.

8.3 How the Unit C4 DC Voltage Collapse Led to the Loss of AC Supply

8.3.1 Introduction

The Unit C4 DC voltage collapse resulted in the activation of a protection system referred to as 'arc flap protection'. This tripped the Unit C4 AC system. The sections that follow introduce the concept of arc flap protection and explain how this protection system responded as if a fault had occurred in the AC system and disconnected AC supply to Unit C4.

8.3.2 Arc Flap Protection

The occurrence of an electrical arc flash – an explosion caused by electricity passing through the air – is a major hazard in high-voltage AC electrical systems. When an electrical arc occurs, it is critical to

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[89] The purple dots in Figure 102 depict the data as measured by the integrated control and monitoring system (ICMS) on the Unit C4 distribution switchboard. The black dot, however, was not recorded by the system. Rather, it has been included as a likely indicative value at the time immediately prior to the interconnector being opened. The basis for this indicative value is discussed in Appendix A3 *Electrical Investigation*.

disconnect the supply to prevent continued arcing. In Callide C, the protection system used to detect and respond to an arc flash in the 6.6 kV electrical cabinets is referred to as 'arc flap protection'.[90]

On the day of the incident, the voltage collapse in the Unit C4 DC system caused the arc flap protection to respond as if a fault had occurred in the unit's AC system. Despite no such fault occurring, the arc flap protection activated and disconnected the AC supply to Unit C4.

8.3.3 The Role of the 6.6 kV Incomer Circuit Breakers in the Unit C4 AC System

Unit C4 has two 6.6 kV incomer circuit breakers that connect the AC system to its source of supply, as indicated in red in Figure 103.

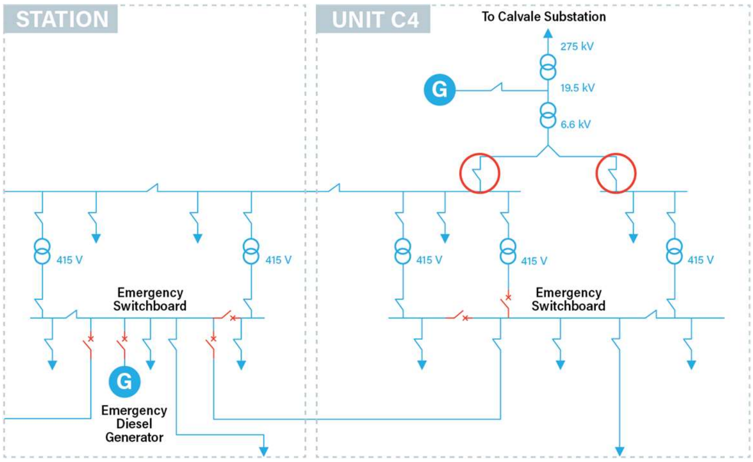

Figure 103 Unit C4 6.6 kV incomer circuit breakers (closed)

On the day of the incident, the arc flap protection operated and tripped the two Unit C4 6.6 kV incomer circuit breakers, disconnecting the AC supply to the Unit C4 AC system, see Figure 104.

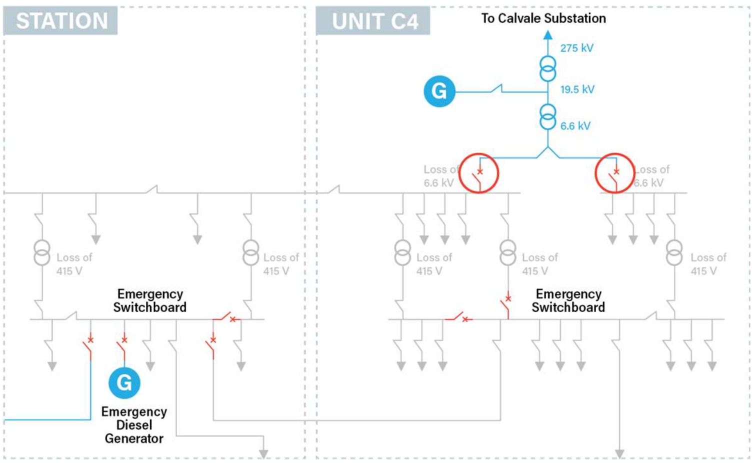

Figure 104 Unit C4 6.6 kV incomer circuit breakers tripped (opened automatically)

90 The term 'arc flap protection' is used within CS Energy (and in this report), rather than the more common industry term 'arc flash protection'.

An explanation of how arc flap protection functions, and why it responded as if a fault had occurred in the AC system, is presented in the following sections.[91]

8.3.4 How Arc Flap Protection Functions

If an electrical arc occurs inside one of the 6.6 kV incomer circuit breaker cabinets, it creates a pressure wave that pushes open a hinged flap on the top of the cabinet. Figure 105 illustrates one of the 6.6 kV incomer circuit breaker cabinets and the hinged flap.

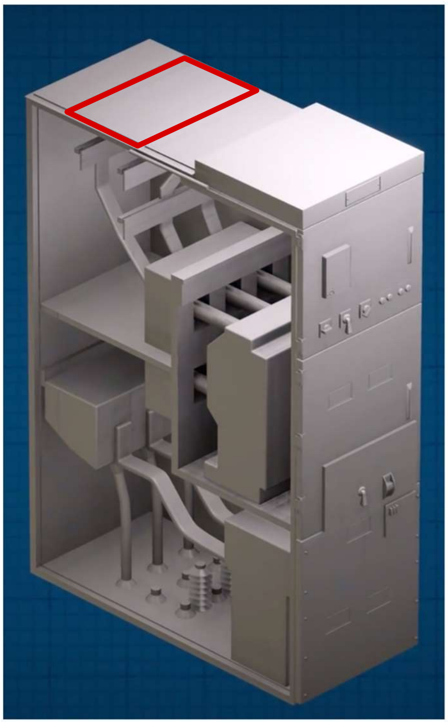

Figure 105 6.6 kV incomer circuit breaker cabinet with hinged arc flap (indicated in red)

When the arc flap is in a closed position, a switch at the top of the cabinet is held closed (i.e., switched on). The DC system voltage is passed through this switch to a protection relay. Figure 106 shows the location of the switch and protection relay, with the DC system voltage depicted by the dashes on the purple line.[92]

[91] It is believed the same arc flap protection logic is fitted to all the 6.6 kV circuit breakers on the Unit C4 and Station switchboards. Only the Unit C4 6.6 kV *incomer circuit breaker* cabinets were considered as part of the Brady Heywood investigation. The other 6.6 kV circuit breakers did not play a relevant role in the incident.

[92] This DC voltage is monitored by the protection relay. The protection relay receives its DC supply by another connection to the DC system. This connection is not shown in these figures.

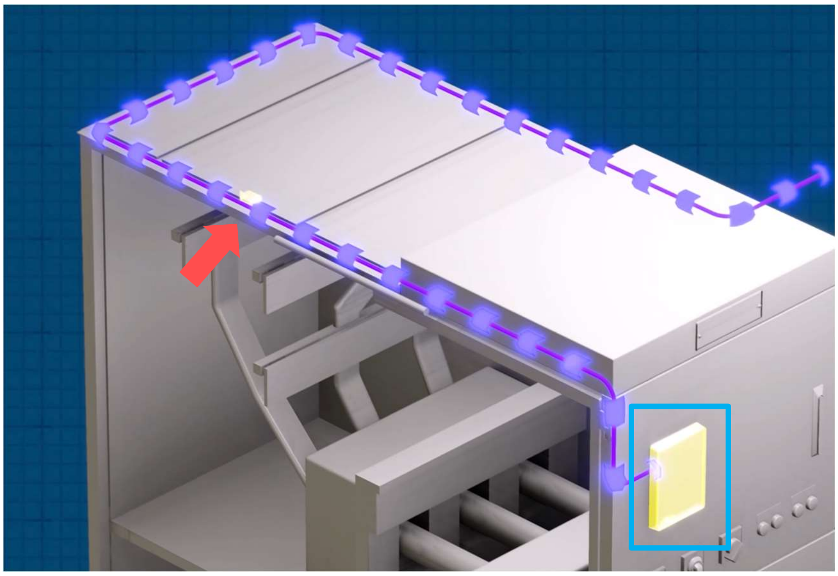

Figure 106 Location of switch (red arrow), protection relay (blue square), and DC voltage (purple dashes)

The protection relay monitors the voltage from the switch. As long as the protection relay detects that the DC voltage is present, it takes no action. However, if an arc occurs and blows the arc flap open, this opens the switch, which collapses the DC voltage being monitored by the protection relay, as indicated by red arrows in Figure 107.

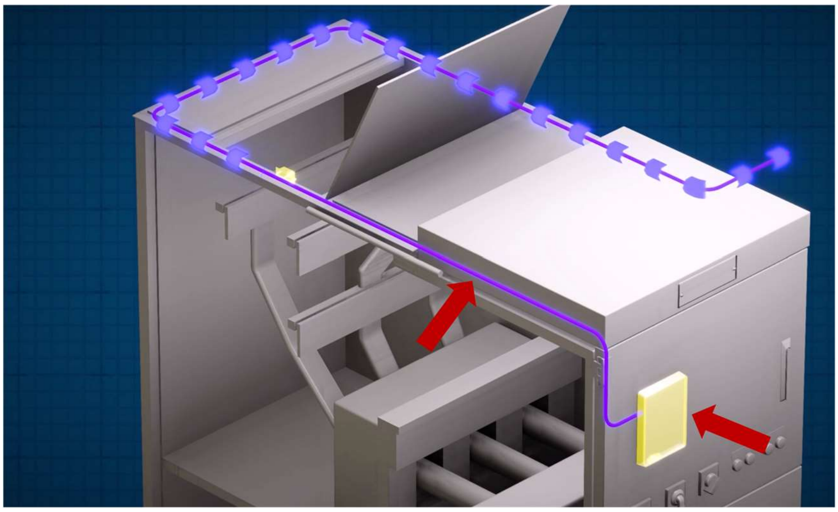

Figure 107 Arc flap opens, leading to opening of switch and collapse in DC voltage

When the protection relay detects that the voltage collapses (in this case, when it drops below 164 V), it responds and sends a trip signal to the circuit breaker inside the cabinet, see Figure 108.[93]

[93] This value of 164 V was measured by the Brady Heywood investigation.

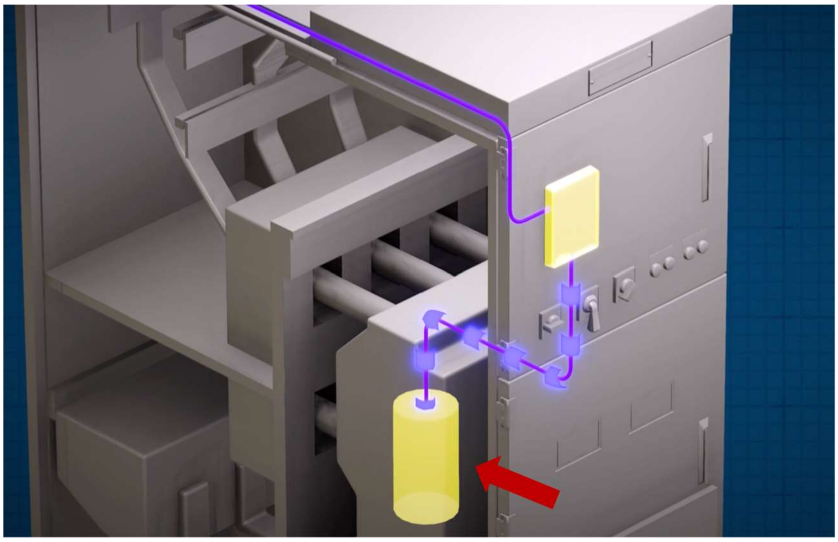

Figure 108 Protection relay sends trip signal to 6.6 kV incomer circuit breaker (trip coil of circuit breaker indicated by red arrow)

When the circuit breaker receives the trip signal, it operates and disconnects the AC supply to prevent further arcing.

8.3.5 Why the Arc Flap Protection Operated as if a Fault Occurred

On the day of the incident, no arc flash occurred in the two Unit C4 6.6 kV incomer circuit breaker cabinets. But when the Unit C4 DC system voltage collapsed to ~120 V, the protection relays detected that the voltage had fallen below 164 V and responded by tripping the two 6.6 kV incomer circuit breakers. In other words, the arc flap protection did not distinguish between a voltage collapse caused by an arc flash and the voltage collapse that occurred on the day of the incident.

8.3.6 Incomer Circuit Breakers Operate and Cause Loss of AC Supply

For the circuit breakers to successfully trip, their DC supply voltage needs to be at least 101 V.[94] Therefore, if the Unit C4 DC system voltage had collapsed to below 101 V instead of collapsing to ~120 V, the protection relays would have been unable to successfully trip the 6.6 kV incomer circuit breakers.

The manner in which the Unit C4 DC supply collapsed, therefore, played a critical role in the loss of AC supply because:

- When the DC voltage collapsed to ~120 V, the protection relays responded as if an arc had occurred and sent a trip signal to the circuit breakers.
- The circuit breakers operated and tripped the AC supply to Unit C4 before the DC voltage had sufficient time to decay below 101 V.

While the voltage collapse from ~243 V to ~120 V was relatively instantaneous, it took time for the voltage to decay below 101 V.[95] Therefore, there was a window of time where the voltage was below

[94] This minimum voltage was determined by tests performed on the Unit C4 6.6 kV incomer circuit breakers as part of the Brady Heywood investigation.

[95] This time is determined by the capacitances, inductances and loads in the system.

164 V (initiating the trip), but above 101 V (the minimum operating voltage for the circuit breaker to trip). This timeframe was of sufficient duration to successfully execute the trip, as illustrated in Figure 109.[96]

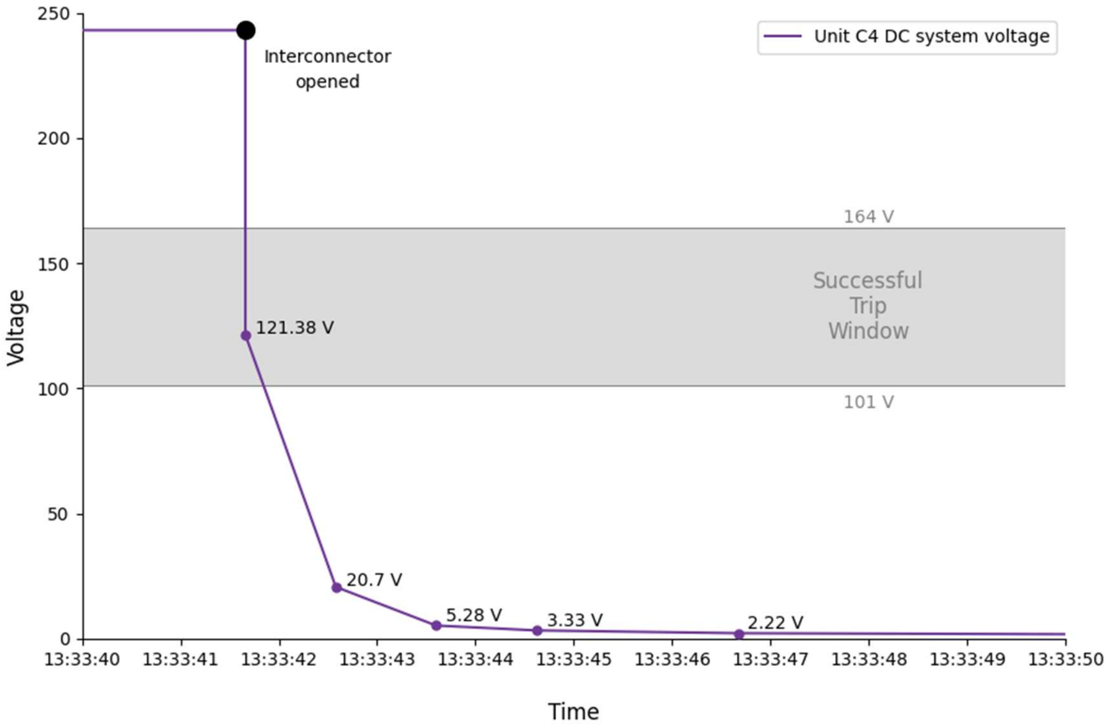

Figure 109 Trip window

When the 6.6 kV incomer circuit breakers tripped, all AC supply was lost to Unit C4 and Station, see Figure 110.

[96] Data from the day of the incident shows that less than 100 milliseconds elapsed between the arc flap being detected by the protection relay and the incomer circuit breaker being opened. PowerPoint Presentation (8 July 2021) *Callide Power Station Unit C4 6.6kV Incomer Circuit Breaker Tripping*, CSE.001.002.9229.

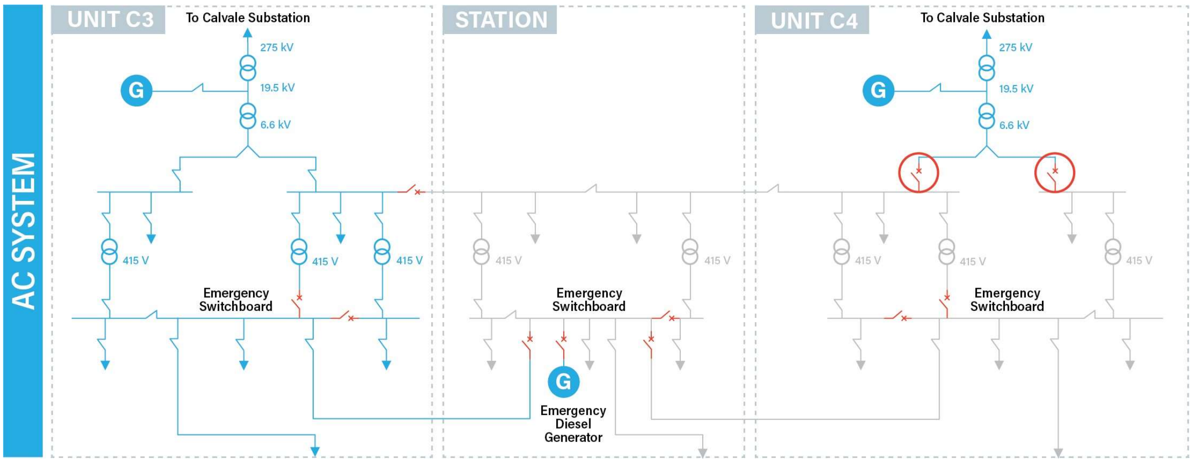

Figure 110 6.6 kV incomer circuit breakers trip and disconnect Unit C4 and Station AC supply

8.3.7 A Note on the Manner of the Collapse of DC Voltage

Had the manner of the collapse of DC voltage been different, then different outcomes may have occurred. For example:

- Had the voltage collapsed, but stayed above 164 V, the protection relays likely would not have initiated a trip.
- Had the voltage collapsed below 101 V, the protection relays likely would have still initiated a trip (because the voltage was below 164 V), but the 6.6 kV incomer circuit breakers would not have tripped because the DC voltage was below 101 V and too low for them to operate.[97]
- Had the voltage collapsed below 80 V, the protection relays likely would have shut down due to a lack of supply and likely would not have initiated a trip.[98]

8.4 How the Loss of AC Supply Led to the Loss of DC Supply

8.4.1 Battery Charger Shuts Down and DC Supply is Lost

The trip of the 6.6kV incomer circuit breakers resulted in a complete loss of AC supply to the Unit C4 AC system, including the AC supply to the Unit C4 battery charger, see Figure 111.

[97] In this scenario, the AC supply may still have been lost: the initial collapse in DC voltage to below 101 V results in insufficient voltage being available to operate the 6.6 kV incomer circuit breakers and they remain closed. Therefore, the battery charger does not shut down because it still has AC supply. With no loss of AC supply, the battery charger then detects that the voltage in the DC system is low and likely responds by increasing it. But, as the voltage begins to recover, it passes up through the trip window of 101 V to 164 V, causing the 6.6 kV incomer circuit breakers to trip (on the way up), leading to a loss of AC supply.

[98] In this scenario, the AC supply may still have been lost by the same mechanism as discussed in the footnote above, provided the protection relay had powered up while the recovering voltage was still within the trip window.

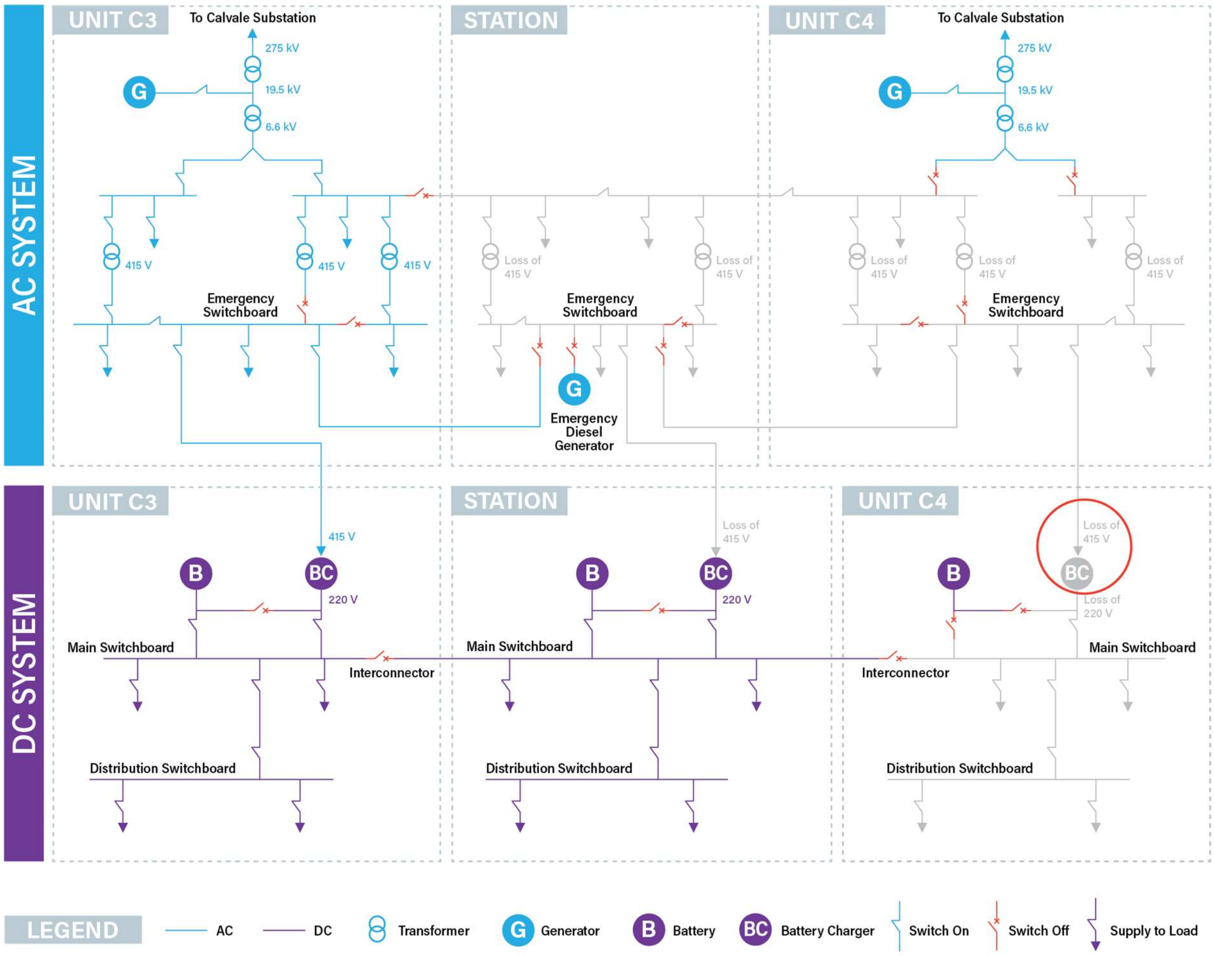

Figure 111 Opening of 6.6 kV incomer circuit breakers causes loss of AC supply to Unit C4 battery charger (indicated in red)

Had the AC supply to the Unit C4 battery charger not been lost, it likely would have responded to the collapse in DC voltage and restored the DC system voltage to its usual level within 2 seconds.[99] However, with no AC supply, the Unit C4 battery charger shut down, leading to a complete loss of DC supply to Unit C4.

8.5 Chapter Summary

This chapter examined how the collapse of the Unit C4 DC system voltage led to the protection relays in the 6.6 kV incomer circuit breakers responding as if an arc had occurred, which resulted in the protection relays initiating a trip of the 6.6 kV AC supply to Unit C4.

The tripping of the 6.6 kV incomer circuit breakers resulted in a loss of AC supply to Unit C4 and Station, including a loss of the 415 V AC supply to the Unit C4 battery charger.

[99] As discussed further in Chapter 9 *How the Battery Charger Led to the DC Voltage Collapse* and in Appendix A4 *Battery Charger Investigation*.

With no AC supply, the Unit C4 battery charger shut down. Because the Unit C4 battery charger was the sole source of supply to the Unit C4 DC system at this time, this led to a loss of DC supply to Unit C4.

Chapter 9 *How the Battery Charger Led to the DC Voltage Collapse* examines how the behaviour of the Unit C4 battery charger led to the collapse in the Unit C4 DC system voltage.

9 HOW THE BATTERY CHARGER LED TO THE DC VOLTAGE COLLAPSE

9.1 Introduction

When Station DC supply was disconnected from the Unit C4 DC system, the Unit C4 battery charger failed to respond and maintain the voltage level in the Unit C4 DC system, despite this being a requirement of the switching sequence.

This chapter discusses the Unit C4 battery charger, how it operates, and how it led to the collapse of the Unit C4 DC system voltage in the incident.

9.2 The Switching Sequence

In the 18 months prior to the incident, an upgrade program was underway to replace the battery chargers in Unit C3, Station and Unit C4.

By the day of the incident, the Unit C4 battery charger had been replaced and a switching sequence was taking place to connect it to the Unit C4 DC system. It was this switching sequence that initiated the incident.

9.3 Brady Heywood Investigation Testing

There was limited data available regarding the behaviour of the Unit C4 battery charger on the day of the incident. The Callide C power station's ICMS only measures and records battery current, battery charger current, and one common battery charge alarm to the ICMS. It does not measure the voltage of the battery charger, but instead measures the voltage at the main switchboard and distribution switchboard.

It was, therefore, necessary for the Brady Heywood investigation to conduct on-site tests on the Unit C4 battery charger. These tests were used to determine the behaviour of the Unit C4 battery charger in conditions similar to those on the day of the incident.

9.4 Principles of Operation of the Unit C4 Battery Charger

In simple terms, the Unit C4 battery charger is a voltage conversion device: it takes in AC voltage at its input and provides a DC voltage at its output.[100]

When the battery charger is connected to a DC system, such as Unit C4's DC system, it will maintain the voltage in that system at a specific level. Any loads connected to the system (e.g., relays) will be supplied by the battery charger, and any battery connected to that system will be charged to this level.[101]

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[100] The battery charger provides the voltage at its output at a specific level. The technicalities of control theory and how the battery charger regulates its output voltage are not discussed in this report.

Some elements of the battery charger's behaviour have been greatly simplified for clarity. A more detailed discussion of the operation of the battery charger is presented in Appendix A4 *Battery Charger Investigation*.

[101] The Unit C4 DC system typically operates with both a battery charger and a battery connected to it. Operation of the battery charger without a battery is discussed in Appendix A4 *Battery Charger Investigation*.

In this report, the specific voltage level at which the battery charger maintains the system is referred to as the battery charger's 'target output voltage'.

During operation, the Unit C4 battery charger continually measures the voltage in the DC system it is connected to and adjusts its output power accordingly:

- When the battery charger measures that the system voltage is *lower* than its target output voltage, it responds by *increasing* its output power, which *increases* the voltage in the DC system.
- When the battery charger measures that the system voltage is *higher* than its target output voltage, it responds by *decreasing* its output power, which *decreases* the voltage in the DC system.

This principle of operation is important in understanding the behaviour of the Unit C4 battery charger during the switching sequence.

9.5 DC System Prior to Connecting the Battery Charger

Prior to connecting the Unit C4 battery charger, the Unit C4 DC system was supplied by the Station DC system. This meant that the Unit C4 DC system was supplied by the Station battery charger, with the Station battery providing redundancy. This meant that the Station battery charger was:

- Supplying all the loads in the Station and Unit C4 DC systems.
- Maintaining the voltage in both DC systems at ~243 V.[102]
- Maintaining the Station battery at a full state of charge.

Figure 112 illustrates the Station battery charger supplying all loads to the Station and Unit C4 DC systems, maintaining the voltage, and charging the Station battery.[103]

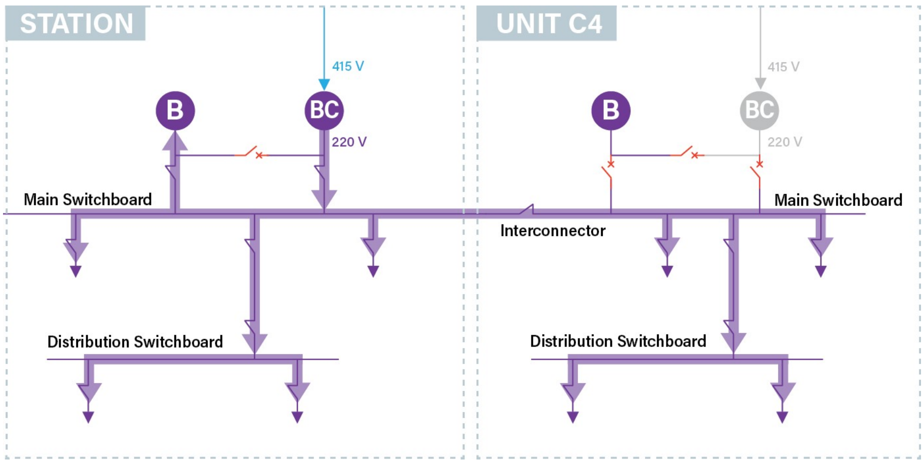

Figure 112 Station battery charger supplies the Station and Unit C4 DC systems

[102] The Station battery charger had been configured to output a voltage of 243 V.

[103] The DC system operates at a nominal voltage of 220 V. This nominal voltage is depicted in the figures in this report. When relevant, the actual (or approximate) voltages of the DC system will be used in the text.

9.6 Behaviour of Unit C4 Battery Charger on Connection to the DC System

The next two steps in the switching sequence were to:

(a) Connect the Unit C4 battery charger to the Unit C4 DC system.

(b) Disconnect the Station DC supply from the Unit C4 DC system.

The Unit C4 battery charger was connected to the DC system at 1:32 pm, as illustrated in Figure 113.

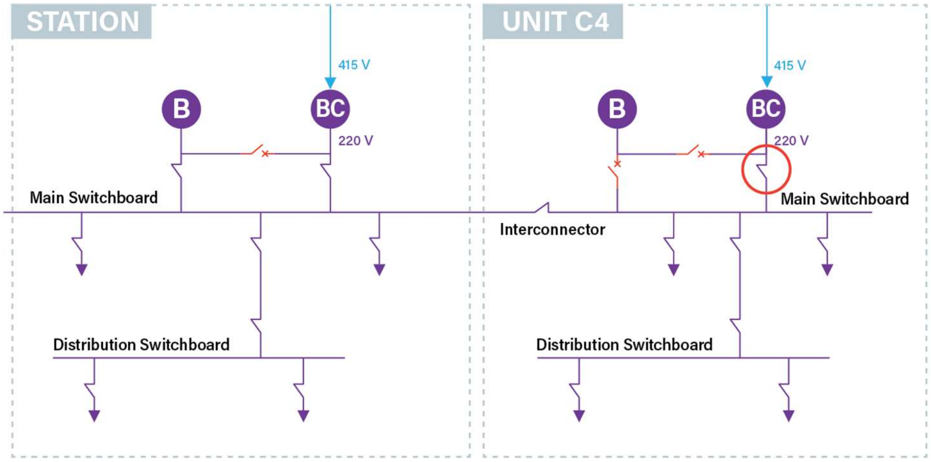

Figure 113 Unit C4 battery charger connected to the DC system

The connected Station and Unit C4 DC systems now had three potential sources of supply: the Station battery charger, the Station battery and the Unit C4 battery charger.

9.6.1 Investigation Testing – Behaviour of the Battery Charger on Connection to a DC System

The Brady Heywood investigation conducted tests to determine the behaviour of the Unit C4 battery charger when it is connected to a DC system with existing sources of supply. These tests reproduced, as far as practically possible, conditions similar to when the Unit C4 battery charger was connected to the DC system during the switching sequence.

The tests showed that, if the voltage in the DC system is *lower* than the battery charger's target output voltage, the battery charger responds by *increasing* its output power, supplying the loads in the DC system, and lifting the voltage in the DC system to the level of its target output voltage. The battery charger will also charge any battery connected to this voltage level.

However, if the voltage in the DC system is *higher* than the battery charger's target output voltage, the battery charger does not output any power. In this situation, when the Unit C4 battery charger is providing no output power, its internal voltage starts to gradually decay (towards 0 V).[104] This gradual decay of the battery charger's internal voltage is illustrated in Figure 114.[105]

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[104] This occurs because the Magellan MCR II battery chargers used in Callide C have a series connected diode at their output, and the feedback signal for the battery charger's control circuitry is likely taken from the load side (cathode) of this diode. This is discussed further in Appendix A4 *Battery Charger Investigation*.

[105] This test was conducted onsite as part of the Brady Heywood investigation. It involved using the Unit C4 battery charger to charge a battery, and then decreasing its configured output voltage by one volt. CSV File (5 December 2022) *143046_221205_CSV.csv*, Worksheet: C3_C4_Relay_Testing, CSE.001.284.0007.

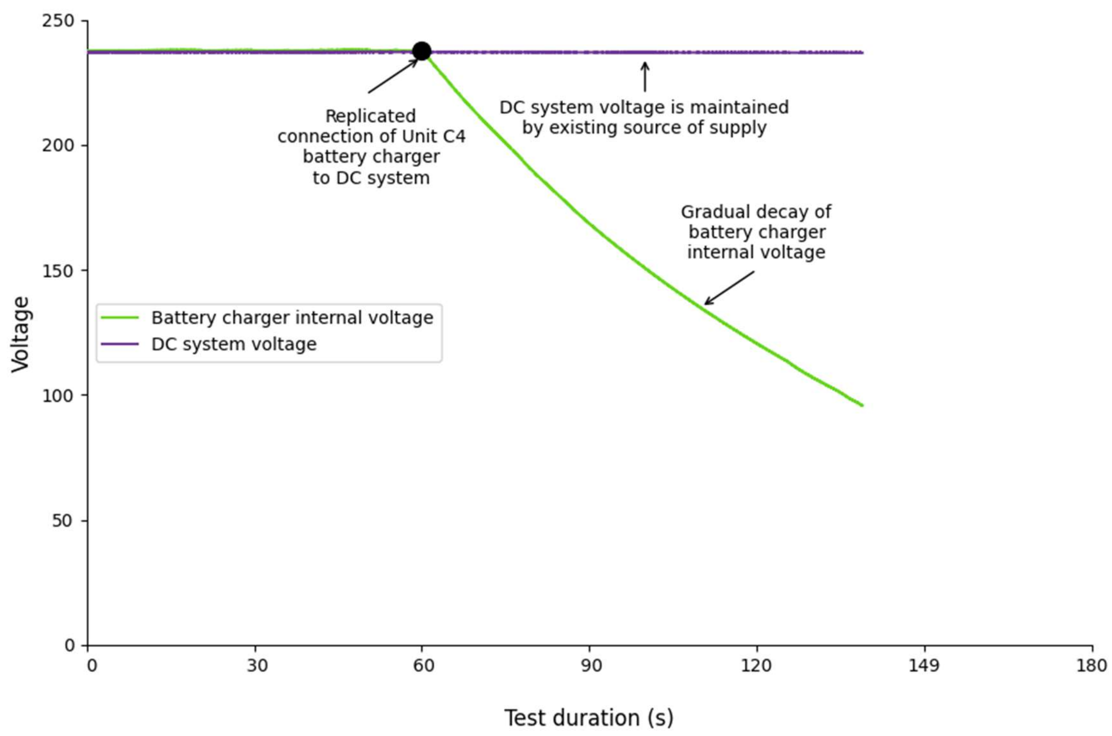

Figure 114 Unit C4 battery charger's internal voltage gradual decay as demonstrated by testing

The purple line depicts the voltage in the DC system (which is maintained by the existing source of supply at a higher voltage), and the green line illustrates the gradual decay of the Unit C4 battery charger's internal voltage.[106]

9.6.2 Day of the Incident – Battery Charger Is Connected to the DC System

ICMS data from the day of the incident shows that, prior to connecting the Unit C4 battery charger, the Station battery charger was supplying all the power to the DC system and maintaining the voltage in the system at ~243 V. When the Unit C4 battery charger was connected, this resulted in the DC system having three possible sources of supply: the Unit C4 battery charger, the Station battery charger and the Station battery.

[106] This behaviour of the Unit C4 battery charger was identified as part of the Brady Heywood investigation. It is behaviour that is specific to the Callide C battery chargers. The reason the internal voltage decays gradually (rather than reducing to zero as soon as the battery charger's output reduces to zero) is because the internal voltage is maintained by capacitors inside the battery charger. It is the gradual discharging of these internal capacitors that leads to the gradual decay of the battery charger's internal voltage. The capacitors are not maintained at the level of the system voltage due to a series diode between the capacitors and the output of the battery charger.

The Brady Heywood investigation tests demonstrated that, when the output of the battery charger reduces to zero, the internal voltage decayed in accordance with an RC decay curve.

This behaviour is consistent with the design of the Unit C4 battery charger. The Unit C4 battery charger has internal filter capacitors, with bleed resistors in parallel. When an RC decay curve is calculated based on the value of the internal capacitors and bleed resistors, this RC decay curve is consistent with the internal voltage decay measured in the Brady Heywood investigation tests. This is discussed in Appendix A4 *Battery Charger Investigation*.

ICMS data shows that following the connection of Unit C4 battery charger, the Station battery charger continued to supply all the power to the DC system, as it had prior to the Unit C4 battery charger being connected. ICMS data also shows the Unit C4 battery charger did not supply any power.[107]

The tests conducted by the Brady Heywood investigation show that the only way this could occur is if the Unit C4 battery charger's target output voltage was lower than the DC system's voltage.[108] If the Unit C4 battery charger's target output voltage had been higher than the DC system voltage, this would have resulted in the Unit C4 battery charger supplying power, and the Station battery charger ceasing to supply power. The ICMS data shows this did not occur.

Given that the Unit C4 battery charger's target output voltage was lower than the DC system's voltage, the Brady Heywood investigation tests showed that, in this situation, the battery charger's internal voltage will begin to gradually decay.

The time that elapsed between connecting the Unit C4 battery charger to the DC system (when its internal voltage would have begun to gradually decay) and disconnecting the Station DC system was 74 seconds. The Brady Heywood investigation tests showed that, in this 74 second period, the internal voltage of the Unit C4 battery charger would likely have decayed to ~120 V, as depicted in Figure 115.

[107] This is based on the ICMS measurements of the battery charger currents and battery current.

[108] The Unit C4 battery charger had been configured to output 245.16 V and the Station battery charger had been configured to output 243 V. No evidence has been sighted that indicates that this difference in configuration was intentional.

However, the target output voltage of the battery charger is not the same as its configured voltage. There are features within the Unit C4 battery charger that cause the target output voltage to differ from its configured output voltage. Appendix A4 *Battery Charger Investigation* discusses the effect that both the Unit C4 uninterruptible power supply (UPS) and the Unit C4 battery charger's temperature compensation have on the target output voltage of the battery charger, and why the target output voltage differs from the configured output voltage.

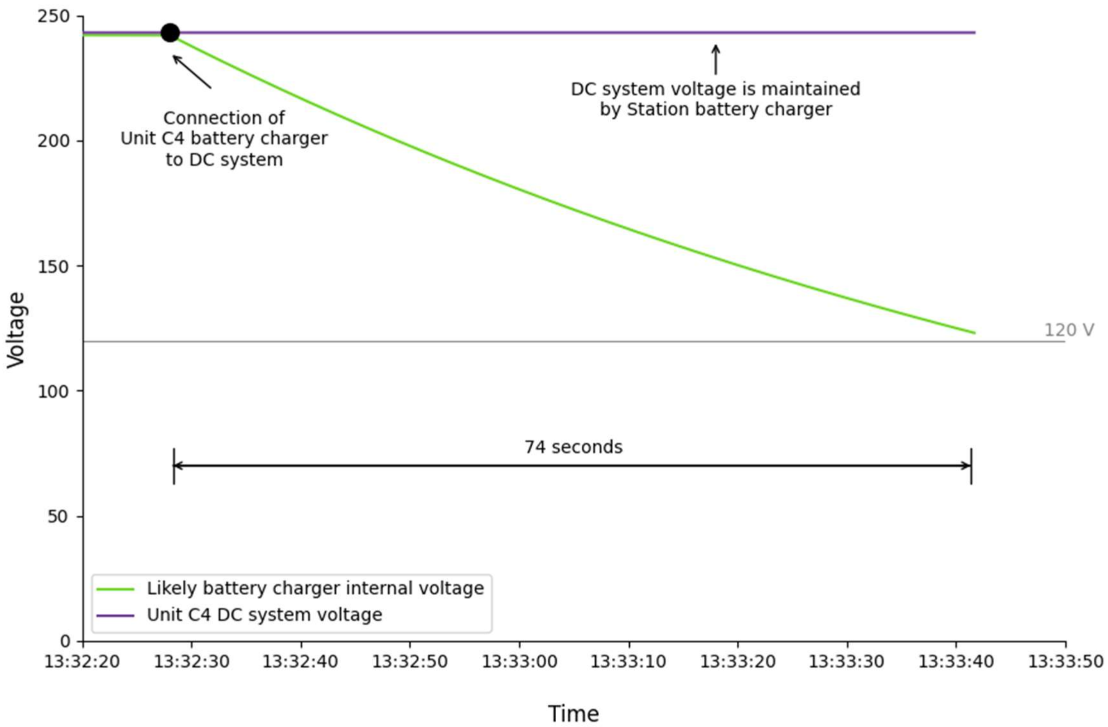

Figure 115 Likely gradual decay of the Unit C4 battery charger's internal voltage to ~120 V

9.7 Behaviour of Unit C4 Battery Charger on Disconnection of Station DC Supply

The next step in the switching sequence was to disconnect the Station DC supply by opening the interconnector, see Figure 116.

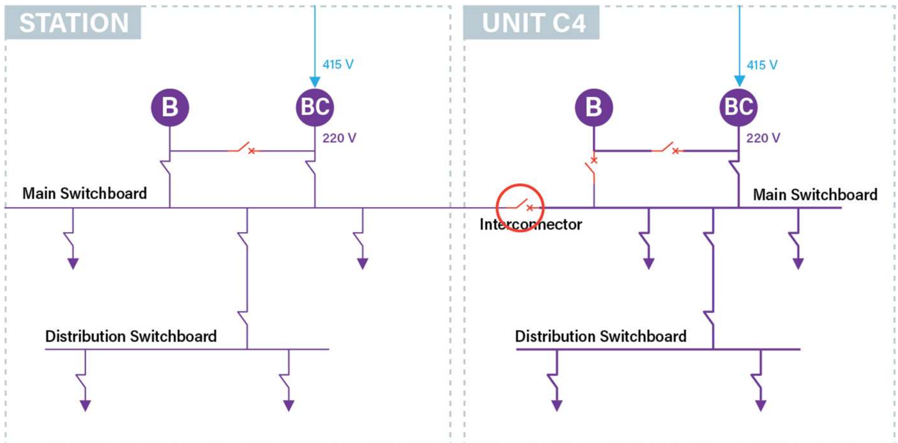

Figure 116 Disconnection of Station DC supply by opening interconnector (indicated in red circle)

This meant the Unit C4 battery charger was the sole source of supply to the Unit C4 DC system. This step was completed at 1:33 pm on the day of the incident.

9.7.1 Investigation Testing – Behaviour of the Battery Charger on Disconnection of a DC Supply

The Brady Heywood investigation conducted tests to determine the behaviour of the Unit C4 battery charger when another source of supply is disconnected from its DC system. These tests reproduced, as far as practically possible, conditions similar to when the Station DC supply was disconnected from the Unit C4 DC system during the switching sequence.

The tests showed that, when the other source of DC supply is disconnected, the Unit C4 battery charger is only capable of outputting a voltage at the level of its internal voltage at that precise time. As a consequence, the voltage in the DC system collapses to the level of this internal voltage. This collapse in voltage is depicted by the purple line in Figure 117.[109]

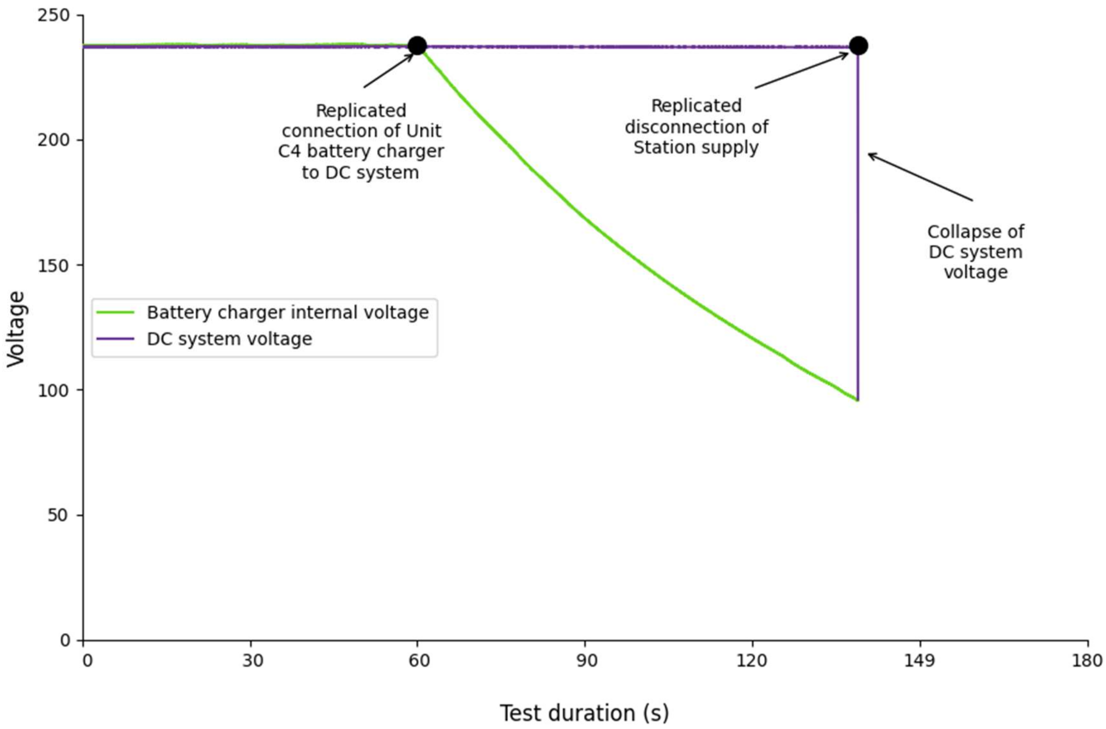

Figure 117 DC system voltage collapses to the level of the battery charger's internal voltage, as demonstrated by testing

When this collapse in DC system voltage occurs, the Unit C4 battery charger detects that the voltage in the DC system is *lower* than its target output voltage and responds by *increasing* its output power. This restores the voltage in the system, as illustrated in Figure 118.[110]

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[109] CSV File (5 December 2022) *143046_221205_CSV.csv*, Worksheet: C3_C4_Relay_Testing, CSE.001.284.0007.

[110] The response time of the battery charger is discussed further in Appendix A4 *Battery Charger Investigation*.

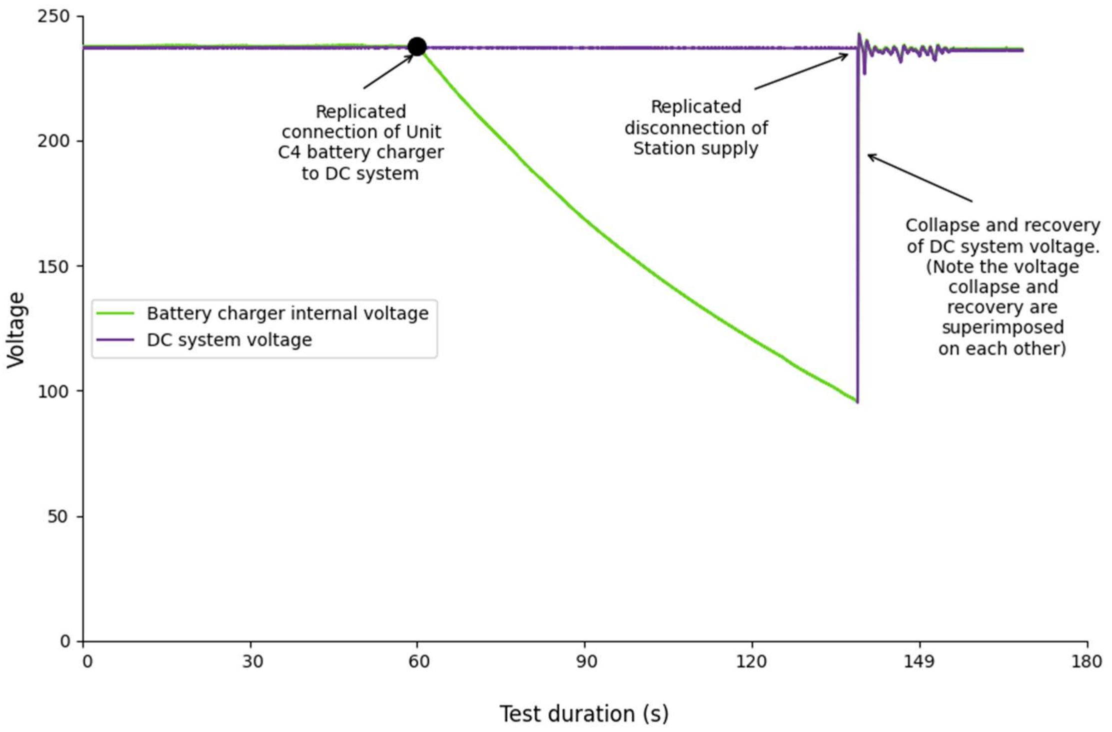

Figure 118 Battery charger recovers DC system voltage

This voltage collapse and recovery is shown in greater detail in Figure 119.

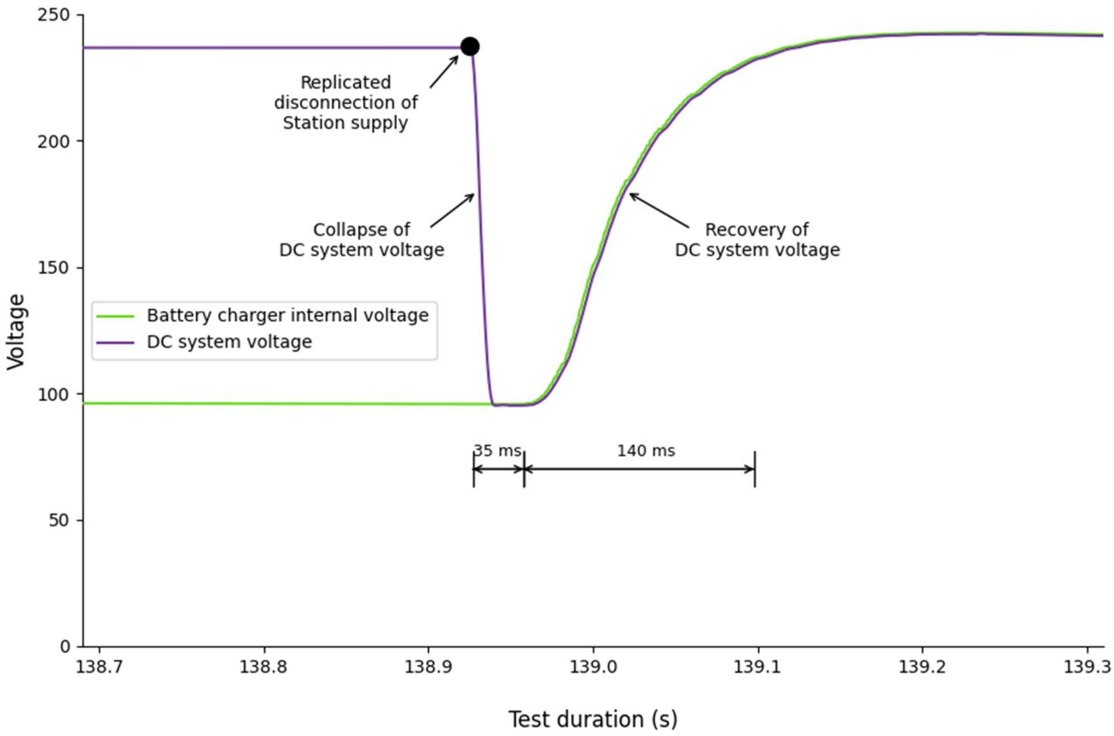

Figure 119 Detail of collapse and recovery of the DC system voltage, as demonstrated by testing

During testing, the battery charger took ~35 milliseconds to respond to the collapse in voltage, and an additional ~140 milliseconds to restore the system voltage to ~240 V.

9.7.2 Day of the Incident – Station DC Supply is Disconnected from the DC System

On the day of the incident, when the Unit C4 battery charger was connected to the Unit C4 DC system, it responded in a manner consistent with the target output voltage being lower than the voltage in the DC system. This likely resulted in the voltage inside the Unit C4 battery charger gradually decaying.[111]

When the interconnector was opened, the voltage in the Unit C4 DC system suddenly collapsed from ~243 V to ~120 V.[112] As discussed previously, ~120 V correlates with the likely level that the Unit C4 battery charger's internal voltage would have decayed to in this 74-second period, see Figure 120.[113]

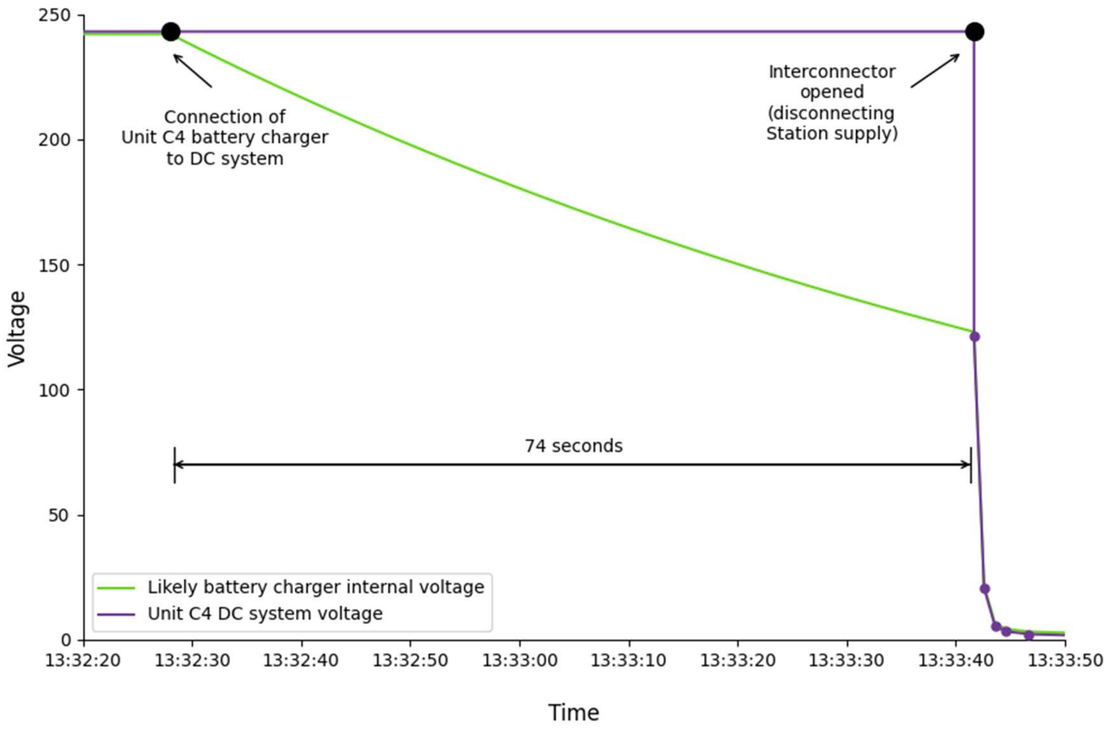

Figure 120 Collapse of DC system voltage to level of Unit C4 battery charger's internal voltage (~120 V)

[111] If the voltage in the DC system had been *lower* than the Unit C4 battery charger's target output voltage, the Unit C4 battery charger's internal voltage would have not decayed, and the voltage level in the DC system likely would not have collapsed in the same manner. Despite this likely resulting in a different outcome, no evidence was sighted that CS Energy were aware of, or considered, the Unit C4 battery charger's behaviour when it was connected to the DC system.

The switching sequence did not include a step that instructed personnel to observe for any specific behaviour of the Unit C4 battery charger, or to check which battery charger was supplying the DC system.

The specification and testing of the battery charger did not include requirements or tests regarding the battery charger's response when it is the sole source of supply in a DC system, nor its response when it is one of a number of supplies in a DC system.

[112] The exact time that the interconnector was opened was not captured by the ICMS, but this time has been established by other means and is discussed further in Appendix A3 *Electrical Investigation*.

[113] The purple dots in the figures are taken from the ICMS voltage readings on the Unit C4 distribution switchboard. The black dots in the figures are not ICMS voltage measurements, but indicate the times that a step in the switching sequence was performed. The Unit C4 distribution switchboard voltages at these times, and the Unit C4 distribution switchboard voltage in between the purple dots, is the likely voltage at that time based on how the ICMS records data.

Following the collapse to ~120 V, the voltage in the DC system did not recover, but rapidly decayed. This rapid decay is shown in greater detail in Figure 121.

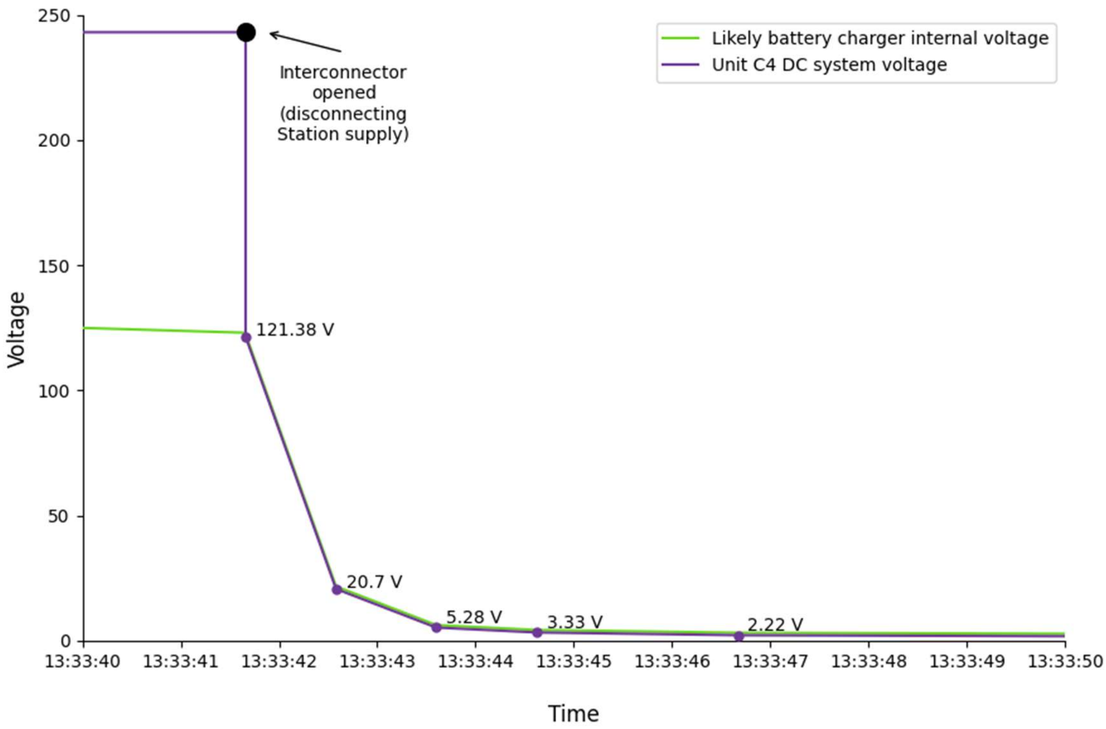

Figure 121 Detail of the rapid decay of the Unit C4 DC voltage

The reason for the rapid decay is twofold:

- The collapse of DC voltage resulted in the loss of AC supply to Unit C4. This loss of AC supply led to the Unit C4 battery charger shutting down and the loss of DC supply to Unit C4.
- With DC supply lost, the existing loads on the Unit C4 system (e.g., relays) continued to draw power. This led to the voltage in the system rapidly decaying.

9.7.3 Investigation Testing – Hypothesised Behaviour of the Battery Charger if AC was not Lost

Had the AC supply to the Unit C4 battery charger not been lost, the battery charger likely would have responded to this drop in voltage and restored the voltage to ~240 V within 2 seconds.[114]

9.8 Chapter Summary

When the Unit C4 battery charger was connected to the DC system, the internal voltage of the Unit C4 battery charger likely gradually decayed due to the voltage in the DC system being higher than the battery charger's target output voltage.

When the Station supply was disconnected, the voltage in the Unit C4 DC system collapsed to the level of the battery charger's internal voltage (i.e., ~120 V).

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[114] As concluded by the Brady Heywood investigation and discussed in Appendix A4 *Battery Charger Investigation*.

This specific manner of the collapse in DC voltage led to the loss of AC supply to Unit C4. Had the AC supply not been lost, the Unit C4 battery charger likely would have responded and recovered the voltage in the DC system within ~2 seconds. However, because the battery charger was supplied by the Unit C4 AC system, the loss of AC supply caused the battery charger to shut down before it could recover the voltage in the DC system.

10 CONCLUSIONS OF PART A: TECHNICAL INVESTIGATION

10.1 Technical Causes of the Incident

The technical causes of the incident are summarised as follows:

(a) **Switching with Unit C4 online without battery redundancy**: The switching sequence was carried out with the unit online, and it included steps with no redundancy to the DC system. The redundancy provided by the Unit C4 battery was unavailable because it was not connected – the switching sequence did not allow its connection until the Station DC supply had been disconnected.

Thus, the switching sequence created a situation whereby when the Station DC supply was disconnected, the battery charger became the sole source of DC supply to Unit C4. The switching sequence, therefore, created the requirement that when the Station DC supply was disconnected, the Unit C4 battery charger needed to respond instantly to maintain the voltage in the Unit C4 DC system.

(b) **The Unit C4 battery charger**: The replacement Unit C4 battery charger did not respond instantly and did not maintain the voltage in the Unit C4 DC system. This caused the voltage to collapse from ~243 V to ~120 V.

The battery charger, however, had not been specified or tested for the requirements of the switching sequence being carried out at the time of the incident (i.e., to maintain the voltage in the Unit C4 DC system after the Station DC supply was disconnected), nor was it capable of doing so under the operating conditions at the time.

(c) **The loss of AC and DC**: The DC voltage collapse in Unit C4 directly led to the loss of AC supply to the unit. This occurred because Unit C4's arc flap protection responded to the DC voltage collapse as if a fault had occurred in the AC system. Despite no fault actually occurring, the arc flap protection activated and disconnected Unit C4's AC supply.

The loss of AC supply then caused the battery charger, which was the sole source of supply to the DC system, to shut down, leading to the complete loss of DC supply to Unit C4.

(d) **The Unit C4 automatic changeover switch**: The Unit C4 automatic changeover switch, which should operate and restore DC supply to parts of the unit as a backup supply in the event of a loss of DC, was inoperable in automatic mode on the day of the incident. Therefore, DC supply was not restored to Unit C4.

These causes combined to result in the incident. The switching sequence was carried out with Unit C4 online, and included steps where the only source of supply to the unit's DC system was the replacement battery charger. There was no redundancy or backup available to the DC system in the form of a battery or the automatic changeover switch. When the battery charger did not respond as required by the switching sequence, both DC and AC supply to Unit C4 were lost. The loss of these supplies, combined with the unit being online, led to it motoring for 34 minutes and resulted in its catastrophic failure.

10.2 Role of the Key Technical Causes

The catastrophic failure of Unit C4 would have been unlikely, or would have been mitigated, if any one of these technical causes had been absent:

(e) **Switching with Unit C4 online without battery redundancy**: The incident would have been avoided if the unit had been offline, with the rotor stationary. In this situation, the turbine generator would not have been damaged despite the loss of AC and DC supplies.

The incident would also have been avoided if the Unit C4 battery had been connected to the Unit C4 DC system. In this situation, the battery would have provided redundancy and removed the requirement for the battery charger, as the sole source of supply, to respond instantly to maintain the DC voltage.

(f) **The Unit C4 battery charger**: The incident would have been avoided if the replacement battery charger had maintained the voltage in the DC system.

(g) **The loss of AC and DC**: The incident would have been avoided if the AC supply had not been lost due to the DC voltage collapse.

If AC supply had not been lost, the Unit C4 battery charger would have likely responded to the collapse in DC voltage and recovered the voltage in the Unit C4 DC system.

(h) **The Unit C4 automatic changeover switch**: The incident could have been mitigated if the Unit C4 automatic changeover switch was operable and had successfully restored DC supply.

Upon restoration of DC supply, the unit’s protection systems would likely have responded and disconnected the unit from the grid. While the unit would likely have sustained significant damage, the turbine missile event would likely have been avoided.

No evidence was found that mechanical or metallurgical failures were likely to have contributed to the incident.

No evidence was found that an IT systems fault or cyberattack (internal or external) were likely to have contributed to the incident.

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Brady Heywood.

Part B: Organisational Investigation

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11 OVERVIEW OF PART B: ORGANISATIONAL INVESTIGATION

11.1 Introduction

This chapter provides a brief overview of the investigation into the organisational factors related to the incident. It summarises the investigation findings, sets out the layout of Part B of this report, discusses the approach taken to the organisational investigation, and introduces the organisational investigation team.

11.2 Summary of Organisational Investigation Findings

The key organisational factor related to the incident can be summarised as a failure to implement effective process safety practices.

These practices could have increased the likelihood of identifying and managing the risks associated with undertaking the switching sequence to bring the replacement battery charger into service, with no redundancy or backup to the DC system, and with the unit online.

The failure to implement effective process safety practices was not unique to the incident on 25 May 2021. Rather, it was consistent with an organisation that did not value or practise effective process safety. In 2017, CS Energy embarked on a project to embed process safety within its organisation, but by 2021 this project had failed to meaningfully improve the management of process safety risk at the Callide power stations. Further, internal reviews conducted by CS Energy's Assurance team identified longstanding and substantive issues with key systems, such as management of change, that are critical for effective process safety. CS Energy's response to these reviews largely treated the symptoms of the issues, as opposed to investigating and rectifying their underlying causes. These process safety practices, if effectively applied, could have increased the likelihood of avoiding the incident on 25 May 2021.

11.3 Layout of Part B: Organisational Investigation Report

Chapter 12 examines what took place on the day of the incident, specifically focusing on the Callide control room operators' response.

Chapter 13 provides a brief overview of key process safety concepts relevant to the incident. It also summarises CS Energy's approach to these concepts.

Chapter 14 to Chapter 17 focus on the wider organisational factors related to the incident. Chapter 14 explores the organisation's history and its operating environment. Chapter 15 discusses the program CS Energy began in 2017 to embed process safety within its organisation. Chapter 16 examines the effectiveness of CS Energy's systems critical for the management of process safety risk, such as management of change. Chapter 17 explores how effectively CS Energy learned from process safety incidents at the Callide site.

Chapter 18 to Chapter 21 focus on the direct organisational factors related to the incident. Chapter 18 examines the factors related to the switching sequence being undertaken to bring the replacement Unit C4 battery charger into service with the unit online, but without DC system redundancy. Chapter 19 examines the lack of effective management of change surrounding the project to replace the Unit C4 battery charger. Chapter 20 discusses CS Energy's consideration of the risks associated with the loss of the Unit C4 AC and DC systems. Chapter 21 examines the organisational factors related to why the Unit C4 automatic changeover switch was inoperable on the day of the incident.

Finally, Chapter 22 provides the conclusions of the organisational investigation.

11.4 Approach to the Organisational Investigation

The approach taken to the organisational investigation included:

- Interviews: Conducting interviews with CS Energy personnel.
- Documentation: Examination of documentary evidence relating to CS Energy and its operations, as well as reports prepared by other parties (e.g., the Australian Energy Market Operator).
- Data analysis: Analysis of various CS Energy data sets.

11.5 Organisational Investigation Team

The organisational investigation team was primarily as follows.

11.5.1 Sean Brady (Lead Investigator)

Dr Sean Brady CPEng, FIEAust, RPEQ is a forensic engineer, and the lead investigator of this incident. He supervised the work conducted by the team, and the opinions expressed in this report are his own.

11.5.2 Ainslie Blunck

Ainslie Blunck CPEng, RPEQ holds a Graduate Diploma in Construction Law. She has more than 25 years experience in the design, project management, and commercial management of infrastructure projects.

11.5.3 Jodi Goodall

Jodi Goodall is an experienced health, safety, and environment leader with more than 18 years expertise in mining, heavy manufacturing, munitions, chemical process plants and logistics. She holds a Master of Science (Occ. Hygiene) from the University of Wollongong.

11.5.4 Daniel Hornibrook

Daniel Hornibrook is a consultant at Brady Heywood, specialising in risk management systems and data analysis. He holds a degree in Economics and Arts from the University of Queensland.

11.5.5 Kiri Parr

Kiri Parr BA LLB and GAICD has more than 25 years experience across legal practice, directorships and in senior executive roles. She is engaged in a variety of roles across academia and industry.

11.5.6 Stephen Pearson

Dr Stephen Pearson, Chartered Chemist, MRSC and MIOSH is an energy industry professional with over 30 years of international experience in health, safety, security, environmental and social performance management. He holds a PhD in Chemistry from the University of Reading and tertiary qualifications in Health and Safety.

11.5.7 Benjamin Reyes

Benjamin Reyes is a specialist in health, safety, and environment management, and for 10 years held executive roles leading the implementation of critical risk management programs across Australia and New Zealand.

11.5.8 Others

Several of the technical experts identified in Chapter 2 *Overview of Part A: Technical Investigation* also participated in the organisational investigation.

12 EVENTS OF THE DAY

12.1 Introduction

This chapter examines how the incident unfolded on 25 May 2021.[116] It begins by presenting some technical background and outlining key information relating to the incident. It then discusses events prior to the incident commencing, examines the initiation of the incident and focuses on the response of CS Energy personnel in the Callide control room.[117]

12.2 Technical Background

From the moment AC and DC supply was lost in the incident, the only available mechanism for the Callide control room operators to disconnect Unit C4 from the grid was for them to request Powerlink open the circuit breaker at Calvale substation.[118] To make this request, the operators needed to be certain that Unit C4 was not being driven by steam and exporting power. It was critical to establish this in order to avoid the risk of an overspeed event, which would have carried significant risk to personnel and to the Callide C power station.

The information available to the operators during the incident was inconclusive and contradictory. The operators did not request Powerlink to open the Calvale substation circuit breaker.

12.3 Key Information Relating to the Incident

This section provides an overview of the third parties relevant to the discussion of the incident and provides details on the data relied upon in the incident response. It also provides a recap of motoring and the risk of an overspeed event.

12.3.1 Australian Energy Market Operator

The Australian Energy Market Operator (AEMO) was established in July 2009, with the purpose of managing the National Electricity Market (NEM). AEMO operates the systems that allow energy to be generated, transmitted and distributed, and operates the financial markets that sell and buy energy.

It is through the NEM where AEMO and electricity generators like CS Energy interact to sell electricity to retailers, who then on-sell to consumers.[119] CS Energy employs traders who interact with AEMO when participating and bidding in the NEM.

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[116] This report does not discuss CS Energy's wider response to the incident, such as the site evacuation, which was outside the scope of the Brady Heywood investigation.

[117] The timeline of events is primarily based on transcripts of interviews conducted by Norton Rose Fulbright with CS Energy personnel following the incident. Transcripts of phone conversations between CS Energy personnel and between CS Energy and AEMO are also relied upon.

[118] The configuration at Calvale means each feeder (e.g., Unit C4 feeder 854) has two circuit breakers. For simplicity, this report refers to these circuit breakers in singular form (i.e., circuit breaker).

[119] AEMO (2024) *AEMO*. https://aemo.com.au/about/who-we-are

AEMO were not contacted as part of this investigation, but AEMO's report into the 25 May 2021 incident has been reviewed and, in some cases, relied upon by the Brady Heywood investigation.[120]

12.3.2 Powerlink

The units at Callide C power station export power to Calvale substation. Calvale substation forms part of the Queensland power grid and is operated by Powerlink. Powerlink is a Queensland government owned corporation that owns, develops, operates and maintains the high-voltage (HV) electricity transmission network in Queensland.

As discussed in Part A of this report, CS Energy's personnel did not have the ability to disconnect Unit C4 from the grid due to the loss of DC supply to the generator circuit breaker. Powerlink, however, did have this ability – Powerlink personnel could open circuit breakers in Calvale substation – which would have stopped the unit motoring. Throughout the incident, numerous phone conversations took place between Powerlink personnel and CS Energy personnel in the Callide control room. These phone conversations were not recorded by CS Energy.

The Brady Heywood investigation requested that Norton Rose Fulbright contact Powerlink and ask for information related to these conversations. Norton Rose Fulbright informed the Brady Heywood investigation that CS Energy and Powerlink had not agreed on the terms upon which this information would be provided.

Consequently, the content of the phone conversations described below between CS Energy and Powerlink are taken from interview transcripts provided by Norton Rose Fulbright. These interviews were conducted by Norton Rose Fulbright with CS Energy personnel post-incident.

12.3.3 A Note on Data Flow

During the incident, generation data from Unit C4 was transmitted from two independent sources:

- Callide C power station, which is measured directly at the output of the Unit C4 generator.[121]
- Powerlink's Calvale substation, which is measured where the power generated by Unit C4 enters the substation at Circuit 854.

The Callide control room, Powerlink, AEMO, Callide Power Trading (Operational Trading) and CS Energy Traders (Commercial Trading) appear to receive data from the Unit C4 generator.[122] This data was affected by the loss of DC supply to Unit C4 and is discussed further below.

In addition to receiving the data measured at the Unit C4 generator, Powerlink also receives power values measured at Calvale substation, which are separate and independent of Callide C power station. As these signals were not affected by the loss of DC supplies to Unit C4, they could have provided

[120] AEMO (2021) *Trip of multiple generators and lines in Central Queensland and associated under-frequency load shedding on 25 May 2021.* https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2021/trip-of-multiple-generators-and-lines-in-qld-and-associated-under-frequency-load-shedding.pdf

[121] This data is the calculated sent-out value (i.e., the net generation once the auxiliary load has been subtracted). The power station would have this data and the total generation data in the control room.

[122] Brady Heywood Investigation (22 December 2023) *Hypothesis on Data Flow*, CSE.001.277.0017.

Powerlink with an independent live data source regarding whether Unit C4 was importing or exporting power.[123] It appears this data source was also made available to AEMO.[124]

In summary, it appears that Powerlink and AEMO received data originating from the Unit C4 generator, and it is likely that Powerlink and AEMO also had access to data from Calvale substation.

The two independent data sources likely would have indicated conflicting information. The Brady Heywood investigation's hypothesis is that data from the Unit C4 generator was *incorrectly* indicating that the unit was exporting power. This hypothesis is based on the following:

- Because Unit C4's DC supply was lost, the DC supply to the sensors on Unit C4 was also lost.
- DC supply, however, was not lost to the ICMS data acquisition system, which receives a separate supply from Station.
- Under these circumstances, the ICMS likely retained the last measurement received from the sensors prior to their loss of DC supply. In the incident, this measurement would have indicated that Unit C4 was exporting power.[125] However, Unit C4 was not exporting power during the incident, but was importing power from when DC and AC supply were lost.

The data from Calvale substation, however, would have *correctly* indicated that Unit C4 was, in fact, importing power and therefore motoring.

12.3.4 A Note on Motoring

As discussed in Part A of this report, motoring in a turbine generator occurs when the unit imports power from the grid and becomes an electric motor. The motoring of Unit C4 continued for 34 minutes from 1:33 pm to 2:07 pm on the day of the incident.

12.3.5 A Note on an Overspeed Event

Also discussed in Part A of this report is a catastrophic failure mechanism in turbine generators known as an 'overspeed event'. During normal operation, when the turbine generator is generating electricity, the rotation of the generator rotor is resisted by the grid. If the generator is disconnected from the grid (e.g., by opening the generator circuit breaker), this resistance is removed. If this resistance is removed while the turbine is still being driven by steam, the turbine generator rapidly speeds up, and can tear itself apart in the order of 10 to 20 seconds.

An overspeed event is highly unlikely to have occurred on Unit C4.

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[123] Based on information received from CS Energy. This data has not been verified by Powerlink.

[124] Based on information received from CS Energy. This data has not been verified by AEMO.

[125] Pacific Power International (1 June 2020) *Callide Power Plant Contract No 193/1997/HO 2220Vdc Distribution Electrical System Diagram,* Drawing Reference A1-C-747600, Rev K, CSE.001.003.2392. The ICMS has two separate DC supplies: one from Unit C4 and one from Station. The loss of the Unit C4 DC system would not result in the loss of DC supply to the ICMS because the Station DC system remained healthy (because of the Station battery). The Unit C4 power transducers are supplied from a single 220 V DC supply to the Generator Metering Panel from the Unit C4 220 V distribution board. When the DC supply to Unit C4 failed, this supply to the power transducers would also have failed and resulted in the loss of signal. Even though the ICMS was operational, and the screens were restored, the supply to the transducers was lost for the entirety of the incident.

Before the operators in the Callide control room could request Powerlink to disconnect Unit C4 from the grid, it was critical to ensure the turbine generator was no longer being driven by steam.

12.4 Prior to Initiation of Incident

12.4.1 Morning of 25 May 2021

On 25 May 2021, the **Unit C4 Control Room Operator** arrived in the control room at 6:50 am. Figure 122 shows the control room for the Callide B and C power stations.

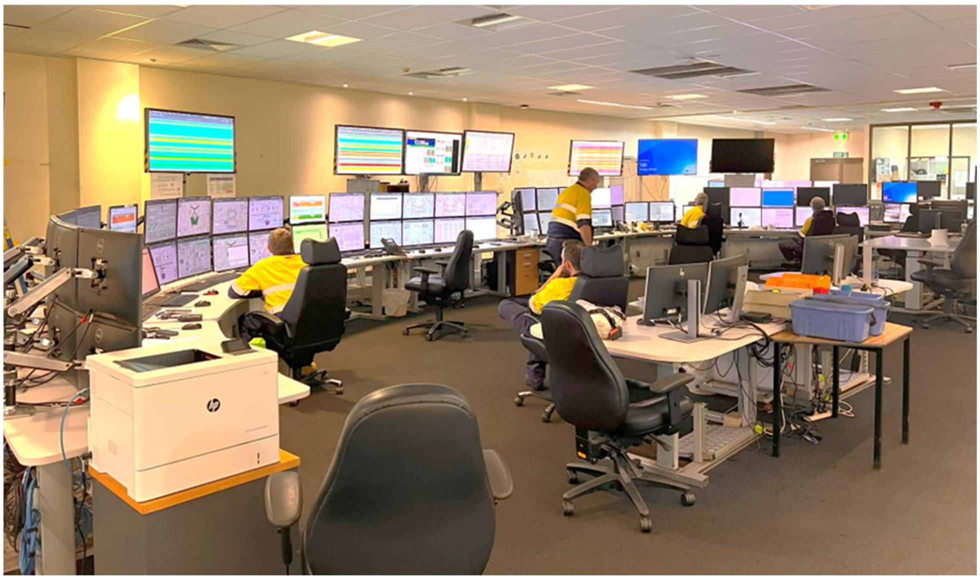

Figure 122 Control room for Callide B and C power stations

CS Energy operators control all four units (Unit B1, Unit B2, Unit C3 and Unit C4) from a single control room located inside the turbine hall building. Operators monitor data fed directly from each turbine generator to specific desk panels and a series of monitors.

B shift was on duty that morning. Nothing notable was raised at the 7:00 am shift meeting, and the **Unit C4 Control Room Operator** completed their routine panel checks of the control room screens and logged the information in the 'J5' diary.[126] They also checked their emails for any operational updates from the previous shift and focused on checking the active daily permits.[127]

12.4.2 Step-Up Supervisor

At 10:00 am, the **B Shift Supervisor** announced they had to leave on a personal matter. Another supervisor assumed the role of B Shift Supervisor (referred to as the **B Shift Step-Up Supervisor** in

[126] The 'J5' diary is essentially an electronic operator log used by the Callide C operators to enter job details, comments, notes, etc.

[127] Transcript (8 June 2021) *Unit C4 Control Room Operator*, 7, CSE.001.006.0888; Transcript (8 June 2021) *Unit B1 Outside Operator,* 17, CSE.001.006.1209; Excel Spreadsheet *2021 2022 - Operations Shift Roster Callide*, Worksheet: 23 May 2021, CSE.001.262.0001.

this report).[128] The **B Shift Supervisor** briefed the **B Shift Step-Up Supervisor** and gave them the shift supervisor's phone. The **B Shift Supervisor** left the control room at around 10:30 am.

12.4.3 Field Checks

At around 12:45 pm, the **C Station Operator** left the control room to attend a periodic face mask fitting in the first aid room.[129]

Instead of leaving the control room to conduct routine in-field checks for Unit C4, the **Unit C4 Control Room Operator** asked the **Unit C3 Control Room Operator** if they could undertake the in-field checks for both Unit C3 and Unit C4. This left the **Unit C4 Control Room Operator** to monitor both Unit C3 and Unit C4.

12.4.4 The Switching Sequence

At approximately 1:00 pm, the **Electrical Supervisor** and **Electrical Technician** entered the control room. They told the **Unit C4 Control Room Operator** they were going to continue with the switching sequence to connect the replacement Unit C4 battery charger to Unit C4.[130] This switching sequence had commenced the previous day.[131]

Explanatory note: *It was during the execution of this switching sequence that the incident occurred.*[132]

12.4.5 The Switching Sequence Commences

At around 1:15 pm, the **Electrical Supervisor** and **Electrical Technician** went to the Unit C4 DC switch room to continue with the switching sequence. Figure 123 shows the Unit C4 DC switch room, which is located on the ground floor of the turbine hall building.[133]

[128] Transcript (6 June 2021) *Unit B2 Outside Operator*, 10, CSE.001.006.1253; Transcript (8 June 2021) *Unit C4 Control Room Operator*, 6, CSE.001.006.0888; Statement (25 August 2021) *B Shift Step-Up Supervisor*, 24, CSE.001.093.0013.

[129] Transcript (14 June 2021) *C Station Operator*, 7, CSE.001.006.0777.

[130] Transcript (8 June 2021) *Unit C4 Control Room Operator*, 8-9, CSE.001.006.0888; Transcript (9 June 2021) *Electrical Technician*, 13, CSE.001.006.0965.

[131] A switching sequence can span several shifts.

[132] A detailed discussion on the switching sequence is contained in Chapter 6 *How the Switching Sequence Initiated the Incident.*

[133] This photograph was taken after the incident when multiple isolations were in place. It is not an accurate representation of the state of the switch room on the day of the incident.

Figure 123 Unit C4 DC switch room

The **Electrical Supervisor** and **Electrical Technician** referred to the switching sheet – the document that details the steps in the switching sequence. They discussed the steps that were completed in the previous shift and the steps they needed to take during their shift.[134]

<u>Explanatory note</u>: *The switching sequence steps completed on the previous day were to connect the Unit C4 battery charger to the Unit C4 battery. This was to ensure the battery was fully charged before it was brought back into service.*

The **Electrical Supervisor** and **Electrical Technician** then, as prescribed on the switching sheet, successfully completed the following steps:

(a) Confirmed the Unit C4 battery was fully charged (Step 180).

(b) Disconnected the Unit C4 battery charger from the Unit C4 battery (Step 190).

(c) Connected the Unit C4 battery charger to the DC system (Step 200).

12.5 Initiation of the Incident

12.5.1 Disconnection of Station DC Supply

At 1:33 pm, the **Electrical Supervisor** and **Electrical Technician** reached switching Step 210 in the switching sequence. This step was to disconnect the Station DC supply from the Unit C4 DC system by opening the interconnector between the Station and Unit C4 DC systems.

This step required that the Unit C4 battery charger be the sole source of supply to the Unit C4 DC system. The **Electrical Technician** completed this step in accordance with the switching sheet.

[134] Transcript (9 June 2021) *Electrical Technician*, 17, CSE.001.006.0965.

12.5.2 Loss of Switch Room Lighting

Upon disconnecting the Station DC supply from the Unit C4 DC system, the switch room lights went out.[135] Both personnel stepped back from the switchboard. The emergency lighting operated automatically, but with only one or two lights there was minimal illumination. The two personnel wondered what had just happened. Within approximately 10 to 15 seconds, they heard a loud bang from the turbine hall.[136] The **Electrical Technician** thought the unit had tripped offline. Then, approximately 10 to 15 seconds later, they heard a second, even louder, bang.

Explanatory note: *The **Electrical Supervisor** and **Electrical Technician** would have no way of knowing that the disconnection of the Station DC supply from Unit C4 (by opening of the interconnector) had led to the voltage collapse in the Unit C4 DC system, which led to the loss of AC supply to Unit C4 (by arc flap protection operating), which then led to the complete loss of DC supply.*

The loss of the AC and DC systems occurred in the order of two seconds. Both personnel in the switch room were unaware of what had taken place. The loud bang was heard by several others and described as 'something large dropping', 'loud building rattling', and 'explosions'.[137]

12.6 Initial Response

12.6.1 Switching Team Leave the Switch Room

Upon hearing the second, louder bang, the **Electrical Supervisor** and **Electrical Technician** left the switch room and went into the turbine hall. As they did so, the **Electrical Supervisor** used their mobile phone to contact the **Unit C4 Control Room Operator** in the control room. There was no answer.

The two personnel drove to the exit of the turbine hall in one of the site utility carts.[138] As they did so, the evacuation alarm sounded. On hearing the alarm, they drove to the evacuation point located adjacent to the power station gatehouse.[139]

Upon reaching the evacuation point, the **Electrical Supervisor** made another call – this time to the Shift Supervisor's phone. The **B Shift Step-Up Supervisor** answered. The **Electrical Supervisor** informed them that they, and the **Electrical Technician**, had opened the interconnector between Station and Unit C4.[140] They told the **B Shift Step-Up Supervisor** that they were no longer in the switch room and were at the evacuation point. The **Electrical Supervisor** and **Electrical Technician** remained offsite for the remainder of the incident.

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[135] Transcript (9 June 2021) *Electrical Technician*, 21, CSE.001.006.0965.

[136] Transcript (9 June 2021) *Electrical Technician*, 21, CSE.001.006.0965.

[137] Transcript (13 October 2021) *Unit B1 Control Room Operator*, 22, CSE.001.099.0037; Transcript (9 June 2021) *Permit to Work Officer 1*, 7, CSE.001.006.0859; Transcript (9 June 2021) *Unit B2 Control Room Operator*, 7, CSE.001.006.0876; Transcript (9 June 2021) *General Manager*, 7, CSE.001.006.0535.

[138] Transcript (9 June 2021) *Electrical Technician*, 21, CSE.001.006.0965; Statement (30 March 2021) *Electrical Supervisor*, 94, CSE.001.093.0238.

[139] Transcript (9 June 2021) *Electrical Technician*, 22, CSE.001.006.0965; Statement (30 March 2021) *Electrical Supervisor*, 95, CSE.001.093.0238.

[140] Statement (30 March 2021) *Electrical Supervisor*, 97, CSE.001.093.0238. They refer to the interconnector as the 'Bus coupler'.

12.6.2 Loss of Unit C4 Operator Screens in the Control Room

At 1:33 pm in the control room, as the **Electrical Supervisor** and **Electrical Technician** performed Step 210 of the switching sequence and opened the interconnector, all the screens used to monitor Unit C4 went black.[141] The **Unit C4 Control Room Operator** no longer had visibility on what was happening with Unit C4.[142]

Explanatory note: *The monitoring screens have two power sources for redundancy. Power is provided by both the AC system and the DC system (which is converted to AC via the Unit C4 uninterruptable power supply (UPS)). Because both AC and DC systems had been lost, the supply to the screens was also lost.*

The **Unit C4 Control Room Operator** heard a loud bang. The **B Shift Step-Up Supervisor**, who had also heard the loud bang, entered the control room to get a two-way radio so that they could go and investigate the situation. The **Unit C4 Control Room Operator** told the **B Shift Step-Up Supervisor** that the Unit C4 screens had gone black.

Explanatory note: *The **Unit C4 Control Room Operator** and **B Shift Step-Up Supervisor** report only hearing one bang, which is likely to have been the second, louder bang heard by the **Electrical Supervisor** and **Electrical Technician.***

12.6.3 Confirmation of Physical Incident

At around 1:34 pm, the **B Shift Step-Up Supervisor** left the control room to investigate. Their mobile phone rang. It was the **Relief Chem Plant Operator**, who was outside the turbine hall. They were calling to advise that they had heard and felt '*loud booms*', and they could see smoke above the turbine hall building.[143] By this time, the **B Shift Step-Up Supervisor** could see very bright, three-metre flames between the turbine and the generator on Unit C4. They also noted that the fire-fighting water deluge system was operating.[144]

Explanatory note: *This fire was likely the result of the ignition of a mix of hydrogen gas escaping from the generator (due to both the AC and DC seal oil pumps being without supply) and oil from the bearings.*

Figure 124 shows Unit C4 in the turbine hall (post-incident). All four units are located in the same building.

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[141] Transcript (8 June 2021) *Unit C4 Control Room Operator*, 11, CSE.001.006.0888. Interview transcripts indicate there were approximately a dozen screens associated with Unit C4 that went black. Some transcripts indicate that control screens for Station and C3 were lost as well.

[142] Transcript (8 June 2021) *Unit C4 Control Room Operator*, 11, CSE.001.006.0888.

[143] The Relief Chem Plant Operator was a Control System Technician who was working as the Relief Chemical Plant Operator on this shift. They report hearing two 'booms' approximately 10 seconds apart, with the second being louder than the first.

[144] Statement (25 August 2021) *B Shift Step-Up Supervisor*, 33, CSE.001.093.0013.

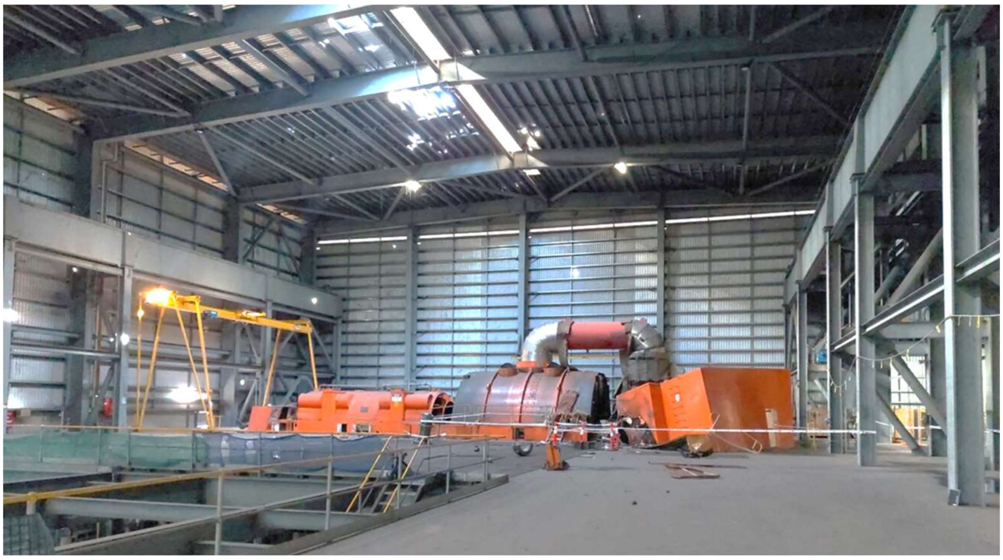

Figure 124 Post-incident Unit C4 in the turbine hall

12.6.4 The Evacuation Signal Sounds

The **B Shift Step-Up Supervisor** quickly returned to the control room. At 1:36 pm, they activated the evacuation siren, informing the **Unit C4 Control Room Operator**, **Unit B2 Control Room Operator**, **Permit to Work Officer 1**, and **Unit B1 Control Room Operator** that they had seen very bright three-metre flames between the turbine and generator on Unit C4.[145] While the site began evacuating, some operators remained to attempt to respond to the incident.

12.6.5 First Call from Callide Power Trading to the Control Room (1:37 pm – 1:39 pm)

At 1:37 pm, approximately four minutes after the initiation of the event, the **Unit C3 Control Room Operator** answered a phone call from the **CS Energy Trading Manager** at Callide Power Trading (based in Brisbane).

The **CS Energy Trading Manager** called because they had issues viewing the data from Unit C4. The **Unit C3 Control Room Operator** informed the **CS Energy Trading Manager** there was a fire on the Unit C4 turbine, and they had lost all of the Unit C4 control room screens.[146]

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[145] Transcript (8 June 2021) *Unit C4 Control Room Operator*, 12, CSE.001.006.0888; Transcript (9 June 2021) *Unit B2 Control Room Operator*, 8, CSE.001.006.0876; Transcript (9 June 2021) *Permit to Work Officer 1*, 8, CSE.001.006.0859; Transcript (13 October 2021) *Unit B1 Control Room Operator*, 22, CSE.001.099.0037; Transcript (7 June 2021) *Relief Chem Plant Operator*, 6, CSE.001.006.0564.

[146] The Unit C3 Control Room Operator also informed the CS Energy Trading Manager that Unit C3 had tripped, that most of the Unit C3 screens were black, that various signals were 'locked', and that Unit C3 was on 'Turbine Follow' mode. The Unit C3 Control Room Operator confirmed to the CS Energy Trading Manager that there were four coal mills in service. Then they asked the CS Energy Trading Manager to follow the load remotely in case the site was evacuated. The call ended at 1:39 pm.

12.6.6 Activity in the Control Room

Soon after hearing the two loud bangs, **Permit to Work Officer 1** and **Permit to Work Officer 2** entered the control room to see if they could assist.[147] **Permit to Work Officer 1** noticed the screens were black on Unit C4, except for one screen on a start-up panel, a little further from the main control panel.[148]

Control Systems Technician 1 and **Control Systems Technician 2** were attempting to re-establish power supply to the Unit C4 screens. They could not find a power board and extension lead in the control room, so **Control Systems Technician 2** ran upstairs to Level 4, removed an extension lead and power board from a desk and returned to the control room. **Control Systems Technician 2** untangled the cables from the black screens so they could connect them to the power board and extension lead. (The extension lead could then be connected to another power source in the control room.)

At some time during this period, the **Unit C4 Control Room Operator** and **B Shift Step Up Supervisor** heard another bang. Soon after, the **Production Manager** made their way to the control room.[149]

Between 1:36 pm and 1:40 pm, the **Unit C4 Control Room Operator** noticed that one of the screens associated with the coal mills was on.[150] The **Unit C4 Control Room Operator** selected the coal mills' page on the screen, which showed that the coal mills had tripped.

Explanatory note: *The coal mills feed coal into the boiler, which then feeds steam to Unit C4. The personnel deduced that if the coal mills had tripped, then there was no coal feeding the boiler, and if there was no coal feeding the boiler, the boiler must have tripped.*

This conversation indicates that there was some level of confusion as the operator sought to understand the status of Unit C3. The Brady Heywood investigation did not investigate if or how Unit C3 screens were lost. Given the loss of the Unit C3 screens and 'locked' signals (likely a reference to the signal not being updated), it is not clear how the Unit C3 Control Room Operator determined that Unit C3 had tripped and was in turbine follow mode. 'Turbine Follow' is a mode of operation where the boiler follows the turbine, adjusting its firing to constantly meet the turbine's requirements. It is not possible for Unit C3 to be on turbine follow mode after it had tripped, and the Brady Heywood investigation concluded that Unit C3 did not trip until closer to 1:44 pm. The reference to '*four coal mills in service*' also suggests the unit was online and generating a high output power. (There are a total of five coal mills per unit, so four mills in service would equate to almost maximum fuel supply, and thus almost maximum pressure.)

[147] This chapter discusses the events of the day from the perspective of those present. As such, some of the events discussed occurred concurrently rather than sequentially.

Permit to Work Officer 1 reports hearing two bangs initially, whereas the Unit C3 Control Room Operator reports hearing only one. Transcript (9 June 2021) *Permit to Work Officer 1*, 7, CSE.001.006.0859.

[148] Permit to Work Officer 1 states that the screens were lost to Station as well. The Brady Heywood investigation did not investigate if or how the Station screens were lost. Transcript (9 June 2021) *Permit to Work Officer 1*, 8, CSE.001.006.0859.

[149] Based on interview transcripts, it is likely that this loud bang occurred at around 1:44pm, when Unit C3 tripped. Transcript (8 June 2021) *Unit C4 Control Room Operator*, 12, CSE.001.006.0888; Statement (25 August 2021) *B Shift Step-Up Supervisor*, 51, CSE.001.093.0013.

[150] It is not clear if this is the screen on the start-up panel that was noticed by Permit to Work Officer 1 earlier.

The **Unit C4 Control Room Operator** also deduced, based on information from the screen associated with the coal mills, that the emergency diesel generator and fire pump were online.[151]

Explanatory note: *While the emergency diesel generator operated and did restore supply to the Station AC system, it did not restore supply to the Unit C4 AC system. This was because the equipment required to configure the Unit C4 AC system to receive this supply was powered by the Unit C4 DC system, which had been lost.*

Having now succeeded in connecting the Unit C4 screens to the power board and extension lead, **Control Systems Technician 2** waited for the screen system to power up.[152]

Explanatory note: *It took several minutes for the programs to start and the screens to start showing data.*[153]

Permit to Work Officer 1 and **Control Systems Technician 2** decided to exit the control room and enter the turbine hall to observe Unit C4. They did not see any fire, but did observe a lot of white smoke and dust in the turbine hall. Not wanting to get any closer because of safety concerns, and convinced something serious was happening, **Permit to Work Officer 1** and **Control Systems Technician 2** returned to the control room.[154]

Permit to Work Officer 1 then contacted the **Relief Chem Plant Operator** in the Chemical Plant and asked them to shut off the hydrogen supply in Callide C power station.

Explanatory note: *Shutting off the hydrogen supply in the power station (and hence Unit C4) would prevent any additional hydrogen from feeding the fire on the Unit C4 generator.*

Unit B1 Outside Operator activated the Unit C4 master fuel trip in an attempt to trip the unit offline.[155]

Explanatory note: *The master fuel trip pushbutton on the ICMS is a manual means to safely shut down the unit and disconnect it from the grid. The loss of DC supply, however, meant there was no way (onsite) to disconnect Unit C4 from the grid, including as part of the master fuel trip.*

Siemens was the control system designer for Callide C power station. One of its technicians (**Siemens Technician**) had been remotely assessing the Callide control system earlier that day for maintenance. Consequently, **Control Systems Technician 1** contacted the **Siemens Technician** to discuss the visibility Siemens had of Unit C4's systems. They asked if the **Siemens Technician** could confirm whether or not they could see if the Unit C4 master fuel trip had activated. The **Siemens Technician** confirmed that Unit C4's control system was visible to them and began talking through the state of the

[151] Transcript (8 June 2021) *Unit C4 Control Room Operator*, 13, CSE.001.006.0888.

[152] Transcript (6 June 2021) *Control Systems Technician 2*, 11-12, CSE.001.006.1060.

[153] Transcript (8 June 2021) *Unit C4 Control Room Operator*, 15, CSE.001.006.0888.

[154] Transcript (6 June 2021) *Control Systems Technician 2*, 9, CSE.001.006.1060.

[155] Unit B1 Outside Operator was not part of the B Shift Crew, but was a Shift Operator responsible as the Unit 1 Outage Coordinator.

equipment with **Control Systems Technician 1**. The information available to the **Siemens Technician** and **Control Systems Technician 1** led them to deduce the master fuel trip had activated.[156]

<u>Explanatory note</u>: *Even if the master fuel trip had activated, the loss of DC supply meant that Unit C4 could not be disconnected from the grid. It is not clear what information the* ***Siemens Technician*** *and* ***Control Systems Technician 1*** *relied upon to make the deduction that the master fuel trip had activated.*[157] *Nor is it clear at what time this deduction was made and how this information may have contributed to the confusion in the control room regarding the status of Unit C4.*

Permit to Work Officer 2 left the control room and headed for the boiler basement on the Ground Level where the coal mills are located. Here, they confirmed that the boiler had tripped.[158]

The **Unit C4 Control Room Operator** asked **Unit B2 Outside Operator** to close the control and instrument air systems interconnection valve between the Callide B and C power station units. By closing this valve, control and instrument air would be prevented from being drawn from Callide B power station and would help Unit B2 remain online. The **Unit B2 Outside Operator** closed the valve located at the edge of Unit C3 and Unit B2, and then immediately returned to the control room.[159]

<u>Explanatory note</u>: *The coal mills and the boiler tripped instantaneously when Unit C4 lost AC and DC supply at 1:33 pm. It took the control room personnel between 3 and 7 minutes to identify Unit C4 as the source of the incident, sound the evacuation siren, isolate Unit C4's hydrogen feed from the chemical plant, and confirm that the coal mills and boiler had tripped. They achieved all of this with only a single functioning screen (i.e., the screen associated with the coal mills.)*

12.7 External Phone Calls (Commencing at Approximately 1:40 pm)

12.7.1 First Call to AEMO (1:40 pm – 1:41 pm)

At 1:40 pm, the **CS Energy Trading Manager** called AEMO and informed **AEMO Operator 1** of the emerging situation with Unit C4.

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[156] Transcript (6 June 2021) *Control Systems Technician 1*, 14, CSE.001.006.0921.

[157] The master fuel trip is the term used at Callide for the boiler protection system. Operation of the master fuel trip will result in the safe shutdown of the boiler, turbine and generator. The master fuel trip can be initiated from several sources, such as the master fuel trip pushbutton, the master fuel trip button on the ICMS screen, by the operation of X and Y protection, the loss of the main boiler fans, and by abnormal steam or boiler conditions.

When the master fuel trip is operated, the boiler is tripped (by tripping the mills, fans and oil burners), the turbine valves are tripped, and the generator is tripped via the X and Y protection systems. The interface between the ICMS, boiler management system and the plant (e.g., the fans, mills and burner fuel oil pump) is via the master fuel trip and interposing relay panel, which relies on a 220 V DC supply to operate the electromechanical relays to send the trip signals to all these devices.

When the Unit B1 Outside Operator pressed the master fuel trip pushbutton, the system could not trip the generator circuit breaker because there was no DC supply to send the trip signal. The loss of AC supply would have tripped the boiler (due to the loss of the AC supply tripping the mills, fans and burners). The turbine valves would also have tripped due to the loss of hydraulic pressure when the pumps tripped from loss of AC supply. On the day of the incident, alarms relating to a master fuel trip were recorded in the ICMS alarm log at 1:44:17, including 'MASTER FUEL TRIP'. CS Energy (5 November 2021) *SPPA-T3000 Event Sequence Report*, CSE.001.054.0063.

[158] Transcript (9 June 2021) *Permit to Work Officer 1*, 10, CSE.001.006.0859.

[159] Transcript (8 June 2021) *Unit C4 Control Room Operator*, 14, CSE.001.006.0888.

12.7.2 First Call from Powerlink

As the **Unit B2 Outside Operator** returned to the control room, the **Unit C4 Control Room Operator** answered a phone call from Powerlink. Powerlink confirmed they could see Unit C3 coming offline.[160]

Explanatory note: *Powerlink was correct. Unit C3 was going offline at 1:44 pm (as per the ICMS). The Brady Heywood investigation's hypothesis is that this data was coming directly from the Unit C3 generator and was a true reflection of its status (because its sensors were unaffected in the incident).*

The **Unit C4 Control Room Operator** asked if Powerlink was sure that it was not Unit C4 they could see coming offline. Powerlink confirmed they could see Unit C3 coming offline, and that Unit C4 was still exporting 280 MW to the grid. The **Unit C4 Control Room Operator** stated to Powerlink that Unit C4 was offline, but that they had no screens to verify this status, and they would phone Powerlink back when they had more information.[161]

Explanatory note: *As discussed earlier, based on evidence that has been sighted, the Brady Heywood investigation's hypothesis is that Powerlink personnel were viewing data sent directly from the Unit C4 generator, which likely would have indicated the unit was still exporting power.*

Because the unit DC supply was lost, the supply to the unit's sensors was also lost. But supply was not lost to the ICMS data acquisition system, which receives a separate supply from Station. Under these circumstances, the ICMS appears to retain the last measurement received, which in this case would indicate the unit was exporting power. Unit C4, however, was not exporting power, but had been importing power from when AC and DC supply was lost.

12.7.3 Updating Traders Regarding Status (1:45 pm)

At 1:45 pm, the **Unit C3 Control Room Operator** in the Callide control room called **CS Energy Physical Trader 1** in Brisbane and informed them that Unit C3 had tripped.

CS Energy Physical Trader 1 asked the **Unit C3 Control Room Operator** if Unit C4 was still running, and the **Unit C3 Control Room Operator** responded that Unit C4 had tripped as well. In disbelief, **CS Energy Physical Trader 1** repeated what **Unit C3 Control Room Operator** had just told them, *'Unit 4 has tripped as well?'*. The **Unit C3 Control Room Operator** affirmed the statement.[162]

[160] Following the trip of AC supply to Station and Unit C4, there was only one air compressor available on Unit C3. This caused the Unit C3 plant air pressure to decay. It is likely that this decay in air pressure led to a low air pressure protection trip on the Unit C3 boiler, although this was not investigated in detail. This reduction in Unit C3 power is reflected in the conversation with AEMO when they queried whether Unit C3 was coming offline. At 1:44 pm, Unit C3 reached the point that the unit tripped from ~417 MW based on the AEMO report. AEMO (October 2021) *Trip of multiple generators and lines in Central Queensland and associated under-frequency load shedding on 25 May 2021*. https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2021/trip-of-multiple-generators-and-lines-in-qld-and-associated-under-frequency-load-shedding.pdf

[161] Transcript (8 June 2021) *Unit C4 Control Room Operator*, 14, CSE.001.006.0888.

[162] Transcript (25 May 2021) *Trader Call 2849*, CSE.001.006.0942.

12.7.4 Second Call to AEMO (1:46 pm – 1:47 pm)

At 1:46 pm, **CS Energy Physical Trader 1** called **AEMO Operator 1**. **CS Energy Physical Trader 1** informed **AEMO Operator 1** that both Unit C3 and Unit C4 had tripped. **AEMO Operator 1** responded *'C4 has tripped?... we're still seeing megawatts from C4'*.[163]

Explanatory note: *Based on evidence that has been sighted, it appears that AEMO also received the same data directly from the Unit C4 generator. They too appeared to be viewing data that indicated Unit C4 was exporting power, when it was actually importing power and motoring.*

CS Energy Physical Trader 1 confirmed to **AEMO Operator 1** that they had just spoken to the operator who had said Unit C4 had tripped.[164] **CS Energy Physical Trader 1** asked **AEMO Operator 1** to advise Powerlink.[165]

CS Energy Physical Trader 1 informed **AEMO Operator 1** that CS Energy Trading was going to put in a zero bid until 5:00 pm to cover off having both Unit C3 and Unit C4 providing no output.

Explanatory note: *A zero bid effectively means Unit C3 and Unit C4 were not expected to output any power to the grid.*

12.7.5 Another Call from Callide Power Trading to the Control Room (1:49 pm – 1:50 pm)

At 1:49 pm, the **Unit B2 Outside Operator** answered a phone call from **CS Energy Physical Trader 1**. **CS Energy Physical Trader 1** asked if Unit C4 was still producing MW, and again received the response, '*Unit 4 is offline*'. **CS Energy Physical Trader 1** asked again, '*It's definitely zero?*'. The **Unit B2 Outside Operator** responded '*Yes, mate – and Unit 3 is also offline*'.[166]

12.7.6 Third Call to AEMO (1:50 pm – 1:52 pm)

Shortly after 1:50 pm, **CS Energy Physical Trader 1** called AEMO again to confirm that Unit C4 was definitely offline. **AEMO Operator 2** answered the call and said they could see Unit C4 had been put into their system as 0 MW (a zero bid). **CS Energy Physical Trader 1** confirmed that they had put the Unit C4 output into the system as 0 MW (a zero bid) already.[167]

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[163] Transcript (25 May 2021) *Trader Call 2850*, CSE.001.006.1104.

[164] It is likely, based on transcripts of previous phone calls, that CS Energy Physical Trader 1 was referring to the Unit C3 Control Room Operator.

[165] Transcript (25 May 2021) *Trader Call 2850*, CSE.001.006.1104.

[166] Transcript (25 May 2021) *Trader Call 2849*, CSE.001.006.0942.

[167] Transcript (25 May 2021) *CS Energy Physical Trader 1*, CSE.001.006.0944.

12.8 Twenty Minutes into the Incident

12.8.1 Power Returned to Control Room Screens (1:53 pm)

At 1:53 pm, 20 minutes after the screens in the control room went black, the power supply was restored to the Unit C4 screens (by the efforts of **Control Systems Technician 1** and **Control Systems Technician 2**) and they began to show data.[168]

Control Systems Technician 1 noticed several discrepancies in the data. It wasn't clear if the turbine steam valves or the generator circuit breaker were open or closed. The turbine speed still indicated 3,000 rpm, and the generated MW indications were inconclusive.[169] This data suggested that the turbine generator was still being driven by steam and exporting power.

The **Unit C4 Control Room Operator** quickly assessed the data as bad feedback or a disturbed signal – it was not 'live/current', but instead was the same data reading from before the screen power was lost. The screens were, therefore, not providing the operators with a coherent or current picture of the status of Unit C4.

<u>Explanatory note</u>: *The lack of a coherent data regarding Unit C4's status suggests the data visible at 1:53 pm was likely the data recorded immediately prior to the incident commencing. The significance of the turbine steam valves being opened or closed was that the operators could not ascertain if steam was still entering and driving the turbine. The significance of the generator circuit breaker was also important: the **Unit C4 Control Room Operator** did not know if Unit C4 was still connected to the grid.*[170]

12.8.2 Motoring Concern (1:53 pm)

Just after 1:53 pm, at the request of **Control Systems Technician 2**, the **Unit C4 Control Room Operator** called Powerlink to check the power readings Powerlink was measuring at Calvale substation.

<u>Explanatory note</u>: *This data was measured at Calvale substation rather than at Unit C4, and would therefore provide an independent data source to confirm if Unit C4 was importing or exporting power.*

Powerlink reported that Unit C4 was importing 50 MW at 300 MVAR, but also exporting 280 MW.[171] This was '*baffling*' to the **Unit C4 Control Room Operator**. Unit C4 could not be both importing power and exporting power at the same time.[172]

<u>Explanatory note</u>: *While the **Unit C4 Control Room Operator** requested information from Powerlink about the measurements taken at the Calvale substation, it is not clear if Powerlink expressly stated what*

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[168] It took several minutes for the screens and programs to start up after power was restored. Transcript (8 June 2021) *Unit C4 Control Room Operator*, 15, CSE.001.006.0888.

[169] Transcript (6 June 2021) *Control Systems Technician 1*, 15, CSE.001.006.0921; Transcript (6 June 2021) *Unit B2 Outside Operator*, 21, CSE.001.006.1253.

[170] Determining if the unit was still connected to the grid was important in determining the risk of an overspeed event.

[171] This is based on the interview transcript of the Unit C4 Control Room Operator, who made the phone call to Powerlink. Based on the information supplied by Powerlink earlier (that the unit was exporting 280 MW), it is likely that Powerlink had access to both the data sources from Unit C4 and from the Calvale substation.

[172] Transcript (8 June 2021) *Unit C4 Control Room Operator*, 15, CSE.001.006.0888.

data sources they relied upon to inform the Callide control room operators that Unit C4 was both importing and exporting power. The Brady Heywood investigation hypothesises that when Powerlink provided information that (incorrectly) indicated Unit C4 was exporting power, this information was likely coming from Unit C4. When Powerlink provided information that (correctly) indicated Unit C4 was importing power, this information likely came from Calvale substation.

Information in the control room up until this point (i.e., from AEMO, from Powerlink, and from the control screens) had indicated that Unit C4 was exporting power. The possibility that the unit was importing power led to a concern that the unit was motoring.

The Callide control room operators could not confirm whether either of the two key conditions necessary for motoring were present: that the unit was still connected to the grid (generator circuit breaker closed), and that the turbine was no longer being driven by steam (steam valves closed).

12.8.3 State of Play in the Control Room

In the control room, there was concern that Unit C4 was motoring, and discussions focused on how to stop it.[173] In typical operating circumstances, personnel would disconnect the unit from the grid, which was usually accomplished by opening the generator circuit breaker.

Explanatory note: *The* ***Unit B1 Outside Operator*** *had already attempted to trip the unit by activating the Unit C4 master fuel trip earlier. This was unsuccessful because there was no power supply to do so (DC supply had been lost since 1:33 pm).*

With the generator circuit breaker inoperable because of the loss of DC supply, the other option to stop Unit C4 motoring was to ask Powerlink to open the 275 kV circuit breaker located in Calvale substation.[174]

The primary concern about this approach related to the status of the Unit C4 steam valves. The operators talked about what could happen if the 275 kV circuit breaker was opened while the steam valves were still open: Unit C4 could experience an overspeed event that could lead to the catastrophic failure of the turbine generator within 10 to 20 seconds (with risk of harm to personnel).

The **Unit C4 Control Room Operator** considered it too dangerous to send the operators to check the status of the steam valves, which are located close to the turbine.[175]

Explanatory note: *The conflict between Powerlink stating that Unit C4 was producing 280 MW and importing 50 MW at 300 MVAR is likely to have introduced doubt in the minds of the operators regarding the unit's status. If the operators asked Powerlink to open the 275 kV circuit breaker located in Calvale substation and the unit was motoring (importing power), then this would stop the motoring. However, if the unit was not motoring and was being driven by steam (exporting power), then this could lead to an overspeed event.*

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[173] Transcript (8 June 2021) *Unit C4 Control Room Operator*, 15, CSE.001.006.0888; Transcript (8 June 2021) *Unit B1 Outside Operator*, 17, CSE.001.006.1209; Transcript (6 June 2021) *Control Systems Technician 1*, 15, CSE.001.006.0921; Transcript (6 June 2021) *Control Systems Technician 2*, 13-14, CSE.001.006.1060; Transcript (9 June 2021) *Permit to Work Officer 1*, 11, CSE.001.006.0859.

[174] Transcript (9 June 2021) *Permit to Work Officer 1*, 11, CSE.001.006.0859.

[175] Transcript (8 June 2021) *Unit C4 Control Room Operator*, 16, CSE.001.006.0888.

At 2:05 pm, **Control Systems Technician 2** attempted to contact CS Energy Engineers based in Brisbane to discuss the Unit C4 motoring concerns. An initial call to **CS Energy Engineer 1** rang out, but a subsequent call to **CS Energy Engineer 2** was answered.[176]

12.8.4 Fourth Call to AEMO (2:06 pm)

At 2:06 pm, **CS Energy Physical Trader 1**, after they had just spoken to **Unit B2 Control Room Operator** in the Callide control room, placed their fourth call to AEMO to update them on the status of Unit C3 and Unit C4.[177] **CS Energy Physical Trader 1** advised **AEMO Operator 1** that Unit C4 screens were back on, and that Unit C3 had tripped.

The call was then interrupted by **AEMO Operator 1**, who apologised and told **CS Energy Physical Trader 1** that they would have to call them back as they thought '*something serious*' had just happened.

Explanatory note: *The 'something serious' that had just happened is likely to have been the initiation of destabilisation of the Queensland power grid. This timing corresponds to when the incident concluded and Calvale substation was disconnected from the wider grid.*

12.9 Catastrophic Failure – the Turbine Missile Event (2:06 pm)

The **Unit C4 Control Room Operator** reached for the phone to call Powerlink with the intent to place them on standby to disconnect Unit C4 from the grid.[178] Then, at 2:06 pm, the turbine missile event occurred.

In the control room, everything went dark, except for the emergency lights. Over the two-way radio they heard reports of shrapnel coming through the turbine hall roof.[179]

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[176] Transcript (6 June 2021) *Control Systems Technician 2*, 14, CSE.001.006.1060.

[177] Transcript (25 May 2021) *Trader Call to 2856*, CSE.001.006.0563.

[178] Transcript (8 June 2021) *Unit C4 Control Room Operator*, 16, CSE.001.006.0888. There is a discrepancy between Unit C4 Control Room Operator's interview transcript and the B Shift Step-Up Supervisor's witness statement. Unit C4 Control Room Operator states, regarding asking Powerlink to open the circuit breaker at Calvale: '*I was reaching for the phone to give Powerlink a call back, to have them on standby for a final decision to be made, and then the final … at that stage the final explosion happened*'. The B Shift Step-Up Supervisor states: '*I heard* Unit C4 Control Room Operator *ask the Powerlink operator to open the Calvale feeder. About 20 seconds to 30 seconds after* Unit C4 Control Room Operator *asked the operator, there was a third, massive boom. It was about 2:06 pm.*'

Based on the Powerlink Event log, Callide Unit B2's 275 kV feeder 852 at Calvale substation tripped at 2:06 pm, Unit C3's 275 kV feeder 853 tripped at 2:11 pm. Unit C4's 275 kV feeder 854 was opened by a command from Powerlink at 2:24 pm. Unit C4's 275 kV feeder 854 had not operated at 2:06 pm. Excel Spreadsheet (4 June 2021) *H024 Calvale 275kV Feeder 852_853_854 events 25052021.xls*, CSE.001.006.1038.

[179] Permit to Work Officer 2 reported shrapnel coming through the roof of the turbine hall. Transcript (9 June 2021) *Permit to Work Officer 1*, 11, CSE.001.006.0859.

The **Production Manager** ordered everyone except the **B Shift Step-Up Supervisor** and **Unit B1 Outside Operator** to evacuate.[180]

12.10 Chapter Summary

On the day of the incident, after AC and DC supply were lost, the Unit C4 display screens in the control room went black. The control room operators were then without access to the data they needed to assess Unit C4's status and take informed actions. Throughout the incident, including when the display screens had been restored (after approximately 20 minutes), the information available to the operators from site personnel, AEMO, Powerlink and the display screens was inconclusive and contradictory.

The loss of DC supply also meant that the only way for the control room operators to disconnect Unit C4 from the grid was to request Powerlink to open a circuit breaker at Calvale substation. This would have stopped Unit C4 from motoring.

Before making this request, however, the operators needed to be certain that Unit C4 was not being driven by steam and exporting power to the grid. If Unit C4 was being driven by steam and was then disconnected from the grid, this likely would result in an overspeed event and the complete destruction of the unit.

Due to the inconclusive and contradictory information available to them during the incident, the operators were unable to reach this certainty before the turbine missile event occurred.

Chapter 13 *What is Process Safety?* provides a brief introduction to process safety concepts relevant to the incident.

[180] Transcript (9 June 2021) *Permit to Work Officer 1*, 12, CSE.001.006.0859; Transcript (8 June 2021) *Unit C4 Control Room Operator*, 16, CSE.001.006.0888; Transcript (8 June 2021) *Unit B1 Outside Operator*, 15, CSE.001.006.1209; Transcript (6 June 2021) *Unit B2 Outside Operator*, 23, CSE.001.006.1253; Transcript (6 June 2021) *Control Systems Technician 1*, 16, CSE.001.006.0921.

13 WHAT IS PROCESS SAFETY?

13.1 Introduction

The key organisational factor related to the incident can be summarised as a failure to implement effective process safety practices. This chapter introduces the discipline of process safety and examines how effectively it was applied in CS Energy.[181]

13.2 Process Safety

Process safety emerged out of the chemical industry in the 1970s.[182] It is a discipline within hazardous industries that helps the prevention and mitigation of catastrophic events.[183] While rare, these events can have significant consequences that can impact workers, communities, physical assets, and the environment.

13.3 An Organisational Culture that Values Process Safety

For process safety to be effective, it must be valued by personnel at all levels in an organisation. The organisation must, therefore, have a culture that values process safety.[184] Such a culture can be described as:[185]

> *A positive environment in which employees at all levels are committed to process safety. This starts at the highest levels of the organization and is shared by all. Process safety leaders nurture this process.*

While the term 'culture' can be thought of as a collection of an organisation's attitudes and beliefs, it is more useful to characterise culture based on an organisation's everyday practices. In other words, how an organisation 'goes about its business'.

In terms of process safety, these practices include:

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[181] This chapter is not intended as a comprehensive introduction to the subject, but rather a brief summary of the process safety concepts relevant to the incident.

[182] Center for Chemical Process Safety (June 2016) *Introduction to Process Safety for Undergraduates and Engineers,* ISBN 978-1-118-94950-4.

[183] A catastrophic risk is one with the potential to result in significant harm to people (i.e., multiple fatalities), property, or the environment. CS Energy call these types of incidents a Major Accident Hazard (MAH). For consistency with CS Energy terminology, the term 'major accident hazard' is used in this report.

The Australian Institute of Health and Safety's (AIHS) Body of Knowledge defines process safety as '*about managing the integrity of operating systems by applying inherently safer design principles, engineering and disciplined operating practices. It deals with the prevention and mitigation of incidents that have the potential for a loss of control of a hazardous material or energy. Such loss of control may lead to severe consequences with fire, explosion and/or toxic effects, and may ultimately result in loss of life, serious injury, extensive property damage, environmental impact and lost production with associated financial and reputational impact'*. Australian Institute of Health and Safety (AIHS) (July 2019) *Managing Process Safety, Core Body of Knowledge for the Generalist OHS Professional*, 2nd edition.

[184] Center for Chemical Process Safety recognises process safety culture as a key aspect of its Risk Based Process Safety Guidelines. Center for Chemical Process Safety (2007) *Guidelines for Risk Based Process Safety*, ISBN 978-0-470-16569-0.

[185] Center for Chemical Process Safety (2007) *Guidelines for Risk Based Process Safety*, ISBN 978-0-470-16569-0.

- The extent to which an organisation integrates process safety hazard identification and risk control into its key processes.
- How an organisation develops process safety risk competence and capability within its workforce and staff.
- How an organisation develops effective indicators to measure process safety performance, and provides leaders with visibility of these indicators.
- How an organisation ensures that its key systems related to process safety – such as management of change, permit to work, and risk management – are effective and how it addresses issues in these systems.
- How an organisation resources and supports transparent incident reporting and learning.

These practices are created and influenced by what an organisation's leaders give attention to, how they allocate resources, and what they reward.[186] In turn, leaders are influenced by an organisation's owners, external pressures, and how they are personally rewarded.

13.3.1 Was Process Safety Valued at CS Energy?

CS Energy commenced a program in 2017 to improve process safety practices within the organisation, but this failed to meaningfully impact the management of process safety risk at the Callide site (as explored in Chapter 15 *Process Safety – Critical Risk Program*). Further, with respect to key safety systems such as management of change, CS Energy had identified substantive and longstanding issues with these systems at the Callide site (as discussed in Chapter 16 *Process Safety – Key Systems*).

13.4 Risk Management

13.4.1 Introduction

For an organisation to have effective process safety, it needs to deeply understand its major accident hazards. If an organisation understands these hazards, then personnel are more likely to recognise and report process safety-related issues earlier, as well as diagnose and solve them more effectively. Having processes and tools to identify hazards, assess and control risks, and communicate information about process safety risks within the organisation is fundamental to achieving good process safety outcomes.[187] There are a range of risk assessment techniques and tools available within high hazard industries to ensure the plant is designed, built, commissioned, operated, maintained, and decommissioned safely.[188] Where possible, an organisation should remove hazards through design,

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[186] Edgar Schein and Peter Schein (2017) *Organizational Culture and Leadership*, 5th edition.

[187] A hazard is defined as source of energy with a potential for injury or ill health. A control is an act, object (engineered), or system (combination of acts and objects) intended to prevent or mitigate a risk. A risk is a description of a situation or event where a hazard could possibly be released, or act in an unplanned way, leading to unwanted consequences (which may or may not occur (i.e., there is a chance of it occurring)).

[188] There are many components of risk management. These include the way risk is managed at the frontline (e.g., task-based risk assessments or permits), the way risk is managed at a project level (e.g., technical risk assessments), and the way risk is managed at an operational level (e.g., bowties and critical control management for operational risks). This chapter does not focus on all aspects of risk management, but rather those most relevant to the incident on 25 May 2021.

rather than control these hazards through procedures and equipment – this is known as 'inherently safer design' principles.

13.4.2 Critical Control Management for Operational Risks

Even where inherently safer design principles are applied, and risks are deliberately designed out of the system, major accident hazards will still exist. These risks must be deeply understood and managed by an organisation through effective controls.

Therefore, an organisation needs to clearly understand:

- What are the major accident hazards?
- What are the controls that need to be in place?
- Are those controls in place and are they effective?[189]

To operate safely and prevent major accidents, these three questions form the basis of risk competence for personnel that are operating, maintaining and making changes to plant or equipment.

13.4.3 Bowties

One method an organisation can use to better understand its major accident hazards is to develop what are known as bowties.[190] As discussed in Chapter 15 *Process Safety – Critical Risk Program*, CS Energy embarked on a project to develop a set of bowties for its major accident hazards. In its initial plan, each major accident hazard would have its own bowtie.

The remainder of this section provides a brief overview of how a bowtie works. The key elements of a bowtie diagram are illustrated in Figure 125.

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[189] Many organisations use variations of these questions, all with similar intent. For example, Contact Energy uses: '*Do we understand what can go wrong? Do we know what our systems are for preventing this? Do we have information to assure us our systems are working effectively?*' Contact Energy (August 2016) *Our Process Safety Story*, CSE.001.247.1325.

[190] Bowties have been used in many high hazard industries, including the power industry. Examples are Scottish Power and Contact Energy. Bowties are also part of the International Council on Mining and Metals (ICMM) good practice guide for critical control management. International Council on Mining and Metals (9 April 2015) *Critical Control Management: Good Practice and Implementation Guide.* http://www.icmm.com/en-gb/guidance/health-safety/2015/ccm-good-practice-guide

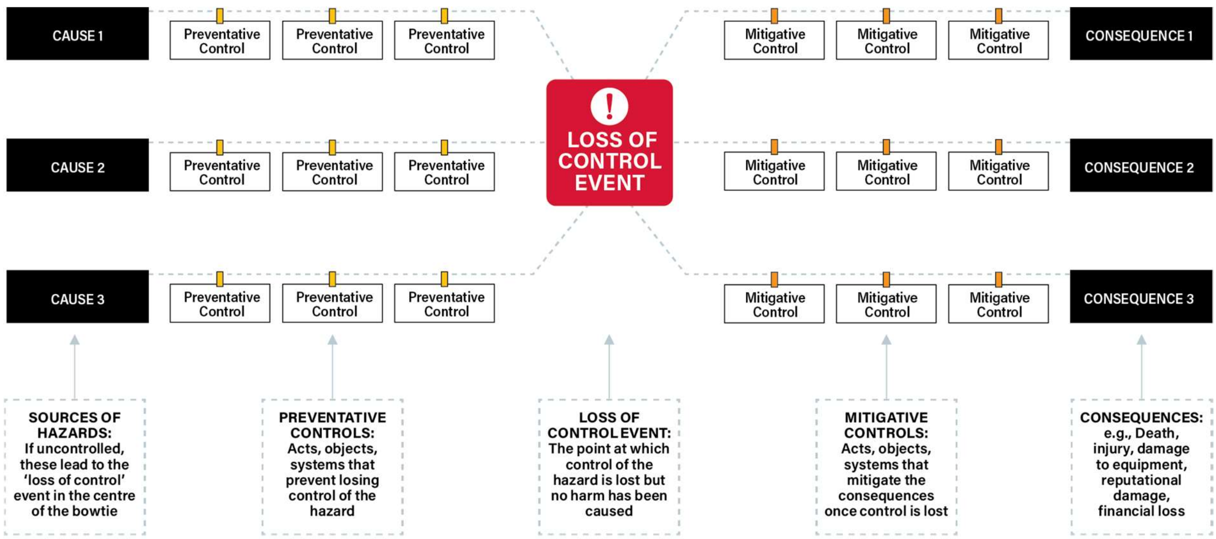

Figure 125 Bowtie diagram

The key elements are:

- Loss of control event: In the centre of the bowtie is the loss of control event.[191] This is the point where control of the hazard has been lost, but before any harm has occurred.
- Causes: On the left of the bowtie are the causes. These are the unique causes of why control of the hazard can be lost.
- Consequences: On the right of the bowtie are the consequences. These are the negative outcomes that can eventuate if control of the hazard is lost.
- Controls: Controls are shown on each cause and consequence line. The controls on the causative side of the bowtie are referred to as the preventative controls, while those on the consequential side are referred to as the mitigative controls. Controls can range from engineering-type controls (such as circuit breakers or backup generators) to systems (such as isolation, permit to work systems, and systems to manage change).
- Critical controls: Some of the controls on the bowtie are deemed critical in preventing or mitigating an event – these are referred to as critical controls. Critical controls should receive more focus to ensure they are healthy and functioning as intended.

A bowtie, therefore, is a powerful visual tool for representing the causes, consequences and controls for a single loss of control event. For example, if a causal line has only one control on it, then the importance of ensuring that particular control is healthy will be evident.

[191] This is also called a 'top event'. This is an adverse event that is deemed to be a significant loss of control in a plant that should never be reached.

A thorough and well-designed set of bowties becomes the foundation for an organisation's knowledge regarding the management of its major accident hazards.[192] This knowledge forms the basis for the risk competence of personnel at all levels in the organisation. Organisations operating without this knowledge will be limited in their awareness of all the possible causal pathways of a major accident hazard or the controls that are meant to be in place to prevent it. Furthermore, in the absence of this knowledge, it is difficult for an organisation to recognise the warning signs that these risks are becoming uncontrolled.

13.4.4 Risk Management at Callide

As discussed in Chapter 15 *Process Safety – Critical Risk Program*, CS Energy embarked on a project to develop bowties for its sites, but bowtie development did not meaningfully progress at the Callide site. In the absence of these bowties, the program to embed process safety did not meaningfully increase the risk competence and knowledge of those onsite with respect to major accident hazards.

Further, as discussed in Chapter 18 *Switching Online Without DC Redundancy* and in Chapter 20 *Risk of the Loss of AC and DC Supply*, there was a failure to understand and assess the risks associated with the switching sequence that was taking place at the time of the incident.

13.5 Management of Change

13.5.1 Introduction

Power stations are complex and have many interconnected systems and equipment. Having a clear process to assess the impacts of change to equipment, and any associated systems, is critical to maintain visibility of plant status and integrity. This is known as management of change.[193]

Ineffective management of change has been identified as a causal factor in many major industrial accidents worldwide, including Piper Alpha in 1988, the Esso Gas Plant explosion in Longford, Australia in 1998, the BP Texas City refinery explosion in the US in 2005, and the Deepwater Horizon explosion in the Gulf of Mexico in 2010.[194]

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[192] Developing bowtie diagrams is only part of the process of critical control management for major accident hazards. The process also involves creating a performance standard for each control that is assessed as 'critical'. A performance standard outlines the acceptable level of performance required for the control to remain effective. The organisation then uses this performance standard to objectively verify each control as being 'effective' or 'not effective'. This gives visibility of the performance of each control to leaders within the organisation and drives improvement of the controls.

[193] Management of change can be applied to many different system elements (e.g., plant changes, organisational changes and ways of working). However, this report focuses on plant and equipment changes. Engineering changes often occur for good reason; however, without the rigorous application of a management of change process, it can be easy for management, maintainers, operators, or engineers to lose sight of the original design intent of the facility, and the plant status can become unknown.

[194] Australian Institute of Health and Safety (AIHS) (July 2019) *Managing Process Safety, Core Body of Knowledge for the Generalist OHS Professional*, 2nd edition. https://www.ohsbok.org.au/wp-content/uploads/2019/11/13-Managing-Process-Safety-updated.pdf

For changes to be implemented effectively and safely, the potential impacts of the change on all aspects of the facility (or organisation) should be evaluated, understood, and communicated.[195] This process should include involving appropriate and competent personnel, and ensuring the change is authorised by appropriate experts and the right level of management. The communication of the change to appropriate personnel and management is also essential to ensure that the plant status, including any abnormal plant conditions, are known and understood by key personnel.

13.5.2 Management of Change at Callide

CS Energy's approach to management of change is discussed in Chapter 16 *Process Safety – Key Systems*, which discusses how CS Energy's Assurance team had identified longstanding and substantive issues with the effectiveness of the organisation's approach to management of change.

These substantive issues are also evident in the organisational factors directly related to the incident. Chapter 19 *The Battery Charger Project* discusses how effective management of change was not applied in the Unit C4 battery charger project. Chapter 21 *The Inoperable Automatic Changeover Switch* discusses how there was a failure to apply any form of formal risk assessment or management of change to the decision-making surrounding the Unit C4 automatic changeover switch being inoperable. These should not be viewed as isolated incidents. Rather, they were consistent with wider systemic issues regarding effective management of change at the Callide site.

13.6 Learning From Incidents

13.6.1 Introduction

When issues, hazards, and process deviations are reported, they provide opportunities to identify weak or ineffective systems or controls prior to negative outcomes. An organisation that values process safety will have a well-structured process to capture these reports, learn the lessons from them with respect to the effectiveness of their controls and systems, and then implement improvements to these controls and systems.

13.6.2 Learning from Incidents at Callide

As discussed in Chapter 17 *Process Safety – Learning from Incidents*, there was very little effective learning and improvement occurring at the Callide site from process safety incidents.

[195] Where the impacts could result in a significant unwanted outcome, more sophisticated risk assessment tools such as a hazard and operability (HAZOP) assessments may be used.

13.7 Personal Safety vs Process Safety

13.7.1 Introduction

Personal safety (often called occupational safety) and process safety share some common themes, however, they need to be managed and monitored in different ways.[196] Failure to identify these differences and develop appropriate management and monitoring practices has been a significant factor in many process safety disasters.[197]

Personal safety is concerned with events where the immediate causal mechanisms are usually controlled by, and localised to a single worker or work group (e.g., a worker being struck by a vehicle or falling from heights). This differs from process safety, which focuses on the safe operation of the system, rather than how individuals interact with the system.

Therefore, specific improvements in the management of personal safety risks are unlikely to have any impact on the management of major accident hazards.

Furthermore, different approaches to measuring personal safety and process safety are also required. Personal safety injury metrics (e.g., Lost Time Injury (LTI) rates, Total Recordable Injury Frequency Rates (TRIFR), or All Injury Frequency Rates (AIFR)) are not effective measures of the health of key systems required to manage process safety.

Andrew Hopkins illustrates this point:[198]

> *Clearly the lost time injury rate is the wrong measure of safety in any industry which faces major hazards. An airline, for instance, would not make the mistake of measuring air safety by looking at the number of routine injuries occurring to its staff. The number of injuries experienced by baggage handlers tells us nothing about flight safety.*

If an organisation relies on injury rates as the only safety metric, it can give the (false) impression that process safety risk is well managed in the organisation.

13.7.2 Personal Safety vs Process Safety at Callide

As discussed in Chapter 14 *CS Energy Organisational Context*, CS Energy's metrics and focus were on the management of personal safety as opposed to process safety.

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[196] Several differences between personal and process safety are:

- The nature of the risks: Process safety usually involves managing higher levels of energy than personal safety.
- The scale of potential consequences: While process safety incidents are less common than personal safety incidents, their consequences are more likely to be severe.
- The focus on engineering and design: Process safety focuses on the safe operation of the system while personal safety is about the safety of those who interact with the system.

[197] Australian Institute of Health and Safety (AIHS) (July 2019) *Managing Process Safety, Core Body of Knowledge for the Generalist OHS Professional*, 2nd edition. https://www.ohsbok.org.au/wp-content/uploads/2019/11/13-Managing-Process-Safety-updated.pdf

[198] Andrew Hopkins (January 2001, uploaded 5 September 2016) *Lessons from Esso's Gas Plant explosion at Longford*. https://www.researchgate.net/publication/248773783_Lessons_from_Esso''''s_Gas_Plant_explosion_at_Longford

13.8 Chapter Summary

There are several key elements required for effective process safety.

The organisation requires a culture that values process safety, and this culture should be evident in the everyday practices of the organisation. The organisation also requires effective risk management processes, which involve identifying hazards, assessing and controlling risks, and communicating this information to the wider organisation to raise risk competence. Effective management of change processes are also vital to maintain plant integrity. These processes assess the impact of changes to equipment on wider systems. The organisation must also have an effective process for learning from incidents to identify where systems and controls are weak, and to drive improvement. Finally, the organisation must manage and monitor personal safety risk differently to process safety risk.

Chapter 14 *CS Energy Organisational Context* explores the organisational context in which CS Energy was operating.

14 CS ENERGY ORGANISATIONAL CONTEXT

14.1 Introduction

This chapter provides CS Energy's organisational context in the years leading up to the incident. The matters discussed in this chapter should not necessarily be considered causative to the incident, rather, they provide important context regarding CS Energy's approach to the management of process safety risk.

14.2 CS Energy History and Structure

14.2.1 The Organisation

In the 1990s, the Queensland Government restructured the Queensland electricity sector to increase competition and prepare for the introduction of the National Electricity Market (NEM). This restructure involved the establishment of several government owned corporations. The state's power-generating assets were transferred to these corporations.

In 1997, CS Energy was registered as a public corporation and given ownership of Callide and Swanbank power stations. Mica Creek power station was also later transferred to its ownership and, in the early 2000s, CS Energy built further power stations at Callide (Callide C in a joint venture) and Kogan Creek.

In 2011, the Queensland Government further restructured the state's energy assets, which led to CS Energy losing Mica Creek and Swanbank power stations and gaining Wivenhoe power station.

In October 2019, Wivenhoe power station was transferred to CleanCo, the Queensland Government's new, and third, electricity generator (in addition to Stanwell Corporation). CleanCo was created to bring the state's renewable energy generation capability under the one company. All non-renewable energy plants would remain with CS Energy and Stanwell Corporation.

14.2.2 Callide Power Stations

The coal-fired Callide power stations (A, B, and C) have been generating electricity to meet Queensland's energy needs for decades. Power generation started with Callide A power station, which was constructed in 1965.[199] It has since been decommissioned.

Callide B and C power stations each consist of two generating units: Unit B1 and Unit B2 for Callide B, and Unit C3 and Unit C4 for Callide C.

Callide B power station was commissioned in 1988 and was designed to have a 40-year technical life. Its planned closure date is 2028.[200] Callide C power station was commissioned in 2001, with a

[199] CS Energy (2018) *Callide Power Station*. https://web.archive.org/web/20180904042417/https://www.csenergy.com.au/what-we-do/generating-energy/callide-power-station

[200] CS Energy (2019) *Statement on the Future of Callide B Power Station*. https://www.csenergy.com.au/news/statement-on-the-future-of-callide-b-power-station

forecasted operating life running to 2050. This has since been revised to a planned closure date of 2038. Both Callide B and C can be considered 'aging' assets.[201]

14.2.3 CS Energy as a Government Owned Corporation

CS Energy is a government owned corporation (GOC) established in 1997 under the *Government Owned Corporations Act 1993* (Qld). It is registered under the *Corporations Act 2001* (Cth), and its shareholders are two Queensland Government ministers (the shareholding Ministers). The shareholding Ministers hold the shares in CS Energy on behalf of the people of Queensland. CS Energy's board is answerable to the shareholding Ministers. The shareholding Ministers' expectations for CS Energy are contained in the Shareholder Mandate, which is issued by the shareholding Ministers to CS Energy approximately every five years.

Every year, CS Energy's board and the shareholding Ministers agree on a formal performance agreement. This agreement sets out yearly financial and non-financial performance targets. These agreements are called Statements of Corporate Intent (SCIs) and are tabled in Parliament each year.

The SCIs are informed by the requirements of the Shareholder Mandate. The SCIs contain CS Energy's strategic targets, including annual targets, across a range of measures. They also include other information, such as key assumptions and risks, capital expenditure, capital structure, a statement of compliance, and financial statements.

14.2.4 CS Energy's Board

At the time of the incident, CS Energy's board consisted of five non-executive directors appointed by the Queensland Government.[202] The board members' backgrounds were as follows.

The chair of the board was appointed in 2015, came from a political background, and did not have a technical engineering or process safety background.

Of the other four directors, one had a power industry operational background, one had a legal and governance background, one had a legal background, and one had a financial background.

The Board Charter states that the board is '*responsible to the Shareholding Ministers for the governance of CS Energy*'.[203] The Charter specifically notes that the Board is responsible for '*[s]etting the Risk Appetite of CS Energy and ensures appropriate oversight of risk, primarily by setting risk policies and through the activity of the Board's Enterprise Risk Committee*'.

At the time of the incident, the board operated with the support of four committees:

- The Audit and Finance Committee, which is responsible for financial risk management, corporate and financial reporting, and the management of external and internal audit functions.

[201] See AEMO (2023) *Draft 2024 Integrated System Plan for the National Electricity Market,* 7. https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2023/draft-2024-isp-consultation/draft-2024-isp.pdf

[202] Non-executive directors do not have operational roles within CS Energy.

[203] CS Energy (July 2018) *Board Charter*, 1, CSE.001.082.5729.

- The Culture and Remuneration Committee, which is responsible for people (personnel) policies, and remuneration strategy, and the policy and structure to support CS Energy's desire for a safe, constructive, and high-performance culture.
- The Safety and Performance Committee, which is responsible for establishing and monitoring CS Energy's health, safety, and environment frameworks, plant reliability, and associated operational risks.
- The Enterprise Risk Committee, which is responsible for establishing and monitoring CS Energy's effective governance, risk, and compliance frameworks.

CS Energy's board meets every month, except December, usually on the last Thursday or Friday of the month. The board committees meet 3–4 times per year, and those committee meetings precede the board meetings.

From the Brady Heywood investigation's analysis of the board meetings in the 12 months preceding the incident, the board meeting duration varied from the shortest at 72 minutes to the longest at 220 minutes (just over 3.5 hours). There were usually eight or nine full-time attendees, and between eight and 17 part-time attendees. The full-time attendees were the chair, the non-executive directors (which varied between three and four across the year), the CEO, the Executive General Manager Corporate Services, the CFO, and the Company Secretary. The part-time attendees were a range of CS Energy executives and staff, and external guests. No Callide-based site personnel attended board meetings in the 12 months leading up to the incident. Of these 11 board meetings, five were held by teleconference (an impact of COVID-19), five were held in Brisbane, and one was held at Kogan Creek power station.

In the five years before the incident, board meetings had been held at the Callide power stations on 27 September 2019 and 23 February 2017.

14.2.5 CS Energy's Operating Locations

CS Energy's Executive team is based in Brisbane, together with the Finance, IT, HR, Asset Management, Legal, Assurance, Learning and Development, Health and Safety, and Energy Trading teams.

CS Energy has two operational sites: Kogan Creek power station, located in Chinchilla (approximately 260 km west of Brisbane), and the Callide power stations, located in Biloela (approximately 570 km north of Brisbane).

14.2.6 Joint Venture Ownership of Callide C

Callide C power station is a 50/50 unincorporated joint venture (JV) between Callide Energy Pty Ltd, and an international power generation company called Genuity Group (formerly known as InterGen Australia). The corporate governance structure is shown in Figure 126.[204]

[204] PWC (2020) *Joint Venture Governance Reviews CS Energy,* 20, CSE.001.082.0391.

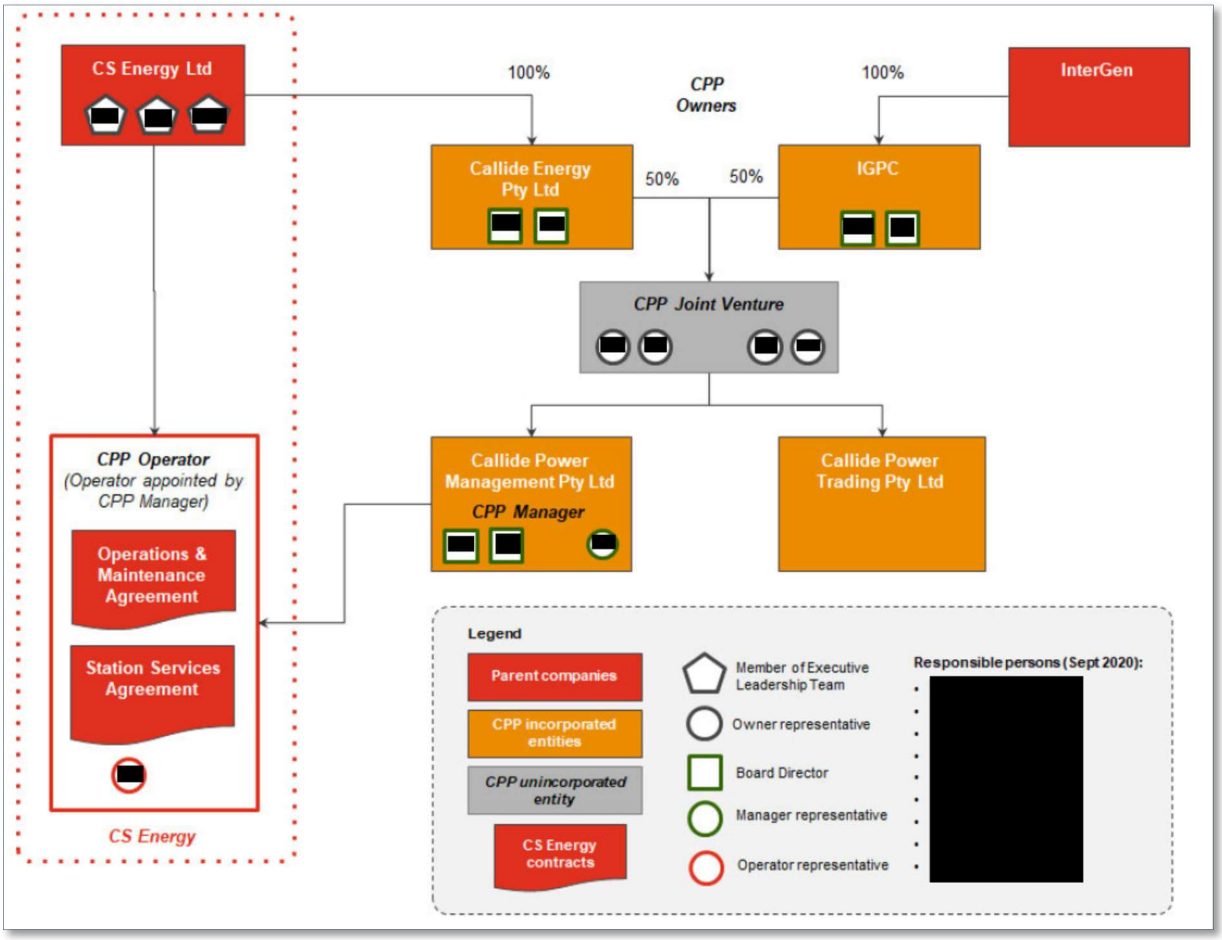

Figure 126 Callide C corporate governance structure

The joint venture was established in 1998 to design, construct, and operate the Callide C power station. The joint venture appointed Callide Power Management Pty Ltd as the management company to develop and manage Callide C power station on its behalf.[205]

Callide Power Management Pty Ltd entered into two agreements with CS Energy Ltd to operate Callide C. These were the Operations and Maintenance Agreement, and the Station Services Agreement.[206]

These two agreements govern the fees payable by Callide Power Management Pty Ltd for the operation of Callide C. The agreements also govern decisions about the management of Callide C, including capital and operational expenditure.

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[205] CS Energy (2021) *Callide C Power Station Asset Management Plan Part 2: Reference Information*, 5, CSE.900.001.1196.

[206] Clayton Utz (11 May 1998, as amended and restated on 5 June 2017) *Callide Power Project Operation and Maintenance Agreement,* CSE.001.021.0266; Clayton Utz (11 May 1998, as amended and restated on 5 June 2017) *Callide Power Project Station Services Agreement,* CSE.001.021.0394.

Since its inception, the joint venture ownership structure has had implications for the management of Callide C. In a governance review, undertaken as part of CS Energy's assurance program in 2020, a key finding was: [207]

> *There is a misalignment of strategy and objectives between the owners of the Callide C JV, which is manifesting as delayed decisions, budget disputes, a short-term focus and inefficiencies in governance and operations.*

The review goes on to state:

> *These are historical and reflect the varying commercial and strategic imperatives for each party and will be difficult to address in the short term particularly in the context of a 50/50 unincorporated joint venture. However, the current 5-year review process for the Operations and Maintenance Agreement (OMA) and Station Services Agreement represents an opportunity for CSE as both operator and owner to further define its strategy, objectives and risks and to develop a negotiation strategy to define and align (as much as possible) the strategic intent for the JV (2020.07.01).*

Other findings in the review included:

- The JV does not clearly or formally identify, manage, or track risks.
- There are issues arising out of CS Energy holding both owner and operator roles that are leading to duplication and ambiguity.
- The different financial years used in InterGen and CS Energy accounting, together with a lack of strategic alignment, causes rework and delays in operational budgets and approvals.

The joint venture was further impacted when InterGen entered receivership on 14 June 2016. The media reported that the insolvency was triggered by InterGen being unable to refinance its debt.[208] InterGen entered into voluntary administration on 22 December 2016, with control shifting from the receivers to external administrators Ferrier Hodgson and PPB Advisory. InterGen emerged from insolvency in early 2018.

Resolution of the administration included settling a dispute between CS Energy and the JV about the base fees payable under the next extension of the Operation and Maintenance Agreement (the 2016 five-year review). This dispute was settled in mid-2017. The settlement agreement locked in the base fees payable under the Operations and Maintenance Agreement, including the operator training fees.[209]

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[207] PWC (2020) *Joint Venture Governance Reviews CS Energy,* 1, CSE.001.082.0391.

[208] Ben Potter and Mark Ludlow (8 July 2016) Callide C power receivership blamed on banks, poor coal supply, *Financial Review.* https://www.afr.com/companies/banks-appoint-receivers-to-us-partner-of-callide-c-power-plant-20160708-gq1a07

[209] Herbert Smith Freehills (25 May 2017) *Callide Power Project – Deed of amendment, settlement, and release*, 8, CSE.001.021.2986.

14.2.7 Financial Performance

Figure 127 tracks the profit and loss history of CS Energy, and the energy price (in $/MWh) between 2010 and 2021. The red boxes indicate loss-making years, while the green boxes represent profitable years.[210]

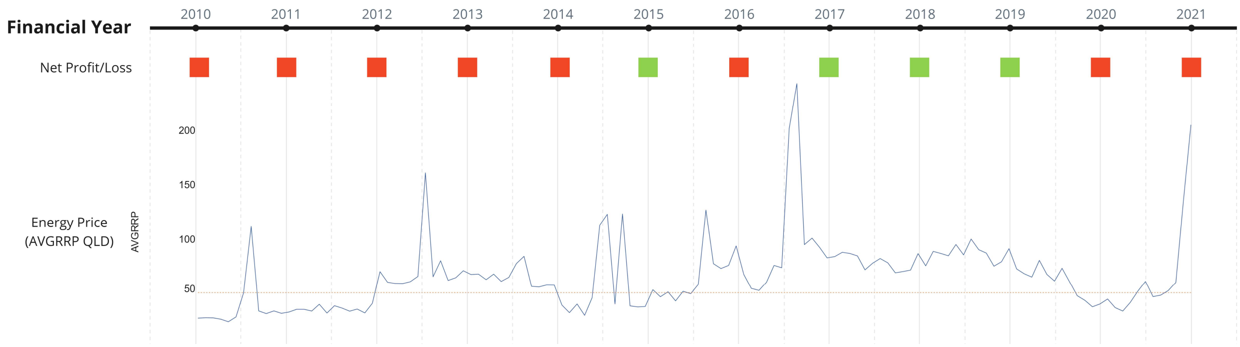

Figure 127 Historical profit and loss of CS Energy, 2010 to 2021

CS Energy experienced an extended period of loss-making from 2008 to 2015 before returning to profitability. This profitability correlates with the return of the average energy price to above $44/MWh. This period of profitability came to an end in 2020, coinciding with the fall in energy prices. Prior to 2015, CS Energy's last recorded profit was in the 2008–09 financial year.

During this seven-year loss-making period between 2008 and 2015, a major cost cutting initiative was launched in 2012 to 2013. This took the form of a strategic objective to reduce operational expenditure along with a debt reduction strategy. This was in line with the shareholding Ministers' expectations, as set out in CS Energy's 'Response to shareholders' expectations letter' in Figure 128.[211]

> **1.2 Response to shareholders' expectations letter**
>
> Consistent with the shareholders' expectations letter, CS Energy is focussed on achieving cost and performance efficiencies from the existing asset base. Overhead costs are a significant focus, with a planned reduction of corporate office staff from 180 to 120 already well progressed and expected to be completed by 31 December 2012. Other non-labour operational costs at corporate office and sites are also being reduced; capital expenditure has been reduced to focus only on essential and committed work and projects.

Figure 128 Extract from 2012–13 SCI describing CS Energy's response to shareholders' expectations letter

[210] The net profit/loss figures were taken from the CS Energy Annual Reports and the energy prices were sourced from AEMO (2022) *National Electricity Market: Data (NEM): Average Price*. https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/data-nem/data-dashboard-nem

[211] CS Energy (2012) *Amended Statement of Corporate Intent 2012/2013*. https://www.csenergy.com.au/ArticleDocuments/191/Statement%20of%20Corporate%20Intent%202012_2013%20-%2028%20Sept%202012.PDF.aspx

CS Energy's 2013–14 annual report states that $35.3 million in cash flow savings was achieved in the year ending June 2013, with a further $46.1 million saved in the year ending June 2014.[212] The savings, which exceeded shareholder targets, were reportedly realised through:

> *increased discipline over costs, the implementation of value based decision making processes, leading to the elimination of non-essential operating and capital expenditures.*
>
> *Ensuring staffing levels are in line with, but do not exceed requirements, is consistent with establishing appropriate cost discipline and eliminating non-essential* costs.[213]

This period also featured a long-running dispute over CS Energy's coal supply with Anglo American,[214] that was not resolved until November 2016, and the potential privatisation of Queensland's energy assets, that was not resolved until December 2015.[215]

14.3 External Context

14.3.1 Climate Change Policy

Climate change policy in Australia posed multiple challenges for CS Energy. This resulted in:

- Regulatory and financial uncertainty created by the introduction of a carbon price by the Federal Government between 2010 and 2014.
- Investment by CS Energy in renewable energy technology research and development projects.[216]
- The establishment of CleanCo (a Queensland GOC) in 2017, which transferred Wivenhoe power station out of CS Energy's generation portfolio, and restricted CS Energy's access to renewable energy as a source of revenue.

14.3.2 Industry – AEMO, AER, Powerlink

The Australian Energy Market Operator (AEMO), formed in 2009, oversees the operation and security of the National Energy Market (NEM) and is responsible for restoring energy systems in the event of an emergency. AEMO is also responsible for providing the framework for the regulation of wholesale electricity and gas markets, which is then regulated by the AER (Australian Energy Regulator).[217]

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[212] CS Energy (2014) *Annual Report 2013/2014*. https://www.csenergy.com.au/ArticleDocuments/191/Annual%20Report%202013_2014%20-%2029%20Sept%202014.pdf.aspx

[213] CS Energy (2014) *Annual Report 2013/2014*, 2. https://www.csenergy.com.au/ArticleDocuments/191/Annual%20Report%202013_2014%20-%2029%20Sept%202014.pdf.aspx

[214] CS Energy, (2017) *Annual Report 2016/2017, 6*. https://www.csenergy.com.au/ArticleDocuments/191/Annual%20Report%202016_2017%20-%2030%20Sept%202017.pdf.aspx

[215] CS Energy, (2016) *Annual Report 2015/2016, 3*. https://www.csenergy.com.au/ArticleDocuments/191/Annual%20Report%202015_2016%20-%2030%20Sept%202016.pdf.aspx

[216] These projects included the Oxyfuel Project at Callide between 2003 and 2012, and the Kogan Creek A Power Station Solar Boost Project, which began in 2011.

[217] AEMO *Who We Are*. https://aemo.com.au/about/who-we-are

The AER was founded in 2005 as a merger between 13 bodies previously in charge of energy regulation across Australia. As well as monitoring the wholesale electricity and gas markets, the AER monitors compliance with national and state legislation relating to the provision of electricity.

The AER regulates Powerlink, who owns, develops, operates, and maintains the high voltage electricity transmission network in Queensland. Powerlink is also a GOC, and was founded in 1995 as part of the restructuring of the Queensland power industry. Powerlink's network covers the majority of Queensland, extending from 1,700 km north of Cairns to the New South Wales border.

14.3.3 Industry – Energy Prices

After a period of rising energy prices from 2015-2017, the market price for energy started to decline from 2018.[218] CS Energy's internal management response to these lowering market prices was a program titled *Project Adams*. The program's objectives included changing the power stations from fixed to flexible generators and reducing the cost of production.[219]

CS Energy's quarterly report to the shareholding Ministers on 31 July 2020 outlined how this impacted the joint venture.[220] The report highlighted that Queensland continued to record the lowest mainland spot price in the NEM. It also stated that, because of low gas prices and increases in large scale renewable generation, contract prices had decreased by up to 10% over the three-year forward market.

The impact of these low prices was a $300 million reduction in the value of CS Energy's generation assets (because of the lower-than-expected future revenue). The report also states that:

> *These financial results demonstrate the importance and urgency of CS Energy's strategy to transform the business from a traditional generator to a diversified energy business.*

14.3.4 Impact of COVID-19

The COVID-19 pandemic emerged in 2020. In 2020, CS Energy ran a 'COVID-safe' major overhaul of Unit B1 and a minor overhaul of Unit C4. These overhauls involved the introduction of approximately 200 contractors to the site, working under hygiene measures. These overhauls took longer than usual to accommodate the COVID-safe measures.[221]

In its 2021 annual report, CS Energy stated that '*Our financial performance and cashflow was not materially impacted by COVID-19 during the year ended 30 June 2021*'.[222] The report also stated that:

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[218] Australian Energy Regulator (2021) *State of the energy market 2021*, 90-91. https://www.aer.gov.au/system/files/State%20of%20the%20energy%20market%202021%20-%20Full%20report_1.pdf

[219] Board Paper (25 February 2021) *Business Transformation – Project Adams*, 2, CSE.001.023.5583; Board Paper (28 May 2021) *Business Transformation – Project Adams*, CSE.001.023.6024.

[220] Correspondence (31 July 2020) *CS Energy Quarterly Report – 1 April 2020 to 30 June 2020*, CSE.001.082.7094.

[221] CS Energy (2021) *Annual Report 2021*, 9. https://www.csenergy.com.au/ArticleDocuments/191/CS%20ENERGY%20ANNUAL%20REPORT%202021%20ONLINE%20240921.pdf.aspx

[222] CS Energy (2021) *Annual Report 2021*, 42. https://www.csenergy.com.au/ArticleDocuments/191/CS%20ENERGY%20ANNUAL%20REPORT%202021%20ONLINE%20240921.pdf.aspx

> *Forecast cash flows have been updated in the short term to reflect observable and publicly available information on the expected impact COVID-19 will have on economic factors impacting the market outlook, including demand projections and fuel price assumptions. Forecast fuel and water pricing and supply contracts have not been materially impacted by COVID-19.*[223]

These statements were repeated in the 2022 annual report and suggest that the financial effect of COVID-19 on CS Energy and the joint venture was not material.[224]

14.4 Strategy and Metrics

14.4.1 2016 Shareholder Mandate

CS Energy's 2016 Shareholder Mandate, which was due to expire around June 2019, required CS Energy to do the following in respect of its operations:[225]

- Not develop, invest in, or own new generation capacity.
- Give priority to the effective management of existing assets.
- Exceed efficiency savings targets. The targets had been set at $500,000 per year, over each of the coming five years, thus giving an expectation of $2.5 million in savings over the financial year period 2015–16 to 2019–20.
- Consider opportunities around asset management (including opportunities to reduce expenditure associated with scheduled outages and overhauls), operation and maintenance costs (noting that benchmarking showed CS Energy was in the mid-range of the industry), and flexibility (considering opportunities to improve flexibility in its existing fleet of assets in a transitioning market).

14.4.2 2020 Shareholder Mandate

CS Energy's 2020 Shareholder Mandate was subject to negotiation between CS Energy and Queensland Treasury from mid-2018 to late-2020 (the 2016 Shareholder Mandate being due to expire in June 2019).

In an assessment of the 2020 draft Shareholder Mandate, CS Energy made the following observations:[226]

- CS Energy did not obtain support from Queensland Treasury for policies that supported more flexible labour and workforce restructures.

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[223] CS Energy (2021) *Annual Report 2021*, 79. https://www.csenergy.com.au/ArticleDocuments/191/CS%20ENERGY%20ANNUAL%20REPORT%202021%20ONLINE%20240921.pdf.aspx

[224] CS Energy (2022) *Annual Report 2022*, 62. https://www.csenergy.com.au/ArticleDocuments/191/CS%20ENERGY%20ANNUAL%20REPORT%202022%20ONLINE.pdf.aspx

[225] Queensland Treasury Corporation (May 2016) *Shareholder Mandate for CS Energy*, 14, 16, CSE.001.082.3776.

[226] Board Paper (28 August 2023) *Shareholder Mandate Update*, CSE.001.082.7213; PowerPoint Presentation (August 2020) *Shareholder Mandate update*, 4, CSE.001.082.7216.

- CS Energy sought to use surplus cash balances for investment in new and existing assets, but received a more limited agreement from Queensland Treasury that debt management must be considered equally with portfolio renewal.
- Limitations were being imposed by Queensland Treasury on CS Energy's investment in renewable energy projects and contracts.

14.4.3 Statement of Corporate Intent

Pursuant to Section 102 of the *Government Owned Corporations Act 1993* (Qld), a GOC must have a Statement of Corporate Intent (SCI) for each financial year. That SCI must:[227]

- Be consistent with the GOC's corporate plan.
- Specify the GOC's financial and non-financial performance targets for the relevant financial year.
- Include matters relating to its community service obligations, as well as employment and industrial relations plans.

The SCI is prepared by the GOC, and then agreed by the GOC with the shareholding Ministers each year.[228] The CS Energy board then undertakes to achieve these yearly targets.[229]

The 2020–21 financial year targets at the time of the incident are shown in Figure 129.[230]

[227] *Government Owned Corporations Act 1993* (Qld), sections 104, 105. https://www.legislation.qld.gov.au/view/pdf/inforce/current/act-1993-028

[228] *Government Owned Corporations Act 1993* (Qld), section 107. https://www.legislation.qld.gov.au/view/pdf/inforce/current/act-1993-028

[229] This undertaking is set out in the SCI published each year by CS Energy.

[230] CS Energy (2021) *Statement of Corporate Intent 2020/21,* 5, CSE.001.082.8111.

Strategic Priority		Full year target	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Strengthen our Foundations	All injury frequency rate (AIFR)[1]	≤28	≤27	≤26	≤26	≤28
	Constructive culture[2]	33	NA	NA	NA	NA
Optimise our Assets	Equivalent unplanned outage rate (%)[3]	6.9	8.5	7.1	4.9	6.9
	Commercial availability (%)[4]	87	86.6	86.9	87.1	87.4
Maximise our Returns	All in unit cost ($MWh)	37.83	42.22	34.81	34.66	39.66
	Trading optimisation EBITDA ($M)[5*]	15	NA	NA	NA	NA
Deliver Future Energy	C&I market share (%)[6*]	9	NA	NA	NA	NA
	Product solutions[7*]	69	NA	NA	NA	NA

Figure 129 SCI targets for 2020–21 financial year

The following are general comments on the SCI targets from a personal safety and process safety perspective:

- There is no target that relates to process safety. The selection of suitable process safety targets is challenging, but their absence can send a message within the organisation that process safety is not a focus. With no process safety targets, the remaining SCI targets provide no information on the effectiveness of CS Energy's approach to process safety.
- The all-injury frequency rate (AIFR) is a lagging indicator, meaning it provides information on the personal injury incidents that have already occurred. Despite its widespread use, AIFR is a poor measure and provides no information on the effectiveness of an organisation's ability to manage personal fatality risks. The causes of incidents that result in fatalities are largely different to the causes of incidents that are recorded in the AIFR.
- The AIFR is also not a measure of the effectiveness of an organisation's management of major accident hazards. In other words, a decreasing AIFR should not be considered indicative of the effective management of process safety risk, since the causes of incidents that contribute to the AIFR metric are different to the causes of process safety incidents. Further, if an organisation relies on the AIFR as the only safety metric, it can give the (false) impression that process safety risk is well managed.
- The use of AIFR as a metric can, in and of itself, lead to a reduction in incident reports (not just in personal safety, but in all forms of reporting). This is typically due to organisational pressure to 'drive down the metric'. This typically inhibits an organisation's ability to collect and analyse the warning signs of potential future failures, including process safety failures.

- The AIFR puts the leadership focus on the prevention of higher frequency, but lower severity, risks, which can take focus away from the events that are rare, but catastrophic. Process safety events are typically rare and potentially catastrophic.
- The Constructive Culture target measures the outcome of a Culture and Engagement survey undertaken every two years within CS Energy. It is not a measure of the effectiveness of an organisation's management of process safety risk.
- The remainder of the metrics in Figure 129 above focus on optimising assets, maximising return on investment, and delivering future energy. None of these metrics reward a meaningful focus on the management of process safety risk. It is important to note that Equivalent unplanned outage rates (%) and Commercial availability (%) are not proxies for the measurement of the effectiveness of the management of major accident hazards. They too, like the AIFR, are lag indicators.
- The effectiveness of how an organisation manages process safety risk is underpinned by clearly defining the major accident hazards and the effectiveness of the controls that manage them. It involves the continuous checking and confirmation that these controls are in place and operative. In the absence of completed and implemented bowties, it would have been difficult for CS Energy to develop the necessary risk competency and metrics to manage major accident hazards at a site, corporate, and board level.

14.4.4 Incentives (AIA Staff)

An incentive structure applies to staff who are on alternative individual agreements (AIAs). This structure applies to most corporate staff, as well as the senior leadership team at the Callide power stations.[231]

Historically, CS Energy was measured on metrics in the SCIs, but 2020 saw the introduction of a broader set of measures linked to new business initiatives and strategic outcomes. These measures are contained in an Enterprise Scorecard.[232] The Enterprise Scorecard for 2020 is presented in Figure 130.[233]

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[231] This incentive structure is in addition to fixed salaries, and it provides for bonus payments of up to 15% of base salary. The incentive structure is governed by CS Energy's Salary and Performance Review process. The incentive is based on a combination of group (Enterprise Scorecard) and individual (Individual Achievement Plan) outcomes. The Executive General Managers and their direct reports have a higher weighting to enterprise outcomes. From a base of 25%, the Executive Leadership Team direct reports carry a 40% weighting; Executive General Managers 50%; and the CEO, 100%. The only precondition to payment of the bonus is base profit (referred to as the Operating Profit Gateway). The incentive is decided in August of each year: first, by the Culture and Remuneration Committee, then it goes to the CS Energy board for approval.

[232] From 2020 onwards, the financial weightings reduced from 45% of the incentive scheme to 25%.

[233] Board Paper (27 September 2019) *Enterprise Scorecard FY20*, 2, CSE.001.082.6373. Note, no bonus was ultimately paid in 2020 because of COVID-19.

Strategic Priority	Measure	Threshold	Target	Stretch	Weighting
Awarded Incentive		50%	75%	100%	
Award for performance between tiers			Linear		
Strengthen our Foundations (30%)	All Injury Frequency Rate (**AIFR**)	<32	<30	<28	15%
	Significant Environmental Incidents (**SEI**)	0	0	0	5%
	Pulse Cultural Survey score (**OCI**)	Casual factor percentile based on FY19 OCI	10% improvement on FY19 OCI	13% improvement on FY19 OCI	10%
Optimise our Assets (25%)	Equivalent Unplanned Outage Rate (**EUOR**)	11%	9%	7%	10%
	Key Time Availability	91% at wholesale market prices > $20/MWh	Threshold ***and*** 91% at wholesale market prices > $50.50/MWh	Target ***and*** 91% at wholesale market prices > $100/MWh	15%
Maximise our Returns (25%)	All-in Unit Cost ($/MWh)	$55.50/MWh	$50.50/MWh	$45.50/MWh	10%
	Underlying Earnings before Interest, Tax, Depreciation and Amortisation (**Underlying EBITDA**)	$288.5 million	$320.5 million	$352.5 million	15%
Deliver Future Energy (20%)	Number of retail customers	3 retail customers signed	5 retail customers signed	7 retail customers signed	10%
	Renewable generation under contract	150MW	175MW	200MW	10%

Figure 130 2020 Enterprise Scorecard

As with the SCIs, the Enterprise Scorecard does not contain a process safety target. The targets in the Scorecard present the same issues as discussed above, namely, the use of the AIFR, availability, and unplanned outage metrics.

14.4.5 Incentives (EA Staff)

The majority of staff at Callide are employed under a site-based enterprise agreement (EA).[234] The EA in place at the time of the incident included an incentive payment scheme known as 'CIPS'.[235] The potential incentive payment of $3,851 per annum was made up of a $1,700 payment based upon a KPI set by the General Manager of Callide, and the balance being a retention incentive component.

[234] The enterprise agreement in place at Callide at the time of the incident came into force on 28 September 2018 and was due to expire on 28 February 2021 but the subsequent enterprise agreement did not come into force until 9 February 2022.

[235] CS Energy (2018), Callide Power Station Enterprise Agreement 2018, 4.9, https://www.fwc.gov.au/document-search/view/3/aHR0cHM6Ly9zYXNyY2RhdGFwcmRhdWVhYS5ibG9iLmNvcmUud2luZG93cy5uZXQvZW50ZXJwcmlzZWFncmVlbWVudHMvMjAxOC85L2FlNTAwMTc0LnBkZg2

14.5 Callide Site Management Turnover

Between 2017 and the incident in 2021, the Callide power stations had had four different general managers, at least two different maintenance managers, and four different production managers.[236] The timing and nature of these changes are mapped in Figure 131.

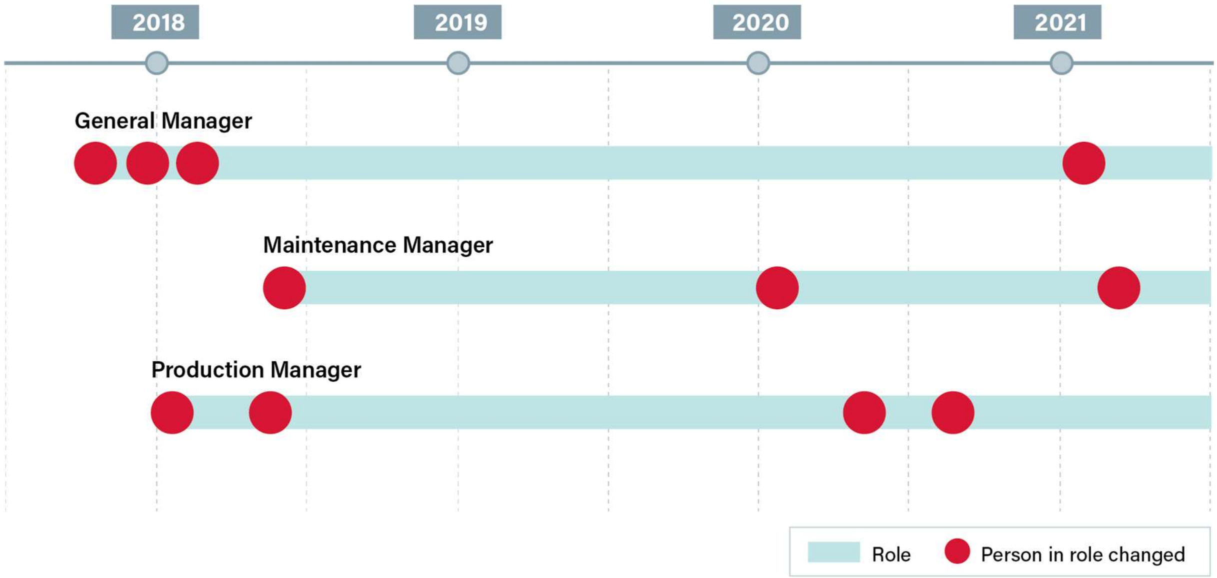

Figure 131 Callide site management turnover

Maintaining a continuity of approach to, and focus on, process safety would have been difficult given these changes in key personnel.

14.6 Initiatives

Between 2017 and the incident in 2021, there had been six initiatives launched within CS Energy that impacted the operations at the Callide power stations. The Callide team would have had to balance multiple cost, time, and resource pressures within the organisation due to the initiatives discussed below.[237]

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[236] There are two known people in the maintenance manager role at Callide in this period. There is a period between 13 January 2020 and 21 March 2021 where it is unknown if there was a third person in the maintenance manager role or if the role was vacant during this time.

This is based on an analysis of roles referred to across various CS Energy records. Where the records suggest a person was in the role for less than one month, these personnel were excluded from the above analysis. Excel Spreadsheet (29 November 2022) *50000793 - General Manager Position Callide*, CSE.001.263.0001; Excel Spreadsheet (29 November 2022) *51028407 - Manager Production Position Callide*, CSE.001.263.0007.

[237] In addition, in 2020, Biloela was selected as the case study for the Queensland Government's *Just Transition* initiative, supporting workers and communities through the transition of the energy sector. Culture and Remuneration Committee Paper (25 February 2021) *People and Culture Report*, 11, CSE.001.023.8686.

14.6.1 Callide Unit C4 Overhaul Report

After the 2017 Callide Unit C4 overhaul, Partners in Performance (known as PIP) were engaged to undertake an independent post-project completion report.[238] That report's findings were presented to CS Energy's board in January 2018 and included:

> *[a] significant shortfall in the expected overhaul. Issues were identified with inconsistent safety performance, Permit to Work breaches, and poor project planning and management.*

In the third quarter of 2017, PIP spent 90 days at the Callide site reviewing operations. This review led to multiple changes to how work was done at site, including new tools and workflows for task management. The new tools focused on improving plant availability, productivity of workers, and reducing costs.[239]

14.6.2 Project Drive

The PIP operations review informed, and in part led to, *Project Drive*, which was the project to separate plant operations from asset management. This restructure was formulated in late 2017 and was implemented in the first half of 2018.[240]

Under this project, the operations personnel at site retained the role of operator and maintainer. The new Asset Management team, led from Brisbane, was the asset owner, taking responsibility for asset management and capital delivery functions. This team were also responsible for asset management plans and equipment strategies, as well as the planning, scoping, and delivery of major projects, outages, and overhauls.[241]

The project was forecast to lead to savings in operating costs over the longer term, including reductions in overtime, contract labour, workforce planning, and joint venture recovery.[242]

14.6.3 Accelerate Program and Project WHAM

Following the restructure of *Project Drive*, the Executive General Manager (Asset Management) directed the new Asset Management team to address the key issues affecting plant availability. This initiative was called the *Accelerate Program*. This program was:

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[238] Board Paper (29 January 2018) *Callide C4 Overhaul – Post Completion Review,* CSE.001.082.3537; PowerPoint Presentation (December 2017) *CS Energy Callide C4 Overhaul Close Out Review*, 3, CSE.001.082.3672.

[239] Board Paper (28 August 2017) *CEO Report,* CSE.001.082.2504; Board Paper (29 September 2017) *CEO Report*, CSE.001.082.2635.

[240] PowerPoint Presentation (23 March 2018) *Asset Management and Plant Operations*, CSE.001.082.4862; Board Paper (23 February 2018) *CEO Report*, 3, CSE.001.082.4765; PowerPoint Presentation (27 July 2018) *Callide Performance Improvement Programme Close out document*, CSE.001.081.7111.

[241] PowerPoint Presentation (15 November 2017) *DRIVE Consultation Phase 1*, CSE.001.086.6280.

[242] PowerPoint Presentation (9 April 2018) *Audit and Risk Committee Updated Five Year Forecast FY19-FY23*, 35, CSE.001.081.9804.

aimed at focusing staff on a goal for improving asset performance and is supported by key improvement projects, plant area 'kaizens',[243] and regular communication.[244]

A subset of the *Accelerate Program* was *Project WHAM* which was about '*WHacking the Moles that are slowing us down*'.[245] This initiative was presented in July 2018 to the Plant Performance Committee and introduced with the statement '*The prime focus must be on AVAILABILITY*'.[246] More than 19 projects for improvements were identified as part of *Project WHAM*. The projects specifically directed at process safety issues were described as '*management of change*' and '*operational procedures*'.[247]

14.6.4 Project Adams

By late 2020, CS Energy had identified that falling market energy prices would challenge the economic viability of CS Energy's power stations, particularly Callide.[248]

In response, *Project Adams* was presented by the Executive General Manager (Asset Management) to CS Energy's board on 25 February 2021.[249] The objective was to change the Callide power stations from fixed to flexible power generators, with the ability to support different running profiles depending on demand. A key objective was to reduce the costs of production at Callide from $[redacted]/MWh to $[redacted]/MWh by a target date of 30 June 2022.

The targeted way to achieve this objective was to move from a high and fixed cost base to a low and variable cost base. This would be achieved by having a more flexible workforce, and by adopting different running profiles for the plant. In the first half of 2021, this initiative involved:[250]

- Rationalising capital investment.
- Improving planning and reducing inventory and spares holdings.
- Streamlining and simplifying services.
- Minimising contracted services.

14.6.5 Safety Programs

In addition to the initiatives in *Project Adams*, there were already long-term safety programs operating at site.

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[243] 'Kaizen' is a Japanese term for continuous improvement. It was formally adopted as a management methodology by CS Energy in 2018. Minutes (28 September 2018) Meeting of the Innovation and Sustainability Committee, 4, CSE.001.023.7215.

[244] Board Paper (30 July 2018) *CEO Report*, 2, CSE.001.082.3993.

[245] PowerPoint Presentation (26 July 2018) *WHAM Process*, 4, CSE.001.081.7059.

[246] Reliability and Plant Performance Committee Paper (26 July 2018) *Accelerate Program and WHAM Briefing*, CSE.001.081.7058; PowerPoint Presentation (26 July 2018) *WHAM Process*, 2, CSE.001.081.7059.

[247] PowerPoint Presentation (26 July 2018) *WHAM Process*, 51, CSE.001.081.7059.

[248] An early reference to the challenge of falling prices and generation is discussed in PowerPoint Presentation (29 March 2019) *Inventory Improvement Project*, 2, CSE.001.081.7870. It is also mentioned in PowerPoint Presentation (December 2020) *Asset Management 15 December Update*, CSE.001.058.5281.

[249] Board Paper (25 February 2021) *Business Transformation – Project Adams*, 25-38, CSE.001.023.5583.

[250] Board Paper (28 May 2021) *Business Transformation – Project Adams*, 24-29, CSE.001.023.6024.

In December 2014, CS Energy embarked on a cultural change program that aimed to build a high-performance constructive culture. It was called the DuPont Felt Leadership Strategy.[251] This program followed a 12-month long investigation by DuPont into CS Energy's incident investigation capability.[252]

In May 2017, CS Energy launched a Cultural Improvement Program (CODE) '*to shift our workforce to a more constructive culture*'.[253] In 2018, a new Health and Safety Handbook and a Mobile App to capture hazards, safety interactions, and inspections, was launched by CS Energy.[254] A specific CODE Resilience program was launched in 2020 to support staff with tools and online training to support their personal mental health and wellbeing.

In 2020, senior leadership were engaged in a series of Inclusive Leadership Workshops to support CS Energy's inclusion and diversity goals.[255]

14.7 Chapter Summary

CS Energy has two significant structural influences: it is a GOC, and shares ownership of the Callide C power station.

As a GOC, CS Energy is obliged to meet Shareholder Mandates, as well as meet the annual key performance indicators contained in the SCI. In the years leading up to the incident, these mandates focused on cost savings, and performance indicators were dominated by financial and production metrics, as well as personal safety-related metrics.

Shared ownership of the Callide C power station led to increased complexity in its management, including competing asset investment priorities.

More broadly, CS Energy had been through an extended loss-making period between 2008 and 2015. This period overlapped a period of political debate around the privatisation of Queensland's energy assets, and overlapped with a prolonged dispute with Anglo American regarding the supply of coal to the Callide power stations.

CS Energy also had to respond to the challenge posed by climate change and the energy transition, which included investment in renewable energy technologies, and commencing the transformation of power stations from fixed to flexible generators to reduce the cost of production.

After CS Energy returned to profitability in 2015, there was a period of significant organisational reform. Multiple initiatives to improve performance were delivered across the organisation, six of which had direct impact on operations at the Callide site. One of those reforms, discussed in more detail in Chapter 15 *Process Safety – Critical Risk Program*, was the launch of the Critical Risk Program. Another was the separation of the asset management and operational functions. This reform

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[251] CS Energy (2015) *Annual Report 2014/15,* 10. https://www.csenergy.com.au/ArticleDocuments/191/Annual%20Report%202014_2015%20-%2030%20Sept%202015.pdf.aspx

[252] DuPont (December 2015) *CS Energy Incident Investigation Report Version 1.2*, CSE.001.081.4897.

[253] CS Energy (2017) *Annual Report 2016/17*, 24. https://www.csenergy.com.au/ArticleDocuments/191/Annual%20Report%202016_2017%20-%2030%20Sept%202017.pdf.aspx

[254] CS Energy (2018) *Annual Report 2018*. https://www.csenergy.com.au/ArticleDocuments/191/CS%20ENERGY%20ANNUAL%20REPORT%202018.pdf.aspx

[255] PowerPoint Presentation (28 August 2020) *Inclusion and Diversity Operational Plan,* 6, CSE.001.082.0807.

overlapped with a period of high turnover of Callide site management: between 2017 and the time of the incident, the Callide power stations had four different general managers, at least two different maintenance managers, and four different production managers.

In the context of a focus on financial and production considerations, with the organisation responding to external pressures such as climate change, special effort was required to foster and maintain an active focus on process safety.

Chapter 15 *Process Safety – Critical Risk Program* examines the Critical Risk Program CS Energy embarked in 2017 to improve both personal and process safety.

15 PROCESS SAFETY – CRITICAL RISK PROGRAM

15.1 Introduction

In 2017, CS Energy developed a program called the Critical Risk Program. This program aimed to develop a better understanding of CS Energy's personal safety and process safety risks in the operation of its business, and to embed process safety across all its sites.

This chapter examines how from 2017 to the time of the incident, this program had not materially impacted the understanding or management of process safety risk on the Callide site. Despite this, internal and external messaging presented a confident view that an effective process safety program had been established within CS Energy.

15.2 Overview

Process safety was first adopted in the power industry by Scottish Power in 2010.[256] In 2014, Scottish Power's process safety advisor worked with Contact Energy, one of New Zealand's largest electricity generators, to introduce process safety to its operations. Contact Energy was subsequently engaged by CS Energy as a process safety advisor in 2017.[257]

In 2016, CS Energy introduced the specific concept of process safety into the organisation.[258] Multiple factors led to this introduction,[259] including external pressure from Workplace Health and Safety Queensland,[260] as well as several process safety-related incidents.[261]

In 2017, CS Energy developed its formal process safety program called the Critical Risk Program. The program involved the management of personal safety risks (Personal Fatality Risks) and major accidents (Major Accident Hazards, or MAHs).[262]

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[256] Case study: Scottish Power (February 2011) *Power generation company gets to grips with process safety, Health and Safety Executive, United Kingdom*. https://www.primatech.com/images/docs/case-study-scottish-power.pdf

[257] Contact Energy (2017) *Consultancy Services Agreement*, CSE.001.019.0800.

[258] While process safety was introduced as a specific concept at this time, various practices consistent with good process safety had already been in place, such as management of change and permit to work. Further, a formal process safety management procedure was introduced in September 2018. CS Energy (2019) *Process Safety Management CS-Risk-08*, CSE.001.113.0001.

[259] The concept was introduced at a workshop held by two CS Energy teams – the Health and Safety team, and the Governance, Risk and Compliance team – in August 2016. PowerPoint Presentation (31 August 2016) *Building on Risk and Safety Maturity: The Process Safety Journey*, CSE.001.232.0071.

[260] Excel Spreadsheet (11 September 2016) *WHSQ Audit Recommendations – 2016.XLS*, CSE.001.088.1848.

[261] See for example: Significant Incident Report (4 May 2016) *C4 Boiler Low O2 Event*, CSE.001.014.8766; Significant Incident Report (14 September 2016) *Chlorine Leak,* CSE.001.088.3371; PowerPoint Presentation (31 August 2016) *Building on Risk and Safety Maturity: The Process Safety Journey*, 9, CSE.001.232.0071.

[262] The term Major Accident Hazard (MAH) is also referred to in the industry as a Major Accident Event (MAE).

In the first half of 2017, a pilot program began at CS Energy's Wivenhoe site.[263] The Critical Risk Program was formally documented in an Operations Review, which was presented to and accepted by the CS Energy board in June 2017.[264]

In its 2018 Annual Report, CS Energy stated it had:

> *established a process safety management system that integrates process safety into our business-as-usual activities. Beginning in FY2019, CS Energy will monitor and measure our process safety performance in line with industry and international standards.*[265]

Similar positive statements were also made regarding process safety in its 2019 and 2020 Annual Reports.[266] Despite these statements, this chapter shows how the Critical Risk Program failed to meaningfully change the management of process safety risk at Callide.

15.3 Commencement and Pilot

15.3.1 Introduction of the Program

The Critical Risk Program was led by two teams: the Health and Safety team and the Governance, Risk and Compliance team. The program was endorsed by CS Energy's board in June 2017 – being described as a key initiative – and was embedded in CS Energy's risk register and Technical Services Plan for 2017–18.[267]

The program was delivered by an internal project manager – the Senior Governance Risk and Compliance Officer – who joined CS Energy in 2016. This project manager was supported by experienced external consulting resources to implement this program.

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[263] See for example: Board Paper (28 August 2017) *CEO Report*, 4, CSE.001.082.2504; Audit and Risk Committee Paper (23 March 2018) *Governance Risk and Compliance Report*, 3, CSE.001.081.8716. Other strategic planning referencing process safety more generally can be found in Board Paper (23 February 2017) *Enterprise Strategy Implementation*, CSE.001.082.3020; Plan (2017) *Technical Services Plan FY 2017/018 Performance Plan,* CSE.001.084.4373.

[264] Board Paper (26 June 2017) *Operations Review*, CSE.001.082.2127; Minutes (26 June 2017) Meeting of the Board of Directors, 6, CSE.001.023.3921.

[265] CS Energy (2018) *Annual Report 2018*, 7, 24. https://www.csenergy.com.au/ArticleDocuments/191/CS%20ENERGY%20ANNUAL%20REPORT%202018.pdf.aspx

[266] The 2019 Annual Report states that '*CS Energy integrated process safety into our business-as-usual activities in FY2019, following the introduction of a process safety management system the year before.*' In 2020 the Annual Report states '*We also continued to embed process safety into our business, consolidating process safety risks with our broader health and safety risks and establishing a Process Safety Frequency Rate metric to effectively measure our performance.*' CS Energy (2019) *Annual Report 2019*, 26. https://www.csenergy.com.au/ArticleDocuments/191/CS%20ENERGY%20ANNUAL%20REPORT%202019.pdf.aspx; CS Energy (2020) *Annual Report 2020*. https://www.csenergy.com.au/ArticleDocuments/191/CS-Energy-Annual-Report-2020.pdf.aspx

[267] Board Minutes (26 June 2017) Meeting of the Board of Directors, 6, CSE.001.023.3921; Report Attachment (18 July 2017) *Governance Risk and Compliance Report – Risk Register,* CSE.001.081.9186. In the risk register, the risk identified was described as '*lack of, or ineffective, critical risk systems leading to a fatality*'. Plan (2017) *Technical Services Plan FY 2017/018 Performance Plan,* CSE.001.084.4373.

The project manager reported to a steering group comprising three senior executives from CS Energy. The program engaged with the organisation though several channels, including a project working group, site sponsors, site project leads, and expert leads.[268]

15.3.2 The Wivenhoe Pilot

The Critical Risk Program began with a pilot program at CS Energy's Wivenhoe site. Phase 1 of this pilot program focused on:

- Raising awareness of critical risks within the teams.
- Identifying critical risk scenarios for the Wivenhoe site.
- Developing bowties.
- Conducting a gap analysis of the critical control elements.[269]

The pilot program at Wivenhoe occurred between March and August 2017.

For the Wivenhoe site, a total of 32 critical risks were identified (15 Personal Fatality Risks and 17 MAHs). Bowties were completed for each of these risks. (For a brief explanation of a bowtie, see Section 13.4.3.) In addition, 13 high priority actions flowed from the pilot to improve controls on the site.[270]

At its conclusion, the pilot program was reported internally as '*very valuable, with some immediate actions being implemented*'.[271] The '*intangible benefits*' of the pilot program, primarily the increased capability of CS Energy's personnel, were described in a subsequent report, see Figure 132.[270]

> **Intangible benefits**
>
> The project has already significantly raised the level of Critical Risk understanding within CS Energy leadership and workforce. Our people can now more clearly articulate what are critical controls are for both Personal Fatality Risk and Major Accident Hazards. The additional benefit of the Critical Risk Programme methodology has been our people more detailed and expanded (ie understanding of the interlinkage and interplay of critical risk scenarios and controls) of our critical risks.

Figure 132 Extract from findings of the Wivenhoe pilot project

The approach taken in the pilot played a key role in raising CS Energy's competency – presumably limited to the Wivenhoe site – in both the recognition and identification of hazards, as well as the controls required to manage them. This was a positive first step for CS Energy, and the focus then turned to undertaking the same approach at the Kogan Creek and Callide sites.

[268] PowerPoint Presentation (9 October 2017) *Critical Risk Project Steering Committee Update*, CSE.001.240.5246.

[269] Contact Energy (2017) Consultancy Services Agreement, CSE.001.019.0800.

[270] CS Energy (October 2017) *Critical Risk Business Case*, 41, CSE.001.240.3514.

[271] Board Paper (28 August 2017) *CEO Report*, 4 CSE.001.082.2504.

15.4 Transition from Pilot to the Full Program

By October 2017, CS Energy had developed a 47-page detailed business case for the complete Critical Risk Program.[272] This detailed the intended approach, delivery options, governance structure, and costs to roll out the entire program across the organisation.

The objectives of the Critical Risk Program, as set out in the business case, were consistent with the principles of process safety discussed in Chapter 13 *What is Process Safety?*, namely, to develop:[273]

> *(1) A common understanding of our critical safety risks providing sufficient knowledge of our major hazards and fatality risks;*
>
> *(2) Controls and the quality of controls in place to manage critical risks are well understood;*
>
> *(3) That gaps in controls are identified and rectified to manage critical risks at an acceptable level;*
>
> *(4) Critical controls are monitored to ensure they are operating effectively;*
>
> *(5) The suitability of and compliance with our systems and processes is adequate to provide a reliable framework for the effective management of critical risks; and*
>
> *(6) Critical Risk management becomes an integrated and embedded part of normal business and our performance discussed and reported at all levels (frontline to Board).*

The program was to be rolled out in three phases:

- Phase 1: This phase focused on identifying the MAHs and Personal Fatality Risks relevant to each site, developing their bowties, and identifying the critical controls for each. Because Wivenhoe had completed its bowties, the focus was on the bowties for Kogan Creek and Callide. Kogan Creek planned to begin its bowties in November 2017, with Callide planning to begin in March 2018.[274]
- Phase 2: This phase focused on control improvements, with the critical controls being identified through Phase 1's bowtie process.
- Phase 3: This phase aimed to develop the framework for an effective critical risk program through the development of the structures, systems, and capability to support the program.

The bowtie development in Phase 1 was to follow a 5-step process, see Figure 133.

[272] CS Energy (October 2017) *Critical Risk Business Case*, 41, CSE.001.240.3514.

[273] CS Energy (October 2017) *Critical Risk Business Case*, 41, CSE.001.240.3514.

[274] The business case recognised that two types of actions could emerge out of the bowties: specific actions that impact only one or two bowties, and systemic actions that effect a number of bowties. An example of a systematic action arising out of the Wivenhoe pilot was the need to focus on maintenance management and management of change. Board Paper (28 August 2017) *CEO Report*, 19, CSE.001.082.2504.

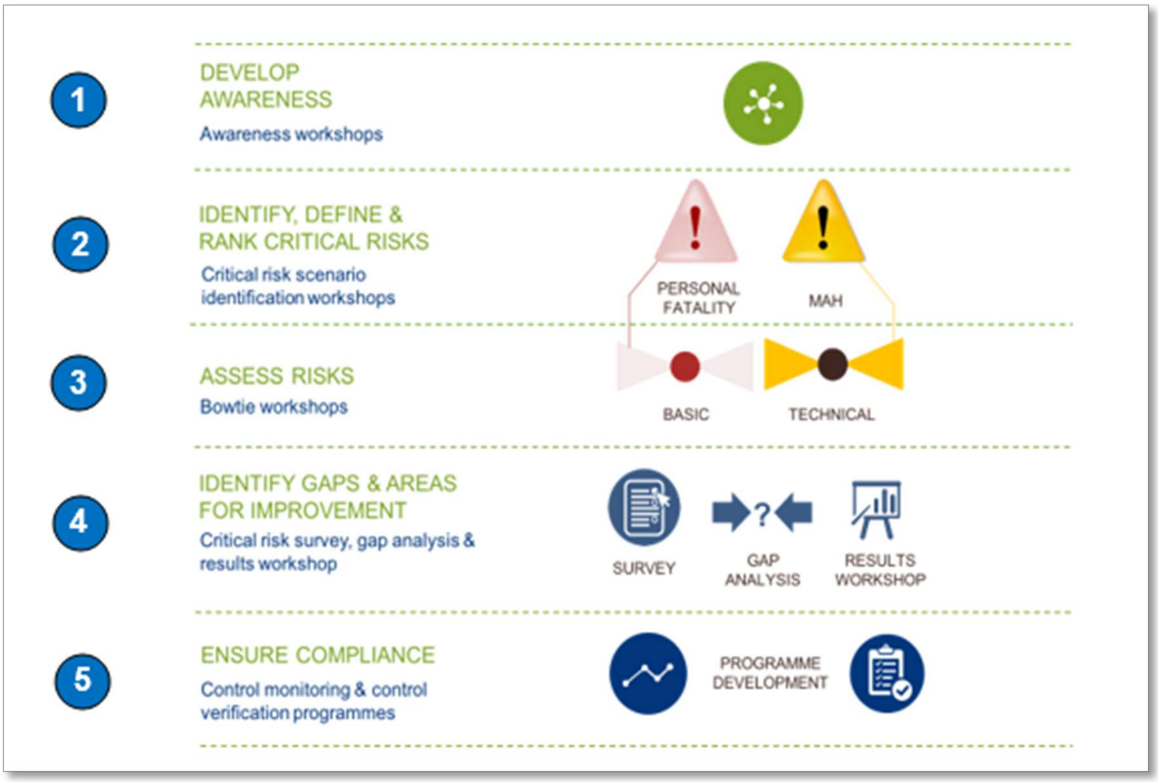

Figure 133 Extract of Critical Risk identification Program

The costs of completing Phase 1 across all of CS Energy's sites was estimated at just under $2 million. However, this business case, with this specific scope, was not approved by the CEO, and before such approval did occur, the scope of the program changed significantly.

15.5 A Change of Direction by CS Energy

15.5.1 Restructuring

In the first half of 2018, a change in organisational structure separated Asset Management from Operations, under *Project Drive*.[275]

Responsibility for the Critical Risk Program and MAHs (as opposed to Personal Fatality Risk) moved from the Health and Safety team to this newly formed Asset Management team.[276] The steering group members were also replaced.[277]

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[275] See Section 14.6.2.

[276] See PowerPoint Presentation (February 2018) *Critical Risk Program – Working Group Phase 2 Workshop*, CSE.001.240.6714; Minutes (22 February 2018) Critical Risk – Steering Committee, CSE.001.241.4838; Audit and Risk Committee Paper (23 March 2018) *Governance Risk and Compliance Report*, CSE.001.081.8716.

[277] Email (8 February 2018) *RE: Critical Risk - Steering Committee*, CSE.001.240.9122.

15.5.2 Resourcing

The restructure resulted in the creation of the new role of Process Safety Manager.[278] The project manager who led the Critical Risk Program for the previous year – the Senior Governance Risk and Compliance Officer – was appointed to this new role.[279]

There was one other dedicated process safety resource – a Process Safety Specialist – appointed to complete the rollout of the Critical Risk Program. This role was appointed under a 6-month contract in late 2017.[280]

15.5.3 A New Approach

Just as the first phase of the Critical Risk Program began to be rolled out, the approach to the program changed. The new approach, as presented to the Audit and Risk Committee in March of 2018, narrowed the focus of the program to two areas:[281]

- Control improvements for the top three systemic priority elements:[282] These elements emerged out of the preceding bowtie work undertaken at the three sites and included management of change.[283]
- Piloting three process safety systems: These systems were incident reporting for critical risks, dashboard reporting, and the critical risk framework.[284]

Excluded from the scope of this new approach were other control improvements identified by work completed under the program to date. Critically, the remaining bowtie work was removed from the scope. Figure 134 shows how the new approach was presented to the Audit and Risk Committee.[285]

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[278] People, Safety and Environment Committee Paper (29 June 2018) *Process Safety Project Update*, CSE.001.081.6154.

[279] It appears the appointment was on an acting basis only, based on the signature block in emails sighted by the Brady Heywood investigation.

[280] CS Energy (21 December 2017) *Terms and Conditions of Employment*, CSE.001.241.2047.

[281] Audit and Risk Committee Paper (23 March 2018) *Governance Risk and Compliance Report*, 2-4, CSE.001.081.8716.

[282] These were identified as Management of Change, Operational Procedures and Staff Competency (system to measure). PowerPoint Presentation (28 February 2018) *Critical Risk project – Working Group Phase 2 Workshop for Ops*, 16, CSE.001.241.8221.

[283] See PowerPoint Presentation (28 February 2018) *Critical Risk project – Working Group Phase 2 Workshop for Ops*, 16, CSE.001.241.8221; discussion of the outcomes of the Wivenhoe Pilot in CS Energy (October 2017) *Critical Risk Business Case*, 44, CSE.001.240.3514; Feasibility Gate Approval Request (March 2018) *Critical Risk – Process Safety*, 8, CSE.001.234.0041. There is evidence that work was done in connection with this Management of Change program, including a reference to the Plant Modifications Procedure being updated, in the handover notes of the Process Safety Specialist: Process Safety Specialist (3 May 2019) *Handover Report* 6, CSE.001.234.0428.

[284] Audit and Risk Committee Paper (23 March 2018) *Governance Risk and Compliance Report*, 3, CSE.001.081.8716.

[285] Audit and Risk Committee Paper (23 March 2018) *Governance Risk and Compliance Report*, 3, CSE.001.081.8716.

Due to changing business structures through the DRIVE program and the transfer of responsibility of the Critical Risk Program to the Asset Management team, there is now an opportunity to accelerate Phase 2 and Phase 3 activities in parallel to deliver the benefits of improved process safety controls to the business sooner. The remaining "Future Work", summarised in Figure 1, will be considered by the Asset Management / Operational Excellence group as future business as usual activity.

Figure1: *Summary of project scope & work to be considered in future.*

Figure 134 Extract Audit and Risk Committee paper

A presentation to the CEO in April 2018 included notes that the program's delivery had now been '*honed to deliver the key foundational pieces for process safety to transition to business as usual.*'[286]

This is an incorrect statement. The new approach focused on implementation, but did so without developing the bowties necessary to develop a foundation in risk competence related to MAH risks and the controls required to manage them.

The business case for the Critical Risk Program was approved by the CEO in April 2018.[287]

15.6 Callide Bowtie Development Status

15.6.1 Introduction

The original Critical Risk Program involved the development of bowties for each site. The status of bowtie development prior to the adoption of the new approach was as follows:

- Wivenhoe bowties were completed during the pilot program.
- Kogan Creek had completed its first tranche of bowties, reviewed its process safety controls, and developed a plan to prioritise control improvements.

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[286] PowerPoint Presentation (4 April 2018) *Critical Risk Presentation*, notes section, CSE.001.245.7708.

[287] Email (26 April 2018) *RE: Contact Energy and CS Energy contractual arrangements*, CSE.001.243.5645. There is evidence that approval for the business case was initially unsuccessful: Email (10 April 2018) *REV2: REVISED: FOR REVIEW: Critical Risk - CEO presentation*, CSE.001.241.4425.

- Callide was yet to commence work on its first tranche of bowties.

The process safety team scheduled work for the Callide site's first tranche of bowtie development between April 2018 and 24 May 2018.[288] The team planned that the first tranche would consist of six Personal Fatality and 27 MAH bowties.

The rollout of *Project Drive* – the organisational restructure discussed previously in Section 14.6.2 and one of the reasons behind the new approach to the process safety program – was, however, resulting in a demanding workload for the Callide site. As a result, the Callide Site Manager resisted the planned bowtie development program, and negotiated and agreed to a revised program with the Group Manager Governance, Risk, and Compliance.[289] This reduced the number of bowties developed from 33 to a maximum of 5 to 8 bowties, which would be delivered in a 6-week period. The Callide Site Manager also requested that the bowties focus on personal safety rather than process safety.[290]

15.6.2 Bowties Completed at Callide

Of the 38 bowties originally planned for Callide, two were removed, and 15 were recorded as 'done'.[291] This information is taken from a master bowtie list titled *Post Stage 1 Completion May 2018*.[292]

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[288] CS Energy (October 2017) *Critical Risk Business Case*, 39, CSE.001.240.3514.

[289] Emails (22 January 2018), CSE.001.242.4481. In this email exchange, the request was made to accommodate the '*workload associated with DRIVE implementation 1st half of 2018*'.

[290] Emails (22 January 2018) *Revised plan for Critical Risk (Callide)*, CSE.001.242.4481.

[291] Of the two bowties removed, one was not applicable to Callide, and the other was combined into another bowtie.

[292] CS Energy (May 2018) *CS Energy Master Bowtie list_rev 8, Callide MAH Bowtie list – Post Stage 1 Completion May 2018*, CSE.001.234.0117. The MAHs for the completed bowties are:

- *Human Factors – Loss of Control.*
- *ST – Generator/H2 system – Hydrogen – LOC.*
- *Electrical Systems – HV Tx tower – Structural failure.*
- *ST – Generator – Rotating Parts – Overspeed – LOC.*
- *Control & Instrumentation – Fire Protection/Detect/Suppress Systems – failure.*
- *Conveying, Storage, Pulverising, Drying and PF Transport Systems – Blockage, LOC.*
- *Boiler – Stack, FG Ducting – Structural Failure.*
- *Boiler – Firing Systems – LOC.*
- *Boiler – Firing Systems – Unburnt Fuel.*
- *Civil Engineering – Cooling Towers/Air Cooled Condensers – Collapse.*
- *Cooling water system, Chemicals – Chlorine – LOC.*
- *Boiler Dosing System, Chemicals – Ammonia – LOC.*
- *Waste Containment Facility – Ash – LOC.*
- *Chemicals – Sulfuric Acid – LOC.*
- *Chemicals – Caustic Soda – LOC.*

The MAHs for bowties which were not completed were:

15.7 Actual Deliverables of the Critical Risk Program

The change in approach to the Critical Risk Program redirected it towards process safety system paperwork, as opposed to meaningfully improving CS Energy's approach to process safety. In 2018, the two-member process safety team delivered:[293]

- A process safety management framework.
- A process safety dashboard (pilot).
- Process safety incident reporting (pilot).
- A process safety awareness e-module for all staff.
- A process safety communication campaign.[294]

- *BOP – Backup electrical systems (site or DC) – Failure.*
- *BOP – Compressed Air System – air – LOC.*
- *BOP – Rotating Equipment Mechanical.*
- *Dropped objects (damage to plant) – LOC.*
- *Electrical Systems – AC Electrical and Battery Systems – Transformer, IPB, Cable Systems, Switchgear, Reactors, Earth System – Electrical Fault.*
- *Electrical Systems – DC Systems DC.*
- *Electrical Systems – Oil Filled HV Transformers – Oil – LOC.*
- *Natural hazards.*
- *Road Traffic Accident – Loss of control leading to accident and loss of containment.*
- *BOP – Raw Water Pond – Water – LOC B.*
- *ST – Generator – Protection Systems – Loss of Protection Systems – Major electrical fault.*
- *ST – Generator – Mechanical/Electrical Failure.*
- *BOP – Storage – Hydrogen – LOC H.*
- *Civil Engineering – ST Generator, Cooling Towers/Air Cooled Condensers, Boiler, Coal Bunkers – Supporting Structures & Foundations – Failure.*
- *Collection, Conveying, Storage and Disposal of Wet and Dry Ash Systems – LOC.*
- *BOP – Aux Boiler inc. tubes, headers – Gas, HP steam – LOC.*
- *ST – Generator – Lube/Hydraulic Oil Systems – LOC.*
- *Feed System – Feedwater/condensate systems – Hot water, steam – LOC.*
- *Boiler – Boiler Tubes and Headers and drums – steam/hot water – LOC.*
- *BOP – Auxiliary Systems – LOC.*
- *BOP – Chemicals including storage (excluding fuels) – LOC.*

Among the incomplete bowties, the MAHs included elements of the electrical systems and auxiliary systems involved in the incident at Callide C. In relation to Kogan Creek, there is a list of 45 potential bowties, with 15 marked as 'complete': Excel Spreadsheet (February 2018) *CS Energy Master Bowtie List,* Worksheet: Kogan MAH Scenarios, CSE.001.234.0200.

[293] CS Energy (November 2018) *Funding Variation Approval Request* CSE.001.247.0581; PowerPoint Presentation (12 June 2018) *PSEC – Process Safety Project Update,* 3, CSE.001.246.4107.

[294] The communication plan was developed in August 2018 and the launch of the process safety campaign was in early 2019. CS Energy (August 2018) *Communication Plan*, CSE.001.247.5163. The campaign was titled 'PS Always on my mind': see for example PowerPoint Presentation (January 2019) *Process Safety Town Hall, Callide*, CSE.001.247.3910.

Around August 2018, efforts to improve process safety began to be referred to as the Process Safety Program.[295]

Despite the bowtie development never being competed at the Callide and Kogan sites, a December 2018 Executive Briefing Paper delivered to CS Energy's Executive and Management team presented a positive view of progress. The paper gave the impression that the 2017–18 Critical Risk Program had delivered the bowties and control improvement phases for the original Critical Risk Program, see Figure 135.[296]

> In 2017/18, the Critical Risk Program was one of CS Energy's 'Big 4' Business Change Initiatives. The Critical Risk Program had two phases:
>
> - **Phase 1 – Identification** – We conducted facilitated sessions with multi-disciplinary teams to identify and assess our critical risks using the Bowtie Methodology and analyse the critical controls required to manage these risks.
> - **Phase 2 – Control improvement and action management** – We prioritised and categorised control improvement actions identified in Phase 1.

Figure 135 Extract from 2018 Executive Briefing Paper

15.8 Challenges to the Process Safety Program

15.8.1 Funding and Resourcing

By the end of 2018 and the start of 2019, forward budgeting for the process safety team became uncertain – the cost of the program was being shifted from strategic funding to operational budgets.[297]

On 2 January 2019, the Process Safety Manager sought confirmation from the Head of Business Improvement that the forward budget would be for a team of three people to continue to deliver the Process Safety Program across the organisation.[298]

On 18 January 2019, the Process Safety Manager wrote a formal memo to the Acting Executive General Manager (Asset Management) seeking appropriate resourcing to continue with the Process Safety Program.[299] The original business case recommended using external support to complete Phase 1 and envisaged the ongoing need for two process safety staff to complete Phases 2 and 3.[300]

The memo outlined the following key points regarding the funding of process safety at CS Energy:

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[295] This term is used in the August 2018 *Communication Plan*: CS Energy (August 2018) *Communication Plan*, CSE.001.247.5163. The Critical Risk Program is described in this document as one of the 2017–18 'Big 4 Business Change Initiatives'.

[296] Executive Briefing Paper (3 December 2018) *Process Safety*, CSE.001.248.1853. As evidence of its presentation to management see Email (3 December 2018) *Process Safety Presentation -12:45*, CSE.001.247.0876; Email (6 December 2018) *FW: Process Safety Pack for Leaders Briefing*, CSE.001.246.4258; Email (6 December 2018) *FW: Process Safety Pack for Leaders Briefing*, 11:35 am, CSE.001.246.3229; Email (11 December 2018) *Process Safety Leadership Briefing: Shift Supervisor Meeting.*, CSE.001.247.2316.

[297] Email (2 January 2019) *Asset Management : Process Safety Budget and Head Count*, CSE.001.247.3582.

[298] Planning referenced in Email (2 January 2019) *Asset Management : Process Safety Budget and Head Count,* CSE.001.247.3582.

[299] Memorandum (18 January 2019) CSE.001.248.2129.

[300] CS Energy (October 2017) *Critical Risk Business Case*, 39, CSE.001.240.3514.

- The organisation had made a substantive financial investment in the Process Safety Program.
- The 'future work' identified in the March 2018 business case was intended to be budgeted by the Asset Management division as a 'business as usual' activity.
- There was no funding currently allocated for process safety resources after 30 June 2019.

In this memo, the Process Safety Manager outlined the risk of not having funding approved for the existing two process safety staff. They also highlighted the risk associated with a lack of strategic funding for a third person for 12 months. Without approved funding, the Process Safety Manager would return to the team they had been seconded from, and the Process Safety Specialist's contract would end, see extract in Figure 136.

KEY RISKS

In the event that the recommended future resourcing of Process Safety at CS Energy does not proceed, the Process Safety team would be dissolved. At 1 July 2019, this would result in the:

- seconded FTE (Process Safety Manager) returning to a substantive position in the Risk and Compliance team, and
- the second (contracted Process Safety Specialist) FTE equivalent would leave the business at 30 June 2019.

The Process Safety team's knowledge, drive and commitment have them positioned as highly respected experts in this priority work. They engage 'hearts and minds' of our people across our sites in their personal commitment to Process Safety and enhancing our overall capability.

Our people across our sites now consider that Process Safety is what we do. The loss of CS Energy's support for dedicated resources to this function is likely to threaten the sustainability of the benefits achieved as well as having a negative cultural impact.

Figure 136 Memo extract – Key Risks

On 22 January 2019, the resourcing request was approved by the then Acting Executive General Manager (Asset Management).[301] But on 1 February 2019, shortly after the return of the Executive General Manager (Asset Management), a significant budget review was launched across the entire Asset Management division.[302]

As discussed in Section 15.8.2, evidence has been sighted that suggests that funding approval was only given for two staff, and there was no further budget allocation for the Process Safety Program.[303]

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301 Email (22 January 2019) *FINAL: FOR REVIEW AND APPROVAL : MEMO - Request for Approval of Additional FTE Resources - Process Safety*, CSE.001.247.5185.

302 Email (1 February 2019) *FW: Asset Management Budget Challenge & Review Pack*, CSE.001.247.8827.

303 Meeting Notes (6 March 2019) Meeting with [redacted] regarding exit survey responses, CSE.001.0285.0129.

15.8.2 Loss of Staff

On 22 February 2019, the [redacted] resigned, and their last day was [redacted].[304] They participated in an exit interview, and meeting notes were taken by CS Energy. Extracts from these meeting notes are quoted below.[305]

The meeting notes record that the [redacted] discussed what they considered was an '*unsafe work environment*' and stated that they were '*quite concerned about process safety at CSE, in particular at Callide.*'

They believed *'the lack of maintenance at Callide over the last few years, pushing out overhaul dates, ageing plant and budget restrictions, four fires in five months and several managers over the past few years is a concern*'. They felt '*that these items together are the tell tale signs that a process safety incident is quite possible.*' They '*did not wish to be alarmist but as a process safety professional there are items [they wish] CSE hadn't cut (maintenance etc).*'

They advised that they had raised these concerns via '*conversations with a number of people*' and they were *'so worried for Callide'*. They considered that '*there are some serious issues with chlorine, hydrogen, fire, [and] obsolete equipment*'.

The [redacted] also expressed their view that '*the business has a bandwidth issue*' and that '*process safety is drowned out by Titan, Overhauls, SAP upgrade, etc …*'. They were also '*concerned that the HSE reporting line is through the Plant Operations division – not in line with what [they are] used to (independent reporting line).*'

They *'believed [they] had 3 people (including [themself]) plus $1M in the budget going forward'* for process safety, however found there would be only two people '*and no budget*'. They compared this to the HSE team who '*have multiple staff and budget …*'

Following the [redacted] exit interview, the meeting notes record that the interviewer met with the CS Energy CEO on the same day and provided the information from the interview, and that the CEO was '*concerned regarding comments on Process Safety at Callide and will investigate further*'.[306]

Soon after the departure of the [redacted], the contracted Process Safety Specialist subsequently also resigned.[307]

While the Asset Management team looked to backfill these roles, there was effectively no process safety team from April 2019 to July 2020. A new [redacted] was to begin in May 2019,[308] and evidence has been sighted that indicates the individual did in fact commence in that role.

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[304] Email (22 February 2019) *Resignation Letter*, CSE.001.248.4283; Letter (22 February 2019) *Resignation Letter*, CSE.001.248.4284. There is correspondence to suggest the [redacted] initially resigned in December 2018: Email (9 December 2018) *Resignation Letter*, CSE.001.247.0620.

[305] Meeting Notes (6 March 2019) Meeting with [redacted] regarding exit survey responses, CSE.001.0285.0129.

[306] Meeting Notes (6 March 2019) Meeting with [redacted] regarding exit survey responses, CSE.001.0285.0129.

[307] The exact date was not confirmed, but a role handover report was produced dated 3 May 2019. Handover Report (3 May 2019) *Process Safety Specialist*, CSE.001.234.0428.

[308] PowerPoint Presentation (5 April 2019) *Process Safety*, CSE.001.250.0034.

However, the records also indicate that this individual was also acting as the of Head of Health and Safety (variously described as 'Acting' or 'Part') from as early as October 2019.[309]

No evidence has been sighted regarding progress on process safety or the Process Safety Program during this time.

Evidence has been sighted that indicates responsibility for process safety then moved back into the Health and Safety team.[310] In July 2020, a single Process Safety Specialist was appointed. This Process Safety Specialist came from within CS Energy's Asset Management team, with prior roles as an Asset Management Specialist and Specialist Risk Advisor.

Figure 137 summarises the resourcing provided to the Critical Risk Program from 2017 to the time of the incident.

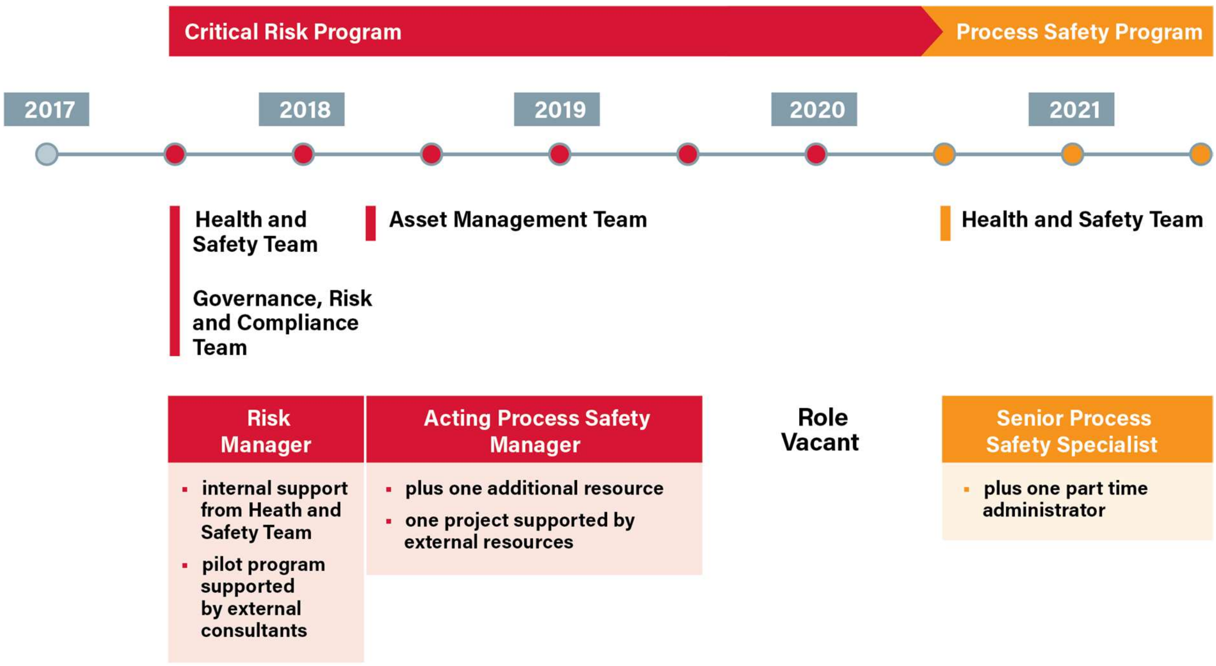

Figure 137 Timeline of process safety ownership and resourcing

This shows that the Critical Risk Program had three different owner teams within CS Energy, never exceeded two dedicated staff, and for approximately 12 months (between May 2019 and July 2020) had no dedicated Process Safety Specialist in the role. From July 2020 up until the time of the incident, there was only one Process Safety Specialist.

309 See for example: Record of Meeting Agenda (10 December 2019) *Peak Consultative Committee Meeting*, 1, CSE.001.083.4141; Minutes (29 November 2019) Meeting of the Performance Committee, 3, CSE.001.023.7490.

310 PowerPoint Presentation (2020) *Health & Safety Strategic Refresh May-August 2020*, CSE.001.088.1003.

15.8.3 Loss of Funding

Based on the [redacted] *Handover Report*, funding cuts impacted the following components of the Process Safety Program:[311]

- The process safety dashboard was reduced to '*meet the bucket of money available*'.
- The scope for the risk assessment software (BowTie XP) '*will need to be reduced*'.
- Bowties and priority actions were impacted, as '*only a portion of the entire portfolios [sic] bowties have been completed, of those completed a priority list of #16 actions were agreed.*'

The Process Safety Specialist's *Handover Report* made the same observations about the funding cuts to the process safety dashboard and the risk assessment software (BowTie XP).[312]

15.9 The Return and Redesign of Process Safety in 2020

15.9.1 Introduction

In mid-2020, as part of the Health and Safety team's five-year plan, the Process Safety Team was restaffed, and a new strategy was designed.[313] A Process Safety Leadership Group was established to help the Process Safety Specialist, as the sole person on the process safety team, to engage with the organisation. This group met for the first time in February 2021.

Two major changes emerged from this new strategy:

- A shift from site-specific bowties to using six company-wide MAH bowties.
- The adoption of the Process Safety Frequency Rate (PSFR) as the process safety performance metric.

These two changes fundamentally and negatively impacted CS Energy's approach to process safety. No evidence was sighted relating to what informed the decisions behind these two changes.

15.9.2 Change 1: The Six MAH Bowties

The first change in the new strategy was to no longer develop site-specific bowties.[314] Instead, the focus was on the development of six high-level MAH bowties. For example, the MAH shifted from being a site-specific risk, such as loss of containment from a site's ash dam, to the general and non-specific risk of the failure of a civil structure.

There are obvious benefits to conducting such high-level bowties, namely, the financial and time savings that result from developing significantly less content. However, this high-level approach is only useful when there is a thorough set of risk assessments that underpin the high-level bowtie.

There are fundamental dangers with creating high-level bowties without detailed underpinning risk assessments. This cannot be understated in its importance. If these unique causes of a MAH are not

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[311] [redacted] (8 March 2019) *Handover Report*, 3–5, CSE.001.248.5449.

[312] Process Safety Specialist (3 May 2019) *Handover Report*, 2, 6, 8, CSE.001.234.0428.

[313] PowerPoint Presentation (2020) *Health & Safety Strategic Refresh May – August 2020,* CSE.001.088.1003.

[314] For a discussion of bowties, refer to Section 13.4.3.

understood, it is unlikely that each causal pathway will be controlled effectively. Furthermore, it is unlikely that the intricacies of the control performance requirements will be understood. This affects both the implementation of the control and the verification intended to ensure the control works effectively in a range of scenarios.

Because of this change in strategy to high-level bowties, the verification of the effectiveness of these controls is also at a higher level. The higher the level of control, the less site and situation-specific it becomes. It therefore becomes more difficult to both define its required performance and to check it is performing satisfactorily. In other words, the controls become too broad brush, which greatly undermines the effectiveness of the verification of that control.

Essentially, not only did CS Energy shift away from its initial detailed suite of bowties planned at the early stages of the Critical Risk Program, it also shifted to a form of bowtie that failed to provide the organisation with detailed insight into the effectiveness of its controls.

This had the potential to result in a loss of the fundamental knowledge for a well-designed and effective process safety management system.

15.9.3 Change 2: Reporting Against PSFR

The other significant change in this new strategy was the adoption, in 2020, of a metric to report on process safety performance called the PSFR (Process Safety Frequency Rate). This is calculated as the number of process safety incidents reported against operating hours.[315]

The issues with the adoption and reliance on this single PSFR metric include:

- The PSFR is a lag indicator. It counts events after they have occurred. It provides no information on whether or not the controls to manage major accident hazards are working effectively.
- The metric is dependent on incidents being reported. If an individual does not recognise that an event may relate to process safety and does not report it as a process safety incident, it will not be counted towards the metric. This can lead to a misleading PSFR figure.
- CS Energy established a target for this metric as not greater than 3 incidents per 100,000 operating hours. As a result, there is evidence that internal discussion of process safety became focused on whether the target was being achieved, and the reasons why it was trending up or down.

  For example, minutes from the Process Safety Leadership Forum in April 2021 record that: '*Process safety frequency is trending up. This is due to reduction in plant operating hours and an increased number of reported PS* [Process Safety] *related incidents compared to the same period last year*.'[316] This example is consistent with the target becoming the goal, as opposed to the intention of the underlying metric – to monitor the effectiveness of the Process Safety Program.

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[315] Prior to this metric, a range of lead and lag indicators were being measured and communicated and, in 2018, a process safety dashboard had been built and piloted. No evidence has been sighted that this dashboard progressed beyond the pilot phase.

[316] Minutes (13 April 2021) Process Safety Leadership Forum, 2, CSE.001.003.2656.

This PSFR metric on its own, if trending downwards, has the tendency to support a confident (but unfounded) view of an organisation's process safety systems. This is because the metric measures the presence of events rather than absence of effective systems (controls).

15.10 CS Energy's Self-Assessment on Process Safety

In February 2021, the Health and Safety team presented to the Process Safety Leadership Group. This presentation included its assessment of the organisation's process safety maturity, see Figure 138.[317]

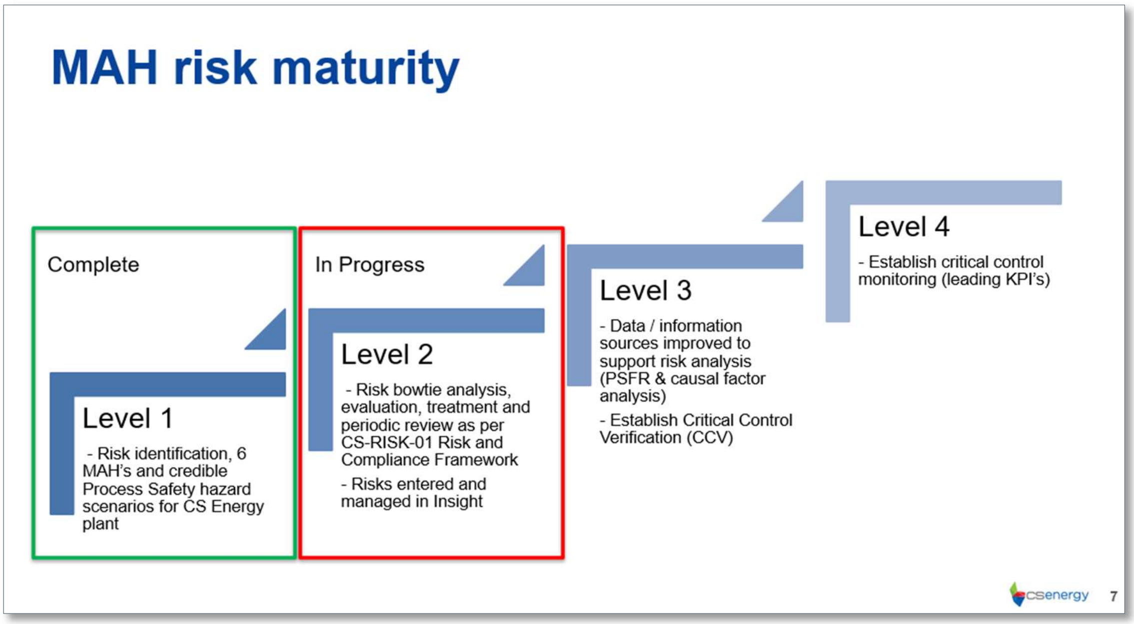

Figure 138 CS Energy's MAH risk maturity

The self-assessment showed that after four years of a focus on process safety very little had been achieved. CS Energy had only just completed its first step – the identification of its six new MAHs – and was yet to complete the bowties for those MAHs.[318]

15.11 Internal and External Messaging on Process Safety

15.11.1 Annual Reports and External Parties

Since 2018, CS Energy had reported favourably on its process safety progress in its annual reports:

[317] PowerPoint Presentation (February 2021) *Process Safety Leadership Workshop*, CSE.001.003.2569.

[318] Progress was reported at the Process Safety Leader Workshop in April 2021. It was described as '*slower than I would like*' – two bowties were active, five were in draft/drafting status, and one was planned. See PowerPoint Presentation (12 April 2021) *Process Safety Leadership Workshop*, 8, 9, CSE.001.003.2676.

- 2016/17 Annual Report: '*We continue to invest prudently in the safety of our people, with major programs being undertaken in 2017/18 for both behavioural and process safety.*'[319]
- 2018 Annual Report: '*We have established a process safety management system that integrates process safety into our business as usual activities.*'[320]
- 2019 Annual Report: '*CS Energy integrated process safety into business as usual activities in FY2019, following the introduction of a process safety management system the year before.*'[321]
- 2020 Annual Report: '*We also continue to embed process safety into our business, consolidating process safety risks with our broader health and safety risks and establishing a Process Safety Frequency Rate metric to effectively measure our performance.*'[322]

In February 2019, CS Energy advised its insurer, as captured in an Engineering Survey Report prepared for the insurer, that:

> *CS Energy also indicated that over the next couple of years they will continue to undertake a significant amount of work in developing Process Safety protocols across their power station operations. The objective of the Process Safety program is to ensure that there is significant clarity in the identification of the potential major accident hazards across each site, and also the confirmation and validation of controls that are in place to manage the potential associated risks.*[323]

15.11.2 Messaging to the Board

In the year prior to the incident, process safety was specifically reported to the board within the quarterly Health, Safety and Environment Reports. Those reports dedicate three to four paragraphs updating the board on resourcing, the six new MAHs and their bowties, the PSFR, and significant incident investigations.[324] No concerns about the Process Safety Program itself were raised in this report.[325]

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[319] CS Energy (2017) *Annual Report 2016/17*, 6. https://www.csenergy.com.au/who-we-are/reports-and-publications/all-reports-and-publications

[320] CS Energy (2018) *Annual Report 2018*, 24. https://www.csenergy.com.au/ArticleDocuments/191/CS%20ENERGY%20ANNUAL%20REPORT%202018.pdf.aspx

[321] CS Energy (2019) *Annual Report 2019*, 26. https://www.csenergy.com.au/ArticleDocuments/191/CS%20ENERGY%20ANNUAL%20REPORT%202019.pdf.aspx

[322] CS Energy (2020) *Annual Report 2020*, 13. https://www.csenergy.com.au/ArticleDocuments/191/CS-Energy-Annual-Report-2020.pdf.aspx

[323] AIG Global Property (February 2019) *Operational ISR Engineering Survey Report*, CSE.001.274.0001.

[324] CS Energy (24 April 2020) *Health, Safety and Environment Report*, 3, CSE.001.082.1380; CS Energy (31 July 2020) *Health, Safety and Environment Report*, 3, 4, CSE.001.082.1467; CS Energy (30 October 2020) *Health, Safety and Environment Report*, 4, CSE.001.082.1480; CS Energy (29 January 2021) *Health, Safety and Environment Report*, 4, CSE.001.082.1473; CS Energy (28 April 2021) *Health, Safety and Environment Report*, 5, CSE.001.082.1570.

[325] Note there had been an in-depth presentation to CS Energy's board in July 2020, where the management team reviewed CS Energy's systems against the Coroner's findings regarding Dreamworld after its 2016 fatal incident. Against an overarching, confident observation that '*CSE has a comprehensive and well-documented safety management system in place which is monitored regularly*', the Process Safety System was identified as an area for improvement. Board Paper (31 July 2020) *Dreamworld Learnings*, CSE.001.082.8324; PowerPoint Presentation (2020) *2016 Dreamworld Tragedy*, CSE.001.082.8326.

15.12 Chapter Summary

CS Energy's Critical Risk Program was piloted in 2017, and then launched in 2018. It initially utilised a site-specific bowtie analysis approach to map out the causal pathways for major risks, and to identify controls to prevent or mitigate the consequences of these risks. The process of developing bowties plays a critical foundational role in the development of an organisation's understanding of its risks, and the controls in place to manage them. It becomes the bedrock for risk competency in an organisation and feeds into critical processes, such as risk assessment and management of change.

But in the two years that followed, the program lost key resources and funding and changed organisational owners. The planned bowtie analysis for the Callide site, necessary to build process safety competence, was never completed.

A new process safety strategy was then developed in mid-2020, which reduced the critical risk program down to two key components: the development of six organisation-wide and high-level bowties, and the adoption of a single lag process safety metric. These two changes fundamentally and negatively impacted the effectiveness of CS Energy's approach to process safety. These new bowties would not provide CS Energy with detailed insights into its specific risks or of the effectiveness of its controls. The lag metric also had the tendency to support a confident (but unfounded) view of the health of CS Energy's process safety systems – it measured the presence of events rather than the absence of effective systems (controls). No evidence has been sighted that CS Energy at the time analysed or understood the implications of this new approach to process safety.

By the time of the incident, the critical risk program had not materially impacted the understanding or management of process safety risk at the Callide site. Despite this, internal and external messaging presented a confident view that an effective process safety program had been established within CS Energy.

The next chapter examines the effectiveness of CS Energy's key systems with respect to process safety.

16 PROCESS SAFETY – KEY SYSTEMS

16.1 Introduction

In the years leading up to the incident, CS Energy conducted reviews into how it managed change, how it conducted maintenance work, how it responded to and learned from incidents, and how effective its Permit to Work systems were. These are all key systems needed for the effective management of process safety.

This chapter examines how these reviews identified substantive issues with each of these systems, and discusses how the majority of CS Energy's actions tended to deal with the symptoms, as opposed to addressing the underlying causes, of these issues.

16.2 Independent Assurance Program

Independent assurance is established under CS Energy's Enterprise Risk and Compliance Management Framework.[326] Its purpose is to provide the CEO, the Executive Leadership team, and the board with assurance that the organisation's internal processes are operating in an efficient, effective, and ethical manner.[327]

This framework achieves this purpose via an independent Assurance team, which, either using its own resources or using external parties, undertakes reviews of parts of the organisation. The team's findings are reported to the Audit and Risk Committee. In response to the findings – as part of the review process – a set of actions is agreed to with CS Energy's management. The team then, at some point in the future, conducts audits to verify whether these actions have been completed.[328]

16.3 Management of Change: Plant Modifications Reviews

16.3.1 Introduction

CS Energy has a documented procedure for managing modifications to the physical plant or processes within its power stations, set out in the *CS Energy Procedure for Plant Modifications, CS-AM-010*.[329] Figure 139 is the introduction to the procedure, which recognises the importance of effective management of change.

[326] CS Energy (2021*) Enterprise Risk and Compliance Management Framework, CS-Risk-01,* CSE.001.049.0094.

[327] CS Energy (2018) *Assurance CS-AUD-01*, CSE.001.081.1386.

[328] The procedure governing the work of the Assurance team is CS Energy (2018) *Assurance CS-AUD-01*, CSE.001.081.1386.

[329] CS Energy (2016) *CS Energy Procedure for Plant Modifications CS-AM-010*, Section 4, CSE.001.243.9479; CS Energy (2019) *CS Energy Procedure for Plant Modifications CS-AM-010*, Section 4, CSE.001.088.5286; CS Energy (2020) *CS Energy Procedure for Plant Modifications CS-AM-010*, Section 4, CSE.001.226.0171.

> Management of Change (MOC) is a critical and essential element of a robust and comprehensive risk-based asset management and safety management system, as changes to plant can introduce new hazards/ defects, or impact on existing risk control measures. There needs to be effective management of all changes to assets and asset systems.

Figure 139 Plant Modifications Procedure – Introduction

The management of change to physical assets or process is carried out using CS Energy's Plant Modifications Procedure.[330] Specifically, the procedure states:

> *Plant modifications will be required from time to time due to new technology, obsolescence, plant performance, reliability, safety, access issues, etc. These modifications require rigid control to ensure that the modification is properly assessed, authorised, implemented and documented.*

16.3.2 The 2016 Review

A Plant Modification assurance review was carried out by an external consultant in 2016. Its objective was to determine whether or not CS Energy employs a '*consistent and controlled approach to the management of plant modifications*'.[331]

The key findings from the 2016 review are summarised as follows:

- Shortcomings still existed in document control, routine monitoring of registers, and training. These shortcomings had been identified in a 2011–12 audit.
- Although the basic elements of the Plant Modifications Procedure had been implemented at Kogan Creek and the Callide power stations, the systems were not fully compliant with this procedure.
- There were 2,202 open modification proposals (across Callide, Kogan Creek, and Wivenhoe sites) in SAP.[332] The 2016 review identified that these open modification proposals were of potentially unknown priority, and they may be masking potential high-risk issues across the Callide, Kogan Creek, and Wivenhoe sites. The management action in response to this finding was a review of the plant modification backlog and register, and an external resource was engaged to assist. This action was due to be completed by 1 August 2016.[333]
- There was uncertainty about the nature of the risk being assessed with respect to '*any new risks being introduced as a result of the proposed modification*'.[334] It was recommended to the

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[330] CS Energy (2016) *CS Energy Procedure for Plant Modifications CS-AM-010*, Section 4, CSE.001.243.9479; CS Energy (2019) *CS Energy Procedure for Plant Modifications CS-AM-010*, Section 4, CSE.001.088.5286; CS Energy (2020) *CS Energy Procedure for Plant Modifications CS-AM-010*, Section 4, CSE.001.226.0171.

[331] O&M Management Consulting (2016) *Plant Modifications Review – 2016.03*, CSE.001.081.5540. Note, the review's scope explicitly excluded whether plant modifications were safe and free from defects, or if risk assessments were completed and reasonable.

[332] 'SAP' was the software package used for maintenance management at CS Energy.

[333] When this action was checked the following year, 2017, the action was only partially verified and it was noted that Callide was '*still working though their mods and prioritising them*'. The due date for the action was extended to 20 June 2017: Audit Actions Implementation Progress Report (21 March 2017) *Plant Modifications Review,* CSE.001.081.5556.

[334] O&M Management Consulting (2016) *Plant Modifications Review – 2016.03*, 11, CSE.001.081.5540.

Callide site that it should confirm that the risk assessment, as part of the Plant Modification Review, should consider '*any new risks being introduced as a result of the proposed modification*', and that training be undertaken. The management action in response to this finding was to review the Plant Modifications Procedure (CS-AMS-010), and to remove the uncertainty with regard to risk assessment.[335]

- Staff knowledge of the modification process was not well understood.[336] The management action in response to this finding was to review the plant modification system training package and complete training at site.

The actions from the 2016 review were checked by the Assurance team in March 2017. Six actions were verified as completed, including updating the Plant Modifications Procedure. Four actions were partially verified.

The new plant modification training had not yet been delivered to operators at Callide, and Callide was still working through its modification backlog.[337] In a spreadsheet used by the Assurance team, the notes on this specific action regarding the modification backlog stated '*nothing has fundamentally changed (yet) at Kogan and Callide. Callide is still working through prioritising and then cutting mod notifications and hopes to be complete by end of June 2017*'.[338]

No evidence has been sighted that the Assurance team revisited this action until the next review in 2020.

16.3.3 The 2020 Review

The next Plant Modification Assurance Review occurred in late 2020 and was completed in January 2021.[339] The review recognised that '*Management of Change is a critical and essential element of a robust and comprehensive risk-based asset management and safety management system*'.[340]

The scope of the 2020 review examined:[341]

- Whether CS Energy's Plant Modifications Procedure '*is aligned to industry best practice*'.
- Whether CS Energy's Plant Modifications Procedure '*follow[s] the full modification process*', including in the context of their initiation and risk assessments.

This review identified the Plant Modifications Procedure was appropriate for the industry, and that its framework and process were mature. This statement is made in the 'Summary of findings' of the

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335 When checked the following year, it was confirmed that the procedure had been updated. The action to provide modifications systems training was yet to be performed for operators. Engineers and maintenance had received training. Audit Actions Implementation Progress Report (21 March 2017) *Plant Modifications Review,* CSE.001.081.5556.

336 The review included '*discussions with key participants at each site and the Brisbane office*'.

337 Report (21 March 2017) *Plant Modifications Review,* CSE.001.081.5556.

338 Excel Spreadsheet (2017) *Plant Modifications Review – Verification of Completed Actions Spreadsheet*, CSE.001.081.5555.

339 CS Energy (2021) *Plant Modifications Review 2020.01*, CSE.001.226.0134. This review was carried out by GHD.

340 CS Energy (2021) *Plant Modifications Review 2020.01*, 3, CSE.001.226.0134.

341 CS Energy (2021) *Plant Modifications Review 2020.01*, 3-4, CSE.001.226.0134. The review's scope excluded an assessment of whether completed plant modifications were free from defects. It also excluded an audit of whether risk assessments were complete and reasonable.

review, but does not include any further reasoning for the basis of this statement, nor is it included in the report's express findings. The statement is written to frame the detailed findings that follow, namely, that the procedures were not always followed in practice.

Three key findings of the 2020 review were as follows:[342]

- *'Risk assessments were not always adequately completed'*.
- *'Modifications were carried out with partial or non-compliance to the process'*.
- *'Project commissions were completed that had not followed the plant modification process'*.

These three findings were risk assessed as moderate, and coloured yellow under CS Energy's risk matrix.[343] Each of these findings is now examined in turn.

Finding 2021.01.01 – Risk assessments not always adequately completed

The detailed findings discuss the underlying causes for why risk assessments were not always completed. Quoting from those findings:[344]

- '*…there is varying clarity on the scope of the risk assessments and that there were varying skill levels observed*'. (This is a repeat concern from the 2016 plant modifications review).
- The Plant Modifications Procedure requires a hazard and operability (HAZOP) study – an advanced methodology to identify risks – be initiated on all proposed high and significant risk modifications. The review found that despite this being part of the procedure, this *'requirement is not well understood by some outside of Engineering'*.[345]

CS Energy identified three actions in response:[346]

- '*Develop a risk assessment template specifically for modifications based on 'Safety in Design' principles'*.
- *'Update the procedure (CS-AM-010) to reference the new template'*.
- *'Communicate the updated risk assessment process to all Engineering Teams'*.

No evidence has been sighted that these actions were completed by the time of the incident.[347]

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[342] CS Energy (2021) Plant Modifications Review 2020.01, 5, CSE.001.226.0134.

[343] The use of CS Energy's risk matrix for the assessment of process safety risks is flawed. The assessment relies on calculating the risk based on likelihood and consequence. Process safety related risks, however, should be assessed on potential consequence alone. Process safety risks are rare, and combining a rare likelihood with a severe or catastrophic outcome will produce a low or moderate risk on the CS Energy risk matrix. By contrast, for example, personal safety risks that have a 'possible' likelihood and a major consequence will be rated as significant.

[344] CS Energy (2021) *Plant Modifications Review 2020.01*, 6, CSE.001.226.0134.

[345] This comment was based on the outcome of interviews conducted by GHD and a review of six sample risk assessments also conducted by GHD.

[346] CS Energy (2021) *Plant Modifications Review 2020.01*, 6, CSE.001.226.0134

[347] These actions were closed in November 2022, with the last status comment from June 2022 noting '*changes to CS-AM-010 have been submitted for tech check. This action is very close to completion. Procedure and risk assessment template updated and registered'*. Extract Assurance database (2024) *2021.01 Plant Mods Review*, CSE.001.268.0003.

Finding 2021.01.02 – Modifications partially compliant or non-compliant to process

The detailed findings discuss underlying causes that relate to why the Plant Modifications Procedure was not always complied with. Quoting from those findings:[348]

- *'The level of understanding and awareness of the Plant Modifications requirements outside of the Engineering department is limited'.*
- *'Adherence to the process often relies on the drive of people in the Engineering teams and it does not appear to be a cultural norm yet'.*
- *'There is a perception from some in the site Maintenance teams that the plant modification process is too hard to follow and that it is too difficult to locate the forms and engage with the right people in the Engineering teams. This is concerning given CSE's aging plant and its large occurrence of obsolete components'.*

The causes given for these findings were:[349]

- *'Lack of understanding of the risks associated with not following the process'.*
- *'Perception that the process is too hard to follow'.*
- *'There are no 'consequences' associated with not following the process'.*

CS Energy identified five actions in response:[350]

- '*Finalise development of the plant modification system in J5'.*[351]
- *'Develop training materials and register in the LMS'.*[352]
- *'Test and implement J5 at all sites'.*
- *'Ensure training matrix in the LMS includes the plant modifications training for relevant roles: - General Awareness to Maintenance & Operations – Modification Officer to all Engineering & project management staff'.*
- *'Ensure appropriate training has been completed – method of delivery (classroom-based or online) to be determined by Site Leadership Teams'.*

No evidence has been sighted that these actions were completed by the time of the incident.[353]

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[348] CS Energy (2021) *Plant Modifications Review 2020.01*, 7, CSE.001.226.0134.

[349] CS Energy (2021) *Plant Modifications Review 2020.01*, 7, CSE.001.226.0134.

[350] CS Energy (2021) *Plant Modifications Review 2020.01*, 7, CSE.001.226.0134.

[351] 'J5' is an electronic operations management system by Hexagon with various modules available.

[352] The LMS is the 'Learning Management System' used by CS Energy to manage staff training, competencies, and qualifications.

[353] The J5 electronic management of change system was developed and the action closed in June 2022. Also, the updated training package was developed and went live in September 2022. Extract Assurance database (2024) *2021.01 Plant Mods Review*, CSE.001.268.0003.

Finding 2021.01.03 – Projects commissioned that have not followed the Plant Modifications Procedure

The reviewers stated that, during interviews, it was mentioned that some projects had been commissioned and were in operation, despite the sign-off steps in the Plant Modifications Procedure not being followed.[354]

The causes given for these findings were:[355]

- '*Pressure to deliver capital works and upgrades in a timely/under budget manner*'.
- *'Plant modifications process adherence not part of project delivery performance measures'*.
- *'There are no 'consequences' associated with not following the process'*.

CS Energy identified three actions in response:[356]

- '*Project management staff to receive Modification Officer training*'.
- *'Ensure all project management staff have plant modification system compliance as a measure in their IAPs'*.[357]
- *'Failure to follow the processes will be managed under fair and just processes'*.

No evidence has been sighted that these actions were completed at the time of the incident.[358]

16.3.4 Messaging of Review Findings Within CS Energy

On 26 March 2021, the 2020 Plant Modification Assurance Review was presented to the Audit and Finance Committee.[359] The report written for the committee painted a positive review of the findings, highlighting the overarching statement that CS Energy's procedures are '*quite mature and represents sound engineering practice*'. Only limited attention was given to the negative findings, which were classified with a risk rating of '*moderate*', see Figure 140.[360]

[354] CS Energy (2021) *Plant Modifications Review 2020.01*, 9, CSE.001.226.0134.

[355] CS Energy (2021) *Plant Modifications Review 2020.01*, 9, CSE.001.226.0134.

[356] CS Energy (2021) *Plant Modifications Review 2020.01*, 9, CSE.001.226.0134.

[357] An 'IAP' is an Individual Achievement Plan, which CS Energy uses to manage staff performance in their role.

[358] The action was closed upon confirmation that all staff received the training by June 2022. Extract Assurance database (2024) *2021.01 Plant Mods Review*, CSE.001.268.0003.

[359] Audit and Finance Committee Paper (26 March 2021) *Executive Summary Assurance*, 2, CSE.001.082.0714. Around the same time, on 21 January 2021, but apparently unconnected, a Category 4 Incident Review from May 2020 is presented to the Safety and Performance Committee in relation to the Callide C3 A Expansion Joint Failure. A corrective action from this incident included the delivery of the management of change improvement plan that emerged from the December 2020 Plant Modification Assurance Review. This was in response to a key learning that '*Adherence to the management of change process for plant modifications continues to be a high focus for the management team'*. A specific action included the creation and communication of a risk assessment guide specific to technical change management (i.e., plant modification).

[360] Audit and Finance Committee Paper (26 March 2021) Executive Summary Assurance, 6, CSE.001.082.0714.

Plant Modifications Review (2021.01)

A review of CSE's plant modification process was performed by GHD.

The review observed that several initiatives in 2020 created a renewed focus on the management of plant modifications, including an update of the Plant Modifications Procedure (CS-AM-010), the introduction of a self-assurance check process and a focus on closing out historical issues.

Overall, it was found that the intent of the plant modifications process is completely appropriate for this industry and when compared to other power generation companies, the framework and process is quite mature and represents sound engineering practice.

Notwithstanding this, three Moderate-rated findings were identified. An Executive Summary can be found in **Attachment 2** with the full report including managements response included in **Attachment 3.**

Assurance has completed the summary report for the **Continuous Assurance Program for Health and Safety and Environment** (2021.07). These reports can be found in **Attachment 4** and **Attachment 5**.

Figure 140 Extract from Plant Modification Assurance Review

The review merely notes that '*three moderate-rated findings were identified*' but does not identify them.

The Committee minutes are also positive, focusing on the maturity of the systems and processes, as well as noting that one-third of Callide's outstanding modifications (i.e., the issues identified back in 2016) have been closed out, see Figure 141.[361]

[redacted] noted that GHD performed the Plant Modification Review which resulted in three moderate findings and confirmed that CS Energy's processes are in line with good industry practice.

[redacted] detailed to the Committee:

- That the review found that CS Energy's framework and process is quite mature and represents sound engineering practice.
- That improvements are being actioned and noted that one third of Callide Power Station modifications have now been closed out.
- That CS Energy now has one process for plant modifications across the company (reduced from 3 procedures).

The Committee queried the process for updating plant drawings. Management confirmed that each site has a contract resource to assist with the drawing process including any backlog.

Figure 141 Extract from Audit and Finance Committee minutes (26 March 2021)

16.3.5 How Plant Modifications Are Managed in *Insight*

Insight is CS Energy's enterprise risk management system. One of the risks tracked in *Insight* is the risk of plant modifications that do not follow organisational procedures.

[361] Minutes (26 March 2021) Meeting of the Audit and Finance Committee, 3, CSE.001.023.8892.

Prior to the 2020 Plant Modification Assurance Review, this risk was rated as 'significant' (orange). This is shown in the Residual Risk Level (Pre-review) column in Figure 142 below.

1.4 Key Risks

The following risk event and controls have been identified as part of this review:

Risk	Controls	Inherent Risk Level	Residual Risk Level (Pre-Review)	Residual Risk Level (Post-Review)
Plant Modification undertaken that has the potential to cause harm or equipment damage	• Plant Modifications training module in the LMS • CS-AM-010 Plant Modifications Procedure being followed • Self-assurance checklist • Site modification registers/ database • All technical requirements implemented into the various CSE systems • Adequate and relevant plant modification impact risk assessment carried out	High	Significant	Moderate

MoC is a key control in the Technical Risk Management area of CSE's Process Safety Framework.

Figure 142 Extract Plant Modification Assurance Review 2020

As part of the review, this rating was reconsidered and was changed from 'significant' to 'moderate', based on the risk and controls identified in the review. This is shown in the Residual Risk Level (Post-review) column in Figure 142 above.

The controls relied upon to reduce this risk to moderate are listed in the second column in Figure 142 above. These controls include – '*CS-AM-010 – Plant Modifications Procedure being followed*' and '*Adequate and relevant plant modification impact risk assessments carried out*'.

This 'moderate' rating is applied even though the review itself raised issues regarding compliance with the Plant Modifications Procedure, and the issue that risk assessments were not always adequate and relevant. The residual risk rating of 'moderate', therefore, assumes that the actions emerging from the review were both completed and effective to overcome the findings.

16.3.6 Summary of Management of Change

The Plant Modification Assurance Review identified a substantive and long-term issue with the effectiveness of the Plant Modifications Procedure.

CS Energy's actions in response to the findings were largely focused on treating the symptoms (as opposed to the cause) of the issue, such as focusing on catch-up work for the backlog, training, and updating procedures.

CS Energy's actions did not focus on addressing the underlying causes of these issues. Instead, a high degree of confidence appears to have been placed in the systems and procedures relating to plant modifications.

The upward reporting of this issue to the board was minimised. The substantive question of whether the Plant Modifications Procedure was effective remained unresolved.

16.4 Maintenance Work Management Review 2019

The Work Management Manual is the procedure CS Energy uses to identify, request, execute and manage work on its assets.[362]

The Maintenance Work Management Review was completed in 2019.[363] The focus of the review was to provide assurance that non-outage-related maintenance work was performed in a timely, safe, and efficient manner.[364]

The key review findings stated that:

- Backlog maintenance exceeds approved limits across all sites. A specific warning was made that '*continuously operating at the current backlog levels increases the risk to the business that sites will experience increased asset failures leading to CSE being unable to achieve its plant availability targets*'.
- Statutory maintenance also suffered backlogs. In the detailed findings on this issue, the observation was made that '*limited use of formal risk assessment processes was also observed for statutory PM changes or overdue statutory PMs resulting in Plant Engineering not being aware of the lack of compliance of safety critical assets*'.
- '*CS Energy's Work Management Manual was inconsistent with industry best practice*' and '*there had been no formal training of work management staff or competency assessment, no work packs being used to undertake maintenance, and little or no quality assurance of maintenance execution*'.

CS Energy's actions agreed upon in response to these findings were to:

- *'Reduce the statutory maintenance backlog'*.
- *'Take a prioritised approach to reducing maintenance backlog'*.
- *'Update the work management manual'* and *'communicate the updated work management manual'*.

The maintenance backlog issue was the subject of a separate presentation to the CS Energy board, dated 31 January 2019, which discussed a substantive process to address this issue.[365]

[362] CS Energy (2 May 2017) *CS Energy Work Management Manual, CS-MAINT-00 Ver: 4.0*, CSE.001.105.0149.

[363] CS Energy (2019) *Maintenance Work Management Review 2019.05*, CSE.001.081.2478.

[364] CS Energy (2019) *CS Energy Maintenance Work Management Review Scope of Work*, CSE.001.081.2249.

[365] PowerPoint Presentation (31 December 2019) *Update: Callide Work Management Improvement and Maintenance Risk Reduction*, CSE.001.089.6581.

The actions from the Maintenance Work Management Review 2019 were not verified at the time of the incident. The Maintenance Work Management Review 2019 was verified in 2022 (i.e., after the incident).[366] The outcomes achieved at the time of verification in 2022 were as follows:[367]

- The maintenance backlog '*had not been brought back within KPI Limits*' and was being addressed by re-prioritising the maintenance actions on a risk basis, '*ensuring all critical work is in the P1-4 range. The majority of backlogged work is now a P5*'.
- There were '*many overdue*' statutory maintenance inspections found at Callide at the date of verification. This led to Callide management deciding to address this backlog work '*as a key priority*', and to '*reinforce [the] requirement that there [will] be no overdue statutory inspections unless a risk assessment has been signed off by [the] Manager and Engineer*'. The action was re-opened so it could continue to be tracked by the Assurance team.
- The updated Work Management Manual was finalised and rolled out in April 2022 (i.e., after the incident).

In summary, the Maintenance Work Management Review 2019 identified that the maintenance backlog was an issue, and CS Energy were warned that a failure to rectify the backlog increased the risk of an asset failure. The actions taken in response to this review focused on reducing the backlog, but did not address the underlying reasons that resulted in the backlog developing. Upon review in 2022, the backlog had not been brought back within KPI limits.

16.5 Incident Management and Resolution Reviews 2016 and 2019

The Learning from Incidents Procedure is used by CS Energy '*to effectively report, notify, investigate and learn from incidents*' in a formalised manner.[368]

An audit into the effectiveness of CS Energy's incident investigations, undertaken by DuPont, first occurred in 2014–15. This 18-month review culminated in a report dated December 2015.[369]

16.5.1 2016 DuPont Review

DuPont assessed CS Energy's safety maturity against the DuPont Bradley Curve. The curve has four stages, which range from poor to more effective: Reactive, Dependent, Independent, and Interdependent.

DuPont assessed CS Energy as '*Reactive and Dependent*'. Dupont describes this level of maturity as:

> *employees see safety as a natural instinct where compliance is the goal and will do the right thing when there is supervision and consequences.*[370]

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[366] CS Energy (2022) *Maintenance Work Management Verification Review, #2019.05*, CSE.001.273.0001.

[367] This summary is based on: CS Energy (2022) *Maintenance Work Management Verification Review, #2019.05*, CSE.001.273.0001; Excel Spreadsheet (24 May 2023) *Extract Assurance (Internal Audit) Tracking Systems, Maintenance Work Management Review*, CSE.001.268.0001.

[368] CS Energy (2018) *Learning from Incidents CS-IM-01,* 4, CSE.001.246.0966.

[369] DuPont (2015) *CS Energy Incident Investigation Report*, CSE.001.081.4897.

[370] DuPont (2015) *CS Energy Incident Investigation Report*, 4, CSE.001.081.4897.

On 21 March 2016, the DuPont Review report was discussed at a meeting of the Audit and Risk Committee.[371] The Committee meeting was provided with the proposed CS Energy 'management response' to the DuPont Review report, which involved a range of training, procedural and process changes to address the issues raised in the report.[372]

On 25 November 2016, the DuPont Review report was discussed at a meeting of the People, Safety and Environment Committee. The Committee accepted the criticisms made of CS Energy as valid. The Committee also recognised that the proposed 'management response' and other recommendations to change the culture of the organisation needed to be taken seriously.[373]

16.5.2 2019 Review

In 2019, there was a subsequent review into CS Energy's Health and Safety incident management and resolution practices. It was conducted internally, and led by the Assurance team. The scope of this review was to provide:

> *assurance as to whether the health and safety and process safety incident investigations are performed in accordance with the CSE Learning from Incidents Procedure, if learnings from incidents are communicated across the business and appropriate corrective actions are developed and implemented.*[374]

In July 2019, an internal CS Energy Work Paper on the incident management and resolution review had identified a range of non-compliances, including:[375]

- *'Health and safety risks in the enterprise risk system are not reviewed following incidents …'.*
- *'Bowties/risks … are not reviewed post-incident to see which controls were absent or failed.'*
- *'Some confusion around how SAP IMD workflows are intended to work.'*
- *'Procedure refers to SAP IMD training in section 5.6, however this is no longer used.'*
- *'Action verification is limited and ad hoc'.*
- *'Only limited [lead indicator] measures have been defined … and these have not been consistently reported on.'*

In September 2019, the CS Energy incident management and resolution review found:[376]

- *'Following the DuPont Review, a number of improvements to the management of health and safety incidents at CSE were made'.*

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371 Minutes (21 March 2016) Meeting of the Audit and Risk Committee, CSE.001.023.6787.

372 Memorandum (2016) *Attachment 5 – Management Response – Effectiveness of Serious Health & Safety Incidents – ARC 21 March 2016*, CSE.001.081.4886. The Responsible Officer for all Management Responses was noted as the EGM People and Safety.

373 Minutes (25 November 2016) Meeting of the People, Safety and Environment Committee, CSE.001.023.6927.

374 CS Energy (2019) *Health and Safety Incident Management and Resolution Review, Scope of Work 2019.06,* 1, CSE.001.081.1550.

375 CS Energy (2019) *Work Paper Incident Management and Resolution Review*, CSE.001.081.1590.

376 CS Energy (2019) *Health and Safety Incident Management and Resolution Review 2019.06*, 4, CSE.001.081.1672.

- *'This review did however note further improvements are required, especially in several areas that are key to preventing a recurrence of a health and safety incident at CSE'.*

The areas for improvement identified in the September 2019 review included that CS Energy needed to:

- Improve its ability to learn from incidents.
- Perform quality assurance over its incident management processes.
- Close-out actions of incident investigations.

Specifically, in relation to process safety incident investigations, the September 2019 review found *'a lack of clarity around management of process safety incidents, including investigation methodology and incident closeout'.*

This review also found that process safety incidents were being treated in the same way as operations incidents, which presented a risk of repeat incidents, see Figure 143.

2019.06.04 Lack of clarity around managing process safety incidents	Risk Level	Moderate
Finding	**Root Cause & Risk**	**Recommendation #**
CS-IM-01 was updated on 30 October 2018 to include process safety incidents. Since then there have been three Category 3 and 4 incidents classified as Process Safety Events (PSEs): 1. IMD 8946 (SO3 plant fire at Callide) – interim investigation report available only. No final report available or green banner issued. This was reportedly due to the scene not being preserved so there was inadequate evidence to perform a root cause analysis. 2. IMD 8996 (Multiple plant modification non-compliances at Callide) – no investigation report available or green banner issued. 3. IMD 9046 (Windbox fire at Callide) – RCA methodology used, final report is available but no green banner was issued. Currently, process safety investigations appear to be treated in the same way as Operations incidents. The Process Safety Improvement Manager is aware of the lack of clarity regarding PSEs and has started assisting Plant Operations to increase the level of understanding.	Root Cause • No training or awareness has been provided on process safety incident management. • Lack of clarity and guidance regarding PSEs. Risk Repeat incidents of a similar nature occur at CSE sites.	5. Process safety 8. Update CS-IM-01
** Moderate risk rating obtained using the following logic:* *Consequence: **Catastrophic** – Safety & Security* *Likelihood: **Rare** – Less than 1% probability*		

Figure 143 Extract from September 2019 review

The action directed specifically at process safety was to provide further training. This action was recorded as completed in 2022 (i.e., after the incident).[377]

This review was included in the 29 November 2019 Audit and Finance Committee Meeting, the minutes of which were included in the January 2020 Board Papers.[378]

16.5.3 Summary

The 2016 and 2019 assurance reviews of CS Energy's incident management systems revealed fundamental issues with CS Energy's system to learn from process safety incidents. Chapter 17 *Process*

[377] Extract Assurance Database (2024*) H&S incident Management and Resolution Review,* Worksheet: 2019.06.04, CSE.001.268.0002.

[378] Minutes (29 November 2019) Meeting of the Audit and Finance Committee, 4, CSE.001.023.7664.

Safety – Learning from Incidents examines the effectiveness of CS Energy's learning from incidents system in more detail.

16.6 Permit to Work Reviews

The Permit to Work (PTW) system is used by CS Energy to provide all workers safe access to plant and equipment and is implemented at all CS Energy's sites.

16.6.1 2015 DuPont Review

In 2015, DuPont conducted a review into CS Energy's incident investigation effectiveness. This review identified incidents in relation to isolation and permit to work.[379] When this review was tabled at the People, Safety and Environment Committee in November 2016, the Committee Chair noted that the PTW system was cumbersome and an area of concern.[380]

The CS Energy EGM Operations' response was that:

> *there is nothing particularly wrong with the system, however the way it is being applied could be improved. There is a lot of bureaucracy and paperwork that is designed to ensure compliance rather than keep people safe. In addition, there are instances where people have chosen to work outside the system, in which case there are no protections.*

The CEO at the time challenged the EGM Operations '*to review the system and its application*' and the Committee noted that the '*criticisms included [in the DuPont review] are valid, and that the recommendations should be taken seriously*.'[381]

16.6.2 2017 O&M Review

In June 2017, O&M Management Consulting conducted a Permit to Work Review.[382] The significant findings of the review, in summary, included:

- The Work Clearance Documents contained known errors, increasing the likelihood of an incident because of a low level of confidence that changes to the power station would be reflected in the templates.
- Management of PTWs during outages need to be better managed to prevent delays.
- There was a large backlog of plant label changes to be made. The findings comment that '*accuracy of plant labels … is critical to safe isolation of plant*'.

[379] DuPont (2015) *CS Energy Incident Investigation Report*, 9, CSE.001.081.4897.

[380] Minutes (25 November 2016) Meeting of the People, Safety and Environment Committee, 5, CSE.001.023.6927.

[381] Minutes (25 November 2016) Meeting of the People, Safety and Environment Committee, 5, CSE.001.023.6927.

[382] O&M Management Consulting (19 June 2017) *Permit to Work Review (2017.04),* CSE.001.081.4432.

16.6.3 2018 Verification Report

In July 2018, an internal verification report of the actions from the 2017 O&M Review was issued.[383] It found that actions were still to be completed, noting the absence of the CS Energy PTW Administrator.[384]

This report was included in the Audit and Risk Committee Papers in July 2018, and the minutes record there was discussion of the outstanding actions, including unavailability of key personnel, such as the PTW Administrator.[385] The minutes state that:

> *Now that the Head of Plant Operations Services is back in [their] role and a PTW Systems Manager has been appointed on a 2-year fixed term contract the system will be simplified, improvements made (with an upgrade due by the end of 2019), and training undertaken.*

On 26 July 2018, this report was raised in the Reliability and Plant Performance Committee Meeting. The minutes record that the committee queried how the corporate PTW Administrator role could be sidelined for nine months, and noted that the PTW system is a focus area and is required to be running on a new platform by the end of 2019.[386]

16.7 Actions Related to Process Safety at CS Energy

The Brady Heywood investigation examined reviews undertaken on four systems critical for process safety:

- Plant Modifications Review.
- Maintenance Work Management Review.
- Health and Safety Incident Management and Resolution Review.
- Permit to Work Review.

The actions taken by CS Energy in response to these reviews were categorised according to the type of action taken (e.g., training, communication document update) and then categorised as either:

- Addressing Symptoms: Actions that treated the symptoms of the issue (e.g., undertaking catch-up work).
- Addressing Causes: Actions that were designed to identify and/or treat the underlying root causes of the issue.

Of the 64 actions reviewed, 53 (~83%) treated the symptoms of the issue, and 11 (~17%) attempted to address underlying root causes. Most of the actions, therefore, did not address systemic issues relating to systems that were critical for process safety.

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[383] CS Energy (2018) *Permit to Work Verification Report*, 2-3, CSE.001.081.4499.

[384] The CS Energy PTW Administrator is authorised by the Executive General Manager Operations to manage the CS Energy PTW system and to provide feedback on incidents, audits, and issues.

[385] Audit and Risk Committee Paper (30 July 2018) *Executive Summary Assurance*, CSE.001.081.8180; Minutes (30 July 2018) Meeting of the Audit and Risk Committee, 5, CSE.001.023.7151.

[386] Minutes (26 July 2018) Meeting of the Reliability and Plant Performance Committee, 3, CSE.001.023.7306.

16.8 Chapter Summary

In the years leading up to the incident, there were reviews of how CS Energy managed change, how it conducted maintenance work, how it responded to and learned from incidents, and how effective its PTW systems were. These are all key systems needed for the effective management of process safety.

Substantive and longstanding issues were identified with each of these systems. The majority of CS Energy's agreed actions in response to these issues tended to address the symptoms and rarely addressed the underlying causes.

In particular, the reviews into how CS Energy conducted management of change (i.e., the Plant Modifications Procedure) identified substantive and long-term issues with the effectiveness of this system. These issues are consistent with those identified in both the Unit C4 battery charger project, and the decision-making surrounding the Unit C4 automatic changeover switch being inoperable.

The next chapter presents a more detailed analysis of the effectiveness of CS Energy's learning from incidents system.

17 PROCESS SAFETY – LEARNING FROM INCIDENTS

17.1 Introduction

Organisational learning is a key part of ensuring the robustness of process safety systems and controls. CS Energy has a formal process for this called the Learning from Incidents Procedure.[387] This chapter explores the effectiveness of CS Energy's processes to learn from incidents that occurred at Callide power station.[388]

In the two-and-a-half-year period leading up to the May 2021 incident, only four process safety incident investigations resulted in both technical and systemic organisational learning. This left CS Energy with a learning from incidents system that provided limited insight into the effectiveness of its process safety systems. Further, pre-cursor events that had technical similarities to elements of the incident in May 2021 had occurred throughout CS Energy's history.

17.2 Purpose of Learning from Incidents

The purpose of a learning from incidents process is to gather and analyse information that assists an organisation to understand how their controls and safety systems are performing in practice. Such learnings provide opportunities to address system deficiencies within the organisation before a major incident occurs.

An effective learning from incidents process requires the following:

(a) Conducting an investigation: An investigation following an incident allows the organisation to understand both the immediate technical causes and the systemic organisational causes of the incident (e.g., systems such as management of change, Permit to Work, and risk assessment).[389] These learnings must then be shared throughout the organisation.

(b) Implementing improvements: The improvements need to address both the immediate technical and systemic organisational causes. These improvements must then be verified to ensure they have been implemented effectively and remain in place.

Effective learning also involves sharing practices and controls that have worked successfully. This increases knowledge of these controls and practices within the organisation.

[387] The Learning from Incidents Procedure was updated on 23 October 2018, and again on 4 February 2021. The version of the procedure in place for most of the period prior to the incident on 25 May 2021 was Rev 5 (in place between 23 October 2018 and 4 February 2021): CS Energy (2018) *Learning from Incidents CS-IM-01,* CSE.001.246.0966.

[388] Callide includes both Callide B and Callide C. The effectiveness of the learning from incidents process at other sites (e.g., Kogan and Wivenhoe) was not assessed.

[389] If an organisation only focuses on understanding and addressing the technical causes of an incident, they increase the likelihood of preventing that particular incident (or very similar incidents) in the future. However, by understanding and addressing the systemic organisational issues related to the incident (in addition to the immediate technical causes), the organisation can improve its key systems that prevent a range of potential incidents.

17.3 Learning Achieved at Callide

17.3.1 Process Safety Incident Reporting

In October 2018, process safety incident reporting was introduced at CS Energy. In the approximate two-and-a-half-year period from October 2018 until the incident in May 2021, there were 776 incidents entered in the incident reporting system (in SAP) at the Callide site.[390]

Table 1 shows the breakdown of reported incidents at Callide by their primary incident type.[391]

Table 1 All incidents reported at Callide (October 2018 to May 2021)

Incident Type	***Number of Incidents Reported***	***% of Total Incident Reports***
Process Safety (PSE)	30	4%
Health and Safety (H&S)	513	66%
Operations (OPS)	184	24%
Environmental (ENV)	47	6%
Security (SEC)	2	0.3%
TOTAL	776	

A total of 30 (~4%) of the incidents reported had a primary incident type of Process Safety.[392] By contrast, there were 17 times more Health and Safety incidents, and six times more Operations incidents. This means there were significantly less learning opportunities from process safety incidents when compared with other incident types.

17.3.2 Process Safety Incident Investigations

Under CS Energy's Learning from Incidents Procedure, when an incident is reported it is assigned an incident category between 1 and 4. Category 1 incidents are the least significant, while Category 4 incidents are the most significant.[393]

[390] These are incidents with an event date between 23 October 2018 and 24 May 2021. This was the date range used for all incident data analysis in this section, unless otherwise stated. SAP was the software package used for reporting and managing incidents at CS Energy.

[391] Incident type refers to the 'log entry type' recorded in SAP. Log entry type AUD (Audit) and HAZ (Hazard) have not been included as these do not differentiate between Process Safety and other incident types (e.g., Environmental or Operations). All incident data analysis was done using SAP data extracts. Extract SAP Incident Database (2024) *01.01.2018-31.12.2018 Incidents*, CSE.001.260.0001; Extract SAP Incident Database (2024) *01.01.2019-25.05.2021 Incidents*, CSE.001.260.0002. Data analysis was completed in Power BI.

While not primarily process safety events (PSEs), incidents with a different incident type (e.g., OPS or H&S) can have process safety as an additional impact. The learnings from these events, which were classified as Category 2, 3 or 4 incidents, were also analysed. There was minimal learning about systemic organisational issues and improvements to organisational systems from these events.

[392] Incidents where the log entry type is 'PSE' in SAP.

[393] CS Energy (2018) *Learning from Incidents CS-IM-01,* CSE.001.246.0966.

Of the 30 process safety incidents reported, the following incident categories were assigned, see Table 2.

Table 2 Process safety incidents by incident category

Incident Category Assigned	***Number of Incidents Reported***	***% of Total Incident Reports***
Category 4 High	1	3%
Category 3 Significant	5	17%
Category 2 Moderate	7	23%
Category 1 Low	17	57%
TOTAL	30	

The majority of process safety incidents reported were Category 1 or 2 (~80%). Only six process safety incidents were Category 3 or 4.

The Learning from Incidents Procedure states that Category 1 incidents only require a SAP record or a '5 Why investigation', while Category 2 incidents must have a 5 Why investigation.[394] The 5 Why investigation method is often simplistic, and is unlikely to result in systemic organisational learnings and improvements.[395] This method is often only appropriate for less complex incidents that do not have the potential for catastrophic outcomes.

Category 3 and 4 process safety incidents require a more detailed method of investigation as per the Learning from Incidents Procedure. The primary investigation methodology for significant Process Safety Events (PSEs) was 'Learning Teams'.[396] This method involves a facilitated discussion with a cross-section of personnel who were involved in the incident (or who have expertise in that type of work) to learn and improve from when the work has '*gone well or when things have gone wrong*'.[397] This can be an effective method to drive organisational system learnings and improvement.[398] No evidence has been sighted that the Learning Teams method was used for any process safety incident investigations.

There is evidence of CS Energy using the 'ICAM' method for process safety incidents. The ICAM method involves assessing the Absent/Failed Defences, Individual/Team Actions, Task/Environmental

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[394] Only Category 2 incidents, which were categorised as 'Tier 2 Process Safety Events' (PSEs), required a Learning Team. Other Category 2 incidents required a 5 Why investigation (at minimum): CS Energy (2018) *Learning from Incidents CS-IM-01*, 10, CSE.001.246.0966.

[395] The 5 Why technique is a structured question-asking technique used to identify a potential root cause of an event. The technique involves repeatedly asking the question, 'Why?', until a root cause is identified. One limitation of its use is that it forces users down a single analytical pathway, which can result in only a single root cause being identified. The CS Energy Learning from Incidents Procedure defines 5 Why investigations as *'a simple process to highlight probable causes of an incident.'*: CS Energy (2018) *Learning from Incidents CS-IM-019*, CSE.001.246.0966

[396] A Learning Team was required for PSEs which were 'Tier 1 or 2 Loss of Containment Events': CS Energy (2018) *Learning from Incidents CS-IM-01*, CSE.001.246.0966.

[397] CS Energy (2018) *Learning from Incidents CS-IM-01*, 9, CSE.001.246.0966.

[398] Learning Teams are also an effective method to build an organisation's 'sensitivity to operations'.

Conditions, and Organisational Factors relevant to the incident. When done effectively, ICAM investigations can result in a detailed understanding of how organisational systems failed to prevent an incident, and how improvements can be made to these systems to avoid incidents occurring in the future.

17.3.3 Effectiveness of Learning and Improvement

The level of learning and improvement from process safety incidents at the Callide site, between October 2018 and May 2021, is shown in Figure 144.[399]

[399] This assessment includes incidents where the log entry type is 'PSE' in SAP with an incident date between 23 October 2018 and 24 May 2021. The level of learning achieved was determined through analysis of the incident investigation reports and resulting actions.

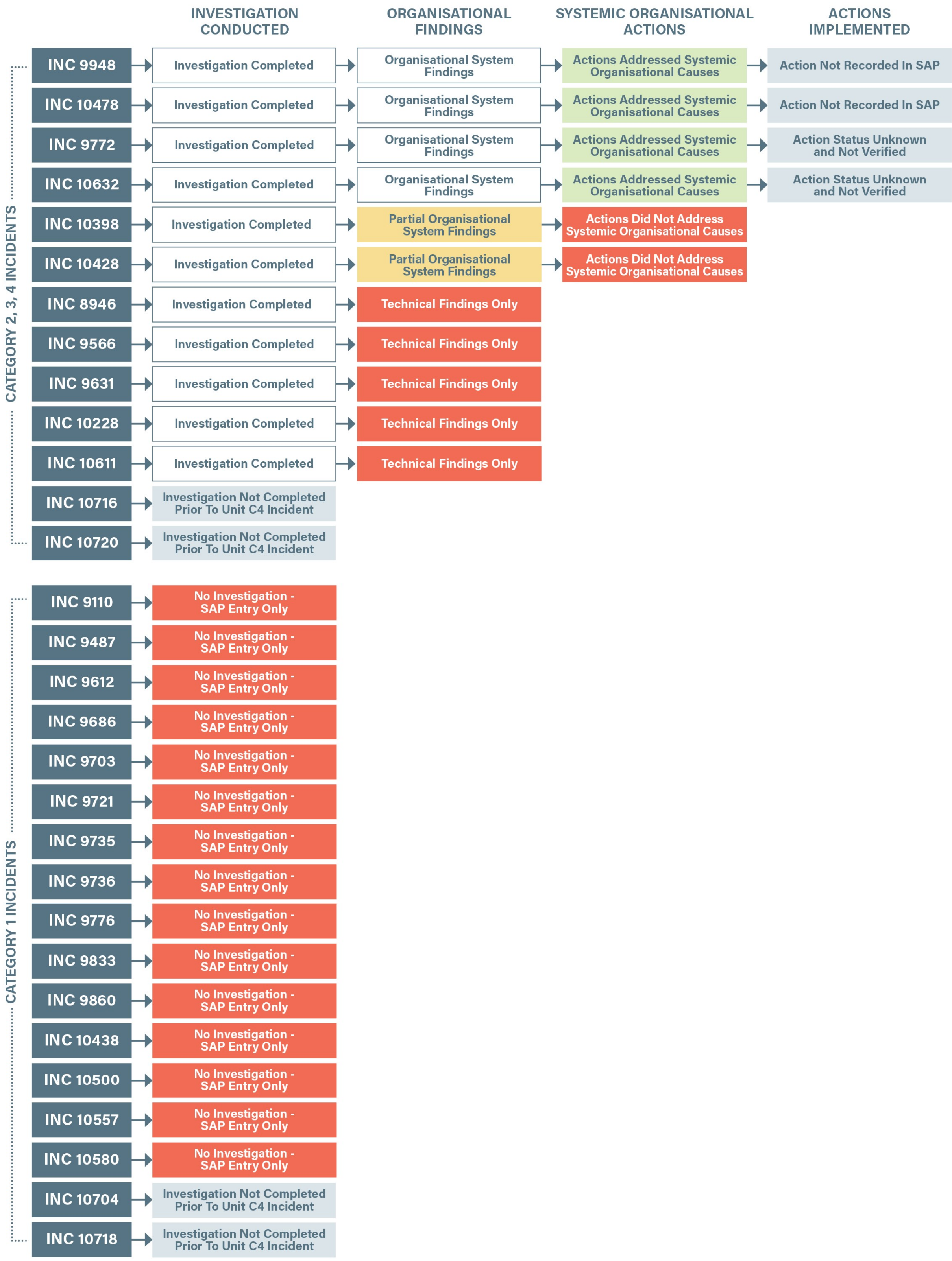

Figure 144 Effectiveness of learning achieved from process safety incidents at the Callide site

As seen in Figure 144 above, the following learning and improvement was achieved from process safety incidents at the Callide site:[400]

- Four process safety incidents resulted in an understanding of both the technical and systemic organisational causes of the incident, and produced actions which aimed to improve those organisational systems. However, no evidence has been sighted that these actions were completed and verified prior to the 25 May 2021 incident.[401]
- Two process safety incidents resulted in a partial understanding of both the technical and systemic organisational causes of the incident. However, these investigations did not produce actions that aimed to improve those organisational systems.[402]
- Five process safety incidents resulted in an understanding of only the immediate technical causes of the event, and there were no findings related to systemic organisational causes.[403]
- 17 process safety incidents were categorised as Category 1 incidents. No evidence has been sighted that any formal investigation (5 Why, ICAM, Learning Teams, or Root Cause Analysis) was conducted for these incidents.[404]

Therefore, across a two-and-a-half-year period, there was very limited learning and improvement related to systemic organisational issues as a result of process safety incidents at the Callide site.[405]

17.3.4 Effective Learnings

When effective learning regarding organisational systems did occur from process safety incidents, the incident investigations conducted by CS Energy resulted in the following findings:

- Two incidents related to a need to improve the management of change process and increase adherence to the process.[406] These improvements included a need to implement hold points

[400] Only investigations which were completed prior to the 25 May 2021 incident were assessed.

[401] The four incidents are numbered: 9772, 10632, 9948, 10478. For Incident 9772 and Incident 10632, the status of the associated actions was unknown by CS Energy, and CS Energy was '*unable to verify*' if the actions had been completed. For Incident 9948 and Incident 10478, the actions related to improvement of systemic organisational issues identified in the investigations were not recorded in SAP. Excel Spreadsheet (22 March 2024) *Cat 2-4 evidence to actions & Cat 1 Investigations,* Worksheet: Cat 2-4, CSE.001.266.0001. The associated actions from Incident 9948, relating to improving the plant modification process, were recorded in *Insight*. However, they were not closed until 2022: Excel Spreadsheet (2024) *2021.01 Plant Mods Review*, Worksheet: Plant Mods Summary, CSE.001.268.0003.

[402] Incidents 10398 and 10428.

[403] Incidents 8946, 9566, 9631, 10228, 10611.

[404] For 15 of these incidents, the investigation type was listed as '*SAP entry only*'. The other two incidents appeared to receive an investigation. However, the investigations were still being conducted and actioned at the time of the 25 May 2021 incident: Excel Spreadsheet (22 March 2024) *Cat 2-4 evidence to actions & Cat 1 Investigations,* Worksheet: Cat 1 events, CSE.001.266.0001.

[405] There were other events that did not have a log entry type of PSE. While not primarily process safety events, incidents with a different incident type (e.g., OPS or H&S) can have process safety as an additional impact. The learnings from these events, which were classified as Category 2, 3 or 4 incidents, were also analysed. There was minimal learning about systemic organisational issues and improvements to organisational systems from these events.

[406] Incident 9948. PowerPoint Presentation (1 January 2021) *Callide C 3A Mill Expansion Joint Failure*, CSE.001.082.1396; Incident 10632: Incident Investigation Report, *CB0 B Air dryer - Incident Report - Cat 1 Cat 2 (11 19) - CS Energy V2 30.7.21.* CSE.001.273.0108.

in the process to ensure that modifications were not completed until the technical and support requirements had been met, and authorisations were in place.

- One incident related to a need to improve organisational learning from incidents. Specifically, the finding highlighted the need for an incident investigation to assess the risk of similar events occurring (e.g., whether a similar incident could occur on a different unit).[407] This would allow actions from an investigation to be implemented in a timely manner to manage this risk.
- One incident related to a need to increase operator capability to respond to emergency or abnormal scenarios, as well as the possible implementation of a training simulator.[408]

17.3.5 Assurance of Learning from Incidents Process

As discussed in Section 16.5, assurance reviews were undertaken to assess the effectiveness of CS Energy's Learning from Incidents process.

The Brady Heywood investigation analysis presented in this chapter identifies some of the same issues raised in these assurance reviews. These included:[409]

- Incident investigation process requirements were not consistently followed.
- There was limited verification of actions resulting from incident investigations.

However, the assurance reviews did not focus on the nature of investigation findings, nor the improvements which resulted from process safety incidents.[410] Instead, these assurance reviews focused on compliance to the Learning from Incidents Procedure.

17.4 Reasons for Limited Effective Learning and Improvement

The limited level of effective learning and improvement from process safety incidents at Callide was likely the result of several factors. These are explored below.

17.4.1 Poor Fundamental Basis

CS Energy did not have the fundamental basis for an effective learning from incidents system, namely, a thorough understanding of the major accident hazards and the controls to prevent and mitigate them. This meant that the success of the learning from incidents process was likely limited from the outset. The prevention of major incidents relies on an understanding of the causes and consequences of each major accident hazard, the controls that prevent or mitigate these causes and consequences, and the required level of performance of each control to ensure reliability.

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[407] Incident 10478: Incident Investigation Report (25 January 2021) *FOR REVIEW – Incident Report – Cat 1 – IMD 10478 – Callide B2 Boiler Damper Failure*, CSE.001.273.0091.

[408] Incident 9772: Significant Incident Report (14 April 2020) *Significant Incident Report Callide B, Unit 1 Boiler Furnace Pressure Excursion*, CSE.001.273.0243.

[409] CS Energy (2019) *Health and Safety Incident Management and Resolution Review*, CSE.001.081.1672.

[410] The objectives and scope of the 2019 Health and Safety Incident Management and Resolution Review state that the review did not '*provide assurance that the incident register is complete and incident actions are relevant and appropriate.*' CS Energy (2019) *Health and Safety Incident Management and Resolution Review*, CSE.001.081.1672.

This understanding is essential to identify the warning signs that these controls (and the organisational systems which support them) are weakening. By not completing and implementing an effective bowtie program, as per the Critical Risk Program discussed in Chapter 15 *Process Safety – Critical Risk Program*, this limited the site's risk competence.

With no formal method to clearly define what constituted warning signs for each risk, it would be difficult to create a systematic method to identify and escalate these within the organisation. This meant CS Energy was reliant on (and limited by) individual personnel's existing risk competency.

Without having completed bowties for the Callide site, it is likely that important process safety-related warning signs were neither recognised nor reported. In the cases where these warning signs were reported, they may have not been categorised at a high enough level to drive detailed investigation.

17.4.2 Focus on Limited Types of Incidents

The number of effective learning opportunities was also limited because of a narrow focus on the types of incidents that received detailed investigation.

Majority of effective learning occurred from actual incidents

The majority of learning from process safety incidents resulted from those with an actual negative outcome, see Table 3.

Table 3 Actual outcome of process safety events which resulted in organisational learning

Incident Number	***Incident Category***	***Summary***[411]	***Was there an actual consequence****?*	***What was the actual consequence****?*[412]
9948	4	3 A mill PA expansion	YES	Minimal plant damage
9772	3	Unit 1 'A' ID fan control damper failed and closed to 9%	YES	Unit output loss of approximately 700 MWH, damage < $5,000
10478	3	CB2 boiler damper failure	YES	Minor flame damage to wiring on the furnace ash conveyor
10398	2	Fire in 3A PF Mill Feeder	YES	Fire damage
10428	2	Ash reclaim water tanks were overflowing	YES	Visible loss of containment from ash reclaim tank onto road
10632	2	Callide B 'B' Compressor dryer not isolated under PTW	NO	No actual consequence

Of the six process safety incidents that resulted in effective or partially effective organisational learning, five of these incidents had an actual consequence (i.e., a visible and tangible result, such as equipment damage or an outage).

However, for every incident where a negative consequence actually eventuated, it would generally be expected that there are many more near-miss events. Near-miss events can provide significant learning potential because they indicate weaknesses in critical process safety systems and controls.[413] This can provide opportunities to improve these systems and controls before an incident actually occurs. This is particularly important in process safety, given situations where an actual negative consequence eventuates are infrequent.

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[411] The summary is the 'Event' field for the incident in SAP.

[412] The actual consequence of the event was determined by reading the relevant investigation report.

[413] The focus of detailed investigations on events with an actual consequence is consistent with the Incident Category Matrix included in the *Learning from Incidents Procedure*. In the matrix, Category 1 PSEs are defined as near-misses where the safety system has been challenged (including safe operating limit excursions, safety critical equipment failures/faults, activations of process safety protecting devices, and errors/gaps in process safety management system requirements). Given that Category 1 PSEs only required a SAP entry or 5 Why investigation, the incident matrix was not driving detailed investigation into high *potential* consequence, but low (or no) *actual* consequence, events.

Comparatively, Category 3 and 4 PSEs (which required more detailed investigation) were defined in the Incident Category Matrix as events with an unplanned or uncontrolled release of material or energy which resulted in a consequence (including a LTI, hospital admission, officially declared community evacuation, fire or explosion resulting in a direct cost to the company >$25,000). These are all events where a negative actual consequence occurred. Therefore, the Incident Category Matrix likely contributed to a focus on learning from events with an actual negative outcome, rather than near-miss events. CS Energy (2018) *Learning from Incidents CS-IM-01,* 22-23, CSE.001.246.0966.

Majority of effective learning occurred from mechanical incidents

The process safety incidents that were effectively investigated (as shown in Table 3 above), also indicate a focus on learning from events that were mechanical, as opposed to electrical, in nature.

Of the six process safety incidents that resulted in effective, or partially effective, learning and improvement of organisational systems, five were mechanical in nature. The other incident was related to electrical risk. However, the event involved a failure to isolate live equipment, creating a personal exposure risk, rather than the risk of a major electrical system failure.

17.4.3 Warning Signs Were Lost in Other Systems

CS Energy had other potential sources of warning signs regarding the effectiveness of process safety systems and controls that were not reported as incidents.

Between October 2018 and the 25 May 2021 incident, there were over 5,000 log entries in the J5 operator log at the Callide site that resulted in a request for work.[414] It is highly likely that some of these log entries were events with opportunities to learn about organisational system weaknesses. However, no evidence has been sighted that organisational learnings were achieved from these events.[415]

Further, there were cases where events were either only recorded in emails, or directly addressed as work orders, without being reported as incidents. When events are not entered into the incident reporting system, they are not systematically assessed to determine their potential consequence, nor do they receive formal investigation. This reduces the ability to effectively learn from them.

17.5 Pre-Cursor Events

As well as examining the learning that occurred from process safety incidents, the Brady Heywood investigation also examined a number of incidents (pre-cursor events) that had technical similarities to elements of the 25 May 2021 incident. The relevant elements include:

- The loss of AC supply to a unit.
- The switching sequence related to the DC system.

The pre-cursor events related to each element are discussed below.

17.5.1 The Loss of AC Supply to a Unit

In 2002, an incident at Callide C power station occurred that indicated a momentary interruption in DC supply could result in the loss of AC supply to Unit C3 and Unit C4. During this 2002 event, a fault in the Unit C3 battery charger led to the operation of the Unit C3 automatic changeover switch, which resulted in a loss of AC. This event resulted in an internal investigation and a third-party report.[416]

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[414] These are log entries which referenced a WCA/WCD/WO/Notification. Extract J5 database (2021) *J5 Operations Logbook Entries Extract for Callide C (C3, C4, CStn) from Sep15 to Nov21*, Worksheet: J5 Data Extract, CSE.001.053.0001.

[415] CS Energy primarily only analysed notification and work order data to understand loss of availability and maintenance costs.

[416] Internal Memorandum (19 August 2002) *Trip Report – Preliminary 3 Unit, Internal Memorandum,* CSE.001.044.0001; Connell Wagner (27 September 2002) *Callide C Power Station 220 V DC System Investigation,* CSE.001.102.0018.

This incident in 2002, following a disruption in DC supply, showed that it was possible to lose AC supply to a unit. However, the mechanism of AC loss in this incident was significantly different to that of the 25 May 2021 incident.

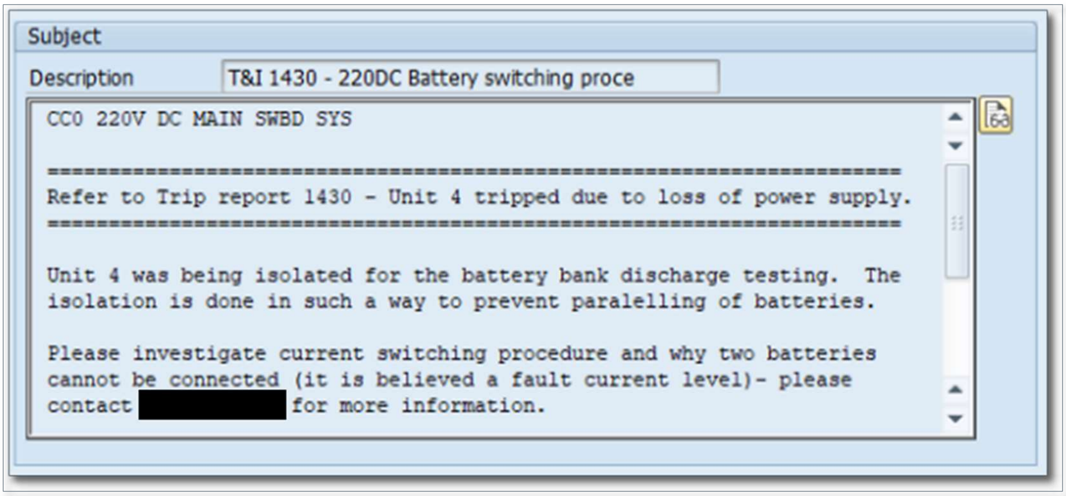
17.5.2 The Switching Sequence Related to the DC System

The switching sequence that initiated the Unit C4 incident in May 2021 involved performing switching operations on the Unit C4 DC system. Some of the risks associated with performing switching on the DC system were highlighted during incidents that occurred during previous switching sequences. Two such incidents that occurred in 2010 and 2021 are discussed below.

12 February 2010 incident

On 12 February 2010, a switching sequence was being undertaken on the DC system to perform routine maintenance. When a switch was operated, as part of the switching sequence, it caused a momentary voltage dip in the DC system, which caused Unit C4 to trip. The incident category assigned to this event is unknown. However, it did result in an investigation and the completion of a Significant Incident Report.[417]

From this investigation, several notifications were raised.[418] Among these, a notification was raised to '*Please investigate current switching procedure and why two batteries cannot be connected*', see Figure 145.[419]



Subject

Description: T&I 1430 - 220DC Battery switching proce

CC0 220V DC MAIN SWBD SYS

==
Refer to Trip report 1430 - Unit 4 tripped due to loss of power supply.
==

Unit 4 was being isolated for the battery bank discharge testing. The isolation is done in such a way to prevent paralelling of batteries.

Please investigate current switching procedure and why two batteries cannot be connected (it is believed a fault current level)- please contact [redacted] for more information.

Figure 145 Notification 10284279

The reference in the above notification that '*two batteries cannot be connected*' refers to a design philosophy of the Callide DC system that meant that two batteries could not be connected to the same

[417] A Significant Incident Report is a report prepared for higher category incidents: CS Energy (2010) *Significant incident Report Unit 4 Tripped on Loss of Power Supply*, CSE.001.253.0074.

[418] Notifications 10284274, 10284275, 10284276, 10284277, 10284278 and 10284279. Extract SAP Maintenance database (2023) *Notifications,* CSE.001.253.0045.

[419] Notification 10284279. Extract SAP Maintenance database (2023) *Notifications,* CSE.001.253.0045.

DC system at the same time (see discussion of trapped key interlock system in Section 6.4). During the 25 May 2021 incident, it was this inability to connect two batteries to the same DC system that resulted in a switching sequence that required the Unit C4 battery charger be the sole source of DC supply to Unit C4.

Notification 10284279 resulted in the creation of Work Order 4429343. This work order was closed out on 26 August 2015, with the comment '*Procedures are deemed suitable to identify any faults…*'.[420] No evidence has been sighted for the basis for this statement, or what investigation (if any) was performed.

There were also three notifications resulting from the incident investigation to conduct further training for the engineering, maintenance and operational staff in the Callide C battery system. These notifications were closed between 2011 and 2014. No evidence has been sighted of this training being completed.[421]

While the risks associated with not being able to connect two batteries to the same DC system were highlighted in the February 2010 incident, no design changes or operational changes were made to address these limitations. The inability to connect two batteries to the same DC system played a causative role in the 25 May 2021 incident.

15 April 2021 incident

On 15 April 2021, a switching sequence taking place on the DC system led to a dip in DC voltage, which caused a loss of AC supply to Unit C4. The unit was offline at the time, but the loss of AC supply led to a loss of display screens in the control room. The incident demonstrated that underlying risks remained when performing switching in the DC system – including the risk of a loss of AC supply to a unit and loss of screens in the control room.

The incident was recorded as a Category 1 incident, the least significant incident category. The investigation of this incident was not complete at the time of the 25 May 2021 incident.[422]

17.6 Chapter Summary

CS Energy's process for learning from process safety incidents was not working effectively at Callide. In the two-and-a-half-year period leading up to the 25 May 2021 incident, the majority of investigations at Callide focused on personal safety, with only four process safety incident investigations resulting in an understanding of both the technical and systemic organisational causes of the incident.

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[420] CS Energy (2023) *Maintenance Order 4429343,* CSE.001.253.0017. The order has the comment: '*Procedures are deemed suitable to identify any faults. If there is an issue – stop switching. Reinstate if required'*. It is unclear what 'reinstate' is referring to, however, this may suggest that the operator should reverse the previously performed step if there is an issue. If this is what 'reinstate' is referring to, it is inconsistent with CS Energy training on switching, discussed in Chapter 18 *Switching Online Without DC Redundancy*.

[421] Notifications 10284275, 10284276, 10284277. Extract SAP Maintenance database (2023) *Notifications,* CSE.001.253.0045.

[422] The completion date of the incident investigation is not known. However, the content in the investigation report for Incident 10644 indicates it was not completed until after the 25 May 2021 incident. Further, all actions from the investigation were due after the 25 May 2021 incident. Incident Report (2021) *R10644-LossofSwitchboards&PCRScreens_20211110034044.677,* CSE.001.080.0054.

This left CS Energy with a learning from incidents system that provided limited insight into the effectiveness of its process safety systems.

Further, pre-cursor events that had technical similarities to elements of the 25 May 2021 incident had occurred throughout CS Energy’s history.

The next chapter explores the switching sequence relevant to the 25 May 2021 incident.

18 SWITCHING ONLINE WITHOUT DC REDUNDANCY

18.1 Introduction

The incident was initiated by a switching sequence that was being carried out to connect the replacement Unit C4 battery charger and existing battery to Unit C4.

This chapter discusses how the planning, execution, and decision-making surrounding the switching sequence did not consider the risks associated with bringing the battery charger into service, with no redundancy to the DC system, and with the unit online. It also discusses how there was no requirement in CS Energy's processes to do so.

18.2 Technical Background

The switching sequence to bring the replacement Unit C4 battery charger into service was carried out with the unit online and included steps where there was no redundancy or backup to the DC system supply. The redundancy provided by the Unit C4 battery was unavailable because it was not connected, and the backup provided by the Unit C4 automatic changeover switch was unavailable because it was inoperable.

When the Station DC supply was disconnected, the Unit C4 battery charger became the sole source of DC supply to Unit C4. The switching sequence, therefore, created a situation where, after the Station DC supply was disconnected, the Unit C4 battery charger was required to respond instantly to maintain the DC voltage in Unit C4.

18.3 Overview of CS Energy's Switching Sequence

18.3.1 Background

CS Energy has a specific obligation to ensure that personnel do not come into direct contact with live electrical equipment.[423] A process known as switching is used to isolate components in the power station so that they can be worked on safely.[424] Switching must be carried out by a Switching Officer, who must have an electrical worker's licence. They must be authorised to perform switching on high-voltage systems or systems where there is more than one source of low-voltage electrical supply.[425]

[423] CS Energy's *Electrical Safety Management* procedure states that CS Energy has a specific obligation to ensure personnel do not come into direct contact with electrical equipment, unless it has been isolated in accordance with Permit to Work procedures, or the work has been authorised in accordance with the *Electrical Safety Management* procedure: CS Energy (2017) *Electrical Safety Management CS-OHS-31,* Section 2, CSE.001.105.0111.

[424] Switching is not used solely for isolation purposes – it is a process for making changes to the electrical system's configuration, which is carried out in accordance with a series of prescriptive sequential steps referred to as a 'switching sequence'.

[425] CS Energy (2019) *Permit To Work Definitions, CS-PTW-02,* 21, CSE.001.230.0005. Low Voltage (LV) is defined as less than 1,000 Vac or 1,500 ripple-free Vdc. High Voltage (HV) is anything higher than this: CS Energy (2016) *Multiple Supply Electrical Equipment Isolation and Access CS-OHS-53*, 27-28, CSE.001.103.0129.

CS Energy has processes that set out the requirements for planning and carrying out switching sequences.[426]

18.3.2 Switching Sheets

Switching sheets document the steps in a switching sequence that must be undertaken to implement an isolation or other change to configuration. Switching must be pre-planned – and executed according to the switching sheets – to ensure isolations render the equipment safe for work (e.g., by removing sources of electrical supply).

18.3.3 Training and Competency

CS Energy's processes require that any person who carries out electrical work at the Callide power stations must fulfil a range of training and competencies.[427]

The personnel involved in the preparation of the switching sheet for the Unit C4 battery charger replacement, and those who carried out the switching sequence, were all deemed competent by CS Energy in accordance with their requirements.[428]

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[426] CS Energy (2016) *Multiple Supply Electrical Equipment Isolation and Access CS-OHS-53*, CSE.001.103.0129; CS Energy (2017) *Electrical Safety Management CS-OHS-31,* CSE.001.105.0111.

[427] CS Energy processes require that any person who carries out electrical work at the Callide power stations must be licensed under the *Electrical Safety Act 2002* (Qld). CS Energy (2017) *Electrical Safety Management CS-OHS-31*, Section 5.1, CSE.001.105.0111; *Electrical Safety Act 2002* (Qld).

Additional requirements apply to Switching Sheet Writers, Switching Sheet Approvers, Switching Officers and Switching Officer Assistants who plan and carry out switching sequences for electrical isolations. CS Energy (2016) *Permit to Work (PTW) Manual CS-PTW-01*, Section 8.10 Electrical Isolation with Multiple Supplies, CSE.001.047.0015.

Completion of an Accredited High Voltage Isolation and Access (HVIA) course, completion of particular on-the-job activities, and refreshment of training at set intervals is required to become an authorised and competent Switching Officer. CS Energy (2020) *Training for Roles in The PTW System CS-PTW-SOP-02*, 15-16, CSE.001.001.7979.

[428] Electrical Work Licence (17 June 2019) *Switching Sheet Writer/Checker #2*, Expiry Date 05 July 2024, CSE.001.230.0004; Statement of Attainment (9 June 2020) *Switching Sheet Writer/Checker #2*, High Voltage Refresher, CSE.001.230.0029; LMS Learning History Report (10 October 2023) *Completed Items*, CSE.001.230.0131; Electrical Work Licence (27 August 2018) *Switching Sheet Writer/Checker #1*, Expiry Date 31 October 2021, CSE.001.230.0132; High Voltage (HV) Authorised Switching Role Nomination and Acceptance (07 August 2018) *Switching Officer*, CSE.001.230.0133; Statement of Attainment (6 April 2021) *Switching Sheet Writer / Checker #1*, CPR, LVR, CSE.001.230.0135; Electrical Work Licence (21 July 2017) *Switching Officer*, Expiry Date 27 July 2022, CSE.001.230.0136; Nomination Form Authorised Role Summative Theory Assessment Permit to Work Officer PTWO (1 March 2016) *Switching Sheet Writer/Checker #1*, CSE.001.230.0137; Statement of Attainment (11 June 2020) Switching Officer's Assistant, *High Voltage Refresher*, CSE.001.230.0142; Statement of Attainment (7 January 2021) *Switching Officer's Assistant*, CPR, LVR, CSE.001.230.0156; Statement of Attainment (11 June 2020) *Switching Sheet Authoriser*, High Voltage Refresher, CSE.001.230.0160; High Voltage (HV) Authorised Switching Role Nomination and Acceptance (1 August 2018) *Switching Sheet Authoriser*, CSE.001.230.0162; Statement of Attainment (7 January 2021) *Switching Officer's Assistant*, CPR, LVR, CSE.001.230.0164; Electrical Work Licence (10 October 2023) *Switching Officer's Assistant*, Expiry Date 28 July 2024, CSE.001.230.0165; Statement of Attainment (9 June 2020) *Switching Officer*, High Voltage Refresher, CSE.001.230.0166; Change of Qualified Business Person (21 January 2020) *Switching Officer*, Queensland Electrical Contractor, CSE.001.230.0168; Electrical Work Licence (6 March 2021) *Switching Officer's Assistant*, Expiry Date 28 July 2024, CSE.001.230.0169; Statement of Attainment (7 January 2021) *Switching Officer*, CPR, LVR, CSE.001.230.0170; Statement of

18.3.4 Permit to Work Requirements

Any work involving isolations requires a Permit to Work (PTW).[429] A PTW is the formal issuance of authorisation to perform work as detailed in a work order. The purpose of the PTW system is to provide workers with safe access to plant and equipment. The process of obtaining the PTW involves steps to ensure that the switching process for electrical isolations has been correctly carried out and checked before the PTW is issued.

The PTW system commences with an application for a PTW. Prior to this step, a Work Order is raised and a form of risk assessment known as a Job Safety Environment Analysis (JSEA) is required to be prepared.[430] This type of risk assessment is focused on personal safety, and it considers the risk of harm to the individuals involved in the relevant task.

No risk assessments are required as part of the PTW system itself. As discussed later in this chapter, there is no requirement to assess and manage the process safety risks posed by a switching sequence on the wider plant.[431]

After a Work Order and a JSEA is completed, an application for a PTW is prepared. A Permit to Work Officer (PTWO) or Senior PTWO (SPTWO) drafts documents outlining the required isolations (based on the switching sheets that are prepared separately). Locks and tags are then issued on the basis of these documents. It is not until after the isolations have been carried out and checked that the PTW is issued. Work on the isolated equipment can then be performed.

After completion of the work, the PTW is surrendered to the PTWO, and a switching sequence is carried out to remove the isolations on the equipment and bring the isolated equipment back into service.

18.3.5 Summary

The Brady Heywood investigation found that all the CS Energy requirements applicable to the switching sequence for the Unit C4 battery charger replacement were complied with. However, there were no requirements to consider process safety risks, or the management of those risks.

Attainment (5 January 2021) *Switching Sheet Writer/Checker #2*, CPR, LVR, CSE.001.230.0171; Statement of Attainment (11 June 2020) *Switching Officer's Assistant*, High Voltage Refresher, CSE.001.230.0172; Statement of Attainment (16 February 2021) *Switching Sheet Authoriser*, CPR, LVR, CSE.001.230.0174; Statement of Attainment (11 June 2020) *Switching Sheet Writer/Checker #1*, High Voltage Refresher, CSE.001.230.0175; Electrical Work Licence (6 March 2021) *Switching Sheet Authoriser*, Expiry Date 25 September 2025, CSE.001.230.0179.

[429] CS Energy (2016) *Permit to Work (PTW) Manual, CS-PTW-01*, 12, CSE.001.047.0015. The PTW system is used at all CS Energy's sites: CS Energy (2016) *Permit to Work (PTW) Manual, CS-PTW-01*, 7, CSE.001.047.0015.

[430] Figure 3 in the *Permit to Work Manual* includes the preparation of a JSEA associated with the 'Work Planned and Scheduled' action, which is carried out 'External to the PTW System': CS Energy (2016) *Permit to Work (PTW) Manual, CS-PTW-01,* Figure 3, CSE.001.047.0015.

[431] CS Energy (2017) *Electrical Safety Management CS-OHS-31,* Section 3.2, CSE.001.105.0111.

18.4 Switching Sheet(s) for the Unit C4 Battery Charger Replacement

18.4.1 Introduction

Two switching sheets were prepared for bringing the Unit C4 battery charger and battery back into service. The first switching sheet was prepared and isolations for the Unit C4 battery charger were carried out. The second was prepared after unauthorised changes were made to the isolations.

18.4.2 First Switching Sheet

In February 2020, the switching sheet for the Unit C4 battery charger replacement was prepared.[432] The preparation of the switching sheet was in accordance with the requirements of CS Energy's procedures.[433]

It was intended that the switching sequence would be carried out shortly after the preparation of the switching sheet, but the impacts of COVID-19 delayed the replacement of the Unit C4 battery charger. The switching sequence for the isolations for the removal of the old Unit C4 battery charger was not carried out until February 2021.[434] Despite this delay, there was no requirement in the CS Energy procedures or processes to review this switching sheet.

18.4.3 Second (Revised) Switching Sheet

In mid-May 2021, CS Energy identified that changes had been made to the isolations for the Unit C4 battery charger carried out in February 2021. These changes occurred during the testing of the replacement battery charger, and were made by an individual who did not have the requisite authorisation.[435] (The unauthorised changes made to the isolations for the Unit C4 battery charger did not play any role in the incident.)

As a result, the switching sheet had to be rewritten to include steps to re-isolate the battery charger and return it to a known state.[436] The switching sequence for the replacement of the battery charger could then continue. This revised switching sheet was also written and checked in accordance with CS Energy requirements.[437]

The revised switching sheet has some differences to the original switching sheet, but both include a step in the sequence where the Unit C4 battery is not connected to Unit C4, and the replacement Unit C4 battery charger is required to be the sole source of supply to the DC system.

However, the timing of the preparation of the revised switching sheet is significant. The original switching sheet was prepared in February 2020, 15 months prior to the replacement Unit C4 battery charger being connected to Unit C4. At the time of writing that switching sheet, the status of the Unit

[432] CS Energy (10 February 2020) *Switching Sheet CC4S20/0003*, CSE.001.280.0003. Note: A single switching sheet is prepared for isolation and reverse switching. The switching sequence for Unit C4 was similar to the switching sequences for the battery charger replacements in Unit C3 and Station due to the keyed interlock requirements.

[433] CS Energy (2016) *Multiple Supply Electrical Equipment Isolation and Access CS-OHS-53*, CSE.001.103.0129.

[434] Emails (10 February 2021) *C4 220V 900A Charger (4BTL10) – Commissioning documents*, 1:39 pm, CSE.001.100.0912.

[435] CS Energy (19 May 2021) *Incident Investigation Report 10720*, CSE.001.054.0271.

[436] CS Energy (19 May 2021) *Switching Sheet CC4S21/0014*, 1-7, CSE.001.226.0027.

[437] CS Energy (2016) *Multiple Supply Electrical Equipment Isolation and Access CS-OHS-53*, CSE.001.103.0129.

C4 DC system at the time of switching would have been unknown. By contrast, when the revised switching sheet was prepared in mid-May 2021, the status of the DC system on 25 May 2021 should have been known – specifically, the inoperable status of the Unit C4 automatic changeover switch. Despite the Unit C4 automatic changeover switch being inoperable, there was no significant change to the planned switching sequence (i.e., it still contained a step where the Unit C4 battery charger was the sole source of supply).

18.5 Switching While Unit C4 was Online

18.5.1 No Clear Guidance

The plant manual for the Callide C DC system provides no specific guidance on whether there are any switching activities that should not be performed with the unit online.[438] The DC operating manuals contain warnings (notes in bold text) about the impact of performing certain switching operations. For example:[439]

- The procedure to take a battery charger out of service contains the warning that interruption of DC supply to critical equipment may occur.
- The procedure to take a battery out of service contains the warning that critical equipment may be without battery backup.

A procedure, PAMC-CH22-S04-P03, includes a switching sequence that removes the battery redundancy and forms part of the training for switching operators. It does not specify whether the unit should be offline or can be online during this switching sequence.[440]

On 25 May 2021, the switching sequence was carried out with the unit online. If the incident had occurred with the unit offline (i.e., with Unit C4 shut down and the rotor not spinning), the damage to the turbine generator would have been avoided.

In summary, CS Energy documentation does not explicitly state that switching sequences similar to that being undertaken on the day of the incident can be conducted while Unit C4 is online nor does it explicitly prohibit it.

18.5.2 The Battery Charger Project

Project approval documentation at the outset of the battery charger project specifically stated that the new battery charger could be returned to service when the unit was online.[441] No evidence has been sighted that a formal risk assessment considered this decision.

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[438] Pacific Power International (November 2001) *Callide Power Project Unit No. 3 & 4 Plant Manuals, Section 1 Plant Description, Volume 1 of 7*, CSE.001.012.6374.

[439] While the DC manuals use the term 'critical loads', the term 'critical equipment' has been used here for simplicity.

[440] CS Energy (2008) *PAMC-CH22-S04-P03, Callide C Power Plant, Production Advice Manual, Loss of 220V DC Charger or Battery Switching Operations*, CSE.001.015.6906.

[441] The Concept Gate Approval Request for the replacement of the battery charger specifically stated that the new battery charger could be returned to service when the units were online. Standard Form (17 January 2018) *Concept Gate Approval Request for Callide C UPS & battery charger replacement*, Project Description, CSE.001.036.1593.

18.6 Removal of Redundancy During the Switching Sequence

18.6.1 Introduction

On the day of the incident, there was no redundancy to the Unit C4 DC supply between two steps in the switching sequence. As discussed in Part A of this report, the Unit C4 DC system is typically supplied by a battery charger and a battery, see Figure 146.

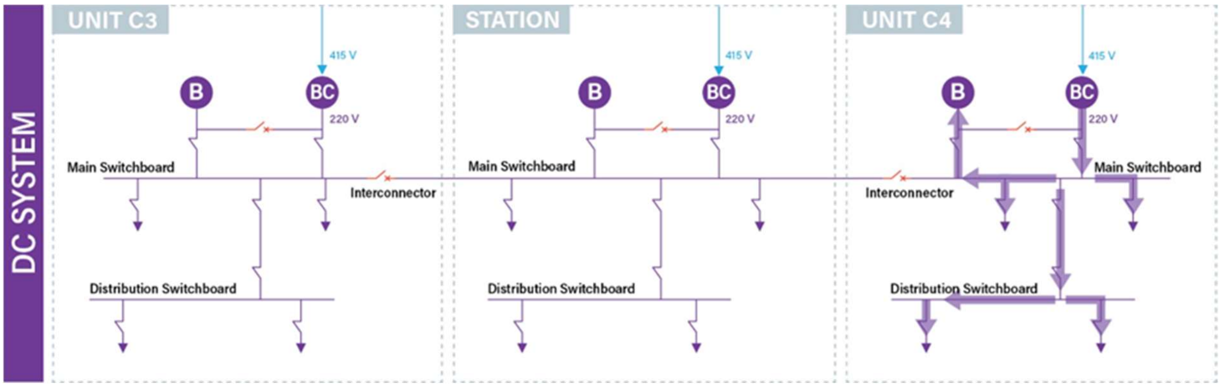

Figure 146 Unit C4 battery charger and battery

The battery provides redundancy should the battery charger cease operation.

The redundancy provided by the battery was unavailable when the switching sequence was being carried out on the day of the incident. This placed a requirement on the Unit C4 battery charger to respond when the Station DC supply was disconnected (by opening the interconnector), with the Unit C4 battery not yet connected, see Figure 147.

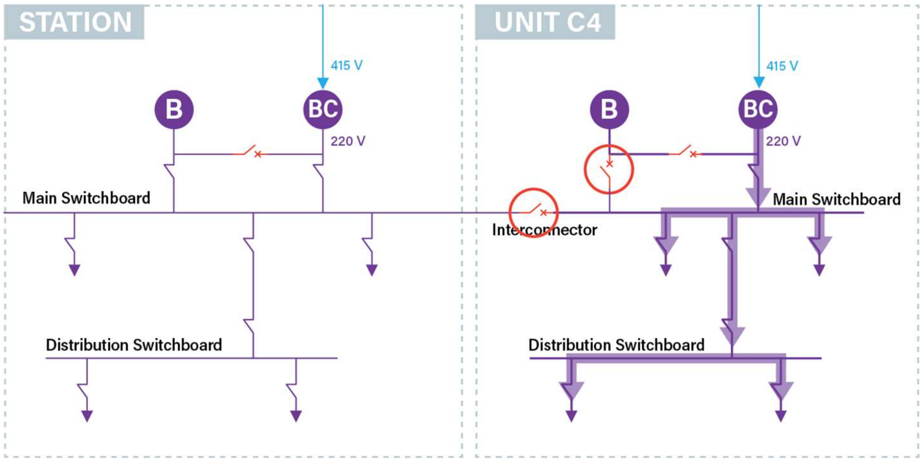

Figure 147 Requirement that the Unit C4 battery charger would maintain DC system voltage in the absence of the Unit C4 battery

This created the situation that, if the battery charger did not operate as required, DC supply to Unit C4 would likely be lost.[442]

18.6.2 No Redundancy Available in the Unit C4 DC System

The design of the Callide C power station dictated that two batteries could not be connected to the same DC system at the same time.[443] When the planned switching sequence commenced, the Station DC system was providing DC supply to Unit C4. But because the Station DC system was supplied by its own battery charger and battery, the Station DC supply (including its battery) had to be disconnected from the Unit C4 DC system before the Unit C4 battery could be connected.

Further, as discussed in Chapter 7 *How the Switching Sequence Initiated the Incident*, the DC system was designed with a physical mechanism, known as a trapped key interlock system, to ensure the switching sequence proceeded without connecting two batteries to the same DC system. The steps in the switching sequence were consistent with the design of the DC system.[444]

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[442] The Brady Heywood investigation considered why the step to open the interconnector was not reversed when it became apparent that something unexpected had occurred.

There are both practical and operational reasons why this step was not reversed.

In the short amount of time between it becoming apparent to the switching team that Unit C4 was not behaving as it should, and when they vacated the area due to safety concerns, the switching team had limited information on what was happening and whether reversing the step would have had positive or negative effects.

The switching team also acted consistently with the Queensland electrical industry standards and CS Energy requirements. The *Queensland Electricity Entity Standard for Safe Access to HV Electrical Apparatus* was developed by a joint industry task force to support the objectives of the various State and National Regulations and Guidelines. Powerlink Queensland, Ergon Energy and Energex (Energy Queensland) developed the Queensland Electricity Entity Standard for Safe Access to HV Electrical Apparatus. Energy Queensland (October 2018) *Queensland Electricity Entity Standard for Safe Access to High Voltage*, 41, Section 8.4, CSE.001.230.0031. It states:

> *A Switching Operator Shall:-*
>
> … *(m) report any Switching performed in error, or any problem / anomaly encountered during Switching, immediately to the Switching Co-ordinator before proceeding further.*

The CS Energy requirements are consistent with this: any variation to the switching sheet can only be carried out in consultation with the Switching Sheet Authoriser/Issuer: CS Energy (2016) *Multiple Supply Electrical Equipment Isolation and Access* (CS-OHS-53), 12, CSE.001.103.0129.

As the switching team was leaving the switch room, the Switching Officer tried to contact the Unit C4 Control Room Operator, but was unsuccessful. About three minutes after they had evacuated Unit C4, the Switching Officer made contact with the B Shift Step-Up Supervisor. See Section 12.6.1.

The switching team was not able to consult with the required personnel to decide if the switching operation should be reversed (at a time when there was an opportunity to do so). By the time contact had been made with the B Shift Step-Up Supervisor, the switching team had evacuated.

[443] Connell Wagner (27 September 2002) *Callide C Power Station 220 V DC System Investigation,* CSE.001.102.0018.

[444] There is documentation that sets out how the trapped key interlock system should be operated. Pacific Power International (1 May 2000) *Callide Power Plant Contract No. 193/1997/HO 220V DC Main Switchboard Key Interlocking System, A3-C-747642, Rev B*, CSE.001.016.0533. It details how connecting the Unit C4 battery charger and battery contains a step in the sequence

The trapped key interlock system and switching sequence, therefore, actively removed redundancy from the Unit C4 DC system. They enforced a step in the switching sequence that left the Unit C4 DC system with no battery connected.

18.6.3 Operating Without Redundancy Led to Issues in the Past

The system limitation of the inability to connect two batteries had been highlighted in previous events. For example, actions proposed in a CS Energy Significant Incident Report following an event in 2010 sought to investigate this limitation.[445] However, the Brady Heywood investigation identified that these actions were not implemented.[446]

18.6.4 Summary

Steps in the switching sequence resulted in the Unit C4 DC system operating without the redundancy provided by a battery. These steps were consistent with the physical constraints of the trapped key interlock system, and with CS Energy documentation, procedures and training for the DC system.

No evidence has been sighted that the lack of redundancy in the DC system was considered during the planning, execution and decision-making associated with the switching sequence.

18.7 No Backup DC Supply During the Switching Sequence

When the switching sequence was carried out on 25 May 2021, the Unit C4 automatic changeover switch was inoperable.[447] If DC supply to the Unit C4 DC system was lost, the automatic changeover switch should have partially restored DC supply. This inoperability removed the backup supply for the Unit C4 DC system.

No evidence has been sighted that the inoperable status of the Unit C4 automatic changeover switch was considered when preparing or executing the switching sequence, despite its inoperability removing backup from the DC system.[448] At the time the second (revised) switching sheet was written, in mid-May 2021, the inoperable status of the Unit C4 ACS was known to CS Energy.

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that results in no battery being connected to the unit. In other words, there is a step in the documentation which creates a situation where the Unit C4 DC system has no redundancy available. This documentation is consistent with the DC system's physical design and the planned switching sequence on the day of the incident.

Further, removal of redundancy in between two steps of a switching sequence also formed part of CS Energy's procedures and training modules. Procedure PAMC-CH22-S04-P03 details the switching sequence to be used in the event of a loss of a battery charger or battery. Training records for switching operators show that this procedure formed part of their training. The switching sequence listed in this procedure also results in the battery charger being the sole source of supply to the DC system, without a battery connected, in between two steps in the sequence. Therefore, the removal of the redundancy provided by the battery formed part of CS Energy's procedures and training.

[445] Report (12 March 2010) *Significant Incident Report, Unit 4 Tripped on loss of power supply,* CSE.001.100.1213; Work Order (16 March 2010*) CSE Work Order 4429343,* CSE.001.0044.0022.

[446] Section 0 discusses this incident in more detail.

[447] Chapter 21 *The Inoperable Automatic Changeover Switch* discusses the status of the automatic changeover switch.

[448] Regarding the Unit C4 automatic changeover switch, a member of the switching team stated they had no awareness of '*any issues or difficulties*' with the Unit C4 automatic changeover switch on the day: Statement (30 March 2022) *Statement of Evidence of Switching Officer*, 28, CSE.001.093.0238.

18.8 Requirement for the Unit C4 Battery Charger to Respond

The lack of redundancy placed a requirement on the Unit C4 battery charger to instantly respond to the removal of the Station DC supply, and maintain the Unit C4 DC system voltage.

No evidence has been sighted that CS Energy understood this requirement, considered the risk of the battery charger not performing as required, nor considered the consequences that could result from a lack of performance with the unit online.

18.9 No Formal Consideration of Risk

No evidence has been sighted that CS Energy understood or formally considered the risks posed by the lack of redundancy and backup supply to the DC system – particularly when combined with Unit C4 being online and exporting power:

- Removal of battery redundancy: The removal of battery redundancy was inherent in the switching. However, no evidence has been sighted that CS Energy considered the risk posed by this removal of redundancy.
- No backup supply: No evidence has been sighted that the inoperable status of the Unit C4 automatic changeover switch was considered in preparing or executing the switching sequence, despite its inoperability removing backup from the DC system.
- Assumption that Unit C4 battery charger could maintain voltage: The lack of redundancy in the DC system placed a requirement on the Unit C4 battery charger to respond instantly to the removal of the Station DC supply, and maintain the Unit C4 DC system voltage. No evidence has been sighted that CS Energy understood this requirement, or considered the risk and consequences of the battery charger not performing as required.
- Unit online: No evidence has been sighted that CS Energy considered the risk of performing the switching sequence with no redundancy or backup to the DC system, with Unit C4 online. If the incident had occurred with the unit offline (i.e., with the unit shut down and rotor not spinning), the damage to the turbine generator would have been avoided.

18.10 No Requirement to Assess Process Safety Risk

CS Energy's processes do not require any formal process safety risk assessment when planning or executing switching sequences.[449] The processes only require consideration of the personal safety risk to those undertaking the work, and not the process safety risk posed to the wider power station.

While formal risk assessments would not necessarily have led to avoidance of the incident, they could have increased the likelihood of identifying and managing the risks associated with proceeding with the switching sequence, with Unit C4 online and without a redundant DC supply or a backup supply.

[449] CS Energy (2016) *Multiple Supply Electrical Equipment Isolation and Access CS-OHS-53*, CSE.001.103.0129.

18.11 Discussion

On the day of the incident, there was no redundancy to the Unit C4 DC supply between two steps in the switching sequence. The Unit C4 DC system is typically supplied by a battery charger and a battery. The battery primarily provides redundancy. The redundancy provided by the Unit C4 battery was unavailable because it was not connected.

No evidence has been sighted that CS Energy understood or formally considered the risks posed by this lack of redundancy, particularly combined with carrying out the switching with the unit online and exporting power. There was an absence of any formal consideration of these risks, and CS Energy's processes do not require any form of formal risk assessment when planning or executing switching sequences. CS Energy's processes only require consideration of the personal safety risk posed to those undertaking the work, not any risks posed to the wider plant by the switching. While formal risk assessments would not necessarily have led to avoidance of the incident, they could have increased the likelihood of identifying the risks associated with proceeding with the switching sequence, with the unit online and without a redundant DC supply.

This lack of redundancy placed a requirement on the Unit C4 battery charger to instantly respond to the removal of the Station DC supply to maintain the Unit C4 DC system voltage. No evidence has been sighted that CS Energy understood this requirement, considered the risk of the battery charger not performing as required, nor considered the consequences that could result from a lack of performance with the unit online. If the incident had occurred with the unit offline, i.e., with the unit shut down and rotor not spinning, the damage to the turbine generator would have been avoided.

While the design, execution, and decision-making regarding the switching sequence were all in accordance with CS Energy's processes, these processes were themselves deficient because they did not require the consideration of the risks posed by the switching sequence to the wider plant.

18.12 Chapter Summary

In summary, the planning, execution, and decision-making around the switching sequence did not consider the risks associated with bringing the battery charger into service, without DC system redundancy and with the unit online. Nor was there any requirement in CS Energy's processes to do so. This created a situation where if the replacement Unit C4 battery charger did not perform as required by the switching sequence, DC supply could be lost to the unit.

19 THE BATTERY CHARGER PROJECT

19.1 Introduction

During the switching sequence being carried out on the day of the incident, the replacement Unit C4 battery charger did not respond instantly and did not maintain the voltage in the Unit C4 DC system, which caused the voltage to collapse from ~243 V to ~120 V.

This chapter examines how replacement Unit C4 battery charger was not capable of maintaining the voltage in the Unit C4 DC system under the operating conditions at the time. Nor was it specified nor tested to do so. It also discusses how the battery charger replacement project should have followed CS Energy's management of change process, but this process was not effective, nor was it effectively applied to the project.

19.2 Technical Background

With no redundancy in the Unit C4 DC system, the switching sequence required the Unit C4 battery charger to maintain the DC system voltage. This did not occur and the DC voltage collapsed, which led to the loss of the Unit C4 AC and DC supplies.

19.3 Overview of the Battery Charger Project

The 'end-of-life' replacement of the battery chargers for Callide C Station, Unit C3, and Unit C4 occurred from 2017 until after the incident in 2021. The replacement of these three battery chargers, plus two inverters, was treated by CS Energy as a single project – the *Callide C UPS & battery charger replacement* project. In this chapter, the replacement of the Unit C4 battery charger only is referred to as the 'battery charger project'.

The formal proposal to replace the Unit C4 battery charger, and the battery chargers in Unit C3 and Station, was first raised in May 2017. The *Callide C UPS & battery charger replacement* project was tendered in early June 2018, and a supply contract for the those works was awarded to Magellan Powertronics Pty Ltd (referred to as 'Magellan') in late June 2018.[450]

The replacement Unit C4 battery charger was originally planned to be brought into service in January 2019.[451] The planned timing was then shifted to April 2020 to be undertaken during a '*C4 mini overhaul*'.[452] Ultimately, the commissioning of the new Unit C4 battery charger did not occur until early 2021 and the return to service did not commence until 24 May 2021, when Unit C4 was online. There were several reasons for the delay:

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[450] This contract with Magellan was coupled with two other equipment replacement projects.

[451] Request for Information (8 August 2018) *Request for Information, Delivery dates and items*, CSE.001.217.8873.

[452] Email (5 March 2020) *RE: 45890013 – C4 220V Charger & Inverter replacement*, 8:36 am, CSE.001.100.0897. The schedule provided by Magellan shows the timing of the Unit C4 'mini overhaul', although this version of the schedule does not show the Unit C4 battery charger replacement scheduled for the Unit C4 'mini overhaul'. The decision to do the installation during the Unit C4 mini overhaul happened after January 2019: Excel Spreadsheet (15 January 2019) *Magellan – Callide schedule*, CSE.001.218.3880.

- The ongoing impacts of COVID-19.[453]
- CS Energy resource shortages.[454]
- Delays caused by Magellan.[455]
- CS Energy concerns about Magellan products.[456]
- The effects of high workload on the site teams.[457]

On 24 May 2021, the Unit C4 battery charger was connected to the Unit C4 battery to restore it up to a full state of charge. On 25 May 2021, the Unit C4 battery charger was connected to the Unit C4 main switchboard for the first time.

19.4 What was Required From the New Battery Charger

The battery charger converts incoming AC to a DC output and its role is to supply the Unit C4 DC system and charge the Unit C4 battery. In typical operating conditions, the battery charger is always connected to a battery. The battery provides redundancy in the event of a failure of the battery charger or a failure of the battery charger's incoming AC supply.

The battery charger, however, is also required to operate under conditions other than typical operating conditions. On the day of the incident, a step in the switching sequence required the Unit C4 battery charger to act as the sole source of DC supply to Unit C4 (the Unit C4 battery was not connected due to the requirements of the switching sequence). When the interconnector from Station was opened, this removed the DC supply to Unit C4 from Station. The new Unit C4 battery charger (as the sole source of supply) did not maintain the voltage in the Unit C4 DC system. This led to the loss of AC and DC supply to Unit C4.

The differences between these operational requirements are significant. In typical operating conditions, when the battery charger operates in combination with a battery, it is the battery that

[453] Letter (30 March 2020) *Callide 2020 Overhaul's Deferral,* CSE.001.100.0084.

[454] External contractors were engaged to assist with workload: Email (18 March 2021) *Callide Control Systems team workload – currently not taking on anymore project work*, CSE.001.100.1085. The Project Lead had to approach other budget-holders to be able to retain a contract engineer for longer: Email (12 June 2020–18 June 2020) *RE: Asset Engineering – [Name]*, CSE.001.100.1172.

[455] There were issues with Magellan equipment, including inverters, which caused CS Energy to pause some work: Email (5 June 2020) *FW: Callide B Magellan Inverters – delay further installs until resolved*, CSE.001.100.0938; Email (24 November 2020) *Remaining Callide B&C STN charger inverter upgrades*, CSE.900.002.0165. There was also many exchanges between CS Energy and Magellan to get the ITPs, test data and punch lists closed out prior to bringing the Unit C4 battery charger back online, see Sections 19.8.6, 19.8.4, 19.8.7, 19.8.7, and 19.8.8.

[456] The Project Lead (who picked up the *Callide C UPS & battery charger replacement* project in January 2019) raised concerns in March 2019 about the compliance of Magellan products: Emails (14 March 2019) *RE: 900A Commissioning CC0BTL10 C STN 220V Charger*, 4:09 pm, CSE.001.100.0907. There were issues with Magellan equipment, discussed in emails: Email (5 June 2020) *FW: Callide B Magellan Inverters – delay further installs until resolved*, CSE.001.100.0938; Email (24 November 2020) *Remaining Callide B&C STN charger inverter upgrades*, CSE.900.002.0165.

[457] In March 2021, the Supervisor (Instrumentation & Control) advised other staff via email that the Callide Control Systems team would not be able to take on any more work due to existing backlog. The email highlighted that the team had been under resource pressures for at least the previous year. Email (18 March 2021) *Callide Control Systems team workload – currently not taking on anymore project work*, CSE.001.100.1085.

caters for any sudden changes in demand on the DC system. For example, if there is a sudden increase in demand, the battery will supply this demand instantly, which provides time for the battery charger to respond. In this situation, with a battery connected, the response time for the battery charger is not critical. By contrast, if a battery charger operates without a battery, then its ability to respond to changes in demand must be carefully considered and specified to ensure the battery charger can maintain supply.

No evidence has been sighted that the battery charger was specified or tested to perform in a manner required by the switching sequence (i.e., to act as the sole source of DC supply to maintain the voltage in the Unit C4 DC system).[458] Rather, it appears that the battery charger was specified and tested to satisfy typical operation only (i.e., to take in AC power, supply power to the DC system in conjunction with battery redundancy, and keep the battery charged).

19.5 The Management of Change Process

As mentioned in Section 16.3, CS Energy has a documented procedure for managing modifications to plant, set out in the *CS Energy Procedure for Plant Modifications, CS-AM-010* (referred to here as the 'Plant Modifications Procedure', or 'Procedure').

The battery charger project commenced when the 2016 version of the Procedure was current. However, the Procedure was updated twice: in 2019 and in 2020 (between when the battery charger project commenced and the date of the incident). This investigation report refers to the 2016 version unless otherwise noted, as this is the version relevant for most of the duration of the battery charger project.

19.5.1 Replacement in Kind

The Plant Modifications Procedure recognises that changes that involve a 'replacement in kind' (i.e., a 'like for like' replacement) are not subject to the Procedure. The Procedure explains a 'replacement in kind' as:[459]

> *A replacement of one item of equipment or component by another that satisfies the same design specification and performance characteristics and does not change the function of the plant / process. Replacements in-kind are not modifications and thus do not require any further action or documentation.*

The Procedure also recognises the challenges in determining if work is a replacement in kind, and it also provides guidance for identifying the difference between a replacement in kind and a plant modification.

[458] No evidence has been sighted that testing was conducted to ensure that the battery charger would perform as part of the larger DC system. The testing undertaken treated the battery charger as a 'standalone' device, as opposed to an integrated part of the Unit C4 DC system.

[459] This quote appears in the 2016, 2019 and 2020 versions of the document: CS Energy (2016) *CS Energy Procedure for Plant Modifications CS-AM-010*, Section 4, CSE.001.243.9479; CS Energy (2019) *CS Energy Procedure for Plant Modifications CS-AM-010*, Section 4, CSE.001.088.5286; CS Energy (2020) *CS Energy Procedure for Plant Modifications CS-AM-010*, Section 4, CSE.001.226.0171.

19.5.2 Plant Modification

The scope of application of the Plant Modifications Procedure is broad. There appears to be little non-maintenance related work that would not be considered a plant modification under the Procedure.

The Procedure provides definitions for '*modification*' and '*replacement-in-kind*' and discusses how to determine whether work is a modification or a replacement in kind. Section 1 of the Procedure defines a 'Modification' as:[460]

> *Any change to the physical plant or process from the "As Built" status which may result in a change in process, operation, maintenance or performance, requires a new drawing or a change to an existing drawing/procedure, and which may affect safety or integrity of people, process or plant.*[461]

Section 4 of the Procedure provides examples of modifications, including:

> *… replacing an item with a different make and model;*
>
> *Equipment/component replacements where documentation or information changes. This includes like for like replacements when one or more of the technical and support requirements listed in section 3 of the Plant Modification Quality Plan and Check Sheet … require supply, updating or replacing.*[462]

In essence, with respect to the replacement of plant, if the work is a replacement in kind and it does not require any changes to documentation, or changes to how it is managed with respect to safety, operation, or maintenance, then it was not a plant modification.[463]

19.5.3 Was the Battery Charger Project a Plant Modification?

The definition of a plant modification

The replacement of the battery charger should have been considered a plant modification, based on the definition of a modification set out in the Plant Modifications Procedure.

The new Magellan battery charger was a different make and model to the existing battery charger. The operating manual for the existing battery charger had to be replaced by the operating manual for the new Magellan-built battery charger. The new battery charger meant that sections in the *Callide Power Project Unit No. 3 & 4 Plant Manuals* had to be updated.[464] Drawings for the existing battery charger

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[460] CS Energy (2016) *CS Energy Procedure for Plant Modifications CS-AM-010*, Section 1, CSE.001.243.9479.

[461] 'As built' in this context refers to how the equipment was when it was first brought into operation, which is reflected in the related documentation and manuals, etc.

[462] The Plant Modification Quality Plan and Check Sheet is discussed in detail in Section 19.6.7. It shows that a number of the technical and support requirements listed in Section 3 of the Plant Modification Quality Plan and Check Sheet were marked as requiring updating or replacing. In accordance with Section 4 of the Procedure, this indicates a modification.

[463] Even if the battery charger replacement was regarded as a like for like replacement, a replacement must follow the Procedure if one or more of the technical and support requirements listed in Section 3 of the Plant Modification Quality Plan and Check Sheet require supply, updating or replacing. The Check Sheet is discussed further in Sections 19.5.4 and 19.6.7.

[464] Pacific Power International (November 2001) *Callide Power Project Unit No. 3 & 4 Plant Manuals, Section 1 Plant Description,* Volume 1, CSE.001.012.6374; Pacific Power International (November 2001) *Callide Power Project Unit No. 3 & 4 Plant Manuals, Section 2 Operating Procedures,* Volume 2, CSE.001.010.3078; Pacific Power International (November 2001) *Callide Power*

had to be replaced with drawings relating to the Magellan battery charger. The spare parts details and inventory also needed to change. Finally, bringing a new piece of equipment into a complex system, such as the Callide C power station, had the potential to affect the safety and integrity of the process and plant.

The guide to determining a modification

Section 4 of the Plant Modifications Procedure makes reference to Attachment 1 of the Procedure which '*contains a guide to determining whether a change is subject to the modification process or not*'.[465] If the answer to any one of the first nine questions in the guide is 'yes', then the full Plant Modifications Procedure must be followed. The response to at least four of the questions (indicated in the red boxes) would have been 'yes' for the battery charger replacement, see Figure 148.

Project Unit No. 3 & 4 Plant Manuals, Section 3 Maintenance Procedures, Volume 3, CSE.001.002.9237; Pacific Power International (November 2001) *Callide Power Project Unit No. 3 & 4 Plant Manuals, Section 3 Maintenance Procedures,* Volume 4 (#3 ITPs), Volume 5 (Station ITPs), Volume 6 (#4 ITPs) CSE.001.012.5895; Pacific Power International (November 2001) *Callide Power Project Unit No. 3 & 4 Plant Manuals, Sections 5 and 6 Concise Data & Spare Parts,* Volume 7, CSE.001.012.5762.

[465] CS Energy (2016) *CS Energy Procedure for Plant Modifications CS-AM-010*, Section 4, CSE.001.243.9479.

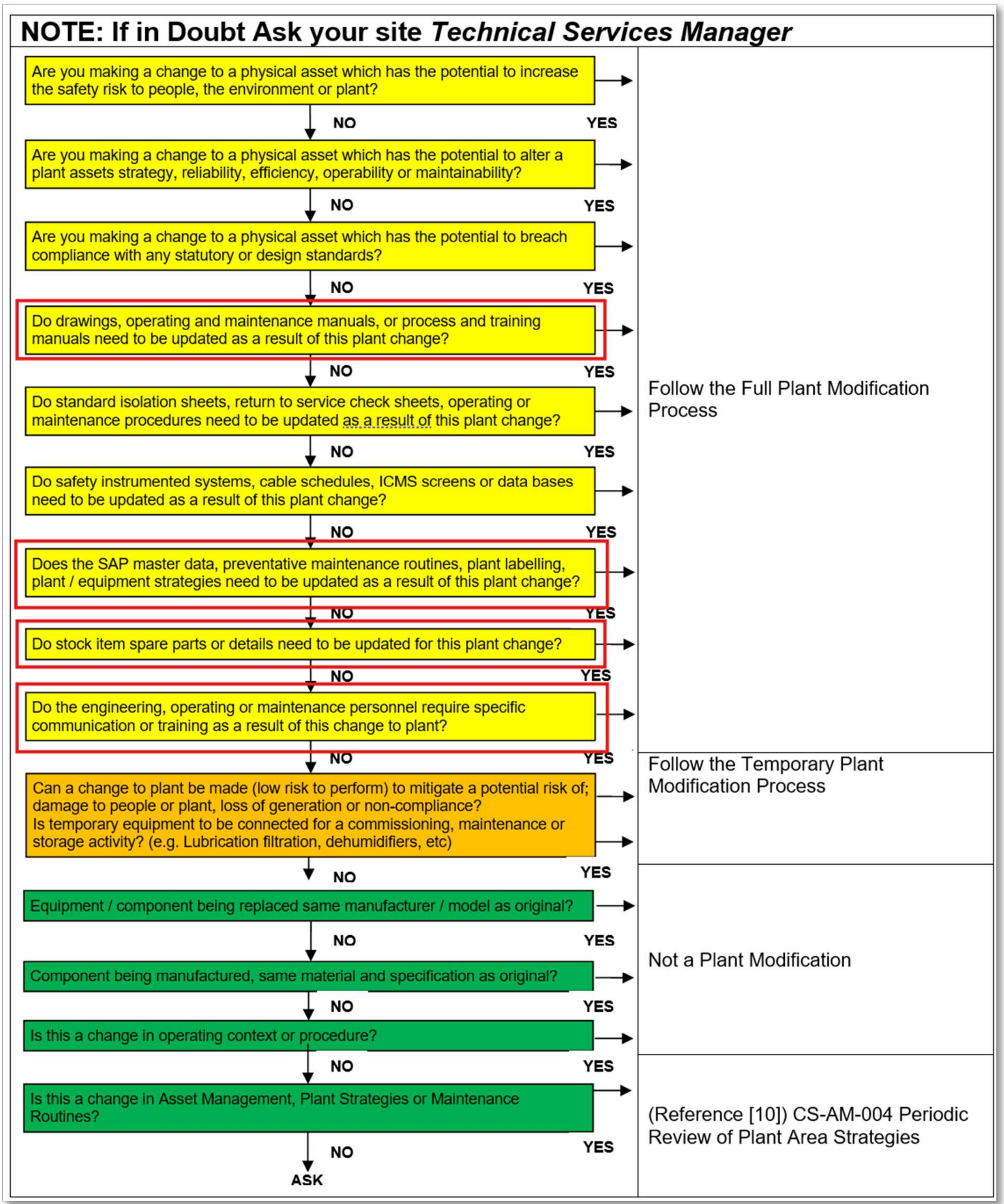

Figure 148 Attachment 1 of the Plant Modifications Procedure (2016)

The Plant Modifications Procedure should have been followed for the Unit C4 battery charger project.

19.5.4 Was the Battery Charger Project Treated as a Modification?

There is evidence that the battery charger project was treated as a plant modification, although there is also evidence that it was considered a like for like replacement.

Between May 2017 and January 2018, several documents prepared by CS Energy in support of the battery charger project described the battery charger project in the following words:

- '*a "straight" replacement for our current charger*'[466]
- '*These chargers would be a straight swap and require minimal commissioning*'[467]
- '*"like for like" replacement*'[468]

The battery charger project is repeatedly referred to in correspondence, and in some formal documentation, as a 'like for like replacement'.

Despite the references to '*like for like*', a Plant Modification Quality Plan and Check Sheet ('Check Sheet'), which is a form under the Plant Modifications Procedure, was initially completed for the project. There was also an entry in the plant modification register.[469] The plant modification register is used to record the progress of every plant modification being carried out at Callide – from the initial notification being raised, to completion of the modification, including any required documentation.

The Check Sheet template has six sections for documenting compliance with the requirements of the Plant Modifications Procedure. On the Check Sheet completed for the *Callide C UPS & battery charger replacement* project (i.e., the three battery chargers for Unit C3, Station and Unit C4 and two inverters), only the first three sections (up to the Design stage) were completed.[470] No evidence has been sighted that the Procedure was complied with from that point onwards.

Figure 149 is a summary of the steps in the Plant Modifications Procedure that were completed for the three battery chargers and two inverters.

466 Email (4 May 2017) *Industrial Battery Charger – CS Energy – Request for Quotation*, CSE.001.213.0044.

467 A memo was prepared to justify the replacement work: Memorandum (31 May 2017) *Justification for Replacement of Callide C 220VDC Battery Chargers*, CSE.001.213.0072.

468 Standard Form (17 January 2018 – 10 July 2018) *Concept Gate Approval Request CS18548 C UPS and Battery charger replacement,* CSE.001.225.0161.

469 Excel Spreadsheet *Callide Power Station Plant Modification Register*, line 718, CSE.001.243.2708.

470 Standard Form (13 February 2018 – 20 February 2018) *Plant Modification Quality Plan and Check Sheet CS21019 – Callide C 240V UPS & 220V battery charger replacement*, CSE.001.225.0156.

	Process Step												
Modification Stage	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Initiation	🔴	🟡	N/A	🟢	N/A	🟢	🟢	🟡	N/A	🟢	🟡	🔴	🟢
Assessment	🟡	🔴	🔴	🟡	🟡	🔴 🟡	🔴						
Design	🔴	🔴	🔴	🟡	🟡	N/A	🔴	🔴	🔴				
Implementation	🟡	🟡	🟡	🟡	🔴	🔴	🟡	🔴					
Review and Acceptance	🔴	🟡	🔴	N/A	🔴								
Closure	N/A	N/A	N/A	N/A									

🔴	Not compliant or no evidence of compliance provided
🟡	Some level of compliance but questions over whether the requirements have been met
🟢	Compliant with the requirements
N/A	Not applicable: for example the modification was not cancelled and thus relevant steps are N/A or if a 'Yes/No' question is identified and 'Yes' is agreed then the 'No' is N/A and vice versa.

Figure 149 Compliance with the Plant Modifications Procedure for the battery charger project

The first signatures on the Check Sheet (in the Initiation stage and one signature in the Assessment stage) were dated 13 February 2018. The latest signatures on the form are dated 20 February 2018, only seven days after the Check Sheet was initiated. The three signatures dated 20 February 2018 are for Approval to proceed from Initiation to Assessment, Approval to proceed from Assessment to Design, and Approval to Implement Modification. The signature signing off the Design as 'completed' was dated two months before the *Callide C UPS & battery charger replacement* project went to tender and before the supplier was determined.

No evidence has been sighted that beyond 20 February 2018, the Plant Modifications Procedure was followed for the battery charger project, despite the battery charger project continuing for three years up to May 2021.[471]

19.5.5 Summary of the Management of Change Process

The battery charger project was repeatedly referred to in correspondence and some formal documentation as a like for like replacement. However, the first sections of the Plant Modification Quality Plan and Check Sheet were initially completed and there was an entry in the plant modification register.

Regardless of the lack of clarity regarding whether the battery charger project was considered by CS Energy as a modification or a replacement in kind, the project progressed to the return to service stage without following the Plant Modifications Procedure (beyond the initial steps).

[471] A *Concept Gate Approval Request Form* is used to seek approval for funding for a project, to take it forward from the concept stage, hence the term 'concept gate'. The *Concept Gate Approval Request* dated 17 January 2018, which is part of the budget approval process, noted '*Change Management Requirements – Callide plant modification process will be followed until close out of the project.*' Standard Form (17 January 2018) *Concept Gate Approval Request* for *Callide C UPS & battery charger replacement,* 4, CSE.001.036.1593. The Concept Gate Approval Request is discussed further in Section 19.7.6.

19.6 Prior to Tendering

19.6.1 CS Energy Email Seeking a Quote

The battery charger project did not start with an official tender process, but an informal email between CS Energy and Magellan. On 4 May 2017, the Technical Officer (Electrical) emailed Magellan's Sales Engineer directly and requested a quote for a 900A DC battery charger, see Figure 150.[472]

> Thanks once again for quoting on our inverter replacement.
>
> We are now also seeking quotes for the supply and installation of a 900A DC battery charger that will be used to charge a 220V battery bank.
>
> As per our inverter, our current charger is also reaching the end of its design life. I have attached the relevant section of our O&M manual but can assist if you require any further information. The required charger will need to be a 'straight' replacement for our current charger.

Figure 150 Email request for quote

It is unclear what section of the O&M (operation and maintenance) manual was provided, as there are seven sections spanning five documents that could be relevant.[473] The O&M manuals tend to focus on the configuration of the existing battery chargers, the maintenance routines, startup and shutdown procedures, and the ability of the DC system to be interconnected via a trapped key interlock system. There is no information in the O&M manuals that indicates how the battery chargers needed to perform during dynamic switching operations, such as the switching sequence that was performed on the day of the incident.

Upon request from Magellan, the CS Energy Technical Officer provided a photo of the existing battery charger and its name plate. The specific photograph sent has not been located, but for illustrative purposes, Figure 151 shows a photograph of a nameplate from one of the existing battery chargers, which was provided in the specification for the Callide C battery charger replacements.[474]

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[472] The original email has not been located and neither have the attachments to it. This email was located in a record containing a series of emails: Emails between CS Energy and Magellan Emails (4 May 2017–7 June 2017) *Industrial Battery Charger – CS Energy – Request for Quotation*, CSE.001.213.0044.

[473] Pacific Power International (November 2001) *Callide Power Project Unit No. 3 & 4 Plant Manuals, Section 1 Plant Description, Volume 1 of 7*, CSE.001.012.6374; Pacific Power International (November 2001) *Callide Power Project Unit No. 3 & 4 Plant Manuals, Section 2 Operating Procedures, Volume 2 of 7*, CSE.001.010.3078; Pacific Power International (November 2001) *Callide Power Project Unit No. 3 & 4 Plant Manuals, Section 3 Maintenance Procedures, Volume 3 of* 7, CSE.001.002.9237; Pacific Power International (November 2001) *Callide Power Project Unit No. 3 & 4 Plant Manuals, Section 3 Maintenance Procedures, Volume 4 of 7 - #3 ITPs, Volume 5 of 7 – Station ITPs, Volume 6 of 7 - #4 ITPs*, CSE.001.012.5895; Pacific Power International (November 2001) *Callide Power Project Unit No. 3 & 4 Plant Manuals, Sections 5 & 6 Concise Data & Spare Parts, Volume 7 of* 7, CSE.001.012.5762.

[474] CS Energy (5 June 2018) *Invitation to Tender (ITT) Section C – Scope of Work* for the *Callide C 220V DC Charger and 240V AC UPS Replacement, Version: 1*, Figure 6, CSE.001.115.0237.

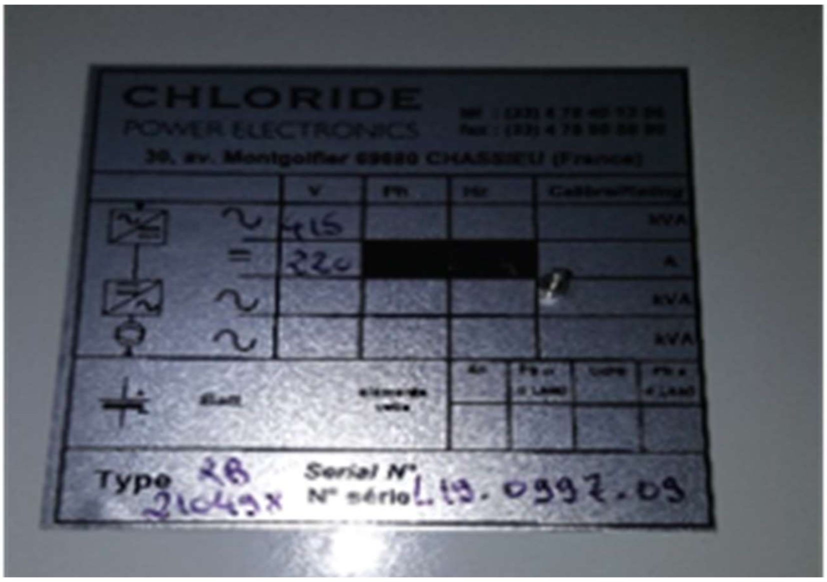

Figure 151 Existing battery charger ratings nameplate (illustrative purposes only) as provided in the specification for the battery charger project

Nameplates provide only basic information, such as voltage and current, and therefore would not have provided Magellan with any detailed information about the battery charger.[475]

19.6.2 Magellan Provides a Quote

In response to CS Energy's request, Magellan provided a quote on 19 May 2017.[476] This was followed with an amended quote on 7 June 2017, in which Magellan explained there was an error in the original pricing provided by their transformer supplier.[477]

The technical details provided by Magellan for the proposed battery charger was a Magellan model MCRII DC Battery Charger brochure and the information shown in Figure 152.

[475] CS Energy (5 June 2018) *Invitation to Tender (ITT) Section C – Scope of Work* for the *Callide C 220V DC Charger and 240V AC UPS Replacement, Version: 1*, CSE.001.115.0237.

[476] The quote provided on this date has not been located, but it is referred to in this email: Email (19 May 2017) *RE Industrial Battery Charger – CS Energy – Request for Quotation*, CSE.001.213.0044.

[477] Email (7 June 2017) *RE Industrial Battery Charger – CS Energy – Request for Quotation*, CSE.001.213.0044; Quote attached to the email, Magellan Power (7 June 2017) *Proposal for 220MCRII900 Industrial Battery Charger*, CSE.001.213.0049.

MCRII Series Industrial Battery Charger with 220VDC and 900A output

Battery Charger:

- MCR-II series phase controlled Battery Charger, **Input:** 415Vac, 50Hz, 3 Phase
- **Output:** 220Vdc, 900A
- Australian made, Australian Standards compliant, Industrial type charger, rugged construction, high reliability with 30 years design life
- The product has the combination of the most rugged and reliable AC to DC conversion, which is transformer and thyristor bridge with the most advanced microprocessor controlled technology to ensure a 30 year design.
- Note: All cabling and internal layouts would be as per Magellan standards.

Protection:

- 3 Pole Input MCB
- Double Pole Battery Output MCB
- Double Pole Load Output MCB

Features Included:

- Alarm Relay Board (voltage free alarm relays – Mains Fail, Battery Fail, Charger Fail, DC High, DC Low, Earth Fault)
- Blocking diode
- Communication Board (RS232/RS485 Modbus, DNP3, TCP/IP, Web Server)
- Battery Temperature compensation

Enclosure:

- **C200-3** Enclosure *(1600mmW x 800mmD x 2000mmH)* RAL 7035 grey – IP-42 rated. This will accommodate the charger.
- **Top cable entry**
  (Please see brochure attached)

Battery Bank:

NA
(Battery Brochures are submitted with the proposal in separate .pdf file)

Figure 152 Details provided in Magellan's quote (7 June 2017)

On 7 June 2017, CS Energy raised the following questions in relation to the quote, with Magellan's responses shown in blue, see Figure 153.[478]

Hopefully you guys have got the purchase order for the industrial inverter we have been discussing. Just had a few queries regarding the quotation you sent for the 900A battery charger.

1/ Please confirm that the cabinet will be suitable for top-entry of cables. Yes, top entry is ok. However, the dimensions will be now 2400mmW x 800mmD x 2000mmH

2/ Input voltage is listed as 415Vac, 3-phase. As a power generating site, our voltages are usually higher than their nominal rating. Could you please confirm the input tolerance (e.g. +-10%)? +/ 10% is not a problem. Would that be sufficient?

3/ The float voltage of the current charger is 240.8Vdc. Please confirm if this is possible with your charger. Yes, no problem, the float voltage will be 240.8VDC if you wish so.

4/ Is output voltage affected by input voltage? (I.E. If input voltage drops to 405Vac, should we expect to see the output DC voltage drop also?) No, its not, the output voltage is steady.

Figure 153 CS Energy queries to Magellan (in black) and Magellan's responses (in blue)

The questions raised by CS Energy above relate to the operation of the battery charger under typical operating conditions.

[478] Email (24 May 2017) *RE Industrial Battery Charger – CS Energy – Request for Quotation*, CSE.001.213.0044.

On 10 January 2018, this email was shared with the Technical Services Manager and then sent to the person who would later become the Modification Officer for the battery charger project. The correspondence did not identify the reason for sharing the information, but the prices quoted by Magellan on 19 May 2017 appear to be the source of the $47,580 quoted for a battery charger in an internal '*justification*' memo sent from Technical Services (Electrical team) dated 31 May 2018.[479]

19.6.3 Commencement

The '*justification*' memo was seeking approval of budget to replace the battery chargers in Unit C3, Station and Unit C4.[480] It did not include the inverters. The process was initiated because the existing battery chargers were requiring significant maintenance and associated costs to keep them operational, and there was a concern about the risk of a loss of availability.

The memo states: '*These chargers would be a straight swap and require minimal commissioning.*'

19.6.4 Concept Gate Approval Request

The CS Energy project approval process appears to commence with a request for a '*Concept Gate Approval*'. The Concept Gate Approval Request is a step in the formal procedure to obtain spending approval to take a project forward.

A Concept Gate Approval Request, dated 17 January 2018, sought approval for the *Callide C UPS & battery charger replacement* project (being the three Callide C battery chargers and the two inverters) from Concept to Execution.[481] The work was described as a '*like for like replacement*' on the Concept Gate Approval Request form. The budget included on the form appears to be based on the quote provided by Magellan on 19 May 2017.

Documents show that the Concept Gate Approval Request was not endorsed by the Major Projects Services Manager until 10 July 2018.[482]

19.6.5 Operations Plant Risk Assessment

A risk assessment was undertaken using the Operations Plant Risk Assessment (OPRA) template.[483] This is a step under the Plant Modifications Procedure, which should involve relevant specialists and disciplines to identify, assess, and determine controls for '*potential hazards/risks that may be introduced or current control measures affected by the proposed change*'.[484]

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[479] Memorandum (31 May 2018) *Justification for Replacement of Callide C 220VDC Battery Chargers*, CSE.001.213.0072. The quote from Magellan on 19 May 2017 has not been located. The quote dated 7 June 2017 of $69,000 was noted as being $21,420 more than the 19 May 2017 price and the memo states a price of $47,580 (i.e., $69,000 minus $21,420): Magellan Power (7 June 2017) *Proposal for 220MCRII900 Industrial Battery Charger*, CSE.001.213.0049.

[480] Memorandum (31 May 2018) *Justification for Replacement of Callide C 220VDC Battery Chargers*, CSE.001.213.0072.

[481] The request was prepared on 17 January 2018: Standard Form (17 January 2018) *Concept Gate Approval Request for Callide C UPS & battery charger replacement,* CSE.001.036.1593.

[482] The approval was given on 10 July 2018: Standard Form (10 July 2018) *Concept Gate Approval Request* for *Callide C UPS & battery charger replacement*, CSE.001.036.1510.

[483] Excel Spreadsheet (18 January 2018) *Callide Concept CS21019 Risk Assessment - Callide C UPS & 220V Battery charger Replacement January 2018*, CSE.001.036.1952.

[484] CS Energy (2016) *CS Energy Procedure for Plant Modifications CS-AM-010*, Section 5.2, Step 2, CSE.001.243.9479.

This risk assessment was the responsibility of the Modification Officer, and its requirements are shown in Figure 154.[485]

2	*Modification Officer*	*Assess risk in conjunction with other relevant specialists / disciplines as required.* *Use* Operations Plant Risk Assessment Template. Basis of risk assessment: what potential hazards/risks may be introduced or current control measures affected by the proposed change?

Figure 154 Requirements of the risk assessment taken from Section 5.2 of the Plant Modifications Procedure (2016)

It is a clear process safety requirement to involve specialists and other key stakeholders in the risk assessment, and to consider the impact on existing plant, but there are no specific requirements for the completion of the OPRA other than to use the template. This means that the quality of the risk assessment is dependent on the risk competency of those who carry it out.

The Check Sheet that was prepared later for the battery charger project stated that:[486]

> *These customs [sic] made critical power supplies impose high LOA risk and must get replaced. The C3, C4 and station(C0) 220V DC chargers and 240V inverters are used on equipment controls and instrumentation vital to the operations of Callide C station.*[487]

However, the OPRA completed on 18 January 2018 did not assess the risks of potential hazards being introduced, or the impact on current control measures.

Instead, the OPRA only examined the risks associated with not replacing the battery chargers. It was essentially an options analysis between replacing and repairing the existing battery chargers, and it did not assess the risks of carrying out the replacement itself, including the risk to the wider DC system.

Figure 155 shows a copy of the completed OPRA.[488]

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[485] CS Energy (2016) *CS Energy Procedure for Plant Modifications CS-AM-010*, Section 5.2, Step 2, CSE.001.243.9479.

[486] Author unknown (13 February 2018–20 February 2018) *Plant Modification Quality Plan and Check Sheet CS21019 – Callide C 240V UPS & 220V battery charger replacement*, CSE.001.225.0156.

[487] Underlining is added for emphasis. LOA = loss of availability.

[488] Excel Spreadsheet (18 January 2018) *Callide Concept CS21019 Risk Assessment – Callide C UPS & 220V Battery charger Replacement January 2018*, CSE.001.036.1952.

OPERATIONS PLANT RISK ASSESSMENT

Activity	**Callide C UPS and 220V Batteyr charger replacement**
Why do we need to carry out this activity?	Above chargers and inverters are original equipments since plant commissioning (2001) reached their useful life, internal electronic cards have started to failing due to aging and difficult to source the parts.
Assessment Team's Residual Risk Level	**SIGNIFICANT**
Assessment Team's Planned Risk Level	**LOW**
Assessment Team's Recommendations	**Option 1 is recommended**
Nominate the risks associated with this activity	Lack of project planning could impact completion delays. Risk = Low x Unlikely = Low
Nominate the advantages of this activity	- Improved safety on operators and maintainers by replacing aged / unreliable equipment - Improved reliability of the plant and minimise potential LOA risk - Parts availability and new equipment design life is for rest of Callide C life -25 years - Reduced operating cost of repairs
OEM's recommended action (if any)	
Risk Assessment Team Leader	[redacted]
Risk Assessment Team Members	[redacted]
Manager Review and Approval	
DATE APPROVED	**DATE APPROVED TO** (will need to be reviewed beyond this date)

Activity, Issue or Concept	Identified Hazards and Adverse Consequences	Existing Control Measures	Residual Risk Level – Consequence	Residual Risk Level – Likelihood	Recommended Control Measures / Treatment Actions	Planned Risk Level – Consequence	Planned Risk Level – Likelihood	Responsible Person
Callide C 220V battery chargers & UPS units are original equipments made in 2001, have already reached their end of life. We have already experienced two failure events of Callide C: station 220V battery charger and station invertor recently due to aged components. Above fault incident investigations and repairs involves with numerous amount of plant resources and time consuming to find out replacement parts .	Repairing these equipments will obviously be costly to design out the replacement with none OEM parts and it will also be a risk to unit production. In event of one charger or ups failure, there is a redundancy to feed from an other charger or feed UPS board from main switch board. Switching additional loads on to existing old chargers is not recommended considering aged equipments. Recovery of a failed charger will obviously be taken approximately 3-4 months. This could lead both units in to a significant LOA risk. **Operational Risk :** 30% probability for a 4 days unit down time for a temporary repair = one event per unit over next three years period is $725K	- Availability of system redundancy to configure the failed inverters out put to be fed from the main board - Failed 220V charger is in repair process - Failed station UPS was replaced with current UPS unit	Medium **Significant**	Likely	**Option 1:** Upgrade with new chargers & inverters **Cost:** $500K **Risk :** Medium x Unlikely: Low	Medium **Low**	Unl kely	**Engineering / Asset management**
					Option 2: Procure design out parts and change out at failure events. Use redundancy (other unit's charger/inverter) during repair period. **Parts Cost:** > $20K **Disadvantage**: Risk of LOA for design out ~$725K **Operational risk :** Medium x Possible : Moderate	Medium **Significant**	Likely	**Engineering / Asset management**

Depending on the activity being assessed you will need to supply / attachment / link:

Supporting information

Equipment age / service duty / redundancy / modification history / maintenance history:
Failed 240V UPS - Repair was delayed due to lack of parts in market, This yunit was alraeady replaced with a new UPS
Failed 220V battery charger is waiting for replacement parts, and technical support after installation to return to service

Figure 155 OPRA for the *Callide C UPS & battery charger replacement* project (i.e., the three battery chargers and two inverters) (January 2018)

If the OPRA had been carried out in accordance with the Plant Modifications Procedure, and relevant specialists and disciplines had been involved to identify, assess, and control potential hazards and risks, this could have increased the likelihood of identifying the risks associated with bringing the replacement battery charger into service. Completed properly, the process of carrying out the risk assessment could have potentially provided awareness across the relevant Callide teams (and, depending on the residual risk level, escalation to more senior staff) of the work and the associated risks.

Only two personnel completed the OPRA

As it was, the OPRA did not consider process safety risks. It was carried out by only two personnel, who were both from the Asset Engineering team.[489] These two personnel also undertook the roles of Modification Officer and the Technical Services Manager for the purposes of the Plant Modification Quality Plan and Check Sheet.[490] Without the involvement of other specialists and personnel from a range of disciplines, as is required by the Procedure, the potential for risk identification was limited to the perspectives of these two personnel.

Further, the Plant Manager and the Technical Services Manager are the only two signatories on the Check Sheet (for non-financial and non-document management aspects), until the Review and Acceptance stage (which occurs after implementation of the modification). In this case, the Modification Officer was also the Plant Engineer, so to the limited extent that the Plant Modifications Procedure was followed, there was no input from anyone other than these two personnel (the Modification Officer and the Technical Services Manager).

The OPRA found that, while replacement of the battery charger reduced the risk from 'significant' to 'low', repair of the battery charger did not reduce the risk level. The Risk Assessment team recommended replacement as the preferred course of action. Because the residual risk was 'low', the OPRA was not required to be signed off by the Group Manager (Assets). It did require sign-off by the Technical Services Manager, but no evidence has been sighted of this sign-off (despite the Technical Services Manager being one of the two personnel who completed the OPRA).[491]

This OPRA is the only evidence that has been sighted of a risk assessment for the replacement of the Unit C4 battery charger. It did not consider the risk associated with the potential impacts of the replacement battery charger on existing equipment.

19.6.6 JV Management Committee Approval

A memo dated 28 February 2018 was sent to the Joint Venture Management Committee (JVMC) seeking approval of a budget of $500,000 for the replacement of three battery chargers and two inverters at Callide C (which are the items that were tendered together as one project: the *Callide C*

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[489] CS Energy at Callide has two main departments: Operations and Asset Management. Asset Management is split into two sections: Asset Maintenance and Asset Engineering.

[490] The Modification Officer is responsible for 'shepherding' the plant modification through to completion. They are responsible for compliance with the Plant Modifications Procedure. (CS Energy (2016) *CS Energy Procedure for Plant Modifications CS-AM-010*, 8.4, CSE.001.243.9479). The Technical Services Manager is the manager responsible for all technical/engineering matters on site. (CS Energy (2016) *CS Energy Procedure for Plant Modifications CS-AM-010*, 1, CSE.001.243.9479). The Risk Assessment Team only consisted of these two personnel (the Modification Officer and the Technical Services Manager). See Figure 155 where only two people are named (redacted).

[491] Further discussion of the Plant Modification Quality Plan and Check Sheet is included in Section 19.6.7 and Figure 156 to Figure 161.

UPS & battery charger replacement project).[492] It was approved at the Joint Venture Operations Meeting in March 2018.[493]

No evidence has been sighted that shows the extent of JVMC visibility over the battery charger project other than this approval.

19.6.7 The Plant Modification Quality Plan and Check Sheet

The only evidence sighted that the Plant Modifications Procedure was complied with (in part) is a partially completed Plant Modification Quality Plan and Check Sheet,[494] and an entry in the plant modification register as noted in Section 19.5.5.

A Plant Modification Quality Plan and Check Sheet was completed for the stages of Initiation, Assessment, and partly, Design. All three of these sections were completed on the same date,[495] and all sections signed off for approval only one week later.[496] The form purported to cover the Unit C3 battery charger, the Unit C4 battery charger, and the Callide C Station battery charger, as well as the two Callide C inverter replacements, see Figure 156.

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[492] Memorandum (28 February 2018) *Joint Venture Management Committee (JVMC) Memorandum, Callide C3 & C4 220V battery chargers and 240V AC UPS replacement*, CSE.001.213.6777.

[493] Minutes (20 March 2018) JV Operations Meeting, Item 5bi, CSE.001.213.7558.

[494] Author unknown (13 February 2018–20 February 2018) *Plant Modification Quality Plan and Check Sheet CS21019 – Callide C 240V UPS & 220V battery charger replacement*, CSE.001.225.0156.

[495] 13 February 2018.

[496] 20 February 2018.

PLANT MODIFICATION QUALITY PLAN AND CHECK SHEET

Note: Refer to CS-AM-010 Plant Modification Procedure for further information

SITE:	☒ Callide ☐ Kogan Creek ☐ Wivenhoe
STATION:	☐ A ☐ B ☒ C ☐ Common ☐ 1 ☐ 2 ☒ 3 ☒ 4

Modification Description:	CS21019 - Callide C 240V UPS & 220V battery charger replacement		
Plant Area Strategy:	CC-PAS-12-EQ08 & 09		
Plant KKS:	CC3*, CC4*, CC0*	**Plant Criticality (A,B,C,D):** (Refer to SAP Functional Location)	B

1	**INITIATION**	
1.1	SAP Notification Number	10531219 PR/18/~~29~~ 68 (~~CS21019~~) CS18548
1.2	Problem Statement:	The Callide C Station power supplies are made in 2001 has reached their end of use full life. These customs made critical power supplies impose high LOA risk and must get replaced. The C3, C4 and station(C0) 220V DC chargers and 240V inverters are used on equipment controls and instrumentation vital to the operations of Callide C station. One 240V AC inverter was failed late last year and was replaced with a current invertor model due to high operational risk of LOA. Out of the three off battery chargers, one was failed last year and is not possible to repair due to incompatibility of parts available. Repairs of these custom-made equipment are costly and time consuming with significant resource involvement with complexity to source and redesign circuits around the ancient components. Concept paper C/D/18/819
1.3	Suggested Solution:	Replace old charger and UPS units during FY19 and FY20 unit summer readiness opportunities
1.4	Define Costs, Benefits & Justification:	• LOA risk reduction for rest of plant life; • Man, hours reduction on investigation and troubleshooting of obsolete equipment failures; • Spare parts and OEM service support availability; • NPV=$250,000; Pay Back 3 years.

Figure 156 Excerpt from Plant Modification Quality Plan and Check Sheet for the new battery chargers for Unit C3, Unit C4 and Station, and new Callide C inverters

In other words, one form was used for all of the works instead of one form per modification.[497]

All signatures on the Check Sheet are dated prior to the battery charger project being tendered (13 February 2018 and 20 February 2018), including the signature (redacted) in Section 3(b) (see Item 3.3 in Figure 160), which indicates that design has been completed and is approved for implementation. It is not known on what basis the design was signed off in February 2018, when, at this time, the design, manufacture, supply and install contract had not even been tendered.[498]

[497] The Plant Modifications Procedure does not specifically state whether several items of work can be treated as a single modification or not. However, even identical work that is repeated in different locations cannot be effectively managed as one modification if each item of work is done at a different time and under different circumstances. It seems apparent that individual modifications to specific items of plant should follow the Procedure as individual modifications. In this case, inverters are different to battery chargers, so the modifications associated with these two types of equipment is not the same.

[498] The plant criticality of the charger is identified in Figure 156 as criticality 'B'.

Figure 157, Figure 158 and Figure 160 show all the signatures (redacted) on the most completed version of the Check Sheet that has been located by the Brady Heywood investigation.

The modification was added to the plant modification register (as a single item even though the Check Sheet covered three battery chargers and two inverters).[499] No evidence has been sighted of the Plant Modifications Procedure being complied with from this point.[500]

Figure 156 and Figure 157 together show the first page of the Check Sheet that covers the items relating to the Initiation stage of the Plant Modifications Procedure. This page has almost been correctly completed, lacking only the signature at Item 1.9 to indicate that the Technical and Support Requirements in Section 3 had been reviewed and preliminarily approved.

		• NPV=$250,000; Pay Back 3 years.					
1.5	**Modification Endorsement** (Plant Engineer) Z3 Notification Status = CHECKED	☒ Yes ☐ No	[redacted]	Date	13	2	18
1.6	**Approval to proceed to Assessment** (Technical Services Manager) Z3 Notification Status = IN PROCESS	☑ Yes ☐ No	[redacted]	Date	20	2	18
1.7	Modification Officer (Nominated by Technical Services Manager)	[redacted]					
1.8	Prioritisation Score: "B/D/11/31607"	(Signature)	[redacted]	Score	250		
1.9	Preliminary assessment of Technical and Support Requirements. Refer to Section 3	(Signature)					
1.10	Z200 Work Order Number. Z200 Work Order Status = CREATED	No WO is required from above Z3 notification. A project work order will be created after on line approval granted					
1.11	Create TRIM folder and enter details into the Register	(Signature)	[redacted]	Date	13	2	18
1.12	Reference TRIM Record No. in the SAP Notification & Work Order:	(Signature)	[redacted]	Date	13	2	18

Figure 157 Signatures on the Initiation page of the Plant Modification Quality Plan and Check Sheet, unsigned at Item 1.9

Figure 158 is the page in the Check Sheet which includes the sign-off for the Assessment stage of the Plant Modifications Procedure.

[499] The Callide C 220 V UPS and battery charger replacements are on the register at Line 718, with MOD number PR/18/29 (the same modification number as for the Callide B 220 V UPS and battery charger replacement project) opened on 13 February 2018. This is the same as the preparation date for the Plant Modification Quality Plan and Check Sheet: Excel Spreadsheet *Callide Power Station Plant Modification Register*, CSE.001.243.2708.

[500] The modification process was referred to in an email from the Project Lead on 24 May 2021, but no evidence has been sighted that directly addresses the prescribed steps in the Plant Modifications Procedure since the early stages of the battery charger project. Email (24 May 2021) *RE: CC4BTL10 Battery Charger RTS,* CSE.001.045.0004.

2	ASSESSMENT						
2.1	Prepare Design Brief. (Modification Officer)	(Signature)	[redacted]	Date	13	2	18
2.2	Complete Risk Assessment for plant change:	What potential hazards or risks may be introduced or current control measures affected by the proposed plant change/s?					
		"B/D/13/15225"	TRIM Record No:	C/D/18/852			
	Risk Level – Introduced or affected by plant change:	(Residual Risk) ☒ Low	☐ Moderate	☐ Significant	☐ High		
	NOTE: "Significant" or "High" residual risks require Group Manager Assets to review and approve.						
	Comments:						
2.3	**Risk Assessment Approval:** (Technical Services Manager)	(Signature)		Date:			
2.4	**Risk Assessment Approval:** (Group Manager Assets)	(Approved for Significant or High Residual Risks)		☐ Yes ☒ N/A			
		(Signature)		Date:			
2.5	**Financial Approval to Proceed to Design Phase** (Note 1) (Financial Delegate)	Cost Centre	(Signature)	Date			
2.6	**Technical Approval to Proceed to Design Phase** (Technical Services Manager) Z200 Work Order Status = RELEASED	☑ Yes ☐ No	[redacted] (Signature)	Date	20	2	18

Figure 158 Signatures (redacted) on the Assessment page of the Plant Modification Quality Plan and Check Sheet, unsigned at Items 2.3 and 2.5

It has been signed to indicate that a Design Brief was prepared and that the outcome of the risk assessment (which is referring to the Operations Plant Risk Assessment, see Section 19.6.5) was a low residual risk, although it has not been signed off to indicate approval of the risk assessment itself, at Item 2.3. (The Financial Approval has not been signed off at Item 2.5 either.) Despite this, Item 2.6 has been signed off as approval to proceed to the Design stage of the Procedure.

Figure 159 documents the first part of the Design stage: the proposed Technical and Support Requirements have been completed, as is required as part of the Initiation stage.

3	DESIGN					
3 (a)	TECHNICAL AND SUPPORT REQUIREMENTS					
Technical and Support Requirements to be Revised / Created	REQUIRED Technical Services Manager must initial if checking "No"		FINALISED Technical Services Manager must initial each as "Finalised"		Description of what evidence is required to demonstrate completion.	Comments / TRIM Record No.
ITP:	☑ Yes ☐ No		☐ Yes		Hard copy of ITP	
Work Packs:	☐ Yes ☑ No		☐ Yes		List of the documents contained in the work pack.	
Plant Area & Equipment Strategies:	☑ Yes ☐ No		☐ Yes		Copy of relevant pages updated in Equipment Strategy.	
Drawings: (CS-AM-001)	☑ Yes ☐ No		☐ Yes		Copy of email confirming registration and attachment to functional location in SAP.	
O&M Manuals:	☑ Yes ☐ No		☐ Yes		Copy of email confirming registration and attachment to functional location in SAP.	
Process & Training Manuals: (Including Operating Procedures)	☑ Yes ☐ No		☐ Yes		Copy of revised operating procedures or advice to operators.	
Standard Isolation Sheets:	☐ Yes ☑ No		☐ Yes		Identification of any SIS that will be impacted.	
Return to Service Check Sheets:	☑ Yes ☐ No		☐ Yes		Documented commissioning and hand over procedure.	
Spares Inventory: (Old-Obsolescence, New – Additional spares, catalogued, BOM identified, standardisation)	☑ Yes ☐ No		☐ Yes		Copy of ZSIR. Copy of BOM.	
Safety Instrumented Systems:	☐ Yes ☑ No		☐ Yes		Copy of the entry in SIS dossier.	
Cable Schedules:	☐ Yes ☑ No		☐ Yes		Copy of entry in cable schedule.	
Lubrication Schedules:	☐ Yes ☑ No		☐ Yes		Copy of PM Change form for lubrication schedule.	
Statutory Registration – Design & Plant: (CS-AM-012)	☐ Yes ☑ No		☐ Yes		Copy of advice to DWPH&S.	
Fire Systems:	☐ Yes ☑ No		☐ Yes		Evidence of compliance with standards.	
KKS Database: (New / Delete)	☐ Yes ☑ No		☐ Yes		Copy of changes or additions to KKS numbering.	
KKS Plant Labels: (New / Delete)	☐ Yes ☑ No		☐ Yes		Photo of labels in place on plant.	
SAP Master Data: (Classification Data)	☐ Yes ☑ No		☐ Yes		Evidence from Planner of implemented changes.	
SAP PM Routines:	☐ Yes ☑ No		☐ Yes		Evidence from Planner of implemented changes.	
ICMS Screens:	☐ Yes ☑ No		☐ Yes		ICMS screen shot showing changes.	
ICMS Databases:	☐ Yes ☑ No		☐ Yes		Copy of Bemex page showing new settings.	
Pressure Equipment: (Register, Manual, Matrix, Forms)	☐ Yes ☑ No		☐ Yes		Copy of email from Chief Mechanical Engineer.	
Staff Training: (Effected Personnel Trained Appropriately)	☑ Yes ☐ No		☐ Yes		Details of training dates and training scope.	
Communication: (Change Effectively Communicated to all Personnel)	☑ Yes ☐ No		☐ Yes		Copy of communications to relevant staff.	
Hazardous Area Dossier:	☐ Yes ☑ No		☐ Yes			
Other:	☐ Yes ☑ No		☐ Yes			
Requirements Finalised: Technical Services Manager	(Signature)				Date:	

Figure 159 Plant Modification Quality Plan and Check Sheet (red boxes indicating lack of signature)

However, these have not been signed off as accepted by the Technical Services Manager. This is also reflected in Figure 157 above where Item 1.9 has not been signed off to indicate the proposed Technical and Support Requirements had been preliminarily assessed by the Technical Services Manager.

Figure 160 shows the second part of the Design section.

3 (b)	DETAILED DESIGN					
3.1	Design Prepared:		☒ Yes ☐ No	TRIM Record No:	C/D/18/~~1873~~ 1874	
3.2	RPEQ, Safety and Environmental Advisors – Approval to Implement:		Where discipline RPEQ or Advisor is not required, tick NO (Technical Services Manager must Initial)			
	Discipline / Advisor	Required?	RPE Number	Name	Signature	Date
	Electrical (Power):	☐ No				
	Electrical (Control):	☐ No				
	Mechanical:	☐ No				
	Civil:	☐ No				
	Chemical:	☐ No				
	Risk & Safety Advisor:	☐ No				
	Environmental Advisor:	☐ No				
	Operations:	☐ No		[redacted]		
	Inventory Specialist:	☐ No				
3.3	Design completed and Approval to Implement Modification: (Technical Services Manager) Z200 Work Order Operation 010 status = FINAL CONFIRMED		(Signature)		Date:	20 2 18

Figure 160 Signature (redacted) on the Design page of the Plant Modification Quality Plan and Check Sheet (red box has not been completed)

Other than a tick box indicating that a design has been prepared, this has not been completed at all. Despite this, the Design stage was signed off (redacted) as completed and approval given to implement the design, as shown at Item 3.3 in Figure 160 above.

As discussed above, the date of this signature is one week after the Check Sheet was prepared and prior to the work being put out to tender.

Figure 161 shows the remaining sections of the form – Implementation, Review and Acceptance and Closure – which were not completed, with the minor exception of a tick indicating it was a Project budget item, although this was not signed off.

4	**IMPLEMENTATION**						
4.1	**Is this project to be implemented as:** • **Operational expense** • **Project capital** • **Overhaul capital**	☐ **Opex** ☑ **Project** ☐ **Overhaul** (Signature) *Finance Representative*		Date:			
4.2	**Implementation complete and in accordance with approved design.** (Project Manager or Delegate)	(Signature)		Date:			
4.3	**Implementation complete and in accordance with approved design** (Modification Officer) Z200 Work Order Operation 020 Status = FINAL CONFIRMED	(Signature)		Date:			
5	**REVIEW AND ACCEPTANCE**						
5.1	**Accepted for Operation:** Technical Services Manager	(Signature)		Date:			
	Plant Manager, Production Manager. Z200 Work Order Operation 030 Status = FINAL CONFIRMED	(Signature)		Date:			
6	**CLOSURE**						
6.1	Technical and Support Requirements Finalised.	(Signature)		Date:			
6.2	Modification Work Order Closed.	(Signature)		Date:			
6.3	Modification Register Finalised.	(Signature)		Date:			
6.4	Modification File Closed. Z200 Work order = TECO	(Signature)		Date:			

Figure 161 The final three sections of the Plant Modification Quality Plan and Check Sheet

19.6.8 Summary of Battery Charger Project Prior to Tendering

Although a Plant Modification Quality Plan and Check Sheet was partially completed for the first three stages of the Plant Modifications Procedure, no evidence has been sighted that shows further stages of the Procedure were followed in the delivery of the battery charger project. Further, the stages that were completed were not in proper accordance with the Procedure.

A failure to carry out a risk assessment using the OPRA template that involved the relevant specialists and disciplines was a missed opportunity to identify, assess, and control potential hazards and risks associated with the battery charger project. Had this been completed, the assessment could have increased the likelihood of identifying the risks associated with bringing the battery charger into service. It could also have potentially provided awareness across the relevant Callide teams (and, depending on the residual risk level, escalation to more senior staff) of the work and the associated risks.

19.7 Tender

19.7.1 Technical Requirements

Despite receiving a quote from Magellan in May 2017 and June 2017 for the replacement of the battery chargers, CS Energy issued a tender package to the market in or around early June 2018 for the replacement of the battery chargers in Unit C3, Unit C4, and Station, and two replacement inverters for the Callide C power station.[501] By way of technical requirements, it only contained the following details for the specification for the Callide Unit C4 Battery Charger, under the heading '*Detailed Scope of Work*' in the Invitation to Tender (Section C – Scope of Work) document:

> *Input: 3 Phase, 415V, 50Hz*
>
> *Output: 220V DC, 900Amp*

The following details were provided regarding the battery that the battery charger would connect to:[502]

> *Note: Callide C station 220V DC system consists of three battery strings.*
>
> *Each C3, C4 and station (C0) battery strings consist of 108 off PowerLYTE PXL 2v2000 Valve regulated Lead- Acid (VRLA) Flame Retardant 2.23V batteries, replaced in year 2015.*

These requirements are consistent with the battery charger in typical operating conditions. The specification did not state requirements for the dynamic response of the battery charger (e.g., as required during the switching sequence). At a minimum, this would have included:

- Specification of how the battery charger was to operate when there was no battery connected.
- How two battery chargers were to operate when connected to the same system (i.e., when the battery chargers are operating in parallel).

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[501] CS Energy (5 June 2018) *Invitation to Tender (ITT) Section A, ITT No. 488636, Callide C 220V DC Charger and 240VAC UPS Replacement – 2018*, CSE.001.115.0170; CS Energy (5 June 2018) *Invitation to Tender (ITT) Section B – Conditions of Contract*, CSE.001.115.0187; CS Energy (5 June 2018) *Invitation to Tender (ITT) Section C – Scope of Work*, CSE.001.115.0237; CS Energy (5 June 2018) *Administrative Schedules A1-A3,* CSE.001.281.0001; CS Energy (5 June 2018) *Administrative Schedules [sic] A4*, CSE.001.281.0009; CS Energy (5 June 2018) *Administrative Schedules A5-A8,* CSE.001.281.0011; CS Energy (5 June 2018) *Contractor Management Process, Health and Safety Prequalification Questionnaire*, CSE.001.281.0019; CS Energy (5 June 2018) *Schedule A10 – Environmental Questionnaire*, CSE.001.281.0020; Drawing (5 June 2018) *C-742848 02.pdf,* CSE.001.115.0276; Drawing (5 June 2018) *C-742849 02.pdf,* CSE.001.115.0277; Drawing (5 June 2018) *C-747537 01-Model.pdf,* CSE.001.115.0278; Drawing (5 June 2018) *C-742539 01-Model.pdf,* CSE.001.115.0279; Drawing (5 June 2018) *C-742549 02-Model.pdf,* CSE.001.115.0280; Drawing (5 June 2018) *C-742568 01.pdf,* CSE.001.115.0281; Drawing (5 June 2018) *C-742572 01-Model.pdf,* CSE.001.115.0282; Drawing (5 June 2018) *C-742574 01-Model.pdf,* CSE.001.115.0283; Drawing (5 June 2018) *C-747600 08.pdf,* CSE.001.115.0284; Drawing (5 June 2018) *C-747601 L.pdf,* CSE.001.115.0285.

[502] There had been a planned change to the float voltage system for some time, but it had still not been implemented by the time of tendering for the battery charger project, so this was also included in the specification:

Callide engineering team has decided to change the current float voltage (240.84VDC) setting to 227.46V in a future modification. This modification will be applied by the time of implementation of these work [sic]. Therefore, the Contractor needs to be aware of the change in battery voltage.

19.7.2 Other Requirements

There was no further information in the tender specific to the design of the battery charger, and there was no detail about testing requirements.[503]

19.7.3 Risk Assessment

The only risk assessments required by the specification were Job Safety and Environment Analyses (JSEA),[504] which focused only on the personal safety of personnel working on the battery charger, and not process safety (which, in this case, includes the potential impacts the new battery chargers could have on the wider system).

19.7.4 Standard Specifications

The specification referenced standard CS Energy and Australian Standards documents. The CS Energy standard documents did not provide information regarding operational requirements of the battery chargers.

19.7.5 Absence of Reference to *AS 4044 – 1992: Battery Chargers for Stationary Batteries*

The specification only directly referenced the following Australian Standards by name, see Figure 162:[505]

The following Australian Standards are referenced. It shall be the vendor's responsibility to obtain copies of the following if required.

Standard no.	Title
AS3000: 2007	Australian Wiring Rules.
AS2467:2008	Maintenance of Electrical Switchgear Registered

Figure 162 Section 8.6 of Invitation to Tender (ITT), Section C – Scope of Work

The Australian Standard for battery chargers, *AS 4044 – 1992: Battery chargers for stationary batteries*,[506] was not named in the specification as a referenced document, even though it is more relevant to the scope of services than the two Standards that were specifically referenced.

AS 4044 – 1992: Battery chargers for stationary batteries was, however, included in a list of 166 documents in *CMP-TL-0048 – Standard Specification – Electrical Design Criteria (08/2017) – Callide*

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[503] The remainder of the Detailed Scope of Work section of the specification contained requirements that were not specific to the equipment being supplied, such as '*install new chargers and inverters*' and '*Test and commission, submit signed ITP's [sic] and test sheets*'. There were only general requirements for the contractor to provide inspection and testing data and certificates and a commissioning plan. The test procedures required approval by CS Energy, but there was no guidance on what was required. CS Energy therefore relied on the supplier to prepare procedures that met CS Energy's requirements. Sections 19.8.7 and 19.8.8 provide further details.

[504] The obligation to complete this JSEA was on Magellan, as the successful tenderer. Specified in CS Energy (5 June 2018) *Invitation to Tender (ITT) Section C – Scope of Work*, Section 2.1, Section 6.1, CSE.001.115.0237.

[505] CS Energy (5 June 2018) *Invitation to Tender (ITT) Section C – Scope of Work*, Section 8.6, CSE.001.115.0237.

[506] Australian Standards are subject to copyright so cannot be reproduced in full in this document. Standards Australia (2010) *AS4044 – 1992: Battery chargers for stationary batteries.* https://store.standards.org.au/product/as-4044-1992

Registered (C/D/17/11564).[507] This was one of the three CS Energy documents identified in the specification that the successful tenderer was required to comply with. It is unknown if Magellan was provided with a copy of *CMP-TL-0048*.[508]

The scope of *AS 4044 – 1992* is shown in Figure 163.

> **1 SCOPE** This Standard specifies requirements for stabilized constant-potential battery chargers that are designed to supply direct current power from an alternating current source, while charging a float-type stationary battery, and which may simultaneously supply power to a connected direct current system load.

Figure 163 Scope section from *AS 4044 – 1992: Battery chargers for stationary batteries*

This Standard sets out the design requirements for a battery charger, and the tests to be carried out to assess the battery charger's performance against requirements.

Appendix A of *AS 4044 – 1992* contains '*Information to be Supplied by the Purchaser*', which recommends the information to be provided by the purchaser to specify the battery charger, including:

> *unusual service conditions may require specific design considerations and the following unusual service conditions should be brought to the attention of the manufacturer … Operation without a battery.*[509]

CS Energy did not provide this information in the specification. Nor did they require Magellan to confirm these details with respect to the battery charger it proposed to supply.

If Appendix A of *AS 4044 – 1992* had been used by CS Energy to specify the Unit C4 battery charger, it could have increased the likelihood of identifying the specific performance requirements of the battery charger without a battery connected.

19.7.6 Concept Gate Approval Request

As discussed above, the Concept Gate Approval Request was dated 17 January 2018 and approval was given on 10 July 2018.[510]

19.7.7 Feasibility Gate Approval Request

The Feasibility Gate Approval Request was the next step to obtain approval for funding to progress a project. On 13 July 2018, a Feasibility Gate Approval Request was prepared for the *Callide C UPS & battery charger replacement* project (three Callide C battery chargers and the two inverters).[511] This was to take the project from Feasibility to Execution.

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[507] The specification references Trim Document Number C/D/17/11564, described as '*Procedure - CMP-TL-0048 – Standard Specification – Electrical Design Criteria (08/2017) – Callide Registered*'. When requested from CS Energy, the following document was provided. It is understood that they are the same document, as the Trim Document Number is identical, even though the documents are dated differently. CS Energy (10 May 2017) *CS Energy Standard for Callide – Electrical Design Criteria, C/D/17/11564*, CSE.001.282.0001.

[508] This CS Energy standard document was listed in the specification. It is not known if Magellan was provided with a copy.

[509] Standards Australia (2010) *AS4044 – 1992: Battery chargers for stationary batteries,* Appendix A, Item 11(q), CSE.001.100.0901.

[510] Standard Form (10 July 2018) *Concept Gate Approval Request*, 5, CSE.001.036.1510.

[511] Standard Form (13 July 2018) *Feasibility Gate Approval Request* for *Callide C 240V UPS and 220V Battery Charger Replacement,* CSE.001.036.1505.

Evidence of an approval of the Feasibility Gate Approval Request has not been sighted.

19.7.8 Assessment of Tender Responses

CS Energy received six responses to the Invitation to Tender from parties invited to tender for the work, which included the replacement of three battery chargers (including Unit C3, Unit C4 and Station) and two inverters, see Table 4.

Table 4 Tender prices received for the *Callide C UPS & battery charger replacement* project

Party	***Tender Price***[512]	***Tender Evaluation Score***
Century Yuasa	$584,149.49	6.69
CPS National	$639,194.10	2.28
Magellan Power	$531,800.00	6.55
Prysmian	Declined	N/A
Voltstar	$406,540.00	1.75

In the tender assessment, Magellan scored marginally lower than the top-scoring tender submitted by Century Yuasa. (There was, however, an error in the compilation of the scores: Magellan's final score should have been 7.682, compared to 7.5985 for Century Yuasa's tender.) Magellan's price was cheaper than Century Yuasa by approximately $52,000.

The technical review of Magellan's tender noted:[513]

> *2 page brochure supplied for battery charger. No technical info on any electrical equipment.*
>
> *Equipment standardised against existing installed plant. No additional requirement for modifications, training, tooling, or parts stocking/allocation.*

Magellan scored an 8 out of 10 against the technical criteria: '*meet required technical specs*', despite no technical information being provided in the tender response. No evidence has been sighted that indicates further information was provided to Magellan, or that Magellan made enquiries to obtain further information about how the battery charger was to operate. No evidence has been sighted of how CS Energy satisfied themselves that Magellan should score 8 out of 10, given they had provided '*No technical info on any electrical equipment*'.[514]

[512] All amounts are understood to be exclusive of GST, although it is not expressly stated other than in Magellan's tender response where it is stated as exclusive of GST, and the final price included in the contract is exclusive of GST, as stated in the Contract between CS Energy and Magellan Powertronics Pty Ltd (2 October 2018) *Design, Manufacture, Supply and Install Contract, Contract No. 488466,* Clause 14.4, CSE.001.004.0028.

[513] Excel Spreadsheet *488636 – Callide C 220V DC Charger and 240VAC UPS Replacement – 2018 – 04 Evaluation Tender Evaluation,* Worksheet: Comments for TAR, CSE.001.080.0121.

[514] Excel Spreadsheet *488636 – Callide C 220V DC Charger and 240VAC UPS Replacement – 2018 – 04 Evaluation Tender Evaluation*, Worksheet: Comments for TAR, Technical Review comment for Magellan, CSE.001.080.0121.

19.7.9 Contract Award

In addition to the tender response for the *Callide C UPS & battery charger replacement* project, Magellan had provided tender responses for two other CS Energy packages of work around the same time.[515] At the end of June 2018, the Plant Engineer (Electrical) recommended that Magellan be awarded the *Callide C UPS & battery charger replacement* project at the same time as the two other package of work, primarily because of the perceived potential to negotiate a more competitive price for all three packages of work, see Figure 164 below.[516]

> I have also put together the attached tender summary document taking into account the following associated works;
>
> 488466 B2 220V DC Charger and 240V AC UPS Replacement
> 488445 Callide B1 B2 48V DC Charger Replacement
>
> Given the similar nature of all three packages, and potential commercial, execution, and project management synergy's I am recommending that we award all three packages to Magellan. As a result I would recommend that we contact Magellan advising them as such in order to obtain a more competitive price.

Figure 164 Recommendation to award to Magellan

A final price for all three packages of $1,232,070 was agreed with Magellan.[517] This was reduced from the total tendered price of $1,310,830, with the *Callide C UPS & battery charger replacement* project reduced to $506,000 from $531,800.[518] The contract for the three packages of work was executed on 2 October 2018.[519]

The information submitted by Magellan with its tender response, and the notes from CS Energy's assessment of Magellan's tender response (including the high technical scoring), suggest that neither party understood the full operational requirements of the battery charger. It appears that the battery charger project was being treated as if it was *only* a battery charger, as opposed to a critical piece of equipment that did more than charge batteries.

19.7.10 Tender Summary

The specification contained in the Invitation to Tender documents issued by CS Energy for the battery charger project specified the requirements for the Unit C4 battery charger under typical operating conditions. The specification did not specify requirements for the behaviour of the battery charger as required by the switching sequence when bringing the new battery charger into service.

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[515] These two other packages were the *Callide B2 220V DC Charger and 240V AC UPS Replacement*, and the *Callide B1 and B2 48V DC Charger Replacement*.

[516] Email (28 June 2018) *RE 488636 – RFI – Callide C 220V DC Charger and 240VAC UPS Replacement – 04 Evaluation*, CSE.001.216.7579.

[517] All amounts are understood to be exclusive of GST, although it is not expressly stated other than in Magellan's tender response where it is stated as exclusive of GST, and the final price included in the contract is exclusive of GST, as stated by the Contract between CS Energy and Magellan Powertronics Pty Ltd (2 October 2018) *Design, Manufacture, Supply and Install Contract, Contract No. 488466,* Clause 14.4, CSE.001.004.0028.

[518] Email (6 September 2018) *RE: CS Energy : Callide Contract*, 12:58 PM, CSE.001.217.9714.

[519] Contract between CS Energy and Magellan Powertronics Pty Ltd (2 October 2018) *Design, Manufacture, Supply and Install Contract, Contract No. 488466,* CSE.001.004.0028.

AS 4044 – 1992: Battery chargers for stationary batteries sets out the design requirements for the type of battery charger that was being procured and provides a recommendation of the information to be provided to suppliers to specify the battery charger required. The specification did not provide the details recommended by the Standard, and did not follow the recommendation that '*unusual service conditions may require specific design considerations and the following unusual service conditions should be brought to the attention of the manufacturer … Operation without a battery*'.[520]

The tender response submitted by Magellan lacked technical information about the battery charger it proposed to install. However, CS Energy expected that a reduced price could be obtained from Magellan if the *Callide C UPS & battery charger replacement* project was awarded to Magellan at the same time as the two other packages for battery charger and inverter works (at Unit C3 and Station). A reduced price was obtained from Magellan, and all three packages were awarded to Magellan.

19.8 Delivery of the Battery Charger Project

19.8.1 Delivery Under the Plant Modifications Procedure

There is evidence that the battery charger project was referred to as a '*like for like replacement*'.[521] There is also evidence that, at the same time, the Plant Modifications Procedure was nominally followed in the initial stages of the battery charger project.

Although no evidence has been sighted to indicate compliance with the Plant Modifications Procedure beyond the Assessment stage, it was conveyed by senior staff in the early stages of the battery charger project that they considered the work to constitute a '*plant modification*'.[522]

On 2 July 2018, the Head of Projects flagged that the '*MOD form*' needed to be updated before he would sign off on the budget for the *Callide C UPS & battery charger replacement* project.[523] At the time of approval of the Concept Gate on 10 July 2018,[524] the Major Projects Services Manager and Project Governance Manager approved it to the Feasibility stage, but stated '*Get plant change request signed off as the design is been [sic] done by a third party*'.[525]

Despite these references to the modification forms in July 2018, no Plant Modification Quality Plan and Check Sheet dated later than February 2018 has been sighted.

[520] Standards Australia (2010) *AS4044 – 1992: Battery chargers for stationary batteries,* Appendix A, Item 11(q), CSE.001.100.0901.

[521] Refer to Section 19.5.4.

[522] Refer to Section 19.6.7.

[523] The correspondence does not specifically refer to the Plant Modifications Procedure but the reference to 'MOD form' is understood to be a reference to the Plant Modification Quality Plan and Check Sheet. It is understood that the reference to '*sign off the paper*' in the email is with reference to the Concept Gate Approval Request, but the original email and its attachments have not been located: Email (2 July 2018) *RE: CS18548 Callide C UPS & 220V Battery Charger Replacement,* CSE.001.216.7657.

[524] Standard Form (10 July 2018) *Concept Gate Approval Request* for *Callide C UPS & battery charger replacement*, CSE.001.036.1510.

[525] '*Plant change request'* is understood to be a reference to the Plant Modification Quality Plan and Check Sheet, as this requires steps in the Plant Modifications Procedure to be approved: Email (11 July 2018) *re : C3 batteries*, Item 4, CSE.001.217.7698.

No evidence has been sighted that requests to update the '*MOD form*' and sign off the '*plant change request*' were completed. No evidence has been sighted that these directions were followed up to ensure they were completed.

19.8.2 Change of Key CS Energy Personnel

In January 2019, there was a change of personnel in two key roles on the battery charger project.[526]

The Project Lead role was transferred to a person who had very recently joined CS Energy and had no existing knowledge of the battery charger project. The person who had been in the Technical Lead for the battery charger project resigned from CS Energy, and it appears this role was not backfilled by anyone. The loss of these two personnel from the battery charger project at the same time meant a considerable loss of project knowledge for the project delivery team.

19.8.3 Magellan Commence Work

Around 10 August 2018, Magellan commenced work based on a purchase order for the *Callide C UPS & battery charger replacement* project.[527] The Unit C4 battery charger was originally part of Phase 2 of the program for the *Callide C UPS & battery charger replacement* project,[528] which was due for delivery in January 2019.[529]

It is unclear why, but the Unit C4 battery charger work was delayed. In March 2019, the focus was on the Unit C3 battery charger, which appears to be the first item for delivery by Magellan.

19.8.4 Issues With Magellan

From March 2019, there appears to have been a more concerted effort, driven by the new Project Lead, to impose some rigour to the management of the battery charger project to ensure CS Energy had adequate oversight and control of the work being carried out by Magellan.[530]

On 13 March 2019, the Project Lead requested several documents from Magellan, including the detailed schedule, inspection and test plans (ITPs) and commissioning plans, and JSEAs and Safe Work Method Statements (SWMS) for the Unit C3 battery charger.[531]

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[526] Minutes (30 January 2019) Progress Meeting Agenda and Minutes – CS Energy & Magellan – Callide Battery Charger*, UPS & Inverter Project,* CSE.001.100.0002.

[527] Emails (10 August 2018) *Magellan P.O – 47000652678*, CSE.001.217.9061.

[528] Request for Information (7 August 2018) *Delivery dates and items,* CSE.001.217.8873.

[529] The email states: '*According to the RFI 3, [CS Energy] stated 7th Jan 2019 (Tentative).*' Email (5 October 2018) *CS Energy – Phase 2 delivery,* CSE.001.218.1584.

[530] In March 2019, the new Project Lead requested inspection and test plans (ITPs) and commissioning plans for the Station battery charger replacement. They proposed internally that CS Energy should establish '*QA, ITP & Commissioning plan*' expectations that Magellan can use as a benchmark for the remaining units. While this was aimed at putting some rigour around the work being undertaken by Magellan, it was limited to quality compliance and acceptance testing around the performance of the battery charger as a standalone piece of equipment and the other items Magellan was due to deliver. It did not extend to the impact of the change to the wider electrical system, Email (13 March 2021) *FW: 900A Commissioning,* CSE.001.100.0100; Email (14 March 2021) *RE: 900A Commissioning CC0BTL10 C STN 220V Charger,* CSE.001.100.0907; Email (19 March 2021) *FW: 900A Commissioning*, CSE.001.100.0899.

[531] Email (13 March 2019) *RE: 900A Commissioning*, 6:38 am, CSE.001.100.0100.

On 13 March 2019, the Project Lead also emailed the CS Energy Manager (Electrical Instrumentation and Controls) and, with reference to the Unit C3 battery charger, suggested '*that CSE step in to establish QA, ITP & Commissioning plan expectations. This can be benchmarked for the remaining 13 units*.'[532]

The next day, 14 March 2019, the Project Lead sent a further email to the CS Energy Manager (Electrical Instrumentation and Controls), raising concerns about the compliance of previously installed inverters and battery charger cubicle designs, which had been managed by staff who had since left CS Energy.[533] The Project Lead was concerned about specification for the work when compared against the original equipment's specification. He suspected that the '*Magellan componentry*' would not be compliant with the CS Energy Preferred Equipment Standards, which was a requirement of the contract.[534]

The email of 14 March 2019 ended with:

> *It looks as though we have all inherited a real cluster.*

In a follow-up email, later on 14 March 2019, the Project Lead noted '*it looks as though the Callide C 900A & Callide B 500A 220V Charger designs have* not *been reviewed and vetted by CSE*',[535] and attached an email from Magellan flagging that this had not been completed.[536] Section 2.1 of the Invitation to Tender (Section C – Scope of Work) stated: '*Issue draft drawings to CS energy site contact for execution approval by RPEQ Engineer. This includes schematics and the equipment GA* [general arrangement] *drawings*.' The Project Lead noted that to do this exercise at this stage would be retrospective.[537] No evidence has been sighted that the review mentioned in the Project Lead's follow-up email was completed.[538]

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[532] Email (13 March 2019) *RE: 900A Commissioning*, 3:34 pm, CSE.001.100.0100.

[533] Email (14 March 2019) *RE: 900A Commissioning CC0BTL10 C STN 220V Charger*, 4:09 pm, CSE.001.100.0907.

[534] CS Energy (6 June 2017) *CMP-TL-0045 – Standard Specification – Preferred Electrical Equipment* specifies the manufacturer, make and, in some cases, model required for supply and purchasing of electrical equipment at CS Energy sites, and applies to any work undertaken for CS Energy whether by contractors and subcontractors or CS Energy staff. It specifies items such as circuit breakers, control valves and actuators, light fittings, plugs and sockets.

[535] Email (14 March 2019) *Magellan Design Reviews*, CSE.001.100.0851.

[536] This was an email from Magellan highlighting that the drawings for the 500A and 900A battery chargers had not been approved by CS Energy: Email (14 March 2019) *Drawing approval – 500A and 900A*, CSE.001.100.0864.

[537] Correspondence indicates that, by March 2019, at least one of the Callide C battery chargers was manufactured and work on the other two had commenced. Purchasing for Phase 2 (which includes the second and third charger) would have commenced. Email (5 October 2018) *CS Energy – Phase 2 delivery,* CSE.001.218.1584. '*Callide C charger assembly would be in progress by now*': Email (6 November 2018) *Callide C charger Design,* CSE.001.218.2186. The Callide C Station battery charger was to be installed in March 2019: Email (11 January 2019) *900A charger Installation schedule*, CSE.001.218.3840.

[538] Drawings for the Callide C Station battery charger 'For Approval' were signed off by CS Energy in August 2018, and 'For Construction' in September 2018, but no signed-off drawings have been located for the battery charger project.

On 19 March 2019, the Project Lead proposed internally that CS Energy should prepare documents to '*assist with the Magellan battery charger & UPS projects*'.[539] The suggested documents included an ITP and commissioning plan and a Manufacturing Data Report (MDR).[540] This was not long after the Project Lead had raised concerns internally about the compliance of Magellan components with CS Energy's stated requirements.[541]

On 20 March 2019, CS Energy requested that Magellan provide an MDR for equipment supplied by Magellan.[542] Magellan's response indicated that they were not familiar with the provision of an MDR,[543] and no evidence of a response to this request has been sighted.

In October 2019, CS Energy issued a formal Notice of Defect to Magellan in relation to the overheating of two battery chargers installed in Callide B.[544]

As set out above, the procurement of the battery chargers from Magellan (and other items of equipment) was impacted by a number of issues originating from Magellan. No evidence has been sighted that the frequency and nature of these issues were identified as a significant risk to the battery charger project. Also, no evidence has been sighted that these issues were considered in the planning for the battery charger's return to service.

19.8.5 Project Resources Stretched

There is evidence that the Project Lead asked for engineering support and it was not provided. Variation documents, dated 19 February 2019, were submitted by the Project Lead for approval of a variation of $164,000 for the *Callide C UPS & battery charger replacement project*.[545] The variation was primarily related to additional project management required on the project.[546]

Callide C Station 'For Approval' drawings: CS Energy (15 August 2018) *Callide C Power Station – 220V 900A Charger General Arrangement*, MAG-CSE-184331-GA-001 Rev A, CSE.001.055.1593; CS Energy, *Callide C Power Station – 220V 900A Charger Schematic*, MAG-CSE-184331-SCH-001 Rev A, CSE.001.055.1593.

Callide C Station 'For Construction' Drawings: CS Energy (28 September 2018) *Callide C 220V 900A Charger General Arrangement*, MAG-CSE-184331-GA-001 Rev 0, Service order No. 4700065009, CSE.001.055.2655; CS Energy (28 September 2018) *Callide C 220V 900A Charger Schematic,* MAG-CSE-184331-SCH-001 Rev 0, Service order No. 4700065009, CSE.001.055.2655.

[539] Emails (19 March 2019) *FW: 900A Commissioning*, 8:38 am, CSE.001.100.0899.

[540] A Manufacturing Data Report (MDR) is used in manufacturing to demonstrate that a manufactured product is in accordance with specified standards.

[541] Email (14 March 2019) *RE: 900A Commissioning CC0BTL10 C STN 220V Charger*, 4:09 pm, CSE.001.100.0907.

[542] Emails (20 March 2019) *RE: CS – MDR*, CSE.001.100.0946.

[543] Emails (20 March 2019) *RE: CS – MDR*, CSE.001.100.0946.

[544] Letter (16 October 2019) *Notice of Defect*, CSE.001.100.0007.

[545] Email (21 February 2019) *CS18548/CSS190124 Callide C Battery Charger & UPS variation*, CSE.001.100.0086.

[546] Excel Spreadsheet (19 February 2019) *Project Estimating and Budgeting Form, Callide C UPS & 220V Battery charger replacement, Version 3*, CSE.001.036.1543.

The evidence indicates that the variation of $164,000 was not approved.[547]

At the time the budget variation was requested (19 February 2019), the Project Lead of the battery charger project was managing a total of nine projects, at varying stages of delivery. The Project Lead described them as three projects of high complexity, four projects of medium complexity, and two projects of low complexity (one of which was the battery charger project).[548]

In mid-June 2020, the Project Lead made enquiries with colleagues for any funding that could be spared from other budgets in order to keep the engineer who had been engaged on a contract basis working on the battery charger project for longer. The contract engineer had originally been engaged because the CS Energy engineering team was too stretched to properly support all projects at Callide. Some funding was spared by the Manager (Electrical, Instrumentation and Controls) from their budget, but it was only $20,000, which would only support the retention of the contract engineer for a short period.[549]

19.8.6 Shifting and Delay of Installation Date

On 5 March 2020, the Project Lead advised the CS Energy Shift Operator Technician that the Unit C4 battery charger would be installed by Magellan '*during the C4 mini overhaul*'.[550] The mini overhaul (or '*Callide C4-Minor FY20*' overhaul) was originally planned for 4 April 2020, but was deferred to 1 August 2020 due to COVID-19.[551]

It appears the work on the Unit C4 battery charger was then further delayed. On 24 November 2020, the Project Lead emailed CS Energy staff about progressing the work for the battery charger project.[552] The Project Lead then followed up on 30 November 2020, directing that the work should be pushed back to January 2021, which appeared to be due to internal CS Energy workload.

On 31 December 2020, Magellan provided the commissioning plan, ITP, and Installation Report to CS Energy for review.[553] It took some time for Magellan to provide further documentation required by CS Energy.[554]

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[547] The Capital Variation Approval Request form notes: '*Due to commercial & JV sensitivities, internal labour associated with the Callide C installations will be amortised across CSS190125 Callide B 220V & CSS190116 Callide B 48VDC Charger projects; under instruction by the PCG on 21/02/2019.*' Standard Form *Capital Variation Approval Request*, CSE.001.036.1611; Email (22 February 2019) *Options for Callide Chargers*, 11:18 am, CSE.001.100.0974; Email (22 February 2019) *CS18548/CSS190124 Callide C Battery Charger & UPS variation*, CSE.001.100.0948.

[548] Email (7 March 2019) *Resource hours*, CSE.001.100.1211; Excel Spreadsheet *Resource hours*, CSE.001.100.1212.

[549] Emails (12 June 2020–18 June 2020) *FW: Asset Engineering – [Name]*, CSE.001.100.1172.

[550] Emails (5 March 2020) *4890013 – C4 220V Charger & Inverter replacement*, CSE.001.100.0897.

[551] Letter (30 March 2020) *Callide 2020 Overhaul's Deferral*, CSE.001.079.7103; Attachment to Email (30 March 2020) *Callide 2020 Overhauls Deferral*, CSE.001.100.0083.

[552] Email (24 November 2020) *Remaining Callide B&C STN charger inverter upgrades*, CSE.900.002.0165.

[553] Email (31 December 2020) *C4 220V 900A Charger (4BTL10) – Commissioning documents.*, CSE.001.056.5699. Attachment to email: Magellan Power *CSE Commissioning Plan, Callide C4 220V 900A Charger*, CSE.001.056.5701; Magellan Power *Inspection Test Plan, Callide C4 220V 900A Charger*, CSE.001.056.5703; Magellan Power *CSE Installation Report, C4 220V 900A Charger*, CSE.001.056.5705.

[554] Email (5 January 2021), *RE: C4 220V 900A Charger (4BTL10) – Commissioning Documents,* CSE.001.100.0912.

On 10 February 2021, the commencement of the switching for the Unit C4 battery charger was rescheduled to 15 February 2021.[555]

19.8.7 Commissioning and Testing

The specification for the battery charger project required certain documentation to be prepared by Magellan, as well as testing to be carried out by or on behalf of Magellan to demonstrate that the supplied battery charger met the requirements of the specification. These were as follows.

The Inspection Test Plan (ITP)

Prepared by Magellan, the ITP sets out the full suite of checks and tests to be undertaken to confirm the correct operation of the battery charger.[556] However, the commissioning and testing focused on confirming the battery charger was capable of operating in its typical manner, as opposed to what was required of it during the switching sequence. The ITP did not consider the requirements of the switching sequence that occurred on the day of the incident.

The ITP was signed off as accepted by CS Energy on 22 April 2021.[557]

The Factory Acceptance Test (FAT)

The FAT is a series of tests that are intended to be carried out at the location of manufacture before an item is shipped to site. The FAT checked that the battery charger was capable of operating in its 'normal' manner, such as operating with the specified input power, and outputting the required power.[558] A start-up test was conducted, which tested that the required output was achieved and the time it took to reach that output level. The FAT did not consider the requirements of the switching sequence that occurred on the date of the incident.

A copy of the FAT provided and signed off by Magellan has been sighted, but a copy countersigned as approved by CS Energy has not been sighted.[559]

The Site Acceptance Test (SAT)

The SAT is very similar to the FAT, but carried out once the item is at site, although some of tests conducted in the factory were not repeated on site.[560] The SAT did not consider the requirements of the switching sequence that occurred on the day of the incident.[561]

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[555] Email (10 February 2021) *C4 220V 900A Charger (4BTL10) – Commissioning documents*, 1:39 pm, CSE.001.100.0912.

[556] Magellan Power (22 April 2021) *Inspection Test Plan, Callide C4 220V 900A Charger*, CSE.001.056.8892.

[557] Magellan Power (22 April 2021) *Inspection Test Plan, Callide C4 220V 900A Charger*, CSE.001.056.8892.

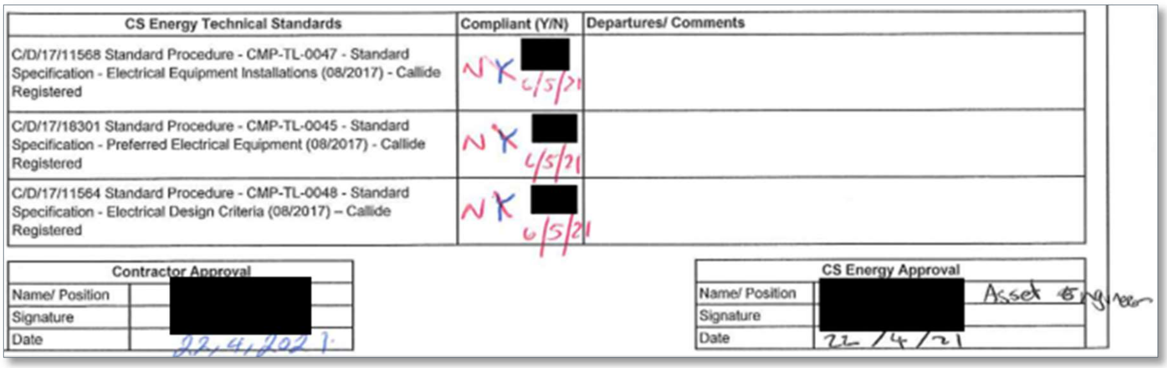
[558] Magellan Power (18 October 2019) *Callide Power Station, Callide C4, 220V 900A Charger, Line 1 FAT, Battery Charger Information Sheet*, CSE.001.056.8899.

[559] Magellan Power (18 October 2019) *Callide Power Station, Callide C4, 220V 900A Charger, Line 1 FAT, Battery Charger Information Sheet*, CSE.001.056.8899.

[560] Magellan Power (22 April 2021) *Callide Power Station, Callide C, 220V 900A Charger C4, Line 1 SAT, Battery Charger Information Sheet*, CSE.001.056.8886.

[561] No evidence has been sighted that the Unit C4 battery charger underwent dynamic response testing. It appears the testing for the Unit C3 battery charger included a dynamic response test, as the results were quoted in an email: Email (21 January 2021) *RE: Callide C3 battery chargers*, CSE.900.001.0793.

There is a copy of the SAT, signed off as approved by CS Energy on 22 April 2021, but there is another version, dated 6 May 2021, on which the section indicating compliance with CS Energy standards has been updated to 'N'.[562] It is unknown why this part of the SAT has been amended on 6 May 2021, after the SAT was approved on 22 April 2021, or what the consequences of this were, if any. Figure 165 contains an excerpt of this updated section of the SAT.



CS Energy Technical Standards	Compliant (Y/N)	Departures/ Comments
C/D/17/11568 Standard Procedure - CMP-TL-0047 - Standard Specification - Electrical Equipment Installations (08/2017) - Callide Registered	N [redacted] 6/5/21	
C/D/17/18301 Standard Procedure - CMP-TL-0045 - Standard Specification - Preferred Electrical Equipment (08/2017) - Callide Registered	N [redacted] 6/5/21	
C/D/17/11564 Standard Procedure - CMP-TL-0048 - Standard Specification - Electrical Design Criteria (08/2017) – Callide Registered	N [redacted] 6/5/21	

Contractor Approval	
Name/ Position	[redacted]
Signature	
Date	22/4/2021

CS Energy Approval	
Name/ Position	[redacted] Asset Engineer
Signature	
Date	22/4/21

Figure 165 Excerpt from SAT for the Unit C4 battery charger

In response to the email of 19 March 2019 (discussed above) – in which the Project Lead proposed internally that CS Energy should prepare some documents to '*assist with the Magellan battery charger & UPS projects*'[563] – a CS Energy electrical engineer wrote, in reference to *AS4044 – 1992 Battery chargers for stationary batteries*: '*I found this standard and it has a number of tests included which I will incorporate*.'[564] It seems that, up until this point, the CS Energy personnel involved on the battery charger project had not been aware of this Australian Standard, or at least it had not been actively utilised by them. It appears that Magellan and/or CS Energy may have referred to this Standard in the development of the FAT and SAT, as these incorporate some tests listed in Appendix A to *AS4044*.[565]

The Commissioning Plan

The Commissioning Plan sets out the actions to be undertaken to prepare the equipment for service.[566] The Commissioning Plan required checks for incoming and outputting power, including the effects of various circuit breakers operating and the performance in charging the batteries (including in the context of a battery discharge test). The only test associated with switching the battery charger on was that there was output voltage available.

[562] Magellan Power (6 May 2021) *Callide Power Station, Callide C, 220V 900A Charger C4, Line 1 SAT, Battery Charger Information Sheet*, CSE.001.004.0151.

[563] Emails (19 March 2019) *FW: 900A Commissioning*, 8:38 am, CSE.001.100.0899.

[564] Emails (19 March 2019) *RE: 900A Commissioning*, 11:23 am, CSE.001.100.0899; Attachment: Standards Australia (2010) *AS4044 –1992: Battery chargers for stationary batteries,* CSE.001.100.0901.

[565] Standards Australia (2010) *AS4044 – 1992: Battery chargers for stationary batteries,* CSE.001.100.0901.

[566] This is the Commissioning Plan prepared by Magellan: Magellan Power *CSE Commissioning Plan, Callide C4 220V 900A Charger*, CSE.001.056.5701.

The Installation Plan

The Installation Plan involved a list of visual checks for physical installation (such as correct labels and correct cables) and an attached punch list.[567] The punch list documents the incomplete or deficient items which need to be addressed prior to the work being considered complete. The punch list items are categorised in accordance with criticality. The Project Lead required that the 'Category A' punch list items were closed out prior to the battery charger being handed over to operations for it to be returned to service.[568] All Category A items were finally closed out on 24 May 2021.[569]

The ITP was fully signed off even though there were items still open on the punch list. The Commissioning Plan and Installation Plan were also closed out sufficiently to allow the return to service of the battery charger.

Internal emails about rating of the battery charger

Also on 22 April 2021, just a month before the incident, there was internal CS Energy email discussion about the rating of the Unit C4 battery charger.[570] CS Energy asserted that, in the design, Magellan assumed an ambient temperature based on an airconditioned room of 25 °C.[571] However, the battery charger should have been designed with an assumed ambient air temperature of 40 °C.[572] This resulted in the battery charger's busbar being smaller in size than what was required for it to operate at this higher ambient temperature.[573]

The CS Energy Asset Engineers (Electrical) considered that the battery charger should be downrated from a current rating of 900 A to 650 A for the battery charger busbar to operate within safe limits.[574] The impact of this would be that the battery charger could not supply 900A if loads demanded it. It would also have the effect of taking longer to charge the batteries, due to the lower current.

Ultimately, it was agreed by the Manager (Electrical Instrumentation and Controls) that the battery charger should be rated at the full current limit of 900A because the battery room was airconditioned, the room would be monitored, and if the average ambient air temperature went above 25°C the rating

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[567] Various documents (22 April 2021) *Inspection Test Plan, Callide C4 220V 900A Charger*, CSE.001.056.8892.

[568] Email correspondence shows that CS Energy required only the Category A punch list items to be closed out before bringing the battery charger back into service: Emails (13 April 2021–21 April 2021) *RE: RPEQ-Signed off Drawings – Batch 1*, 11:22 am, CSE.001.225.1508; Emails (21 April 2021) *RE: C4 Battery charger punchlist items*, 1:06 pm–4:39 pm, CSE.001.225.1508.

Updated punch list provided by Magellan: Email (14 May 2021) *C4 Battery charger punchlist items*, CSE.001.056.8872. Attachment to email: Excel Spreadsheet (14 May 2021) *Punch List – C4 Charger 140521-W,* CSE.001.056.8898.

[569] Excel Spreadsheet (24 May 2021) *Magellan Punchlist – Callide C*, CSE.001.225.1502.

[570] Emails (1 April 2021–21 April 2021) *RE: RPEQ-Signed off Drawings – Batch 1*, CSE.001.100.0924; Emails (21 April 2021– 6 May 2021) *RE: C4 Battery charger punchlist items*, CSE.001.100.0924.

[571] Magellan (21 April 2021), *Bus Bar Sizing Calculation, Rev:1,* CSE.001.056.8769.

[572] It is not known where the design temperature of 40°C was taken from.

[573] Magellan (21 April 2021), *Bus Bar Sizing Calculation, Rev:1,* CSE.001.056.8769.

[574] The busbar in the battery charger has a limit on the current at which it can operate. This is to avoid overheating. An increase in ambient temperature reduces the operating current limit of the busbar and therefore of the battery charger.

could be reduced.[575] The Manager also noted that, operationally, it was not expected that the battery charger would be run above 650A.

19.8.8 Sign-Off and Punch List

Magellan sign-off

It was a requirement that Magellan's design was signed off by a Registered Professional Engineer, Queensland (RPEQ). It was not until 8 March 2021 that Magellan provided the first lot of as-built drawings signed off by a RPEQ for the Unit C4 battery charger.[576] Initially, on 19 February 2021, Magellan stated that RPEQ sign-off was not required under the contract.[577] In an email exchange between the Project Lead and Magellan, the Project Lead noted that this had been already covered with Magellan staff '*several times*'. Ultimately, Magellan engaged a third party who provided the RPEQ sign-off.

A CS Energy RPEQ needed to sign off the project commissioning checklist before the new battery charger could be brought into service.[578]

In April 2021, CS Energy followed up with Magellan several times to close out items on the punch list for the Unit C4 battery charger.[579] The punch lists themselves did not require RPEQ sign-off, but the CS Energy RPEQ sign-off could not occur until the punch lists were satisfactorily completed. On 21 April 2021, Magellan advised that they were getting RPEQ sign-off for some revised calculations, after which the Project Lead advised internally that one Category A item could be dropped to a Category B so that '*RTS activities'* could be continued that afternoon.[580] They also asked a CS Energy asset engineer to arrange CS Energy RPEQ sign-off.

However, on 23 April 2021, the Project Lead confirmed that the Unit C4 battery charger was not to be put back into service *'until the project commissioning checklist has RPEQ lines signed off'* by CS Energy.[581] Also, there were some items on the punch list that still needed to be closed out before the battery charger could be put into service.

On 4 May 2021, some alarms activated on Unit C4 that were thought to be linked to the unit's DC supply coming from Station. This prompted the Project Lead to send an internal email to the engineers, asking '*Are we comfortable enough to place the C4 Charger in service?*'[582] The Project Lead

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[575] Emails (6 May 2021) *RE: C4 Battery charger punchlist items*, 2:48 pm, CSE.001.225.1508.

[576] Email (8 March 2021) *RPEQ-Signed off Drawings – Batch 1*, CSE.001.225.0044.

[577] Email (19 February 2021) *RE: ITP CSE CODE 1. RE:C4 900A 220V Charger – Progress*, CSE.001.100.0952.

[578] Emails (22 April 2021) *RE: C4 Battery charger punchlist items*, 4:20 pm, CSE.001.056.8872.

[579] Email (26 February 2021) *RE: ITP CSE CODE 1. RE: C4 900A 220V Charger – Progress*, CSE.001.100.0960; Excel Spreadsheet (14 May 2021) *Punch List – C4 Charger 140521-WY*, CSE.001.056.8898.

[580] Emails (21 April 2021) *RE: C4 Battery charger punchlist items*, 1:06 pm, CSE.001.225.1508. '*RTS*' = return to service.

[581] Email (23 April 2021) *RE: CC4 Battery Charger*, CSE.001.100.0943; Form (6 May 2021) *Project Commissioning Checklist*, CSE.001.100.0082. A Registered Professional Engineer Queensland (RPEQ) from CS Energy was required to countersign the commissioning checklist that was signed off by Magellan.

[582] Emails (4 May 2021) *RE: C4 Battery charger punchlist items*, 2:54 pm, CSE.001.056.8872.

also noted that there were still some issues with the Unit C4 battery charger, but that they were administrative and could be managed via the punch list and contractual mechanisms.

It is not clear precisely when the Magellan RPEQ sign-off on the final calculation was completed, as no specific evidence has been sighted. However, there is correspondence that says it would be obtained, and evidence that CS Energy subsequently proceeded with its RPEQ sign-off of the project commissioning checklist on 6 May 2021.[583]

On 7 May 2021, the Project Lead advised the battery charger had been released for service and required Magellan to confirm rectification actions for outstanding items on the punch list by 14 May 2021.[584]

On 14 May 2021, Magellan returned the updated punch list where they had added proposed rectification actions.[585] Magellan also provided the FAT for sign-off by CS Energy,[586] SAT test results signed off by CS Energy,[587] the signed-off ITP, and signed-off installation report for the Unit C4 battery charger.[588] (Note: These were not RPEQ sign-offs.) The installation report noted that some Category A items were not yet closed off, but needed to be by the end of Stage 3 commissioning (which is when the unit is energised but not yet returned to service). The last of the Category A items were signed off on 24 May 2021.[589]

Time pressures

The Unit C4 battery charger project was running years behind schedule, partly because of the effects of COVID-19 in delaying production and travel to the Callide site.[590] In early 2021, there was an unexplained sawtooth wave in the DC supply to Unit C4 from Station that could not be investigated until Unit C4 could be separated from Station.[591] There was also recognition that there was a risk related to the lack of system redundancy while the new Unit C4 battery charger was not in service.[592]

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583 Emails (21 April 2021) *RE: C4 Battery charger punchlist items*, 11:22 am, CSE.001.225.1508; Emails (21 April 2021) *RE: C4 Battery charger punchlist items*, 4:39 pm, CSE.001.225.1508; Emails (6 May 2021) *RE: C4 Battery charger punchlist items*, 2:48 pm, CSE.001.225.1508; Form (6 May 2021) *Project Commissioning Checklist* for *Callide C4, CC4BTL10*, TRIM Record No C/D/21/3561, CSE.001.100.0082.

584 Emails (7 May 2021) *RE: C4 Battery charger punchlist items*, 7:27 am, CSE.001.056.8872.

585 Excel Spreadsheet (14 May 2021) *Punch List – C4 Charger 140521-WY*, CSE.001.225.0073.

586 Form (18 October 2019) *Callide Power Station, Callide C4, 220V 900A Charger, Line 1 FAT*, *Battery Charger Information Sheet*, CSE.001.225.0074.

587 Form (22 April 2021) *Callide Power Station, Callide C, 220V 900A Charger C4, Line 1 SAT*, *Battery Charger Information Sheet*, CSE.001.225.0088.

588 Form (22 April 2021) *Inspection Test Plan, Callide C4 220V 900A Charger*, CSE.001.225.0094.

589 Excel Spreadsheet (24 May 2021) *Magellan Punchlist – Callide C.xlsx*, CSE.001.225.1502.

590 The battery charger was part of Phase 2 which was originally scheduled for completion in January 2019. The email states: '*According to the RFI 3, [CS Energy] stated 7th Jan 2019 (Tentative)*'. Email (5 October 2018) *CS Energy – Phase 2 delivery*, CSE.001.218.1584.

591 Email (11 March 2021) *C3/C4 double trip incident report*, CSE.001.102.0076; Emails (26 April 2021–6 May 2021) *RE: C4 Frequency issues – Transducers?*, CSE.001.102.0238; CS Energy (18 May 2021) *Notification 10611726, Order 4979503, CC4; Unit 240V AC; UPS Inverter. Possible fault with C4 inverter*, CSE.001.054.0285.

592 Email (10 February 2021) *C4 900A 220V Charger – Progress*, 5:32 am, CSE.001.100.0912.

In May 2021, the Project Lead and some Shift Supervisors were pushing to have the Unit C4 battery charger brought into service as it had been '*sitting waiting for a while now*'. [593]

CS Energy sign-off

On 4 May 2021, the Project Lead emailed internally noting that the '*remaining issues are administrative & can be managed through the Punchlist & contractual/payment withholding processes*'. [594]

The project commissioning checklist was signed off by the CS Energy RPEQ on 6 May 2021.[595] These signatures indicated that the battery charger was released for commissioning and available for return to service. An excerpt of the signed sections (redacted) of the form are in Figure 166.

4.1.6	Project released for commissioning			6/5/21	[redacted]
4.1.7	Project available for RTS			6/5/21	[redacted]

Figure 166 RPEQ sign-off of the Project Commissioning Checklist for the Unit C4 battery charger

19.8.9 Release for Service

On Friday 7 May 2021, the battery charger was released for service.[596] As above, the punch list and ITPs were followed up for close out with Magellan. There were some follow-up communications from Shift Supervisors about completing the return to service.[597] The other preparations for the return to service were carried out.[598]

After the completion of the commissioning and the return of the Permit to Work, the switching of the new battery charger was handed over to Operations, and was no longer being dealt with by the Asset Engineering team, who had managed the battery charger project up until handover.

19.8.10 Initial Startup

On 24 May 2021, there was an attempt to start up the new Unit C4 battery charger using Magellan's start-up procedure. The battery charger behaved in an unexpected manner, with erratic current and voltage readings, and the DC output breaker appeared to be tripped, followed by abnormal sounds from within the battery charger. The startup was abandoned. After this failed startup, CS Energy

[593] Email (4 May 2021) *RE: C4 Battery charger punchlist items*, 2:54 pm, CSE.001.056.8872; Email (13 May 2021) *FW: CC4BTL10 Battery Charger RTS*, 8:56 pm, CSE.001.045.0001; Emails (16 May 2021) *RE: CC4BTL10 Battery Charger RTS*, 2:42 am, CSE.001.102.0275.

[594] Email (4 May 2021) *RE: C4 Battery charger punchlist items,* 2:54 pm, CSE.001.056.8872.

[595] Form (6 May 2021) *Project Commissioning Checklist* for *Callide C4, CC4BTL10*, TRIM Record No C/D/21/3561, CSE.001.100.0082.

[596] Emails (7 May 2021) *RE: C4 Battery charger punchlist items,* 7:27 am, CSE.001.225.0059.

[597] Emails (13 May 2021) *FW: CC4BTL10 Battery Charger RTS,* 8:56 pm, CSE.001.045.0001; Email (16 May 2021) *RE: CC4BTL10 Battery Charger RTS*, CSE.001.102.0275.

[598] Switching Sheets were prepared, Permit to Work was obtained, Isolation Sheets prepared, JSEA completed, and other preparatory documentation was completed: Various documents (various dates) *PTW for switching1.pdf,* CSE.001.003.1999.

contacted Magellan by email, requesting clarification on the start-up procedure.[599] A response from Magellan has not been sighted, but a second attempt was made to start the battery charger and it started successfully. The Unit C4 battery, which had a low charge after being isolated since 8 February 2021, was charged overnight by the battery charger.

19.8.11 Return to Service

The battery charger had been specified and installed without consideration of the switching sequence. Further, all testing that had been conducted was following the specification, so none of the tests confirmed the effectiveness of the battery charger in the switching sequence.

On 25 May 2021, the switching sequence continued (it had commenced the previous day) and the battery charger failed to maintain the voltage in the Unit C4 DC system after the interconnector between Station and Unit C4 was opened.[600]

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[599] Email (24 May 2021) *Operating manual – Section 5.1 Start up – CC4BTL10 C4 900A 220V Charger*, CSE.001.100.0884.

[600] The Station and Unit C3 replacement battery chargers were brought into service before the Unit C4 battery charger. No evidence has been sighted that suggests there were any issues while bringing these battery chargers into service.

- *Station Battery Charger Return to Service*

  The commissioning of the Callide C Station battery charger was carried out in March 2019: CS Energy *Project Commissioning Checklist, Callide C3 Power Station,* CSE.001.225.0641. It is believed that it was brought into service on 1 April 2019, using a similar switching sequence to the Unit C4 battery charger. (No record confirming the return to service date has been sighted, but a comparison of the switching sheet (CCOS19/0003 WCD10114839, WCD TEST10114838) with the ICMS data on 1 April 2019 shows a correlation between the Station battery charger being offline and then online. This occurred at the same time of day noted on the switching sheet for when the Station battery charger was connected to the Station DC system (CS Energy switching sheet CCOS19/0003 WCD10114839, WCD TEST10114838, CSE.001.006.0005).

  In this case, it was the Station and Unit C3 DC systems that had been connected via an interconnector. Both the Unit C3 battery charger and battery remained connected to the Unit C3 DC system, and it was the Station battery charger that was required to operate as the sole source of supply to the Station DC system when the interconnector was opened.

  No evidence has been sighted that shows there were issues when bringing the new Station battery charger back into service. ICMS data indicates that, when the interconnector was opened, the Station battery charger commenced providing supply to the Station main switchboard as soon as it was connected. (This indicates that some load sharing between the Unit C3 and Station battery chargers may have occurred prior to the opening of the interconnector. After the interconnector was opened, the Station battery charger continued to maintain the voltage in the Station DC system. Excel Spreadsheet *20190401_PiData*, CSE.001.284.0001.

- *Unit C3 Battery Charger Return to Service*

  The replacement Unit C3 battery charger was brought into service on 8 November 2019, using a similar switching sequence to the Unit C4 battery charger. (A record confirming the return to service date has not been sighted but a comparison of the WCA 11133154 on switching sheet CC3S17/0023 WCD10104431 with the ICMS data align with what would be observed when the battery charger is brought back into service: CS Energy switching sheet CC3S17/0023 WCD10104431, CSE.001.006.0021.) ICMS data shows that Unit C3 was offline at the time. (ICMS data provided by CS Energy: Excel Spreadsheet (14 October 2023) *CC3 BAC10 GS100.XV01_8-11-19_Request 10.csv*, CSE.001.284.0025; Excel Spreadsheet (14 October 2023) *CC3 BAC10 GS100.XV02_8-11-19_Request 10.csv*, CSE.001.284.0027; Excel Spreadsheet (14 October 2023) *CC3 BAC10 GS101.XB01_8-11-19_Request 10.csv*, CSE.001.284.0029; Excel Spreadsheet (14 October 2023) *CC3 BAC10 GS101.XB02_8-11-19_Request 10.csv*, CSE.001.284.0031.)

19.9 What if the Plant Modifications Procedure had Been Followed Effectively?

Central to the effectiveness of the Plant Modifications Procedure is the risk assessment. This risk assessment is required to involve relevant specialists and disciplines on two separate occasions: the risk assessment is carried out in the second stage of the Procedure (Assessment), and then reviewed during the Design stage, prior to Implementation.

Figure 167 shows the description for the preparation of the risk assessment as part of the Assessment stage.[601] The Modification Officer is responsible for this activity.

2	*Modification Officer*	*Assess risk in conjunction with other relevant specialists / disciplines as required.* Use Operations Plant Risk Assessment Template. Basis of risk assessment: what potential hazards/risks may be introduced or current control measures affected by the proposed change?

Figure 167 Requirements of the risk assessment from Section 5.2 of the Plant Modifications Procedure (2016)

The Procedure requires that, as part of the Assessment stage, risk is assessed *'in conjunction with other relevant specialists/disciplines as required*' and the basis of the risk assessment is '*what potential hazards/risks may be introduced or current control measures affected by the proposed change*'.

The risk assessment was carried out in the form of the OPRA (discussed in Section 19.6.5), but it was not completed in accordance with the requirements set out in the Procedure shown in Figure 167. No evidence has been sighted that shows the risk assessment involved relevant specialists and disciplines, or that it considered the risks introduced to the process and plant by the new battery charger.

The risk assessment is required to be reviewed as part of the Design stage, prior to the design receiving approval to be implemented, see Figure 168.[602]

The ICMS data indicates there were some disturbances to the Unit C3 DC voltage, likely during the switching process to bring the battery charge back into service, but no evidence has been sighted that shows there were any issues. (ICMS data for the voltages at the Unit C3 main switchboard indicate some momentary dips and spikes in the voltage level. The ICMS data shows no indication of a loss of AC supply during this switching sequence: Excel Spreadsheet *20191108_PiData.xlsx,* CSE.001.284.0002.) If Unit C3 had been online at the time, it is not clear whether the disturbances could have caused issues.

[601] CS Energy (2016) *CS Energy Procedure for Plant Modifications CS-AM-010*, Section 5.2, Step 2, CSE.001.243.9479.

[602] CS Energy (2016) *CS Energy Procedure for Plant Modifications CS-AM-010*, Section 5.3, Steps 2 and 3, CSE.001.243.9479.

2	*Modification Officer*	Revisit risk assessment in conjunction with RPEQ's and relevant advisors in line with the final design.
3	*Modification Officer*	Consult / review with *Stakeholders* and gain *Approval* from *RPEQ's / Advisors. Technical Services Manager* signs *Quality Plan & Check Sheet* where *RPEQ* disciplines / advisors not required.

Figure 168 Requirements for review of the risk assessment from Section 5.3 of the Plant Modifications Procedure (2016)

As shown in Figure 168 above, step 2 of the process specifically requires the involvement of RPEQs and other relevant advisors in the review of the risk assessment.[603] These personnel are also required to approve the design in step 3 of the Design stage.

No evidence has been sighted that shows the OPRA was reviewed by anyone as part of the Design stage. The Plant Modification Quality Plan and Check Sheet (see Section 19.6.7 and Figure 160) was not signed off by RPEQs.

While compliance with the Procedure would not necessarily have avoided the incident, if the risk assessment had been carried out and reviewed in accordance with the Procedure, this could have increased the likelihood of identifying the risks associated with bringing the battery charger into service in this specific switching sequence.[604]

[603] 'RPEQ' stands for Registered Professional Engineer of Queensland, as defined under the *Professional Engineers Act 2002* (Qld).

[604] While following the Plant Modifications Procedure could have increased the likelihood of identifying issues with the battery charger project, shortcomings in the Procedure have been noted. The Procedure includes aspects that are important for the adoption of a change into a process: risk assessment, design in accordance with relevant standards, review and approval, identification of records that must be updated, and identification of people to engage with. The Procedure also has deficiencies, summarised as follows:

- The failure to require oversight of the determination that work is not a plant modification (and therefore does not need to follow the Procedure). Work that is actually a plant modification could bypass the Procedure.
- A 'one size fits all' approach. A process which is too onerous for minor modifications will be worked around, setting a precedence for all modifications. Minor and major changes should not be treated in the same manner.
- There is no clear direction whether or not multiple modifications can be grouped for the purposes of the Procedure.
- There is a lack of specific direction for the risk assessment, including specific requirements for who should be involved in order to maximise the quality of the risk assessment. The risk assessment is a key element of this Procedure.
- The lack of risk competency (and lack of HAZOPs and bowties) within CS Energy is a wider issue than this Procedure, but it does significantly impact the Procedure by reducing the value of any risk assessments completed.
- There is no mechanism for oversight of the degree to which the Procedure is followed.

19.10 Discussion

With no redundancy in the Unit C4 DC system between steps in the switching sequence, there was a requirement that the Unit C4 battery charger maintain the DC system voltage. This did not occur and the DC voltage collapsed, which led to the loss of the Unit C4 AC and DC supplies.

Before being put into service, the replacement Unit C4 battery charger was specified as part of CS Energy's procurement process and was subject to various tests to confirm its compliance with the specification. However, it was neither specified nor tested for the requirements of the switching sequence and it did not meet them. The replacement battery charger's technical specification appears to have only considered its performance in typical operation (i.e., supplying Unit C4 DC in combination with a battery). It did not specify its performance when operating without a battery.

The differences between these operational requirements are significant. In typical operation, when the battery charger operates in combination with a battery, it is the battery that caters for any sudden changes in demand on the DC system. For example, if there is a sudden increase in demand, the battery will supply this demand instantly, which provides time for the battery charger to respond. In this situation, with a battery connected, the response time for the battery charger is not critical. By contrast, if a battery charger operates without a battery, then its ability to respond to changes in demand must be carefully considered and specified to ensure the battery charger can maintain supply.

The specification for the replacement Unit C4 battery charger contained no such requirements. This contributed to a battery charger that could not meet the requirements of the switching sequence.

In addition to the Unit C4 battery charger not being specified for the requirements of the switching sequence, the battery charger project did not follow an effective management of change process. A failure to effectively manage change is a common causal factor in many major industrial accidents, and effective management of change provides opportunities to understand, evaluate, and mitigate the risks associated with any changes to plant. The project to replace the battery charger should have been subject to CS Energy's management of change process. While there is some evidence that this process was followed in the very early stages of the project, no evidence has been sighted that it was followed in later stages. Further, when these processes were followed, they were ineffective in both identifying and understanding the risks associated with the battery charger project, and in producing an adequate specification for the battery charger. The Unit C4 battery charger was, therefore, specified, installed, tested, and brought into service without effective management of change.

19.11 Chapter Summary

The replacement Unit C4 battery charger was neither specified nor tested for the requirements of the switching sequence being carried out at the time of the incident, nor was it capable of maintaining the voltage in the Unit C4 DC system under the operating conditions at the time.

The battery charger project should have followed CS Energy's management of change process, but this process was not effective nor was it effectively applied to the battery charger project.

While following an effective management of change process would not have necessarily led to the avoidance of the incident, it could have increased the likelihood of identifying the performance requirements for the battery charger. It could also have increased the likelihood of identifying the risks and consequences of the battery charger failing to perform in accordance with these requirements.

20 RISK OF THE LOSS OF AC AND DC SUPPLY

20.1 Introduction

This chapter provides a brief discussion of the organisational factors related to the loss of AC and DC supply to Unit C4.

20.2 Technical Background

During the incident, the voltage collapse in the Unit C4 DC system directly led to the loss of AC supply to Unit C4 when the arc flap protection operated. The loss of AC supply directly led to the loss of the DC supply to Unit C4 when the battery charger shut down.

The loss of DC supply prevented the emergency diesel generator from restoring AC supply to Unit C4. This was because without DC supply, the AC system could not be configured to route the backup AC supply from the emergency diesel generator to the Unit C4 emergency switchboard.

20.3 Collapse of DC Supply Leading to Loss of AC Supply

It is highly unlikely that CS Energy could have anticipated the mechanism that led to the loss of AC supply to Unit C4. In order for the collapse of DC voltage to result in the loss of AC supply, the DC voltage had to collapse low enough for the arc flap protection to operate, yet remain high enough (for long enough) to successfully trip the incomer circuit breakers. If it collapsed to zero too quickly, the incomer circuit breakers likely would not have tripped.[605]

It is highly unlikely that CS Energy could have anticipated that a DC system voltage collapse could result in the arc flap protection operating and lead to the loss of AC supply to Unit C4. For CS Energy to be aware that a collapse of DC supply could result in a loss of AC supply by arc flap protection, they would need to have prior understanding that a DC collapse, in the specific manner that occurred during the incident, was possible. It is considered highly unlikely that CS Energy could have had this awareness.

20.4 Failure of the Emergency Diesel Generator to Restore AC Supply

In the event of an unexpected loss of AC supply, the DC system provides supply to emergency equipment to facilitate safe shutdown of Unit C4. The emergency diesel generator also starts and supplies AC to the Station emergency switchboard. AC switchgear is then configured to route this supply from the Station emergency switchboard to the Unit C4 emergency switchboard.

Configuration of the AC switchgear does, however, require DC supply to be available. While the emergency diesel generator automatically started and restored AC supply to the Station emergency switchboard on the day of the incident, DC supply was not available to the AC switchgear to configure the Unit C4 emergency switchboard to receive this supply.

[605] This behaviour has been confirmed by Brady Heywood investigation testing.

It is understood that, while the emergency diesel generator was routinely tested to ensure it would operate in the event of a loss of AC supply, no evidence has been sighted that CS Energy were aware that a loss of DC supply would prevent a restoration of AC supply.

Further, it was identified after the incident that an undocumented design feature of some of the AC switchgear may have prevented AC supply from being routed to the Unit C4 emergency switchboard, even if DC supply was available. This is discussed in Appendix A3 *Electrical Investigation*, but it appears that if AC had been restored to Unit C4, it would have likely been immediately lost again. No evidence has been sighted that suggests CS Energy understood or assessed this risk.

20.5 Chapter Summary

No evidence has been sighted to suggest CS Energy considered the risk of the loss of AC supply during the switching sequence. It is highly unlikely, however, that CS Energy could have anticipated that a DC system voltage collapse could result in the arc flap protection operating and leading to the loss of AC supply to Unit C4. This is due to the highly unusual manner of the DC voltage collapse.

No evidence has been sighted that the risks and impact of the loss of DC supply were considered with respect to carrying out the switching sequence with the unit online.

21 THE INOPERABLE AUTOMATIC CHANGEOVER SWITCH

21.1 Introduction

The Unit C4 automatic changeover switch, which should operate and restore DC supply to parts of the unit in the event of a loss of DC, was inoperable on the day of the incident.

This chapter examines how it is likely that CS Energy intentionally left the Unit C4 automatic changeover switch inoperable following an electrical incident in January 2021.

This chapter begins by revisiting how the automatic changeover switch operates and explains how all three of the automatic changeover switches at Callide C power station were inoperable on the day of the incident. It concludes by considering the failure of CS Energy to assess the risk relating to the inoperability of the automatic changeover switch.

21.2 Technical Background

When the DC voltage in Unit C4 was lost, the Unit C4 automatic changeover switch (ACS) should have operated and partially restored DC supply.[606] However, the Unit C4 ACS was inoperable on the day of the incident.[607] If the ACS had been operable, and it had partially restored DC to the unit, the turbine missile event would likely have been avoided, but the unit would still have sustained significant damage.[608]

21.3 Unit C4 Automatic Changeover Switch

21.3.1 Overview of the ACS Functionality

The Unit C4 ACS, and its incoming supplies from the Unit C4 main switchboard and the Station main switchboard, are illustrated in Figure 169.[609]

[606] At CS Energy, an ACS is also known as an automatic transfer switch (ATS). For consistency, in this report it is referred to as the automatic changeover switch and abbreviated to ACS in this chapter.

[607] In this report, 'inoperable' means 'inoperable in automatic mode', unless otherwise stated. While the Unit C4 ACS was operable in manual mode on the day of the incident, manual operation of the switch was not a practical response to the collapse and loss of DC supply in Unit C4.

[608] Even if the Unit C4 ACS had been operational in automatic mode on the day of the incident, it is not confirmed that it would have successfully operated and restored DC supply to the Unit C4 distribution switchboard. The Brady Heywood investigation found that the ACSs at Callide C power station could not be relied on to operate, as briefly discussed in footnotes in Chapter 7.

[609] The figures in this chapter use different coloured lines to distinguish the different DC systems. The green, yellow and purple lines represent the DC systems in Unit C3, Station and Unit C4, respectively. Grey lines indicate an absence of power/voltage.

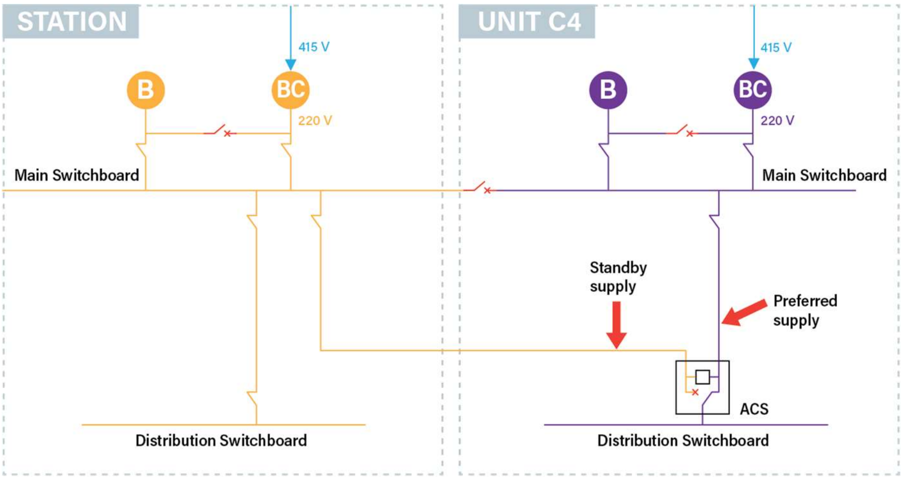

Figure 169 Unit C4 ACS

The Unit C4 DC main switchboard is the 'preferred' supply to the Unit C4 DC distribution switchboard, and the Station DC main switchboard is the 'standby' supply.[610] In its typical configuration, the Unit C4 ACS is set so that the Unit C4 distribution switchboard is supplied by the preferred supply, as illustrated in Figure 170.

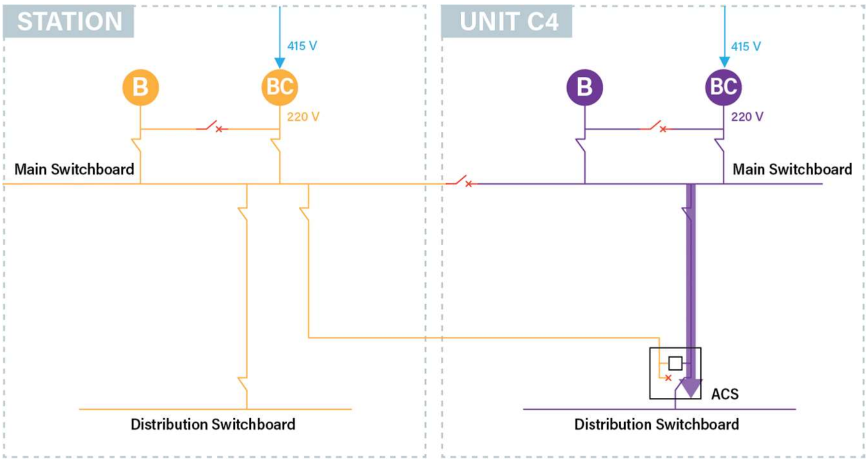

Figure 170 Unit C4 distribution board supplied by preferred supply (Unit C4 main switchboard)

If the DC supply from the Unit C4 main switchboard is lost, then the Unit C4 ACS should operate automatically.[611] After it operates, the Unit C4 DC distribution switchboard is instead supplied by the Station DC main switchboard, as illustrated in Figure 171.

[610] The preferred supply is sometimes referred to as the 'main supply' and the standby supply is sometimes referred to as the 'backup supply'.

[611] The ACS should operate when the DC voltage drops below approximately 190 V. However, for simplicity, in this chapter 'loss' of supply is used to describe circumstances where the DC voltage drops low enough that it should trigger operation of the ACS.

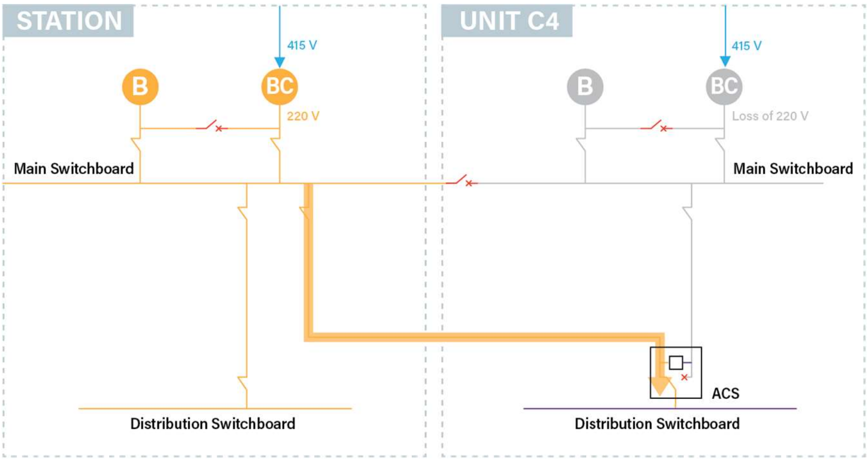

Figure 171 Unit C4 distribution board supplied by the standby supply (Station main switchboard) following changeover of the ACS

The ACS is a backup system that operates automatically to restore DC supply to a unit's distribution switchboard. This ensures the unit can maintain critical systems, such as the Y protection system, even if the unit's preferred DC supply is lost.

21.3.2 Components of the Unit C4 ACS

The Unit C4 ACS is located on the Unit C4 DC distribution switchboard in the Unit C4 DC switch room. The ACS is housed in two cabinets: one contains the automatic changeover control circuitry and the other contains the motorised changeover switch, see Figure 172.[612]

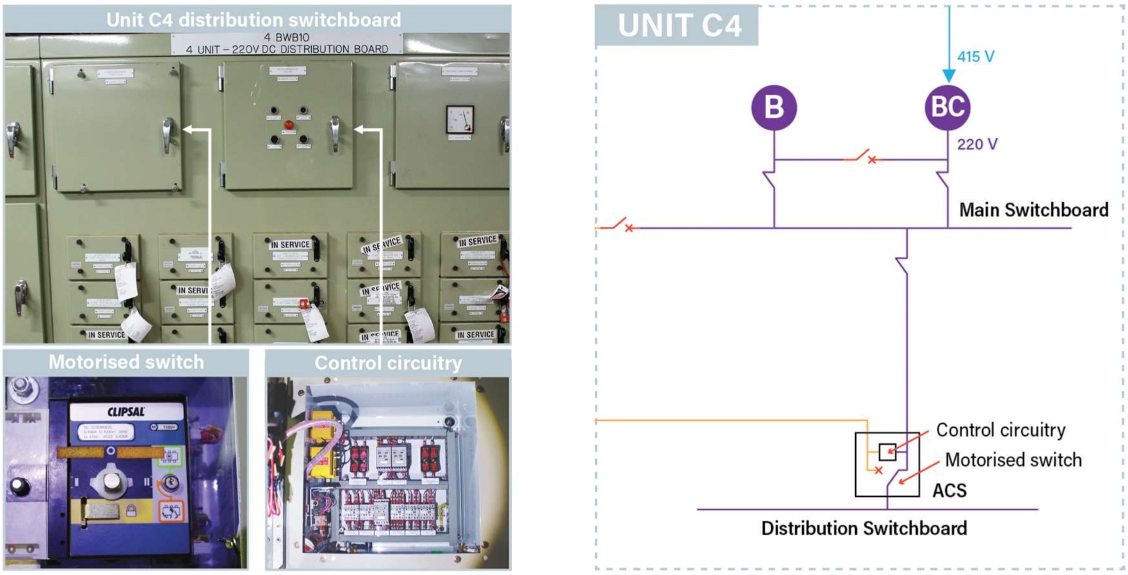

Figure 172 Unit C4 ACS

[612] The ACSs in Unit C3 and Station have a similar arrangement to the Unit C4 ACS.

Figure 173 illustrates some key components of the Unit C4 ACS.

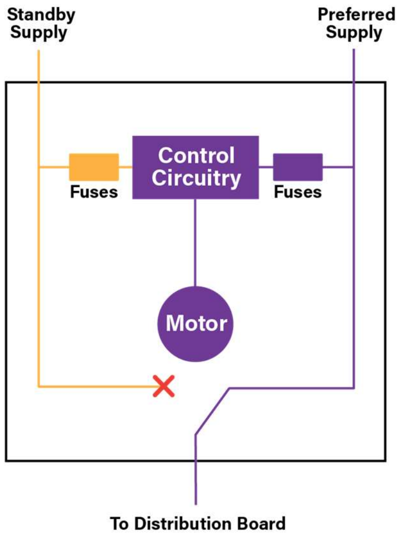

Figure 173 Key components of the ACS

Figure 173 shows:

- Preferred supply: For the Unit C4 ACS, the preferred supply comes from the Unit C4 main switchboard.
- Standby supply: For the Unit C4 ACS, the standby supply comes from the Station main switchboard.
- Control circuitry: The control circuitry monitors the voltage of the preferred supply and initiates the changeover (when in automatic mode).[613]
- Motor: If a changeover is required, the control circuitry activates the motor that physically 'changes over' the switch.
- Fuses: The ACS control circuitry contains two sets of fuses, each set connecting a supply to the ACS control circuitry.[614]

The ACS control circuitry receives its own supply from both the preferred and standby supplies. If the preferred supply is lost, the standby supply continues to power the ACS control circuitry, which in turn supplies the motor.

[613] While the ACS's primary role is to operate automatically, it can also be operated manually. If the ACS is set in automatic mode, the circuitry sends a signal for the switch to be mechanically changed over by the motor. If the ACS is set in manual mode, human action is required to physically change the switch. When the ACS is set to manual mode, it disables its ability to respond automatically to a supply loss. Manual operation of the switch was not a practical response to the collapse and loss of DC supply to Unit C4 during the incident.

[614] There are a total of four fuses in each ACS: two on each supply to the control circuitry. There is a fuse on both the positive and negative conductors of the preferred supply, and both the positive and negative conductors of the standby supply. For simplicity, the diagrams used in this chapter represent the electrical connections using a single line, rather than a line for each of the positive and negative conductors.

21.4 Unit C4 ACS Status on the Day of the Incident

21.4.1 Introduction

Understanding why the Unit C4 ACS was inoperable on the day of the incident requires an examination of CS Energy's organisational response to an event that occurred four months prior. On 13 January 2021, an electrical fault in Unit C4 led to both Unit C3 and Unit C4 tripping (i.e., both units shutting down and disconnecting from the grid). This event is hereafter referred to as the 'January 2021 dual trip event'.[615]

The January 2021 dual trip event occurred because an electrical fault propagated between the two units through the control circuitry of the ACSs and other equipment (known as the 'interposing relay panels').[616]

The sections that follow discuss the status of the Unit C4 ACS from the January 2021 dual trip event until the day of the incident. The wider implications of the January 2021 dual trip event will then be examined.

21.4.2 Unit C4 ACS Blown Fuses

On 15 January 2021, when investigating the dual trip event from two days prior, CS Energy identified that both sets of fuses in the control circuitry of the Unit C4 ACS were blown, as illustrated in Figure 174.[617]

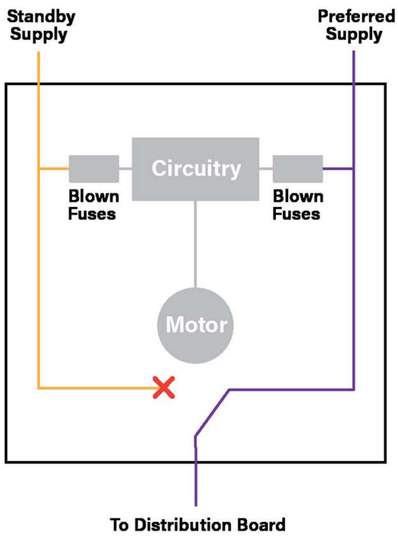

Figure 174 Blown fuses in the Unit C4 ACS

[615] The term 'event' is deliberately used to describe the dual trip of Unit C3 and Unit C4 on 13 January 2021 in order to avoid any confusion, or any inferred similarity, with the incident on 25 May 2021. No special meaning should be ascribed to the use of the word 'event.'

[616] There is an interposing relay panel (IRP) between Unit C3 and Station, and between Station and Unit C4. IRPs are discussed in Section 21.5.4.

[617] Email (15 January 2021) *RE: 10465 – Incident Folder*, CSE.001.042.4254; Statement (12 October 2022) *CS Energy Electrical Engineer 2*, 19, CSE.001.278.0009.

These blown fuses meant that the control circuitry was not supplied from either the preferred supply or the standby supply.[618] As a result, the ACS was inoperable in automatic mode: the control circuitry had no supply to detect a loss of the preferred supply, and there was no supply to the motor to operate the switch.[619]

21.4.3 CS Energy Awareness of Unit C4 ACS Inoperability

CS Energy was aware that blown fuses could '*limit functionality*' of the ACS and acknowledged this in an email on 15 January 2021.[620] Testing on 18 February 2021 confirmed that all four fuses were blown.[621]

21.4.4 Notification Raised to Replace Fuses

To perform work at the Callide power stations, a work order is required.[622] First, a notification is raised, which is a formal request that identifies the required work. Then, a work order is raised in relation to the notification.

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[618] While it is likely that these fuses were blown during the January 2021 dual trip event, this could not be confirmed. The fuses could have blown in a previous event, but not been identified by CS Energy until investigation of the January 2021 dual trip event.

[619] The maintenance notification raised on 15 January 2021 (as a result of the January 2021 dual trip event) requested that the blown fuses be replaced and the control circuitry be checked – indicating it could have been damaged in the January 2021 dual trip event. CS Energy (15 January 2021) *CC4 Unit 220VDC DB Auto Changeover,* Notification 10603823, CSE.001.102.0074. The ACS would not operate automatically if the fuses were replaced, but the circuitry was damaged.

While it is clear that the fuses were blown prior to the 25 May 2021 incident, it is unclear if they were removed prior to the incident. In a letter to the Office of Industrial Relations dated 6 August 2021, CS Energy advised that '*the fuses that control the automatic changeover switch were removed*', in response to a question asking how the automatic changeover switch was disabled on 25 May 2021. Letter (6 August 2021) *Callide Power Station – Notice to give information to the Regulator,* CSE.001.226.0009.

Removal of the fuses, if they were not blown, would have prevented automatic operation of the ACS. But as the ACS was already inoperable in automatic mode (due to the blown fuses), the removal of the fuses would not have made any difference. CS Energy was unable to provide evidence to the Brady Heywood investigation to confirm how they knew that the fuses had been removed prior to 25 May 2021. The Brady Heywood investigation considers it likely that if the fuses had been removed prior to the incident, it was because they were found to be blown. It is considered less likely that they were removed as a means to disable the ACS. No evidence has been sighted that indicates CS Energy intended to deliberately disable the Unit C4 ACS or took any steps to do so. If CS Energy had intentionally disabled the Unit C4 ACS by removing its fuses, this method of disabling the ACS is inconsistent with how they intentionally disabled the Unit C3 and Station ACSs (by opening their isolators).

[620] On 15 January 2021, an internal CS Energy email identified that the fuses were blown and acknowledged that this could affect the ACS's functionality. Email (15 January 2021) *RE: 10465 – Incident Folder*, CSE.001.042.4254. A maintenance notification to check and replace '*possible blown fuses*' on the Unit C4 ACS was raised on 15 January 2021. CS Energy (15 January 2021) Notification 10603823, CSE.001.102.0074. The notification also asked for the control circuit to be checked. CS Energy later conducted further testing on the ACSs (as part of an unrelated work order), and in an internal CS Energy email on 18 February 2021 it was confirmed that all four fuses in the Unit C4 ACS were blown. Email (18 February 2021) *RE: Investigation Report - DC circuit*, CSE.001.257.9930.

[621] Email (18 February 2021) *RE: Investigation Report - DC circuit*, CSE.001.257.9930

[622] The CS Energy Work Management Manual (WMM) outlines the work order process. CS Energy (May 2017) *Work Management Manual*, CSE.001.105.0149.

On 15 January 2021, a maintenance notification was raised regarding '*the possible blown fuses*' in the Unit C4 ACS. The notification requested that the fuses be replaced and the ACS be checked to ensure it was operational in automatic mode, see Figure 175.[623]

Suggested Repair / resources (e.g labour,equipment etc):
suggest consulting with engineering to replace these fuses and check control circuit to ensure that auto changeover will work in the result of a loss of one incomming supply

MOVED TO EP2 - ENG TO PROVIDE ASSISTANCE
[redacted] 15.02.21

End of report

Figure 175 Actions suggested on the notification

The notification was classified as Priority 4 – Low Consequence. Because it was classified as a Priority 4, in accordance with the CS Energy Work Management Manual, the work appears to have been considered a low priority. Priority 4 required the notification to be actioned by 9 April 2021, within 12 weeks of the date the notification being raised.[624] The notification itself proposed an end date of 16 March 2021

21.4.5 Absence of a Work Order

No evidence has been sighted that indicates any action had been taken with respect to the notification, prior to 16 March or 9 April 2021, or any time afterwards. No evidence of a work order relating to this notification has been sighted either. Other notifications were raised after the January 2021 dual trip event, and work orders were raised for those notifications.[625]

As a result, the Unit C4 ACS was still inoperable in automatic mode on 25 May 2021.

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[623] CS Energy (15 January 2021) Notification 10603823, CSE.001.102.0074. It is noted that the body of the notification refers to Station, but this is regarded as a typographical error, as the information provided at the top of the form identifies the Unit C4 ACS as the location in several places.

[624] By contrast, a Priority 1 notification should be addressed '*immediately*', a Priority 2 notification on same day or within seven days and a Priority 3 notification within four weeks. CS Energy (May 2017) *Work Management Manual*, 2.4, CSE.001.105.0149.

[625] The following notifications appear to have been raised during the investigation of the January 2021 dual trip event, with corresponding work orders raised:

- Notification 10604056 / Work Order 4957924 (18 January 2021) CC0 C Main DC board earth fault, line item 36657.
- Notification 10604097 / Work Order 4958002 (19 January 2021) Earth fault Relay Constant Alarm, line 36667.
- Notification 10604172 / Work Order 4977212 (19 January 2021) Earth Flt in Motor Protection Relay, line 366894.
- Notification 10604265 / Work Order 4959065 (20 January 2021) Neu earth fault Gen TX Y Diff 220 Alarm, line 36716.

Excel Spreadsheet (9 November 2021) *Notifications Created Since 20161001.xlsx*, CSE.001.054.0310; Email (19 February 2021) *RE: Investigation Report – DC circuit*, CSE.001.257.8161; Email (19 February 2021) *RE: Investigation Report – DC circuit*, CSE.001.258.1242.

21.4.6 Accidentally or Intentionally Left Inoperable?

The reason the fuses in the Unit C4 ACS had not been replaced was either an oversight or an intentional decision by CS Energy to leave the ACS inoperable. To form a view on this requires a discussion of the wider organisational response to the January 2021 dual trip event, along with consideration of the status of the ACSs for Station and Unit C3.

21.5 The January 2021 Dual Trip Event

21.5.1 Introduction

CS Energy's wider response to the January 2021 dual trip event affected the operational status of all three ACSs in Callide C power station. This section begins by discussing the electrical connectivity between the DC systems of Unit C3, Station, and Unit C4. It then examines the specific type of connectivity that allowed an electrical fault to propagate between the units and cause the January 2021 dual unit trip event.[626]

21.5.2 Active Connectivity of the DC Systems via the Interconnectors and ACSs

As discussed in Part A of this report, Callide C power station has three separate DC systems, as shown in Figure 176.[627]

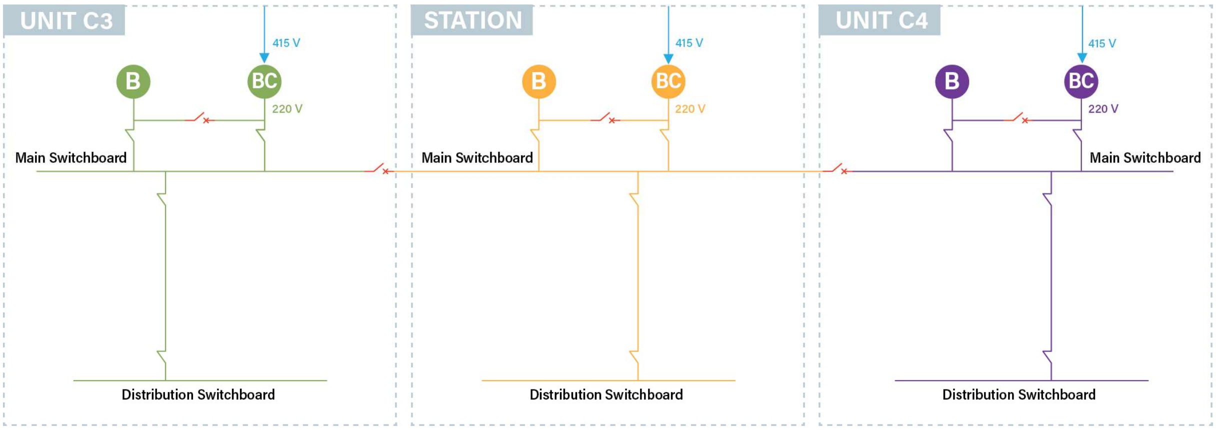

Figure 176 The three Callide C DC systems

Part A also discusses how these three systems can be connected via interconnectors. (Station and Unit C4 were connected via an interconnector on the day of the incident.) The systems are also connected if the ACS operates. Both the ACS and the interconnector are, therefore, a form of active connection between DC systems (i.e., an action needs to occur to connect the systems).

[626] The term 'connectivity' in this context is used to describe the joining of DC systems via diode auctioneering circuits. It was the diode auctioneering circuits that allowed the specific fault in the January 2021 dual trip event to propagate from Unit C4 to the Station and Unit C3 DC systems.

[627] Figure 176 also shows the interconnectors between the three systems (in open position) which are discussed in Part A: Technical Investigation of this report. These interconnectors need to be manually closed and opened to connect and disconnect the systems.

The section that follows discusses how these DC systems are inherently connected to one another.[628] It was this inherent connection that played a role in the January 2021 dual trip event. The inherent connection exists in two ways: via each ACS's control circuitry, and via two interposing relay panels (IRPs). The function of the two IRPs themselves is not relevant to this investigation, but it is relevant that the IRPs provide inherent connectivity between each unit's DC system and Station.

21.5.3 Inherent Connectivity via ACS Control Circuitry

Figure 177 illustrates how the Unit C4 ACS inherently connects the Station DC system to the Unit C4 DC system.

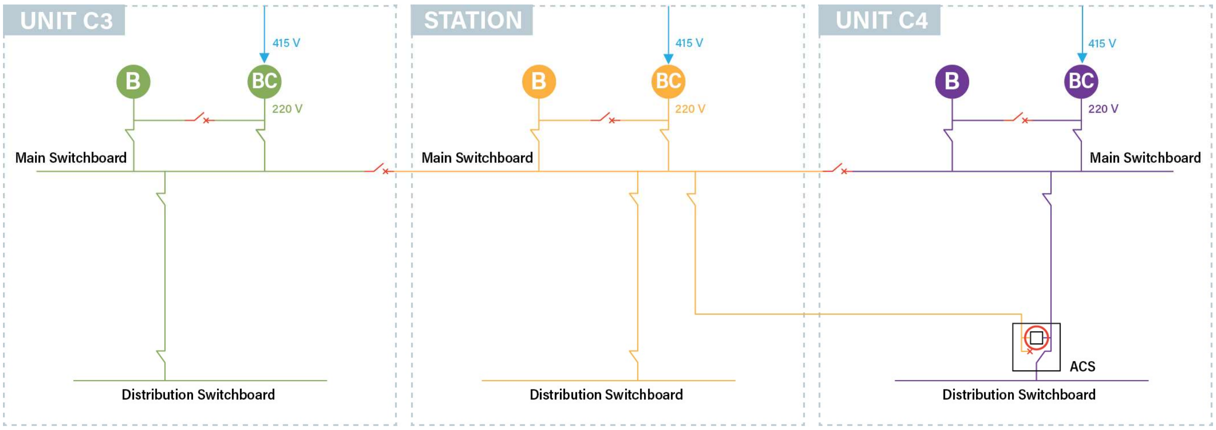

Figure 177 Unit C4 ACS control circuitry inherently connecting Station DC system to Unit C4 DC system

This inherent connectivity is not a result of the ACS changing from the preferred supply to the standby supply, but rather it occurs through the ACS's control circuitry.[629]

Similarly, the Station ACS control circuitry inherently connects the Station DC system to the Unit C3 DC system, see Figure 178.

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[628] This inherent connectivity was demonstrated by CS Energy during their investigations into the January dual trip event on 22 January 2021.

[629] The relevant part of the circuitry is the 'diode auctioneering circuit'. The connectivity provided by the diode auctioneering circuit is specific to the nature of electrical fault that led to the January 2021 dual trip event.

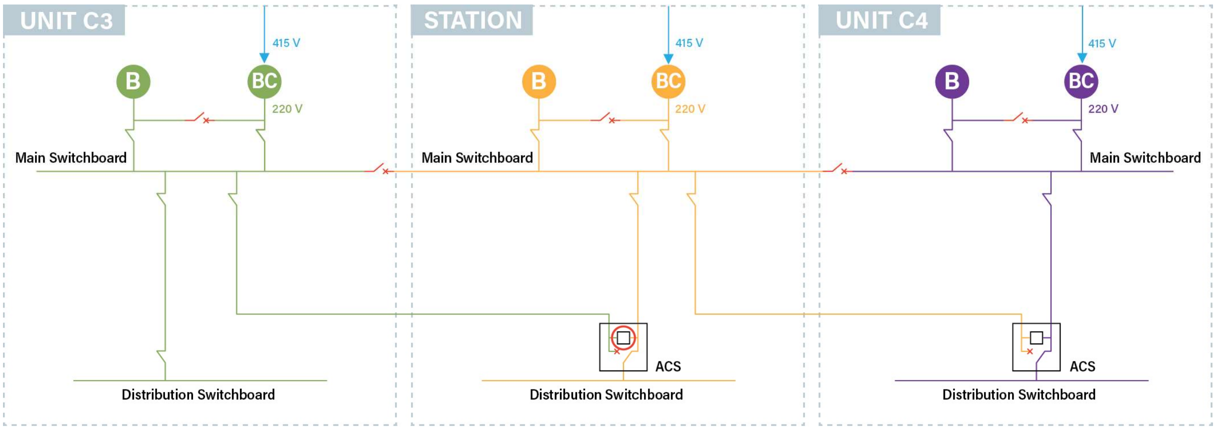

Figure 178 Station ACS control circuitry inherently connecting Unit C3 DC system to Station DC system

Finally, the Station and Unit C3 DC systems are also inherently connected via the Unit C3 ACS control circuitry, see Figure 179.

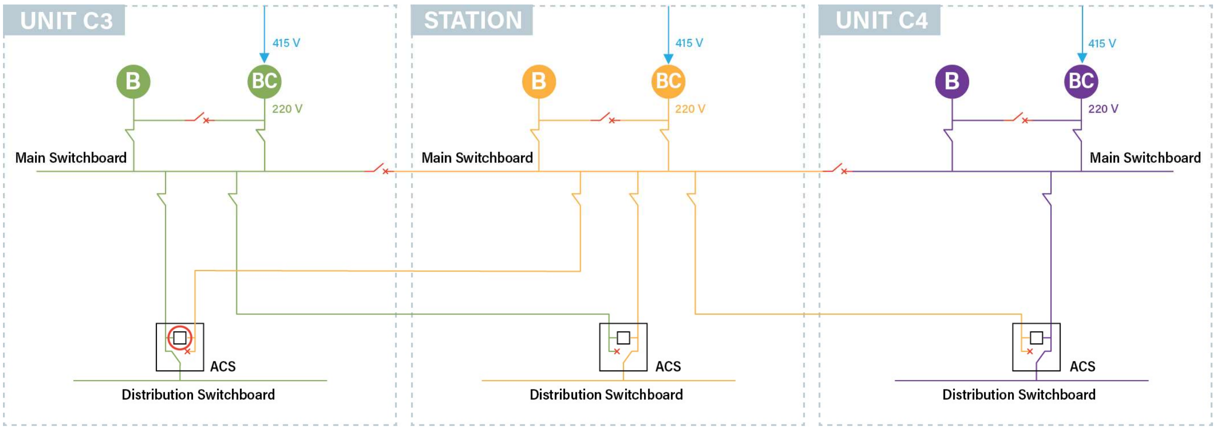

Figure 179 Unit C3 ACS control circuitry inherently connecting Station DC system to Unit C3 DC system

21.5.4 Inherent Connectivity via IRPs

This same inherent connectivity between the DC systems also exists due to the IRPs.[630] Each unit's IRP is connected to the Station DC system, as illustrated in Figure 180.

[630] This inherent connectivity also occurs through the diode auctioneering circuitry found in the IRPs.

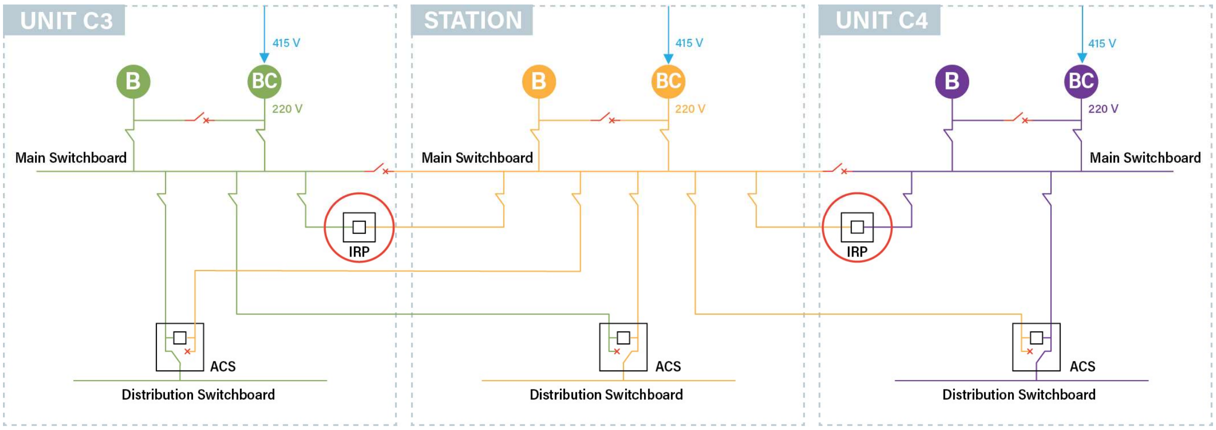

Figure 180 IRPs on Unit C3 and Unit C4 DC systems connect the units to Station DC system

21.5.5 The Role of Connectivity in the January 2021 Dual Trip Event

The cause of the January 2021 dual trip event was an electrical fault in the Unit C4 DC system that propagated to the Station and Unit C3 DC systems.[631] The CS Energy investigation into the event determined that the fault propagated from Unit C4 to Station, via the Unit C4 ACS control circuitry and the interposing relay panel between Unit C4 and Station, see Figure 181.[632]

[631] The CS Energy incident investigation report into the January 2021 dual trip event states that the cause of the event was an electrical fault that developed between the AC and DC systems on Unit C4, leading to an AC waveform to be superimposed on the DC system. A faulty circuit breaker did not interrupt the fault. This allowed the fault to remain. The AC waveform propagated onto the Station and DC systems through diode auctioneering circuits in the ACS control circuitry and the IRPs. This fault led to interference on the MW transducer signals for each unit, causing the ICMS to respond and trip the units. CS Energy (23 February 2021) *Callide C Power Station, Callide C3 and C4 Simultaneous Unit Trip, 13th January 2021, Investigation Report*, CSE.001.052.0241.

[632] As discussed in Section 21.3.2, the control circuitry connects the preferred supply to the standby supply. For the electrical fault that caused the dual trip event to have propagated through the Unit C4 ACS, it would have first travelled from the Unit C4 main switchboard, through the fuses (on the preferred supply side of the ACS control circuitry), then continued through the control circuitry and through the fuses (on the standby supply side of the ACS control circuitry) to reach the Station main switchboard.

If, however, the fuses had been blown before (or if the fuses blew during) the dual trip event, the inherent connectivity would be removed, and the fault would not propagate through the ACS. However, the IRP (which does not have fuses) provides inherent connectivity between Unit C4 and Station via the same mechanism.

It is likely that the fault that caused the dual trip event propagated via both paths initially (the ACS and IRP), and when the fuses in the ACS blew, the fault continued to propagate via the IRP only.

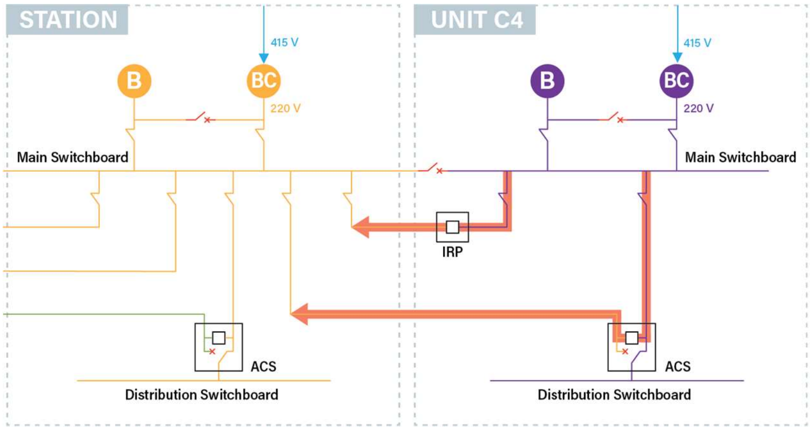

Figure 181 Electrical fault propagated from Unit C4 to Station

Similarly, the fault then propagated from the Station DC system to the Unit C3 DC system, via the Station ACS, the Unit C3 ACS, and Unit C3 IRP, see Figure 182.

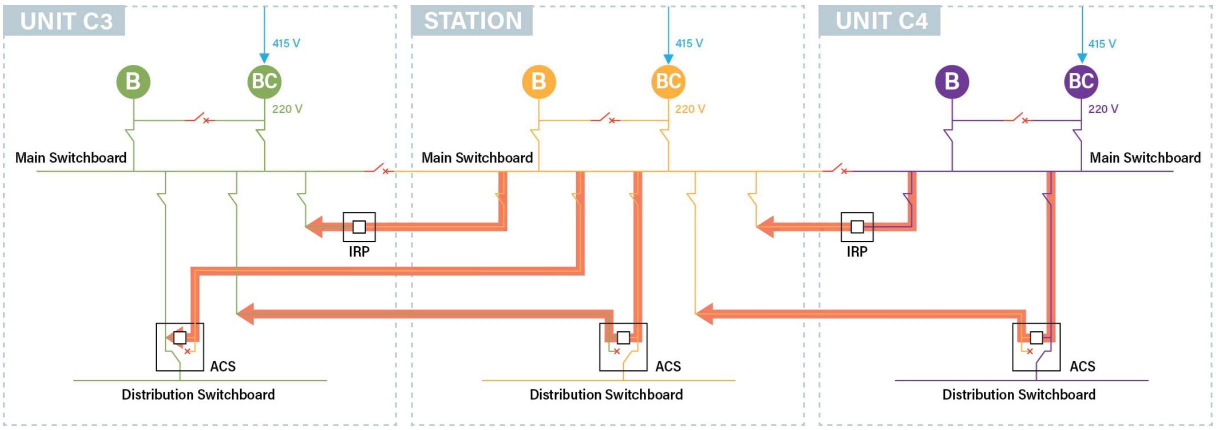

Figure 182 Electrical fault propagated from Station to Unit C3

The propagated electrical fault caused both Unit C4 and Unit C3 to trip and likely caused damage to several pieces of equipment.[633]

21.5.6 Impact of the January 2021 Dual Trip Event

On 14 January 2021, as a result of the dual trip event the day prior, the Australian Energy Market Operator (AEMO) imposed restrictions on Callide C power station. These restrictions limited the amount of power Callide C power station could export.[634]

[633] Examples include earth faults in the DC system, and a failed relay in the Unit C4 interposing relay panel. Email (19 February 2021) *RE: Investigation Report – DC circuit*, CSE.001.257.8161; Email (19 February 2021) *RE: Investigation Report – DC circuit*, CSE.001.258.1242

[634] This was to reduce the impact on the grid if there was another dual unit trip. The dual trip on 13 January 2021 caused a sudden removal of a large amount of generated power from the grid.

Before the restrictions would be lifted, AEMO required CS Energy to investigate the dual trip event, document the investigation in a report to AEMO, and demonstrate to AEMO that steps had been taken to remove the risk of the same dual trip event occurring in the future.[635]

CS Energy prepared a report about the incident, dated 23 February 2021, and provided it to AEMO on 1 March 2021.[636]

The following section examines CS Energy's interim response to the January 2021 dual trip event.

21.6 CS Energy's Interim Solution

21.6.1 Removal of Unit C3 and Station DC System Connectivity

On 22 January 2021, CS Energy advised AEMO that it had determined that the inherent connectivity between the DC systems allowed the electrical fault to propagate from Unit C4 to Unit C3. This propagation caused both units to trip.

To meet AEMO's requirements (so that AEMO would lift the restrictions), CS Energy informed AEMO they would make changes that would effectively remove the connectivity between Unit C3 and Station. This is illustrated conceptually by the red line in Figure 183.

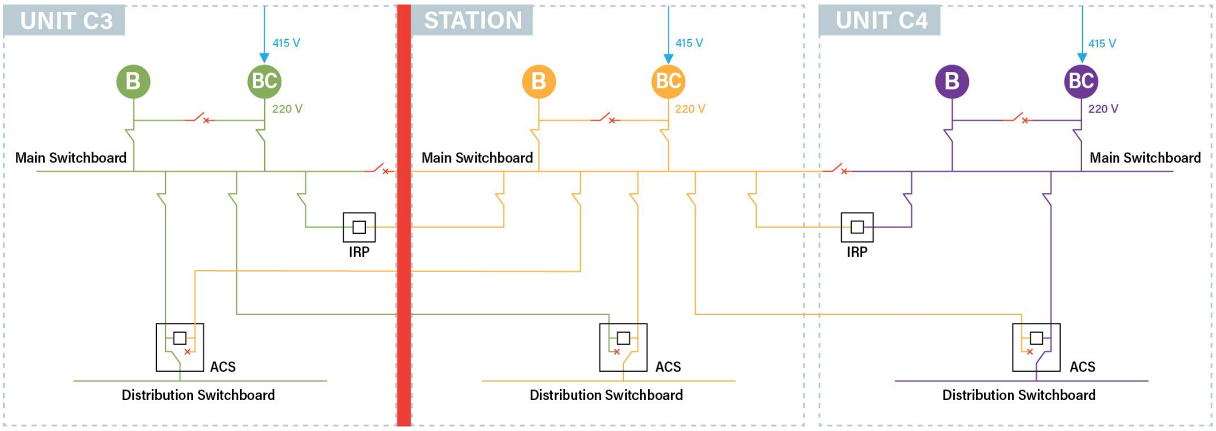

Figure 183 The proposed separation of Unit C3 and Station (indicated by red line)

Removal of connectivity between these two systems would also remove connectivity between Unit C3 and Unit C4. (It was not necessary to remove connectivity between Station and Unit C4 as separating Unit C3 from Station was sufficient – this broke the link between Unit C4 and Unit C3.) CS Energy's

[635] Email (14 January 2021) *Reclassification of the simultaneous tripping of Callide units C3 and C4*, CSE.900.001.1263. Statement (12 October 2022) *CS Energy Electrical Engineer 2*, 11 and 15, CSE.001.278.0009.

[636] Email (1 March 2021) *Callide C Double Unit Trip – Investigation Report*, CSE.001.257.7922; Report (23 February 2021) *Callide C Power Station, Callide C3 and C4 Simultaneous Unit Trip, 13th January 2021, Investigation Report*, CSE.001.257.7943.

solution was on the basis that removing this connectivity would remove the risk of a similar dual trip event in the future.[637]

CS Energy informed AEMO via email that this removal of connectivity would be achieved by performing several '*isolations*', meaning that certain switches (known as 'isolators') would be opened.[638] This email included a sketch showing the proposed isolations. Figure 184 is a simplified version of that sketch, showing the isolations in the DC systems (isolations circled in red).[639]

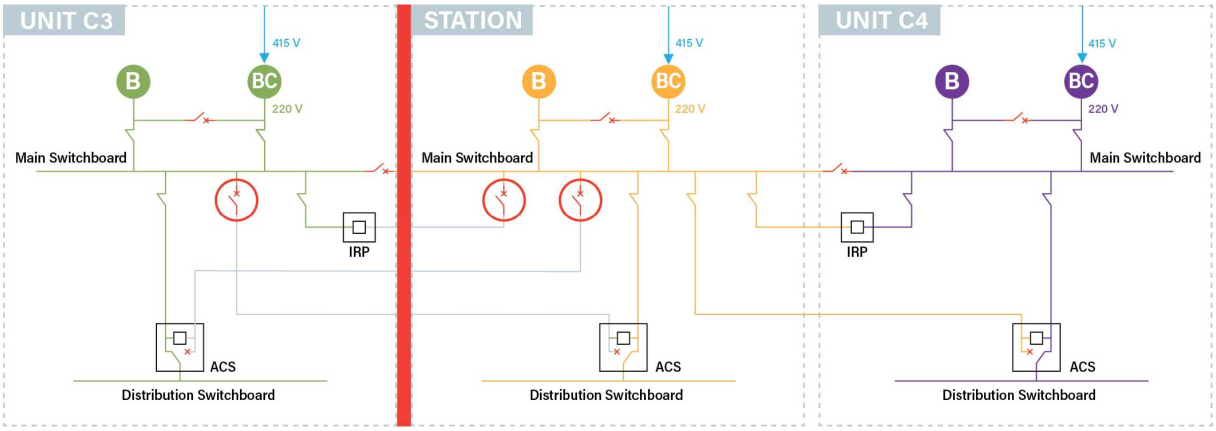

Figure 184 CS Energy advised AEMO on 25 January 2021 that these isolations (circled in red) had been made

Figure 184 shows the isolations that were proposed (from left to right), as follows:

- The standby DC supply from Unit C3 to the Station ACS.
- The DC supply from Station to the IRP between Station and Unit C3.
- The standby DC supply from Station to Unit C3 ACS.

These isolations removed the inherent connectivity, via the ACS control circuitry and IRP, between the Unit C3 DC system and the Station DC system. This, in turn, removed the connectivity between Unit C3 and Unit C4 and likely removed the risk of a dual trip event by the same mechanism in the future.

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637 Testing carried out by CS Energy on 22 January 2021 only removed the connectivity between Unit C3 and Station to test the proposed solution (achieved by removal of one supply to the Unit C3 ACS, the Station ACS and the Unit C3 IRP). This testing confirmed that removing the connectivity between Unit C3 from Station also removed the connectivity between Unit C3 and Unit C4. Email (22 January 2021) *RE: Ac coupling – split U3/U4 to Investigate signal propagation,* CSE.001.049.0084.

However, it appears CS Energy initially planned to remove the connectivity between the Unit C3, Station and Unit C4 DC systems to prevent the propagation of a fault between the units. An email sent on 22 January 2021 refers to removal of supply to '*each interposing relay.*' Email (22 January 2021) *Brief Update – RE: Reclassification of the simultaneous tripping of Callide units C3 and C4- Rectification Actions,* CSE.001.049.0136. There are two IRPs, so the use of plural suggests the inclusion of the Unit C4 IRP. In the absence of identifying specific ACSs, this would suggest that reference to removal of supply to '*each changeover switch*' is also a reference to all three ACSs.

The Brady Heywood investigation concluded that, while CS Energy initially intended to remove connection between all three DC systems, they ultimately decided to only remove the connectivity between Unit C3 and Station.

638 Email (25 January 2021) *RE: Callide C Double Unit Trip – Investigation Report,* 10:19 am, CSE.001.102.0254.

639 Email (25 January 2021) *RE: Callide C Double Unit Trip – Investigation Report,* 10:19 am, CSE.001.102.0254.

These changes deliberately rendered the Unit C3 and Station ACSs inoperable. As a result, if a loss of DC supply occurred in either Unit C3 or Station, the ACS would be unavailable to restore supply.

It is important to note that no isolations were undertaken to deliberately render the Unit C4 ACS inoperable in the same manner as the Unit C3 and Station ACSs. The isolator from the Station DC mainboard to the Unit C4 ACS was not opened, nor was the isolator to the IRP.[640] The grey circles in Figure 185 show the isolators that would have needed to have been opened to deliberately render the Unit C4 ACS inoperable and electrically isolate the Unit C4 DC system from the Station DC system.

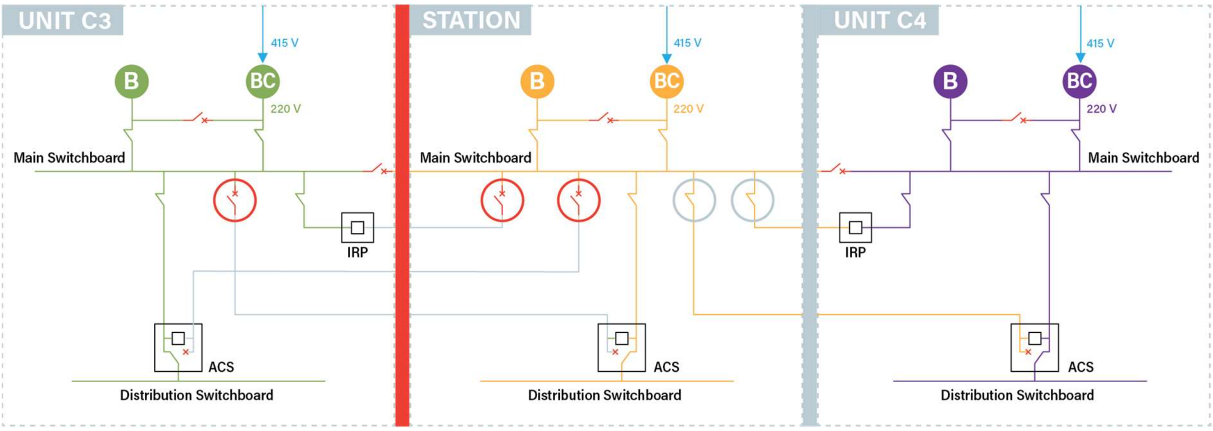

Figure 185 CS Energy did not perform isolations to remove the inherent connectivity between the Unit C4 and Station DC systems

It is likely that both of these isolators would have been opened if the intention had been to separate the Unit C4 and Station DC systems and render the Unit C4 ACS inoperable.[641] These isolations did not occur.

[640] The Brady Heywood investigation concluded that these isolations were not made. The ICMS feedback on the status of the isolator to the standby supply to the Unit C4 ACS was faulty, so while the ICMS data indicates that this isolator had been opened (since 2004), it was not. Excel Spreadsheet (13 October 2023) *CC4 BWB10 GS102.XG01_Request 4c.csv*, CSE.001.0285.0019; Maintenance Order (May 2022) *Maintenance Order 95019244*, CSE.001.253.0025. This isolator, and the isolator to the IRP, were not included on the switching sheets used to perform the isolations discussed in this chapter. Extract SAP Incident database (27 May 2021) *CC3 -220V DC MN SWBD (BUS A)*, CSE.001.251.0001. No switching sheets have been sighted that indicate either of these isolators were operated between the January 2021 dual trip event and the 25 May 2021 incident.

[641] It has not been confirmed why the inherent connectivity was removed between Unit C3 and Station, as opposed to between Station and Unit C4. The Brady Heywood investigation hypothesises that inherent connectivity between Station and Unit C4 was not removed because CS Energy planned that the Unit C4 DC system would be connected to the Station DC system (via the interconnector) during the battery charger replacement project.

21.6.2 Isolations Carried Out by CS Energy

ICMS data confirms that the isolations to the Unit C3 ACS, the Station ACS and the IRP between Unit C3 and Station were performed on 27 January 2021.[642] These isolations electrically separated the Unit C3 and Station DC systems.

21.6.3 AEMO Lifts Restrictions

In response to these isolations, on 28 January 2021, AEMO lifted the restrictions on the amount of power Callide C could export to the grid.[643]

21.7 Consequences of the Removal of DC System Connectivity

21.7.1 Disabling of Unit C3 and Station ACSs

Opening these isolators on the supplies to the Unit C3 and Station ACSs removed the standby supply to both of these ACSs, as illustrated in Figure 186.

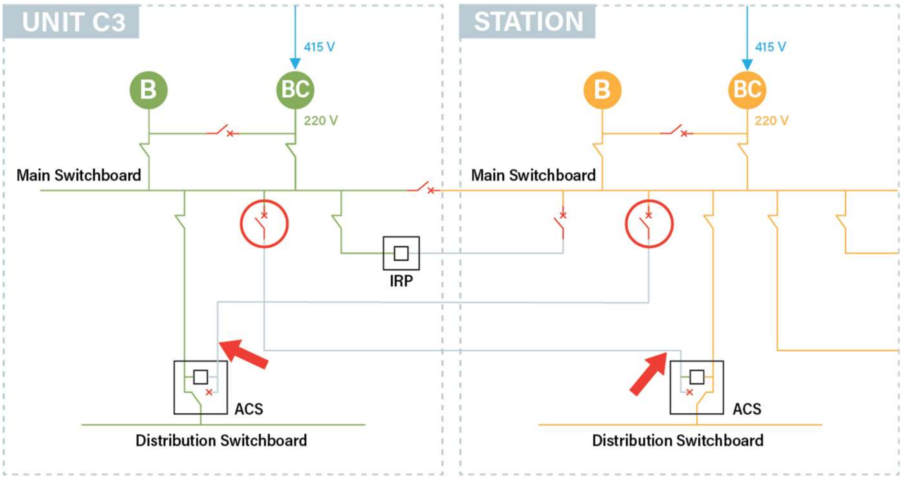

Figure 186 Standby supplies to both the Unit C3 and Station ACSs (red arrows) were disconnected by the isolations (red circles)

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[642] Despite informing AEMO on 25 January 2021 that the isolations had been made, ICMS data shows that the standby power supplies to the Unit C3 ACS, the Station ACS and the IRP between Unit C3 and Station were actually isolated on 27 January 2021.

While the isolations were initially performed on 22 January 2021 (for testing as part of the investigation into the dual trip event), these initial isolations were reversed at the conclusion of the testing that same day. Excel Spreadsheet (13 October 2023) *CC4 BWB10 GS102.XG01_Request 4c.csv*, CSE.001.0285.0019; Extract SAP Incident database (27 May 2021) *CC3 -220V DC MN SWBD (BUS A)*, CSE.001.251.0001.

CS Energy's interim solution also involved addressing one of the causes of the dual trip by modifying the ICMS control signal from the MW transducers on both units. Emails (12 March 2021) *RE: Callide C Double Unit Trip - Investigation Report,* 1:13 pm, CSE.001.049.0171.

[643] Emails (28 January 2021) *RE: Brief Update - RE: Reclassification of the simultaneous tripping of Callide units C3 and C4- Rectification Actions*, 2:07 pm, CSE.001.049.0171.

With these standby supplies removed, if a loss of DC were to occur in the Unit C3 or Station main switchboards (the preferred supplies in each case), the Unit C3 or Station ACSs would not automatically change over.[644]

21.7.2 Removal of 'Designed Redundancy'

CS Energy was aware that disabling the Unit C3 and Station ACSs would remove redundancy from the DC systems. The investigation report into the January 2021 dual trip event acknowledges that the disabling of ACSs was the removal of designed redundancy: '*The DC Isolations were effective but left the Unit DC system without the designed redundancy contained in the Automatic Transfer Switches and the interposing relay panel.*'[645]

21.7.3 Plan for a Permanent Solution

On 12 March 2021, CS Energy informed AEMO that these isolations would remain in place until a more permanent solution was implemented.[646] When complete, this permanent solution would restore the operation of the ACSs, while maintaining the electrical separation between the DC systems.

21.8 CS Energy's Permanent Solution

21.8.1 Proposed Redesign of ACSs and IRPs

CS Energy's investigation report into the 13 January 2021 dual trip event proposed to permanently remove the inherent connectivity between the DC systems by redesigning the ACS control circuitry and IRPs.[647] The proposed redesign was intended to be implemented on all three ACSs – Unit C3, Station and Unit C4 – and both IRPs.[648]

The proposed redesign would maintain the electrical separation between the DC systems and allow the restoration of the ACSs.[649] Once the design was implemented, the isolations could be reversed to

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644 Removing the standby supplies resulted in the inability of the ACSs to operate automatically. The ACS receives supply from both the preferred and standby supply. If the preferred supply fails, the standby supply provides supply to the motor inside the ACS that operates the changeover switch. Without a standby supply, if the primary supply fails, not only is there no standby supply to provide supply to the distribution board, but there is also no supply available for the motor inside the ACS to operate the changeover switch.

The removal of the standby supply also resulted in the inability of the ACS to be operated manually. Even if the ACS was manually operated, there would be no standby supply to provide supply to the distribution board. See Section 21.3.2.

645 CS Energy (23 February 2021) *Callide C Power Station, Callide C3 and C4 Simultaneous Unit Trip, 13th January 2021, Investigation Report,* CSE.001.052.0241.

646 Email (12 March 2021) *RE: Callide C Double Unit Trip - Investigation Report,* 1:13 pm, CSE.001.049.0171.

647 The report stated that the permanent solution would also address the cause of the original electrical fault by replacing electrical switches and equipment due to '*end of life*', and further address the causes of the dual trip by modifying the power supplies to the MW transducers on both units. Report (23 February 2021) *Callide C3 and C4 Double Unit Trip 13 January 2021*, 26, CSE.001.052.0241.

648 Statement (12 October 2022) *CS Energy Electrical Engineer 2*, 23, CSE.001.278.0009.

649 The redesign involved removing the diode auctioneering circuit that allowed the ACS control circuitry to be powered from both the preferred supply and standby supply, and powering the circuitry from the standby supply only. This would address the issue of similar faults propagating from Unit C3 to Unit C4, and vice versa, but would still allow the ACS to automatically operate and change over to the standby supply if the preferred supply was lost.

restore the standby supplies to the Unit C3 and Station ACSs. This would restore the ACSs' automatic functionality.

21.8.2 Implementation of the Proposed Redesign of ACSs and IRPs

On 12 March 2021, AEMO asked CS Energy to confirm the timing for implementing the recommendations in the investigation report. CS Energy responded on the same day, advising that the redesign was:

> *… targeted to start next financial year as we need to apply for new funds for it due to the cost and resources required. We have put a deadline of 30th of November for this project. In the meantime the isolations placed back in January will remain in place.* [650]

This email confirms that CS Energy planned to leave the Unit C3 and Station ACSs in an inoperable state until the redesign of the ACSs and IRPs were implemented by November 2021.[651]

21.9 Station and Unit C3 ACSs Deliberately Disabled

Therefore, two weeks after the January 2021 dual trip event, the Station and Unit C3 ACSs were deliberately disabled and rendered inoperable by CS Energy. CS Energy planned for these ACSs to remain inoperable for up to ten months until November 2021. It was planned that at that point the permanent solution would be implemented, which would make them operable again.

On the day of the incident, therefore, the Unit C3 and Station ACSs were inoperable. They did not, however, contribute to the incident.

21.10 Unit C4 ACS Status Post-January 2021 Dual Trip Event

21.10.1 Introduction

This section discusses whether the Unit C4 ACS was intentionally left in an inoperable state following the January 2021 dual trip event.

21.10.2 Inoperability of Unit C4 ACS Identified

As discussed above, there is internal CS Energy correspondence in January and February 2021 that shows CS Energy was aware of the blown fuses and inoperability of the Unit C4 ACS. The first instance that the fuses were identified as blown was on 15 January 2021.[652]

21.10.3 Inoperability of Unit C4 ACS Discussed with AEMO

The status of the Unit C4 ACS was also raised in correspondence between CS Energy and AEMO regarding the isolations performed on Unit C3 and Station. On 27 January 2021, an email from CS

[650] Email (12 March 2021) *RE: Callide C Double Unit Trip - Investigation Report*, 1:13 pm, CSE.001.049.0171.

[651] The Unit C3 and Station ACS would be inoperable in both automatic mode and manual mode (due to the standby supply being unavailable because it had been isolated).

[652] Email (15 January 2021) *RE: 10465 – Incident Folder*, CSE.001.042.4254; Statement (12 October 2022) *CS Energy Electrical Engineer 2*, 19, CSE.001.278; CS Energy (15 January 2021) *Notification 10603823*, CSE.001.102.0074.

Energy to AEMO included a marked-up drawing of the Callide C power station DC system, see Figure 187.[653]

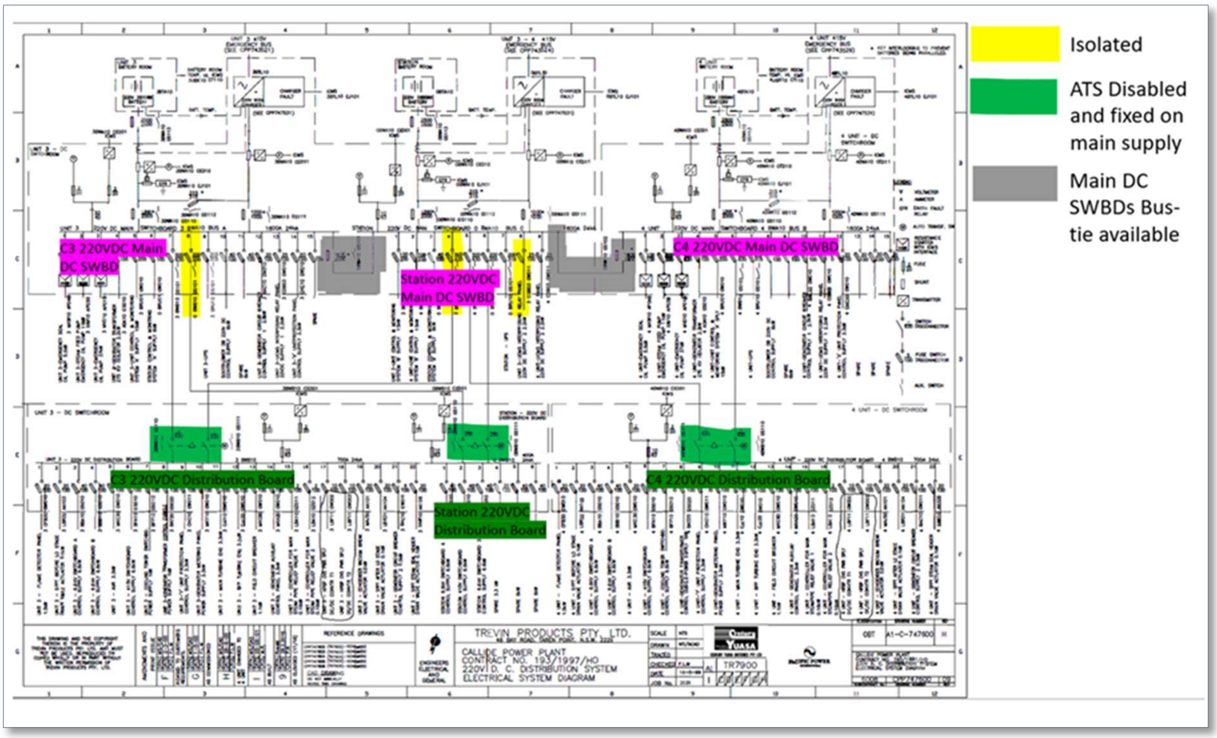

Figure 187 Marked-up drawing in email from CS Energy to AEMO on 27 January 2021

For simplicity, Figure 188 shows a simplified sketch of this marked-up drawing.

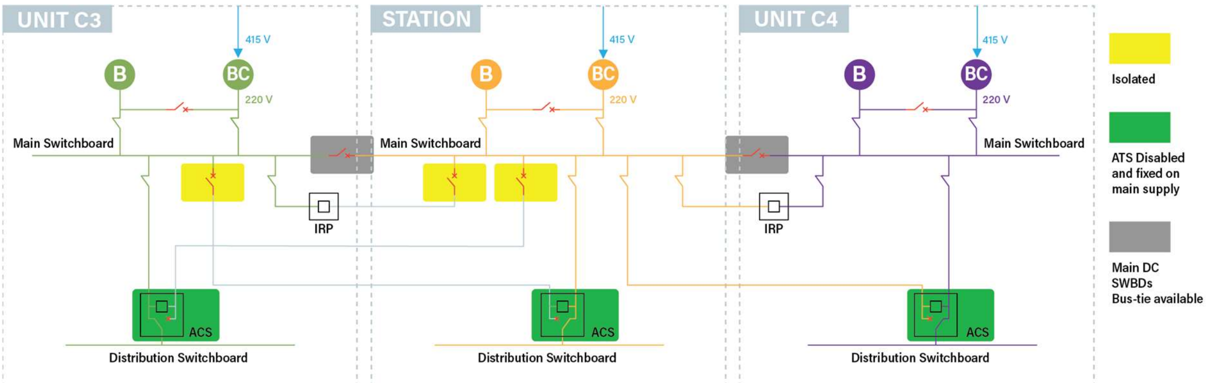

Figure 188 Simplified sketch of marked-up drawing

653 The email stated that '*the automatic changeovers to the 220VDC Distribution Boards have been isolated as these were the location where the DC coupling occurred*'. 'DC coupling' means the same as the electrical connectivity. Email (27 January 2021) *Brief Update – RE: Reclassification of the simultaneous tripping of Callide units C3 and C4-Rectification Actions*, 12:16 pm, CSE.001.102.0254.

The key points with respect to this sketch are the following:[654]

- Isolated: The yellow boxes indicate where isolations have taken place. These are consistent with the isolations that CS Energy made to deliberately disable the Unit C3 and Station ACSs.
- ATS disabled and fixed on main supply: The green boxes identify where the ACSs (in this case referred to as 'ATSs') are identified as being disabled and fixed on main supply (i.e., preferred supply). All three ACSs are identified in this manner.

With respect to the Unit C4 ACS being identified as disabled, it is not clear if this indicates an intention to actively disable it or an indication of its current status as of 27 January 2021. It is also not clear if CS Energy viewed the disabled Unit C4 ACS as part of the interim solution to remove connectivity between Unit C4 and Station.

At the time this email was sent to AMEO, CS Energy was aware that the fuses in the Unit C4 ACS had blown and would also have been aware that these blown fuses could impact the automatic operation of the ACS. It is, therefore, likely that the green highlighting of the Unit C4 ACS in Figure 187 above, is to indicate that the Unit C4 ACS was inoperable (because of the blown fuses), and that no action was taken to deliberately render it inoperable.[655]

21.10.4 Further Testing on the Unit C4 ACS

CS Energy later conducted further testing on the ACSs (as part of an unrelated work order), and, in an internal CS Energy email on 18 February 2021, it was confirmed that all four fuses in the Unit C4 ACS were blown.[656]

21.11 Inoperability of Unit C4 ACS on 25 May 2021

The Brady Heywood investigation concluded that it is likely that CS Energy intentionally left the Unit C4 ACS inoperable, and that it is unlikely that CS Energy failed to replace the fuses because of oversight. This conclusion is based on the following:

- The wider response to the January 2021 dual trip event involved deliberately rendering the Unit C3 and Station ACSs inoperable, despite this being recognised as a removal of design redundancy. There was, therefore, a willingness within CS Energy to tolerate inoperable ACSs. Leaving the Unit C4 ACS inoperable in automatic mode was not inconsistent with the measures put in place on Unit C3 and Station.

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[654] With respect to the grey in the legend (i.e., Main DC SWBDs Bus-tie available), CS Energy also advised AEMO in the email that if redundancy between Unit C4 and Station was required, '*The main 220VDC switchboard bus-ties are available to be manually switched … and tie … the Unit 4 and Station main DC SWBDS in the case of a failure of the main battery charger[s] or battery bank[s]*.' Email (27 January 2021) *Brief Update – RE: Reclassification of the simultaneous tripping of Callide units C3 and C4-Rectification Actions*, 12:16 pm, CSE.001.049.0171.

[655] This is corroborated in a statement by a senior electrical engineer at Callide that stated that '*None of the work that [redacted] and I had requested be performed required anything to be done to the Unit C4 ACS or its supplies*.': Statement (12 October 2022) *Senior Electrical Engineer*, 19, CSE.001.278.0009.

[656] Email (18 February 2021) *RE: Investigation Report - DC circuit*, CSE.001.257.9930.

- A notification to replace the fuses had been raised immediately after the January 2021 dual trip event, but it was given a low priority, suggesting that it was not considered urgent.
- No work order was raised to replace the fuses.
- The correspondence with AEMO on 27 January 2021 identified the Unit C4 ACS as disabled, yet no evidence has been sighted to suggest this prompted a follow up regarding the replacement of the fuses.
- Further testing, conducted as late as 18 February 2021, again confirmed that the Unit C4 ACS fuses were blown, but no evidence has been sighted that this resulted in a follow up regarding their replacement.
- Finally, CS Energy communicated to AEMO that it proposed to leave Unit C3 and Station DC systems without backup (in the form of an ACS) for potentially ten months until the redesign was implemented. The Unit C4 ACS would be modified as part of this work (as well as the Unit C3 and Station ACSs).

While deliberate actions were taken by CS Energy to render the Unit C3 and Station ACSs inoperable, no evidence has been sighted that shows CS Energy took deliberate actions to render the Unit C4 ACS inoperable.[657] However, the Unit C4 ACS was inoperable in automatic mode because of its blown fuses, and it is considered likely that CS Energy intentionally left it in this inoperable state.

21.12 Assessment of Risk and Management of Change of Inoperable ACSs

No evidence has been sighted of any formal assessment of the risk associated with leaving the ACSs inoperable for a prolonged period. Rather, it appears that, in January 2021, CS Energy had a singular focus on developing an interim solution that would result in AEMO lifting the restrictions on Callide C power station.[658]

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[657] On 6 August 2021, in response to specific questions about the Unit C4 ACS, CS Energy advised the Office of Industrial Relations that the Unit C4 ACS control circuits were damaged in the dual trip event on 13 January 2021, rendering the automatic function of the ACS inoperable. It stated that a redesign of the ACS was planned to remove the electrical connectivity between Unit C4, and Station and Unit C3. The automatic changeover functionality was to be left out of service until the redesign was implemented. The letter does not specifically mention the blown fuses in the Unit C4 ACS (that CS Energy was aware of since February 2021 or earlier). It is not clear if the reference to the damaged control circuits included the blown fuses.

However, in response to the question '*How was the automatic changeover switch disabled?*', CS Energy responded, '*The fuses that control the automatic changeover switch were removed.*' Letter (6 August 2021) *Callide Power Station – Notice to give information to the Regulator*, CSE.001.226.0009.

The Brady Heywood investigation considers it likely that if the fuses had been removed prior to the incident, it was because they had been found to be blown. It is considered less likely that they were removed as a means to disable the ACS.

[658] The wording in the Plant Modification Quality Plan and Check Sheet, prepared on 14 January 2021 in relation to the MW transducer after the January 2021 dual trip event, appears to be aimed at having the restrictions lifted. It describes the Problem and Impact as: '*AEMO restrictions following a simultaneous trip of C3 and C4 on 13.01.21 due to all 6 MW transducers (3 per unit) going unhealthy. AEMO have agreed to lift restrictions (limit of 720MW if insufficient FCAS) if the unit trip is*

The removal of standby supplies from the Unit C3 and Station ACSs should have been subject to CS Energy's management of change process, which requires assessment of process safety risk. CS Energy's Plant Modifications Procedure (CS-AM-010) applies to both permanent changes and temporary changes, and it has the primary objective of managing the risk associated with change. No evidence has been sighted that indicates the Plant Modifications Procedure was considered or followed.

If this Procedure had been followed, the required risk assessment could have increased the likelihood of identifying the risks associated with the removal of backup from the DC systems for Unit C3, Station, and Unit C4.[659]

21.13 Discussion

In the January 2021 dual trip event, both Unit C3 and C4 tripped simultaneously. Following this event, AEMO placed restrictions on Callide C's power generation capacity. In order to have these restrictions lifted, CS Energy implemented changes to Callide C power station to prevent another dual trip event occurring. These changes included the ACSs for Unit C3 and Station being deliberately rendered inoperable by being isolated. As a result, if a loss of DC supply occurred in either Unit C3 or Station, the ACSs would be unavailable to restore supply.

In contrast, CS Energy does not appear to have deliberately rendered the Unit C4 ACS inoperable in the same way as in Unit C3 and Station. Following the January 2021 dual trip event, CS Energy identified that the Unit C4 ACS was inoperable in automatic mode (as it had blown fuses). While a notification was raised to repair it, no evidence has been sighted of a work order to complete the repair. On the day of the incident, the Unit C4 ACS was still unrepaired and inoperable in automatic mode.

Therefore, by the time of the incident, the Unit C3 and Station ACSs had been deliberately rendered inoperable, and the Unit C4 ACS, with its blown fuses, was also inoperable. CS Energy's investigation report into the January 2021 dual trip event shows they were aware that an inoperable ACS was removing 'designed redundancy' from the DC systems.

To restore this redundancy in the long term, CS Energy planned to redesign the Unit C3, Station, and Unit C4 ACSs. This redesign was planned to be implemented by the end of November 2021, ten months after the January 2021 event. CS Energy, therefore, planned to leave the Unit C3 and Station

prevented on the logic on loss of MW transducers.' The details added to describe the Benefits and Justification are: '*If this modification is not undertaken, restrictions will remain on unit until full understanding of cross coupling of voltages between CC3 and CC4 DC systems is found. this is expected to take significant time and investigation to resolve. The Trading and reputational impact of not solving this quickly will far outweigh the cost of the modification.*' Standard Form (14 January 2021) *Plant Modification Quality Plan and Check Sheet, MW Transducer unhealthy – open look control,* CSE.001.014.8971.

[659] The Procedure requires the Modification Officer to '*Assess concept risk in conjunction with other relevant specialists/disciplines as required'*. If this had taken place and the resultant residual risk was 'significant or high' (given the 'loss of designed redundancy'), then the Head of Engineering would be required to evaluate and approve the change and it would also have triggered a HAZOP study.

Further, at the review and acceptance stage within the Procedure, the Responsible Engineering Manager, Maintenance Manager and Production Manager would be required to accept the modification to be put into operation. This should have raised awareness of the change among appropriate operational staff on site of the status of the ACSs. CS Energy (2020) *CS Energy Procedure, Plant Modifications CS-AM-010*, 20, CSE.001.226.0171.

ACSs inoperable for this ten-month period. It is likely that the Unit C4 ACS was intentionally left inoperable for this time. It is unlikely that the failure to repair the Unit C4 ACS was an oversight.

While CS Energy was aware that inoperable ACSs were a removal of ‘designed redundancy’, no evidence has been sighted to show that any management of change or formal risk assessments were undertaken that considered the risks associated with leaving the ACSs in this state. The decision to deliberately render the Unit C3 and Station ACSs inoperable, and leave the Unit C4 ACS inoperable, should have been subject to CS Energy’s management of change process. This is because these changes were modifications to the operation of the Callide C power station.

No evidence has been sighted of a wider discussion within CS Energy regarding the decision to leave the ACSs inoperable, or evidence of a discussion on the risk this posed to the wider power station. For example, the personnel undertaking the switching sequence were unaware the Unit C4 ACS was inoperable. No evidence has been sighted to ascertain whether or not the status of the Unit C4 ACS was considered in the preparation of, or decision to proceed with, the switching sequence with Unit C4 online.

21.14 Chapter Summary

The Unit C4 ACS, which should operate and restore DC supply to parts of the unit in the event of a loss of DC, was inoperable on the day of the incident. Therefore, DC supply was not restored to Unit C4.

It is likely that CS Energy intentionally left the Unit C4 ACS inoperable after it was found to be inoperable following a previous event in January 2021.

Despite an acknowledgement by CS Energy that an inoperable ACS was a removal of redundancy from the DC system, no evidence has been sighted that shows any formal risk assessments or management of change were undertaken with respect to the Unit C4 ACS being, or being left, in an inoperable state.

22 CONCLUSIONS OF PART B: ORGANISATIONAL INVESTIGATION

22.1 Organisational Investigation – Control Room Response

On the day of the incident, after AC and DC supply were lost, the Unit C4 display screens in the control room went black. The control room operators were then without access to the data they needed to assess Unit C4's status and take informed actions. Throughout the incident, including when the display screens had been restored (after approximately 20 minutes), the information available to the operators from site personnel, AEMO, Powerlink and the display screens was inconclusive and contradictory.

The loss of DC supply also meant that the only way for the control room operators to disconnect Unit C4 from the grid was to request Powerlink to open a circuit breaker at Calvale substation. This would have stopped Unit C4 from motoring.

Before making this request, however, the operators needed to be certain that Unit C4 was not being driven by steam and exporting power to the grid. If Unit C4 was being driven by steam and was then disconnected from the grid, this likely would result in an 'overspeed' event and the complete destruction of the unit.

Due to the inconclusive and contradictory information available to them during the incident, the operators were unable to reach this certainty before the turbine missile event occurred.

22.2 Organisational Investigation – Direct Factors

22.2.1 Switching With Unit C4 Online and Without Battery Redundancy

On the day of the incident, there was no redundancy to the Unit C4 DC supply between two steps in the switching sequence. The Unit C4 DC system is typically supplied by a battery charger and a battery, with the battery providing redundancy. The redundancy provided by the Unit C4 battery was unavailable because it was not connected.

No evidence has been sighted that CS Energy understood or formally considered the risks posed by this lack of redundancy, particularly combined with carrying out the switching sequence with the unit online and exporting power. If the incident had occurred with the unit offline (i.e., with the unit shut down and rotor not spinning), the damage to the turbine generator could have been avoided.

CS Energy's processes, however, did not require any form of formal risk assessment when planning or executing switching sequences. Its processes only required consideration of the personal safety risk posed to those personnel undertaking the work, not of any risks posed to the wider plant. While formal risk assessments would not necessarily have led to avoidance of the incident, they could have increased the likelihood of identifying the risks associated with proceeding with the switching sequence with the unit online and without DC redundancy.

This lack of redundancy in the Unit C4 DC system, therefore, placed a requirement on the Unit C4 battery charger to respond instantly to maintain the Unit C4 DC system voltage when the Station DC supply was disconnected. No evidence has been sighted that CS Energy understood this requirement, considered the risk of the battery charger not performing as required, nor considered the consequences that could result from the battery charger not performing as required with the unit online.

While the design, execution and decision-making regarding the switching sequence were all in accordance with CS Energy's processes, these processes were deficient because they did not require consideration of the risks posed by the switching sequence to the wider plant.

22.2.2 The Battery Charger Project

The replacement Unit C4 battery charger was neither specified nor tested for the requirements of the switching sequence being carried out at the time of the incident, nor was it capable of maintaining the voltage in the Unit C4 DC system under the operating conditions at the time.

The battery charger replacement project should have followed CS Energy's management of change process, but this process was not effective nor was it effectively applied to the project.

While following an effective management of change process would not have necessarily led to the avoidance of the incident, it could have increased the likelihood of identifying the performance requirements for the battery charger. It could also have increased the likelihood of identifying the risks and consequences of the battery charger failing to perform in accordance with these requirements.

22.2.3 Risk of the Loss of AC and DC Systems

No evidence has been sighted to suggest CS Energy considered the risk of the loss of AC supply during the switching sequence. It is highly unlikely, however, that CS Energy could have anticipated that a DC system voltage collapse could result in arc flap protection operating and leading to the loss of AC supply to Unit C4. This is due to the highly unusual manner of the DC voltage collapse.

No evidence has been sighted that the risks and impact of the loss of DC supply were considered with respect to carrying out the switching sequence with the unit online.

22.2.4 The Inoperable Automatic Changeover Switch

The Unit C4 automatic changeover switch, which should operate and restore DC supply to parts of the unit in the event of a loss of DC, was inoperable in automatic mode on the day of the incident. Therefore, DC supply was not restored to Unit C4.

It is likely that CS Energy intentionally left the Unit C4 ACS inoperable after it was found to be inoperable following a previous event in January 2021.

Despite an acknowledgement by CS Energy that an inoperable automatic changeover switch was a removal of redundancy from the DC system, no evidence has been sighted of any formal risk assessments or management of change undertaken with respect to the Unit C4 automatic changeover switch being in an inoperable state.

No evidence has been sighted that indicates the inoperable state of the Unit C4 automatic changeover switch was considered in preparing for or deciding to proceed with the switching sequence with Unit C4 online, nor has any evidence been sighted that the inoperable state of the Unit C4 automatic changeover switch was widely communicated within CS Energy.

22.3 Organisational Investigation – Wider Factors

22.3.1 Process Safety

Within high hazard industries, there is a widely accepted and well-established approach to managing the risk of catastrophic failure known as 'process safety'.

Process safety consists of practices that companies adopt in order to understand and control the catastrophic risks associated with their operations. From an organisational perspective, the catastrophic failure of Unit C4 should be examined through the lens of process safety.

The Brady Heywood investigation examined the following process safety aspects at CS Energy:

- CS Energy's organisational context.
- CS Energy's Critical Risk Program.
- The effectiveness of CS Energy's systems, such as management of change.

22.3.2 Organisational Context

CS Energy has two significant structural influences: it is a government owned corporation, and it shares ownership of Callide C power station. As a government owned corporation, CS Energy is obliged to meet Shareholder Mandates, as well as meet agreed annual key performance indicators. In the years leading up to the incident, these mandates focused on cost savings, and performance indicators were dominated by financial and production metrics, as well as personal safety-related metrics. Shared ownership of Callide C power station led to increased complexity in its management, including competing asset investment priorities.

From 2015 onwards, there was a period of significant organisational reform. Multiple initiatives to improve performance were delivered across the organisation – six of which had direct impact on operations at the Callide site. This reform overlapped with a period of high turnover of Callide site management.

In this context, special effort was required to foster and maintain a focus on process safety.

22.3.3 The Critical Risk Program

CS Energy's Critical Risk Program was piloted in 2017, and then launched in 2018. This program aimed to develop a better understanding and management of risk across all CS Energy's sites.

The program started well, and was consistent with emerging best practice regarding process safety in the industry. But in the two years that followed, the program lost key resources and funding. By the time of the incident, the Critical Risk Program had not materially impacted the understanding or management of process safety risk on the Callide site.

Despite this, internal and external messaging presented a confident view that an effective process safety program had been established within CS Energy.

22.3.4 Effectiveness of CS Energy's Systems

In the years leading up to the incident, CS Energy conducted reviews into how it managed change, how it conducted maintenance work, how it responded and learned from incidents, and the effectiveness of its Permit to Work system. These are all key systems needed for the effective management of process safety.

Substantive issues were identified with each of these systems. CS Energy's agreed actions in response to these issues tended to address the symptoms and rarely addressed underlying causes.

In particular, the reviews into how CS Energy conducted management of change (i.e., its Plant Modifications Procedure) identified longstanding issues with the effectiveness of how CS Energy applied management of change. These issues are consistent with those identified in both the procurement of the battery charger and the decision-making surrounding the Unit C4 automatic changeover switch being inoperable.

22.4 Organisational Investigation – Summary

The key organisational factor related to the incident can be summarised as a failure to implement effective process safety practices.

These practices could have increased the likelihood of identifying and managing the risks associated with undertaking the switching sequence to bring the replacement battery charger into service, with no redundancy or backup to the DC system, and with the unit online.

CS Energy had substantive and longstanding issues with systems that are critical for process safety, and its project to embed process safety within the organisation lost key resources and funding, and did not materially impact the management of process safety risk.

The failure to implement effective process safety practices was not unique to the incident on 25 May 2021. Rather, it was consistent with an organisation that did not value or practise effective process safety.