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Attachment 7.2

September 15, 2023

Control & Protection System Renewal

document control

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Table 1.1: Revision Record

Version	Date	Updated By	Changes Made
0.1	*12/05/2023*		*Initial draft*
0.2	*16/08/2023*		*Feedback received from group discussions*
1	*15/09/2023*		*Final*

Table 1.2: Review and Distribution

Name	Role	Action	Sections
Greg Mather	*HVDC Systems & Project Manager*	*Input*	*All*
Jamie Horwood	*AP&L Specialist*	*Input*	*All*
Tom Slee	*Senior Feasibility Engineer*	*Input*	*All*
Prasoon Premachandran	*Team Lead Project Delivery*	*Input*	*All*
Mark Allen	*Regulatory Manager*	*Review*	*All*
Eric Kocoj	*Head of Infrastructure Projects*	*Review*	*All*

This document requires the following approvals. Approvals are inserted as an object in the table below (preferred) or stored with the approved document in electronic version on the Project Site in Project Server.

Table 4: Approvals

Name	Role	Approval	Date Approved
Angela Cam	*Asset Manager*		
Paul Alexander	*GM Asset Management*		

Other project specific approvers can be added if required.

Delegation Policy

Contents

1. Executive Summary

1.1. Action Requested

This business case seeks approval of $39.6 million ($2023) to undertake the Control and Protection System replacement project. This project will replace Basslink's Human Machine Interface (HMI) and Control and Protection System.

This project will result in the lowest lifecycle costs to ensure ongoing safe and reliable operations.

The project is due to commence July 2025 and is scheduled to be completed by June 2030.

1.2. Options Considered

Option 1 – Control and Protection System replaced by 2026.

Option 2 – Control and Protection System replaced by 2030 (recommended option).

Option 3 – Control and Protection System replaced by 2035.

1.3. Project Overview

Basslink is the HVDC interconnector which connects the Tasmanian and Victorian AC grids. Commissioned in 2006, Basslink is critical to the electricity systems in Tasmania and Victoria, protecting against the risk of energy shortages and providing peak load power.

The Control and Protection System is the 'brain' or 'supercomputer' which ensures the safe and reliable operation, and seamless integration with the existing AC grids. The HMI is the system which allows the Control and Protection System to be controlled.

As with all computer systems, the technology underpinning the hardware and software of the Control and Protection System and HMI will be obsolete well before the end of the design life of other Basslink components. This obsolescence occurs as improvements in technology, design, hardware, and software, as well as changes in system requirements (such as cybersecurity), leads vendors to withdraw support and cease spare parts production in favour of new replacement products and platforms. Individual components are also expected to start failing at higher rates leading to a reduction in reliability.

Operating obsolete systems beyond their design life escalates the risk of failure, brings challenges around spare part availability, and risks more frequent and more prolonged outages. Bearing this additional risk doesn't deliver any material benefits. Extending the life of the initial system directly shortens the operational (and economic) life of its successor, given its life is limited by the life of the thyristor valves.

Relevant considerations include:

- Basslink's design which assumes a replacement of the control and protection equipment midway through the design life of the thyristor valves and again when the thyristor valves are replaced.
- CIGRÉ (the International Council on Large Electric Systems) recommends that these systems are refreshed midway through the design life of the thyristor valves.
- Due to the criticality of HVDC interconnectors, global practice is to replace these systems at around 20 years.

In turn, optimisation of lifecycle costs requires balancing:

- the replacement of the Control and Protection System close to the midpoint of the thyristor valve design life to maximise the economic value of both the initial and the replacement system and to reduce the risk of failure, and
- replacing the Control and Protection System at the beginning of a new product life cycle to ensure the system is in place for the longest period before becoming obsolete.

Given the importance of this decision, we have engaged our customers through multiple deep and broad channels to understand their views on when to replace the Control and Protection System. Most customers – between 68% and 77% depending on customer location – told us that they supported replacement of the system 2025-30 to avoid the potential negative impacts of a Basslink failure. About one quarter considered that we should wait to ensure access to newer technology while a smaller proportion supported delaying investment due to current cost-of-living pressures.

We have also considered increasing market pressures due to a forecast bow-wave of Control and Protection System replacements and new HVDC system. Given the limited number of vendors available, delaying the replacement of the Control and Protection System is likely to reduce our bargaining power increasing prices and risking availability.

Given these factors, replacing the Control and Protection System by 2030 is the preferred approach as it:

1. is consistent with consumer preferences to replace the system by 2030 to reduce reliability risks.
2. enables the transition to the next generation of Control and Protection Systems (which is also consistent with feedback from our customers).
3. reduces the difference in economic life between first and second Control and Protection System.
4. reduces market pricing and availability risks.

1.1. Consistency with the National Electricity Rules

The forecast capital expenditure for this project is required to achieve the capital expenditure objectives, specifically, in relation to the requirements on Basslink under the Basslink Operating Agreement (BOA) (between Basslink and the Tasmanian Government) to comply with Good Electricity Industry Practice (see description in Attachment 7)

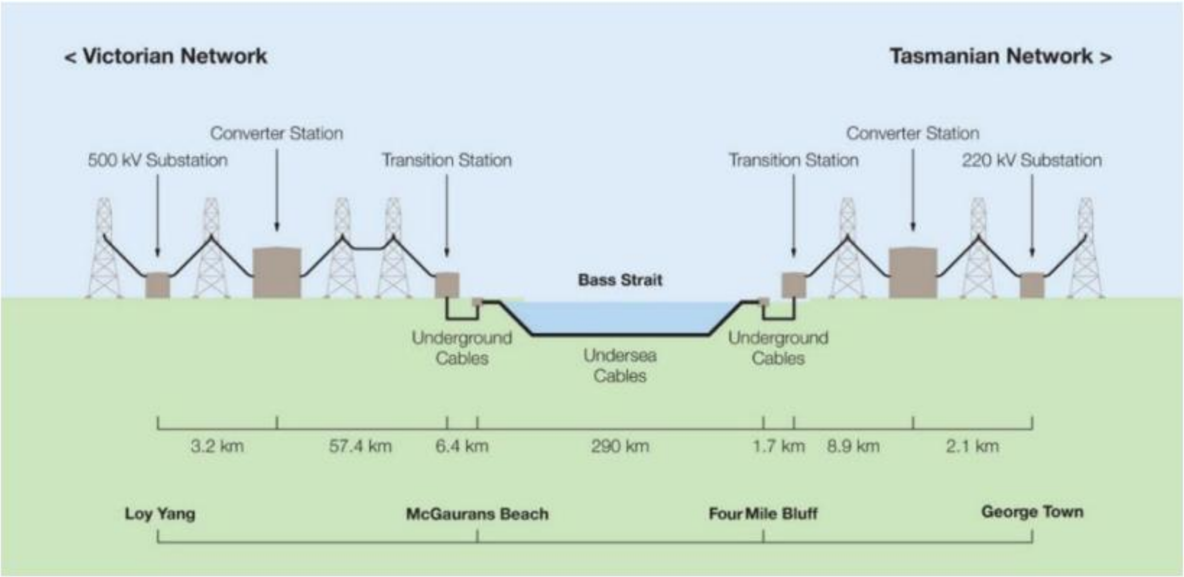
2. Background

2.1. Basslink

Basslink is a 370 km high voltage direct current (HVDC) electricity interconnector between Loy Yang Victoria and George Town Tasmania. Basslink enhances security of supply on both sides of Bass Strait; protecting Tasmania against the risk of drought-constrained energy shortages and protecting Victoria and the southern states against the shortage of peak load power.

Basslink is comprised of several major components including overhead transmission lines, underground cables, undersea cables as well as transition, and converter stations.

Figure 2.1 Basslink Network Overview (including substation connection points)



2.2. HVDC interconnectors

HVDC interconnectors are complex, integrated systems with several components and advanced sub-systems. Many elements are common to other infrastructure, such as breakers, disconnectors, transformers, reactors, capacitors etc – which can have a longer life expectancy.

However, HVDC interconnectors have several unique elements that differ to typical AC infrastructure such as the valves and the sophisticated Control and Protection System. These components are specialised and subjected to unique electrical stresses requiring highly specialised design and materials. Compared to AC systems, there's limited data on failure modes for HVDC interconnectors – especially when operated beyond their design life – due to factors such as the:

- Small number of HVDC interconnectors in operation.
- Diverse range of HVDC technologies (due to differences in vendors and advances over time).
- High levels of criticality. HVDC interconnectors are the backbone of many electricity systems which leads to proactive renewals and limited in service failures.

- Unique electrical and harmonic stressors (such as high voltage gradients) requiring highly specialised design and materials. In turn this requires increased insulation requirements higher thermal management requirements including cooling systems.

Figure 2.2 Basslink's Thyristor Valve Hall

Implications of LCC and VSC Technologies in HVDC Interconnectors for Control and Protection Systems

There are two main technologies adopted across different HVDC interconnectors:

- Line Commutated Converters (LCC) technology – also referred to as Current Source Converters (CSC) or simply 'HVDC classic.' This technology is more mature and was originally used with mercury arc valves in the 1950s and 1960s, before the development of thyristors in the late 1970s. Basslink is based on LCC technology.
- Voltage Source Converters (VSC), also referred to as either 'HVDC plus' (Siemens) or 'HVDC light' (Hitachi), was initially introduced in the late 1990s. Murraylink and Directlink employ VSC technology.

There are capability, functionality, and technology differences between LCC and VSC systems. In the context of a Control and Protection System, a key difference to note is that LCC-based HVDC systems rely on the AC system for the commutation, or switching, of the current direction, a process which can introduce harmonics into the AC system. This requires the use of AC harmonic filters. VSC based systems can switch the current direction independently of the AC system reducing or eliminating the need for AC harmonic filters. Consequently, the scope of the Control and Protection System of a LCC based HVDC system is broader – as it also needs to monitor the harmonics and continuously operate AC filters.

Figure 2.3 Basslink's AC filters

2.3. Control and Protection System

Role of the Control and Protection System in a HVDC interconnector

HVDC interconnector Control and Protection Systems are the ‘supercomputers’ or ‘brains’ which ensure their safe and reliable operation. Control and Protection Systems maintain the integrity of the system and prevent any incidents that could cause harm to people or equipment damage.

Broadly, Control and Protection Systems perform two major functions:

- Controlling the AC/DC conversion process, managing the power flow and voltage levels (ensuring that the power is transmitted at the required voltage in the right direction) and ensuring the seamless integration of the HVDC system with the existing AC grids. The system monitors various parameters (such as the temperature and voltage levels), runs sophisticated algorithms extremely quickly and continuously sends signals to control key components such as the valves, cooling system, AC filters etc.

- Protecting the system by detecting and isolating faults that may occur. Faults can occur due to various reasons, such as lightning strikes, equipment failure, or human error. The system operates various devices, including circuit breakers and relays, to detect and clear faults before they can cause damage. The system is critical to ensuring the safety of the system and preventing damage to equipment or people and the connected AC grids. As with the control system, the protection system must operate extremely quickly.

Accordingly, the Control and Protection System for a HVDC interconnector is materially different to conventional AC protection and control equipment.

Function and scope of the Basslink Control and Protection System

Basslink's Control and Protection System consists of:

- Station control – the control and protection functions for the AC feeder and AC harmonic filters.
- Pole Control – the control and protection functions for thyristor firing pulses, DC yard and converter transformers as well as valve cooling.

The Control and Protection System enables the link to operate autonomously at a continuous transfer rating of 500 MW.

Figure 2.4 presents a schematic overview of how the HMI, Control and Protection System and process layers work together.

Figure 2.4 Basslink control and protection schematic overview

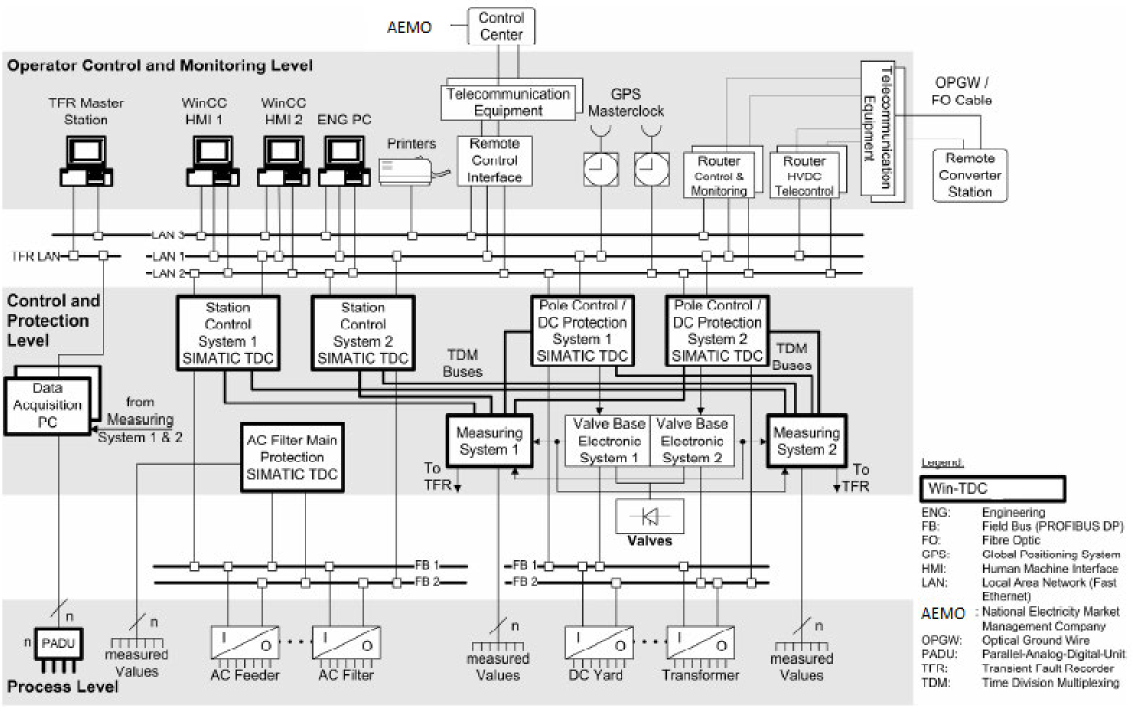


Figure 2.5 Basslink's Control and Protection System

2.4. Lifecycle planning

There are two key considerations in determining the optimal replacement of a Control and Protection System for a HVDC interconnector:

1. The lifecycle of the HVDC interconnector.
2. The lifecycle of the Control and Protection System technology.

This section outlines the key factors for each and the key considerations in considering the timing of replacing a Control and Protection System.

2.4.1. Lifecycle of a HVDC interconnector

Basslink

Basslink commenced operation on 28 April 2006. Basslink is made up of several components each with different design lives. However, significant parts of Basslink are designed to undergo a rebuild at the 40-year mark. At this point the converter stations (valves, control system transformers) would need to be replaced and together with other components depending on their condition (such as the marine cable).

As a result:

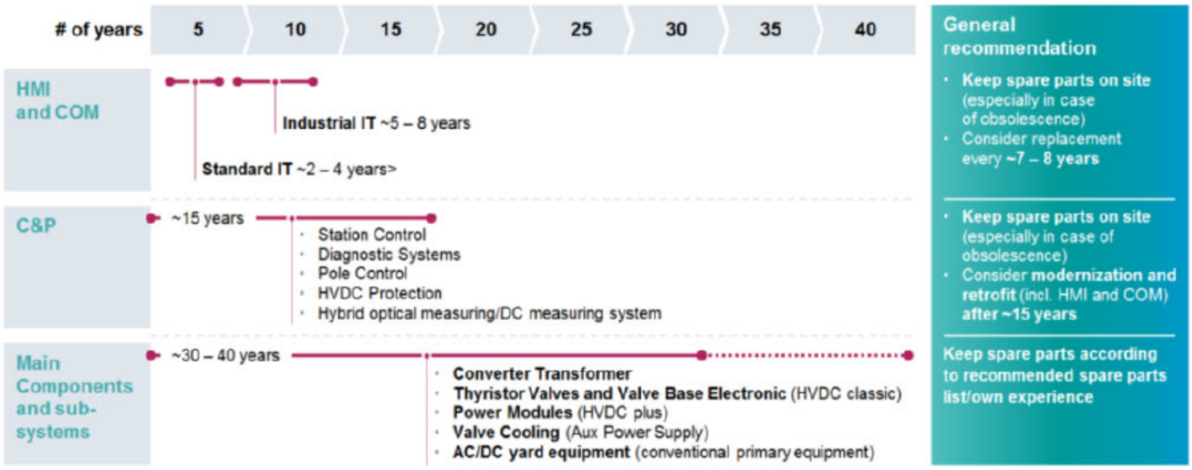
- By 2026 Basslink will be 20 years old – or 50% though the thyristor valve design life.
- By 2030 Basslink will be 24 years old – or 60% through the thyristor valve design life.
- By 2035 Basslink will be 29 years old – or 72.5% through the thyristor valve design life.

Typical lifecycle of a Siemens' HVDC interconnector

The design life of a HVDC system can be split into three main groups (as set out in Figure 2.6):

- 2 – 8 years – Human Machine Interface (HMI) and communication equipment (COM).
- 15 – 20 years – The Control and Protection System.
- 30 – 40 years – Main components and sub-systems.

Figure 2.6 Typical lifecycle of a Siemens' HVDC interconnector



2.4.2. Human Machine Interface Lifecycle

The HMI layer is based on computers with modern operating systems (such as Windows or Linux). These systems have a design life of between 2 and 8 years due to modern software and computer development timeframes to maintain support, functionality, and updates to reflect the latest security patches etc.

Basslink's HMI was last replaced in 2011 and is now 12 years old. [redacted]

An upgraded ISO 27001 (Information security Management Systems standard) certified HMI system which implements a protected zone concept is now available. This new system includes the newest security patches latest software and deploys a virtualisation solution (allowing the abstraction of physical hardware from the operational system). The new HMI system is required to progress beyond Australian Energy Sector Cyber Security Framework (AESCSF) maturity level 1.

The virtualisation option also breaks the Microsoft Windows update cycle. Currently a change to hardware requires a new operating system, application software and bespoke drivers (not available off the shelf). Virtualisation enables hardware upgrades to occur seamlessly without software changes.

[redacted]

Figure 2.7 Basslink's Human Machine Interface

2.4.3. Control and Protection System lifecycle

The core of the Control and Protection Systems is the computer hardware and software that operates the closed loop systems which control the interconnector.

The Control and Protection System is made up of high-performance specialised, real-time computers and digital signal processors. Rapid improvements in technology, design, hardware and software, as well as changes in system requirements (for instance with respect to cyber security) make the life of these systems relatively short (although longer than for the HMI). There has been no change to these systems since commissioning in 2006.

Drivers to refresh these systems include:

1. Ongoing access to support and spares. As vendors shift to new platforms, they often reduce or halt the production of spare parts and withdraw support.
2. Compatibility with other parts of the HVDC interconnector (importantly the valves given the interconnectedness of the control and firing systems).
3. Obtain additional functionality and reliability unlocked by the latest platform and software.

In the case of Basslink the key driver relates to the need for ongoing access to support and spares. As outlined in Figure 2.6 Siemens indicate that a refresh of the Control and Protection System should occur after 15 years. Without access to new spares reliability will decline.

CIGRE Working Group guidelines on life extensions

CIGRE considers that experience since the initial installation of digital control systems indicates that at least one control system replacement can be expected in any system.[1] As a result, CIGRE specified a general life expectancy of between 15 to 25 years for control systems.[2]

CIGRE also summarised life extension activities undertaken for HVDC interconnectors constructed in the 1980s with replacements occurring for:[3]

- Control and Protection Systems: between 23 and 27 years in service.
- Valve cooling systems: after 24 years in service.
- Valves (together with valve cooling): after 27 years in service.

Data reported to CIGRE indicates that about 8% – 9% of outage events are due to Control and Protection Systems,[4] illustrating the high importance of these systems to the safe and reliable operation of HVDC interconnectors.

Benchmark replacement timeframes

Table 1.1 lists a set of Control and Protection System replacements for HVDC programs around the world, as reported by Siemens, Hitachi and in trade media for HVDC interconnectors commissioned in the 1990s and 2000s.

Note that not all the links may have originally been installed with digital controls (for instance, Hitachi's MACH control system was first installed with Skagerrak 3, commissioned in 1993). We have also excluded Control and Protection System upgrades which we understand to be limited to the HMI layer such as the 2018 upgrade to the TransBay Cable (commissioned in 2010).[5]

Consistent with CIGRE findings, this data indicates Control and Protection Systems are generally replaced between 15 and 20 years following commissioning – with more recent links being replaced at shorter intervals. Given international good electricity industry practice is to replace these systems, no replacement was not considered to be a feasible option.

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[1] CIGRE 2016, *Guidelines for life extension of existing HVDC systems.* p.73
[2] CIGRE 2016, *Guidelines for life extension of existing HVDC systems.* p.73.
[3] CIGRE 2016, *Guidelines for life extension of existing HVDC systems.* p.15
[4] 8% over the period from 1993 to 2008 and 8.9% between 2009 and 2010. See: CIGRE 2016, *Guidelines for life extension of existing HVDC systems.* p.61
[5] See here.

Table 2.1 HVDC Control and Protection System upgrades 1990s and 2000s[6]

HVDC System	Power rating	Country	Initial commissioning	Upgrade commissioned	Age at replacement
Initial commissioning 2000s					
Al-Fadhili	3 x 600 MW	Saudi Arabia	2009	2026	17
BorWin1	400MW	Germany	2009	2022	13
Rapid City	2 x 100MW	USA	2003	2020	17
Cross Sound Cable	330MW	USA	2002	2022	20
Murraylink	220 MW	Australia	2002	2020	18
Moyle Interconnector[7]	2 x 250MW	United Kingdom	2001	2022	21
Directlink	3 x 60MW	Australia	2000	2019	19
Swepol link	600 MW	Sweden-Poland	2000	2024	24
Initial commissioning 1990s					
Gotland Light	400 MW	Sweden	1999	2024	25
Welsh HVDC Station[8]	600 MW	USA	1995	2017	22
Kontek	600 MW	Denmark - Germany	1995	2016	21
Jeju Island link 1[9]	300 MW	South Korea	1994	2020	24
Baltic cable	600 MW	Sweden	1994	2019	25
Skagerrak 3	440MW	Norway - Denmark	1993	2014	21
Inter-island Connector Pole 2	1,200	New Zealand	1992	2013	21
Quebec – New England Transmission	2,000MW	Canada / USA	1990-1992	2015-2016	24-26
Rihand - Dadri	1,568 MW	India	1990	2021	31

For completeness, we also report on the Control and Protection System replacements for HVDC interconnectors commissioned in the 1970s and 1980s in Appendix 1. The life of the Control and

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[6] Based on public data released by major suppliers. Most identified upgrades undertaken by Hitachi (previously ABB) as outlined here. Upgrades undertaken by other suppliers are referenced separately with a link to a news release or article.

[7] See here.

[8] See here.

[9] See here.

Protection Systems in these links is generally longer as they operate using customised analogue systems.[10]

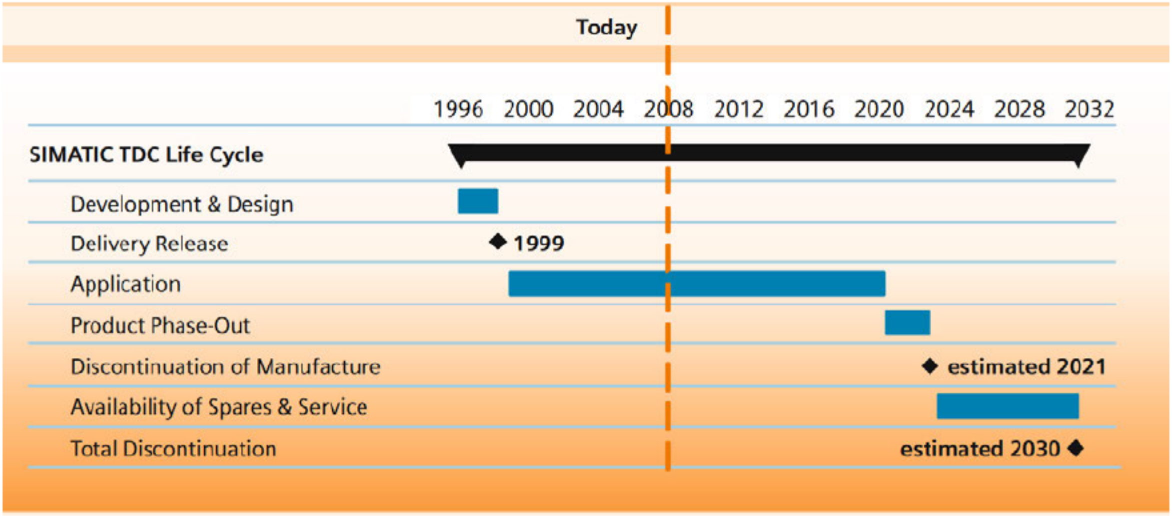
Future platform

Basslink's control and protection system is currently based on the Win-TDC platform where:

- Win represents the Windows operating system at the operator control and monitoring level.
- TDC is the Siemens Simatic Technology and Drive control system. This system is a digital automation system featuring very high computing power and the ability to process very large programs. The TDC system is typically used in large plant environments such as steel rolling mills but has been adapted for use in HVDC systems.

Basslink was the first commissioned interconnector to use this platform in 2006. Figure 2.8 sets out the product life cycle of Simatic TDC in 2008.

Figure 2.8 Simatic TDC Lifecycle in 2008



As of May 2023, product phase-out has not yet occurred. [redacted]

Based on prior Siemen's lifecycles, such as the plans announced in 2008 and the announced Product Lifecyle Management for the Simatic HMI,[11] we would expect that spares, service and support will be available for 10 additional years – or until 2035-37. This would be when Basslink is 31 years old or 77.5% though its thyristor valve design life.

2.4.4. Control and Protection System timing trade-offs

Given that a Control and Protection System replacement is going to be required, the challenge is determining the optimal timing for this to occur. We need to consider:

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[10] Analog systems are no longer installed in modern HVDC interconnectors due to the bespoke engineering requirements, reduced functionality, lower redundancy and high degree of monitoring required (as their many discrete components age and deteriorate over time).

[11] See here.

- Basslink's thyristor valve 40-year design life, given the interlinkage between the two systems, specifically the firing pulses. To maximise the utilisation of the first and second Control and Protection Systems, a replacement should occur at the 20-year mid-point given:
    - Replacing the system earlier would:
        - result in the under-utilisation of the first system.
        - risk that the second system is operated beyond its design life or the need for a third replacement to ensure reliability (for instance if spares and support were unavailable).
    - Replacing the system later would:
        - operate the system beyond its design life increasing the risk of asset failures and reliability degradation.
        - reduce the economic life of the second system (as a new Control and Protection System will likely be required with any valve refurbishment, depending on the technology available at the time).
        - delay the transition to a newer and generally better system based on improved technology (e.g., improved reliability, function and improve cyber security protections).
- Technology refresh cycles. Ideally the Control and Protection System would be replaced at the beginning of a product lifecycle:
    - Replacing a system with a soon to be replaced platform risks installing a system which is obsolete before the end of its economic life. Replacing the system too early would also forgo the benefits of additional functionality and reliability from newer technology.

2.5. Market factors

There are several market factors which complicate Control and Protection System replacement:

- Limited number of HVDC vendors – which limits our bargaining power, particularly given the challenges of vendor switching (outlined below).
- Supply chain shortages, such as those in respect to semiconductors which have affected vendors such as Siemens.[12] Semiconductors are the core components of Control and Protection Systems.
- A bow wave of HVDC interconnectors due for a mid-life refresh of their Control and Protection Systems, see Figure 2.9. Notably Basslink was the first (and therefore the oldest) HVDC interconnector with the Win-TDC control system.
- Increasing demand for HVDC technology with the global trends towards decarbonisation and electrification driving a greater need for transmission. These projects are becoming increasing larger and higher value increasing demand for high voltage electricity projects and putting further pressure on the supply chain.

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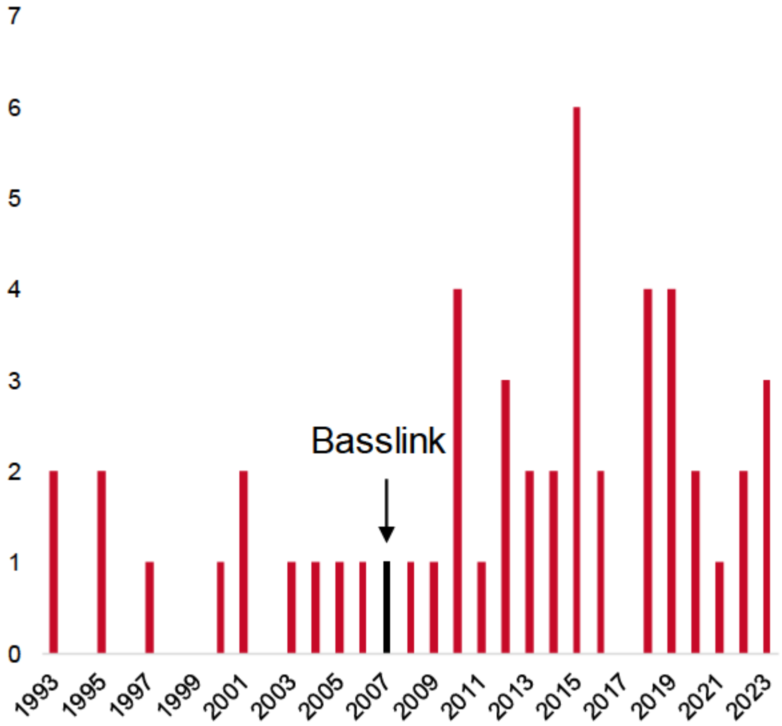
[12] See here.

Discussions with the manufacturer indicate a current lead time of 3 years. This is expected to increase as other HVDC interconnector systems fall due for their Control and Protection System replacement. There is also a significant risk that the overall cost will increase over time.

Figure 2.9 Commissioning dates of Siemens HVDC systems over the last 30 years



Challenges and Implications of Vendor Switching for HVDC Control and Protection Systems and Valves

The Control and Protection System and thyristor valves of a HVDC interconnector are intricately linked. Moving to another vendor would require either:

- The replacement of the valves in addition to the Control and Protection System. This option would incur significant additional costs to replace an asset which is currently functional and has significant remaining design life.
- Engineering a bespoke system to adjust a vendors standard Control and Protection System so that it could work with the Siemens valves. This option would incur additional costs and uncertainty with the replacement project. It would also limit and complicate ongoing support with both the control system vendor and Siemens with the valves.

We are only aware of a single example of the installation of a third-party Control and Protection System. This occurred as part of the 2013 upgrades to New Zealand's inter-island link which included the installation of Pole 3 and an upgrade of Pole 2 (originally commissioned by ABB in 1992).

There were significant differences between the Siemen's pole control system and valves which would require special bespoke hardware modules to be designed to interface between the two systems. This would incur additional cost (relative to implementing complementary systems) and complexity. It also means any issue could be attributed to three different sections (control system, interface, or valves) complicating support (relative to a single vendor model).

Accordingly, we are unaware of any HVDC interconnector which has attempted or resolved the engineering challenges in installing a third-party Control and Protection Systems on Siemens valves.

2.6. Consumer views

Given the materiality of this project and the difficulty in quantifying the risk (most Control and Protection Systems are replaced in advance of failure given their criticality), we sought customers views on whether we should replace the system in the 2025-30 or 2030-35 periods.

We engaged consumers through online focus groups, in person workshops and an online quantitative survey.

Online focus groups

The first activity conducted was two online focus groups with Victorian and Tasmanian consumers and small businesses. The objective was to test clarity and comprehension of information provided ahead of the consumer workshops.

We found that consumers understood the topic well and demonstrated their understanding of the key trade-offs between cost and reliability.

Overall, these consumers indicated a preference towards investing earlier. Tasmanian residents questioned the need on the basis that they did not need to rely on electricity from Victoria for their supply needs and were concerned whether the system could become redundant as new technologies develop.

In person workshops

The second activity was in-person workshops in Melbourne and Launceston to inform consumers and understand their preferences.

Most (77% in Melbourne and 69% in Launceston) supported replacing the system earlier. The main reason for this preference was to avoid potential negative impacts on households and businesses – with several participants raising concerns about the flow on effects and cost implications of a disrupted energy supply. Consumers highlighted that investing sooner decreased the risk of the system failure or of APA being unable to acquire a new one before the current system failed.

A quarter of participants preferred to wait to replace the system on the basis that waiting would provide access to future technology (as they had seen with TVs and Laptops). A smaller proportion also noted a preference to delay spending given the current cost-of-living pressures.

Online quantitative survey

To test and validate the outcomes from the consumer workshops an online quantitative survey was conducted. The survey found that the majority are willing to pay sooner as they believed that this option is more cost-effective, efficient and presents less risk.

Consumers told us they considered that paying sooner would be cheaper in the long run. Many respondents told us that they believed investing sooner would have a lower risk of electricity outages and could allow Basslink to operate better or more efficiently.

3. Options

We have considered three replacement timeframes for the Control and Protection System: 2026, 2030 and 2035. The benefits and dis-benefits of each option are explained below.

In each option the HMI is replaced over 2025-26 and 2026-27. Given cyber security risks this replacement cannot be delayed and due to supplier availability cannot be moved forward.

3.1. Option 1 – Control and Protection System replaced by 2026

3.1.1. The cost of the option

- $39.6 million ($2023) capital expenditure or $36.4 million once the time value of money has been taken into account.

3.1.2. The expected benefit

- Replacement at the mid-point of the thyristor valve design life of 40 years, consistent with manufacturer and good electricity industry practice.
- Maximises the economic life of the replacement Control and Protection System.

3.1.3. Any expected dis-benefits

- Next generation technology platform is not expected to be available. As a result, a replacement at this point would be a like-for-like replacement of the current platform. The new system would be obsolete by around 2035-37 – when the thyristor valves are 31 years old or 77.5% through their design life. This would create risks around ongoing support, spares and in turn reliability.
- May experience delays due to semiconductor shortages and long-lead times.

3.2. Option 2 – Control and Protection System replaced by 2030

3.2.1. The cost of the option

- $39.6 million ($2023) capital expenditure or $32.9 million once the time value of money has been taken into account.

3.2.2. The expected benefit

- Consistent with the preferences of customers: as this option reduces the risk to their electricity supply by decreasing the risk of a system failure or APA being unable to acquire a new system.
- Next generation technology will be available. This will allow the replacement Control and Protection System to be refreshed with the latest functionality and risks around long-term support and spares to be minimised. We also note this approach is consistent with the preferences of consumers who did not support investing in 2030. These consumers suggested a delay to ensure we would move to the next generation of technology (based on their experience with laptops and TVs). Delaying the investment further to 2035 is unlikely lead to a better platform as development lifecycles of Control and Protection Systems are longer than consumer electronics.

3.2.3. Any expected dis-benefits

- Reduced economic life of the second Control and Protection System. It will be installed when the thyristor valves are 24 years old (60% of its design life) and can only be expected to be in place for 16 years. However, the system could be extended 5-10 years if the life the thyristor valves are extended prior to rebuild or decommissioning.
- The original Control and Protection System is run past its original design life, increasing the risk of reliability issues.

3.3. Option 3 – Control and Protection System replaced by 2035

3.3.1. The cost of the option

- $41.5 million ($2023) capital expenditure or $31.9 million once the time value of money has been taken into account. This includes:
  - Purchase additional spares in 2030.
  - Replacing the remainder of the Control and Protection System in 2035. Note that this cost estimate does not factor in any adjustment for market risks.

3.3.2. The expected benefit

- Maximises the economic life of the initial Control and Protection System.
- The next generation technology platform will be available.

3.3.3. Any expected dis-benefits

- Customers did not support this option as they considered that investing sooner was the better option given the reliability risks.
- Delays access to technology improvements from the newer version of the Control and Protection System platform.
- The second Control and Protection System will have a reduced economic life, as it will be installed when the thyristor valves are 29 years old, or 72.5% through their design life. Accordingly, it can only be expected to remain in place for 11 years. However, this also means if the life of the thyristor valves are extended (prior to rebuild or decommissioning) the Control and Protection System's life could be extended by approximately 10 to 15 years.
- Market risk – Replacing our Control and Protection System at this point is likely to lead to a poorer bargaining position given the wave of other HVDC interconnectors also due for control and protection upgrades. This is likely to result in higher prices or replacement delays before 2035. We have not quantified this risk given the high level of uncertainty around the price impact.
- Reliability risk – Running the Control and Protection System beyond its design life will lead to additional planned outages and longer recovery times as individual components fail as they age.

  We expect to see an increased number of component failures and have more limited access to spares (and we may encounter delays). We may need to cannibalise systems which would mean we could not continue to operate a second redundant system. These factors increase the risk of more frequent and longer outages.

While we do not have robust data on these risks, we can estimate the lower bound of the cost of an outage using revenue (noting that the market costs are higher) and using a range of possible outages:

- 1 additional outage days (24 hours) per year over 2030 to 2035: $1.1 million
- 5 additional outage days (120 hours) per year over 2030 to 2035: $5.6 million.
- 10 additional outage days (240 hours) per year over 2030 to 2035: $11.3 million.

Notably 10 additional outages days is consistent with the recent performance of the Chandrapur HVDC link (commissioned in 1998). This link experienced 246.6 and 276.2 hours of forced outages related to its Control and Protection System in 2019 and 2020.

- Risk of early replacement – While the intention in this option is to extend the life of the Control and Protection System until 2035 a series of failures and/or limited access to spares may require an unplanned replacement occurring between 2030 and 2025. An accelerated replacement will incur a cost premium (relative to a project with more time for planning and to prepare for key lead times). Our analysis indicates that a 1% chance per year of this event occurring results in a risk cost of $0.05 million in present value terms. The risk cost represents the probability weighted cost of an accelerated replacement.

3.4. Option Comparison

Option 2 Replacement by 2030 is recommended as it is consistent with customer preferences and achieves the best possible balance between optimising replacement mid-way through the thyristor valve design life with replacement at the beginning of a technology product life. It also reduces the impact of market risks – by ensuring Basslink is at the front of the que for the next Control and Protection System platform.

As outlined in Table 3.1, option 3 has slightly lower capital costs (largely due to the time value of money). However, these benefits are likely offset by risks around an unplanned replacement and reliability risks even before market risks are considered.

Lastly, option 1 is not recommended primarily as it would miss an opportunity to shift to the next generation technology platform with more ongoing support, better access to spares, and improved functionality. We note that many of our customers told us to wait until the next version of technology is available.

Table 3.1 Option comparison (Present value terms, $millions)

Option	Description	Capex	Early replacement risk	Reliability risk	NPV
1	Replacement by 2026	36.3	-	-	**36.3**
2	Replacement by 2030	32.9	-	-	**32.9**
3	Replacement by 2035	31.9	0.05	1.1 to 11.3	**33.1 to 43.4**

4. Project Deliverables

4.1. Scope

The project comprises the design, engineering, manufacturing, factory testing, construction, site installation, testing, commissioning and documentation of new Control and Protection Systems.

Specifically, the works will replace the current Basslink control system without changing the current functionality, capacity, performance, harmonics audible sound generation or external interfaces.

The project includes (but is not limited to):

- Communication (COM) systems.
- Human Machine Interface (HMI) – this will occur initially ahead of the wider system.
- Pole Control and Protection frameworks, and control system computers.
- Valve Control Unit communication interface modifications.
- Cooling Control and Protection frameworks.
- Engineering Server systems including all necessary maintenance, fault finding and developing tools for supporting the new control system.
- Station Control and Monitoring systems providing persistent storage of all events and transient fault records produced in the Control and Protection System.
- Spares to ensure continued operation until 2030.

4.1.1. In Scope

The items considered in scope are:

In Scope	
1	Assess with OEM Support which components & elements of the Control and Protection System will no longer be/are no longer supported
2	Procure Spares to enable continued operation through to planned upgrade date
3	OEM to design, fabricate, factory test and install new control and protection equipment in in parallel with the existing, operational equipment at both converter stations
4	OEM & APA to power-up and pre-commission new equipment
5	An outage of 5-days to install the HMI followed by an outage of ~10-20 days to enable completion of:

In Scope	
	- Cutover of field wiring from existing C&P System Connections to new C&P System Connections - Complete pre-commissioning and pre-energisation testing - Complete commissioning activities - Two commissioning teams required working in tandem, one at each converter station
6	Decommission and remove superseded control and protection equipment

4.1.2. Out of Scope

The items considered out of scope are:

Out of Scope	
1	Additional engineering to fit a third-party Control and Protection System.

4.2. Project costs and Schedule

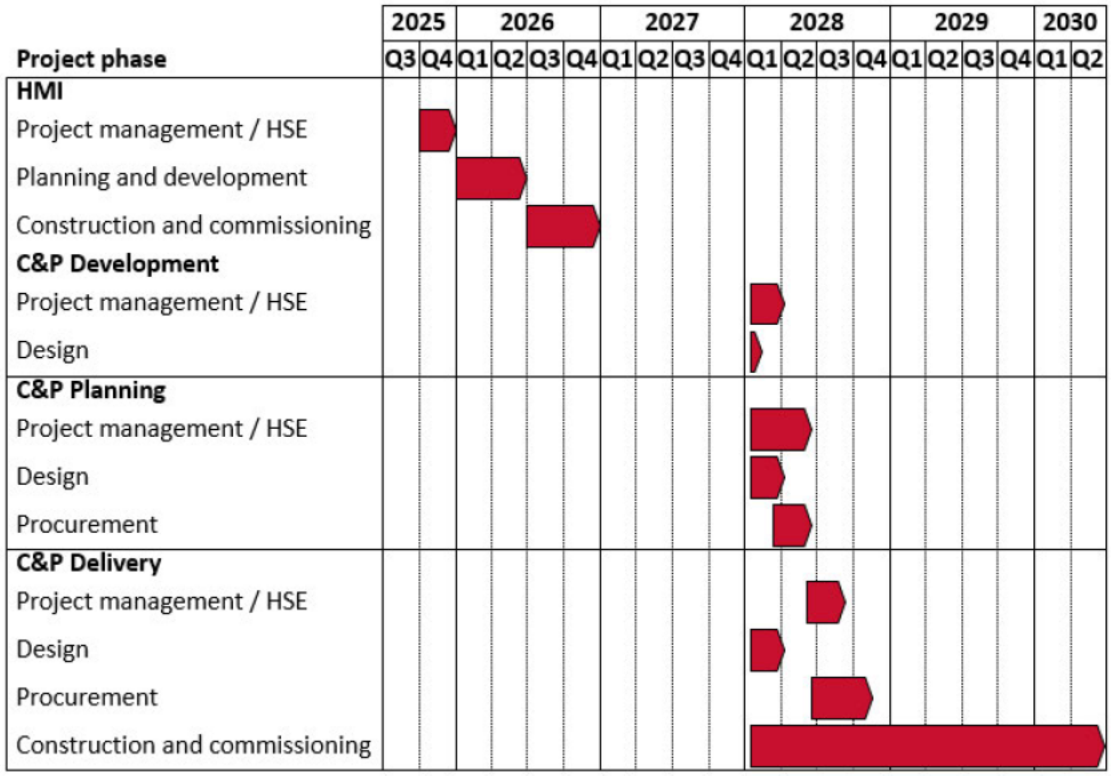
The estimated costs for the project are set out in Table 1.1.

Table 4.1 Control and Protection Refresh costs ($2023, millions)

	2026	2027	2028	2029	2030	Total
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]			[redacted]	[redacted]
[redacted]	[redacted]	[redacted]			[redacted]	[redacted]
[redacted]	[redacted]	[redacted]		[redacted]	[redacted]	[redacted]
Total	**7.2**	**5.8**	**2.8**	**7.6**	**16.3**	**39.6**

A high level- overview of the project schedule and key stages is provided in Figure 4.1.

Figure 4.1 Indicative project schedule



Appendix 1 – HVDC Control and Protection System upgrades

Table 0.1 HVDC Control and Protection System upgrades 1970s and 1980s[13]

HVDC System	Power rating	Country	Initial commissioning	Upgrade commissioned	Age at replacement
Initial commissioning 1980s					
Vindhyachal	500 MW	India	1989	2021	32
Fenno-Skan I	500 MW	Sweden - Finland	1989	2012	23
Intermountain Power Project	2,400 MW	USA	1986	2010	24
Kontiskan	550 MW	Sweden - Denmark	1988 / 2006	2019	31, 13
Highgate	200 MW	Canada	1985	2012	27
Eel River	350 MW	Canada	1985	2014	29
Madawaska	350 MW	Canada	1985	2016	31
Blackwater II	200MW	USA	1985	2009	24
Châteauguay	2 x 500MW	Canada	1984	2009	25
Gotland 2&3	130 MW	Sweden	1983/1987	2018	35
Inga-Kolwezi	560 MW	Congo	1982	2013	31
Initial commissioning 1970s					
CU Project	1,000MW	USA	1979	2004, 2019	25, 15
Cahora Bassa, Apollo	1,930 MW	Mozambique – South Africa	1977-79	2008	31
Square Butte	500MW	USA	1977	2004	27
Skagerrak 1 & 2	500MW	Norway - Denmark	1976-77	2007	29-30
Pacific Intertie Sylmar	1,440MW	USA	1970	2004, 2018-19	34, 14-15
Pacific Intertie. Celilo	1,440MW	USA	1970	2016	46

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[13] Based on public data released by major suppliers. Most identified upgrades undertaken by Hitachi (previously ABB) as outlined here. Upgrades undertaken by other suppliers are referenced separately with a link to a news release or article.