Plan

Asset

Basslink Lifecycle Management Plan

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Owner		Shane Matthews – Manager Operations and Maintenance Vic			
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1 Introduction

APA operates and maintains Basslink, the high voltage direct current electricity interconnector that links the Victorian and Tasmanian electricity grids by a 400kV direct current (DC) monopole electricity connector with a metallic return, the interconnector includes land and subsea components.

All infrastructure requires expenditure in the form of repairs and maintenance, in addition to a capital replacement program to achieve design availability throughout the entire life of the asset.

The purpose of this document is to forecast the timing of capital expenditure (CAPEX) on the Basslink interconnector and includes performance benchmarking against similar plant.

In the pursuit of continuous improvement, a benchmark comparison is also made to operational performance of similar HVDC systems.

CIGRÉ Technical Brochure 590 2014 B4-04 Protocol for reporting the operational performance of HVDC Transmission Systems provides the opportunity to compare the performance of the Basslink interconnector to similar plant.

2 Scope

This document applies to the Basslink Interconnector.

3 Roles and Responsibilities

Role	Responsibilities
Manager Operations and Maintenance Vic	Responsible for ensuring this report is regularly updated to ensure APA actively manages the long-term asset life cycle CAPEX

3.1 Records Management

The Document Management Record is located at the end of this document.

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4 Terms and Definitions

Basslink Failure Report:	Basslink failure rate is calculated from the Basslink historical component failures experienced.
CIGRÉ Equipment Lifetimes:	The CIGRÉ Equipment Lifetimes information has been extracted from Table 5-1 in the Guidelines for Life Extension of Existing HVDC Systems, CIGRÉ Technical Brochure TB649 and is provided in a tabular summary for each system. The information is generalised, from the experience of the contributing members and not specific to the equipment installed on the Basslink interconnector.
Consequence of Failure:	The consequence of failure of a system is represented by a simplified traffic light displaying the risk of a trip, the duration of the outage is not assessed.
Failure Rate (λ):	The annual failure rate is calculated from the formula below: $$failure\ rate\ per\ year\ \% = \frac{\frac{number\ of\ failed\ components}{number\ of\ years\ in\ service}}{number\ of\ components} \times 100$$ **or** $$\lambda = \frac{1}{MTBF}$$
Manufacturer's Replacement Information:	Is a letter from Siemens dated June 25, 2020, titled: Major Refurbishment or Replacement on HVDC Classic. The information is provided in a tabular summary for each system.
Monopole	A Configuration with single points of failure including single cable or converter failure.
MTBF:	The mean time between failures of a component is the average time between the instant when a failure occurs, is rectified and the instant when a subsequent failure occurs.
MTTF:	Mean time to failure is the length of time a component or device is expected to last in operation.
MTTR:	Is a basic measure of the maintainability of repairable items. It represents the average time required to repair a failed component or device.
Single Point of Failure:	A single point of failure is when no redundant component is available to continue power transfer and as a result of that failure the plant will trip, resulting in a forced outage.
Theoretical Reliability:	Theoretical reliability is extracted from PTDH171/P-000090/ED1.083-0 Basslink Reliability and Availability Study Report and is provided in a tabular summary for each system providing MTBF and MTTR.

5 Executive Summary

The Basslink interconnector consists of interconnected sub systems with differing design life spans and so this document is presented in the modified format of the Siemens document system to identify these sub systems[1] and uses the following to forecast CAPEX timing:

- Manufacturer's Information on replacement[2]
- CIGRÉ expected equipment lifetimes[3]
- Basslink historical performance

The actual timing of the expenditure for each sub system or component will be based on a detailed condition assessment including asset performance, availability of spares and future replacement requirements.

In reviewing Basslink and CIGRÉ reliability and availability reports it is evident the performance of the Basslink interconnector compares favourably with other HVDC interconnectors, including the impact of low availability due to cable outages, external to the HVDC converters.

The comparison against similar international HVDC systems, reporting to the same protocol, confirms that the performance of the Basslink interconnector is that of a world class monopole and validates the equipment design, documentation and the operations and maintenance practices performed on the Basslink interconnector.

Figure 1 (blue markers) displays the forecast timeline for expenditure on each system.

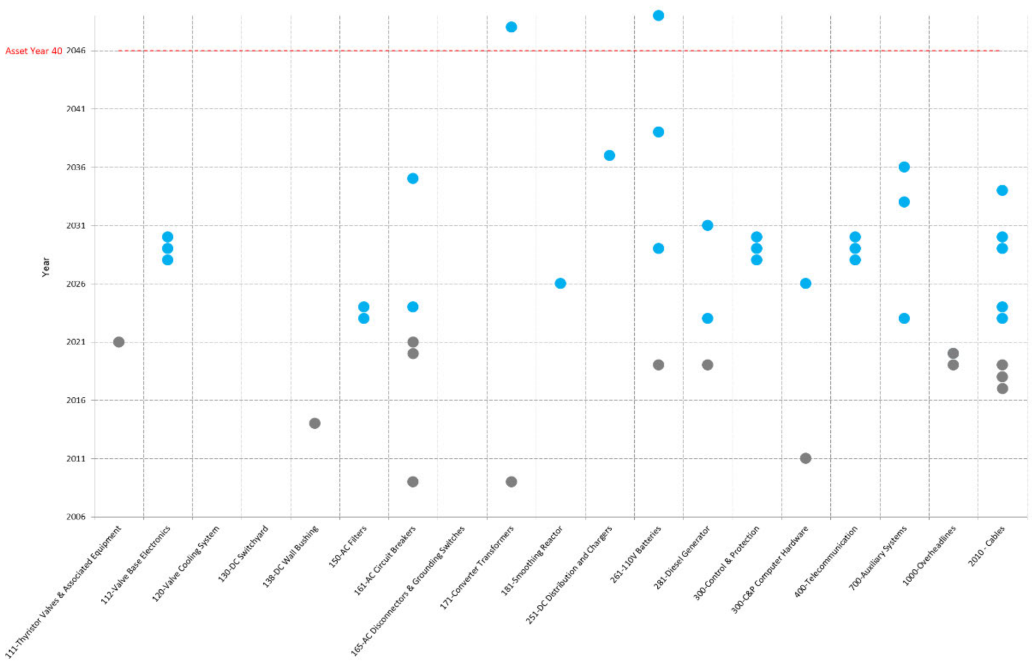

Figure 1. Forecast (Blue Markers) & Previous (Grey Markers) CAPEX by each HVDC System

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[1] PTDH171/P-000090/ED3.001.CTV-I Basslink Documentation System

[2] Siemens Major Refurbishment or Replacement on HVDC Classic

[3] CIGRÉ, Technical Brochure,649, Guidelines for life extension of existing HVDC systems, WG B4.54, 2016

Figure 1 (grey markers) displays the historical life cycle management CAPEX:

- 111 - Thyristor Valves & Associated Equipment
  - 2021, additional spare thyristors purchased following Estlink2 event
- 138 – DC Wall Bushing
  - 2014, additional spare wall bushing in to reduce return to service time experienced from transport delays with a common spare
- 161 – AC Circuit Beakers
  - 2009, additional circuit breaker heads for the Tasmania Converter Station
  - 2020, 5 replacement circuit breakers for the Victoria converter
  - 2021, 3 replacement circuit breakers for the Tasmania converter
- 171 – Converter Transformers
  - 2009, retrofitted diverter oil filters, increasing service interval to 100,000 operations
- 261 – 110v Batteries
  - 2019, replaced all station batteries
- 281 – Diesel generators
  - 2018, replaced diesel generator at Tasmania transition station
- 300 – C&P Computer Hardware
  - 2011, replaced computer hardware due to obsolescence
- 1000 – Overhead lines
- 2019, transmission tower fall arrest equipment
- 2010 – Cables
- 2017, cable joint kits
  - 2018, spare cables
  - 2019, cable jointing equipment & repair equipment

5.1 General Information

Basslink commenced commercial operation in 2006 with a design life of 40 years.

With spare components and correct maintenance procedures the interconnector can continue to operate throughout this period and beyond.

All the information to perform the correct maintenance procedures is contained within each system maintenance manual.

CAPEX shall be planned by considering the following principles:

- Maximising availability while minimising the number of service interruptions.
- Considering the balance between performance, cost, and risks.

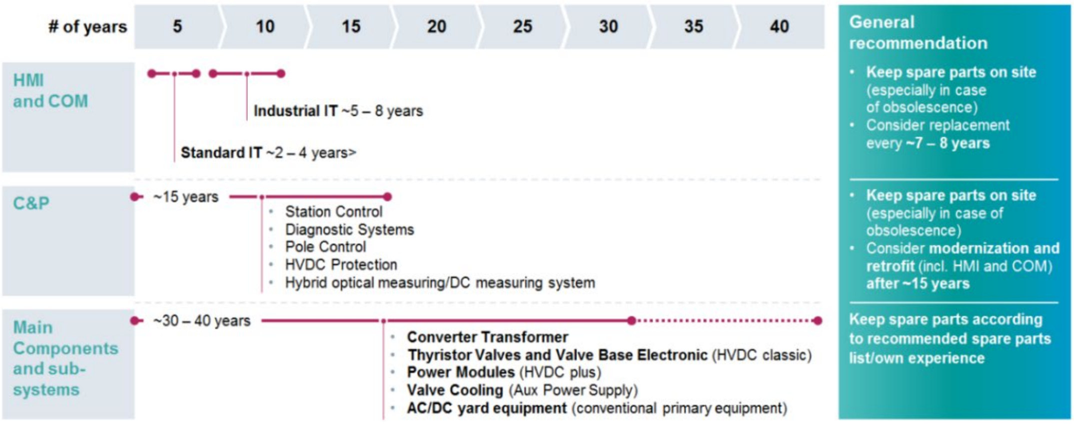

Figure 2. Typical HVDC Systems Life Cycles

Figure 2 displays the typical life cycles of individual HVDC systems; however, this information is not Basslink specific, some sub systems or components may be replaced at different intervals or as internal and external factors change the interconnector may need to be adapted for, but not limited to the following factors:

- External AC networks changing short circuit levels
- Regulatory changes
- Cyber security requirements
- Performance of sub systems or components

APA will monitor component failure rates, if the failure rate increases above the theoretical failure rate, a root cause analysis will be performed on the failed components to determine a course of action to maintain availability.

APA will perform external benchmarking by regular communication with the Original Equipment Manufacturer (OEM), other interconnectors through the Interconnector Owners Group (IOG) and CIGRÉ to monitor obsolescence and carrying out scheduled maintenance activities.

6 Life Cycle Planning by HVDC System

6.1 111 – Thyristor Valves and Associated Equipment

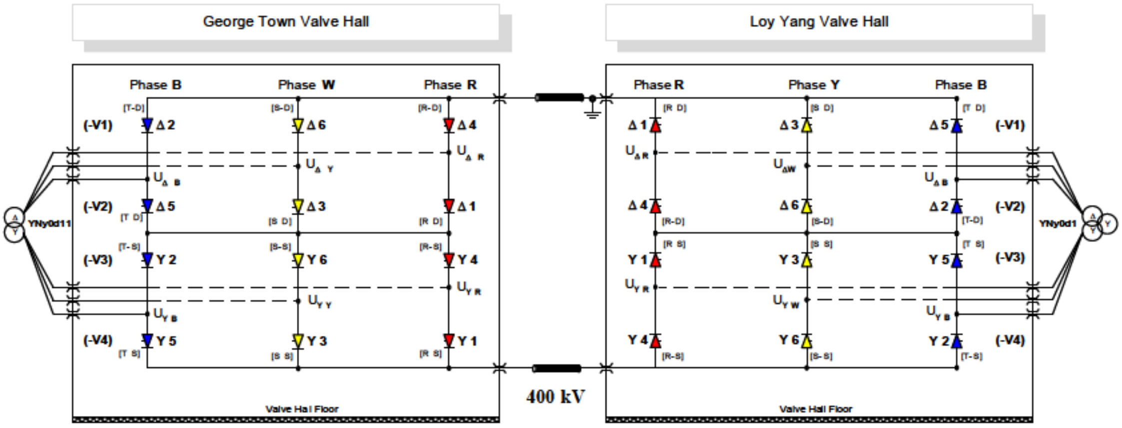

Figure 3. Thyristor Valves & Associated Equipment Overview

The thyristor valves and associated equipment convert the AC transmission system wave forms to DC and back to AC to transfer power.

The thyristor valves consist of 60 water cooled thyristor circuits per equivalent thyristor in each 12 pulse graetz bridge, described in figure 3.

720 thyristor circuits per converter – 1440 thyristors for both stations.

The associated equipment consists of the following:

- RC snubbers and thyristor Voltage Monitoring cards
- Reactors
- Grading capacitors
- Light guides
- Star couplers
- DC measurement shunts
- HV Surge arrestors
- Earth switches
- Valve Arrestor[4]

[4] PTDH171/P-000090/EB4.111.CTV-R, Thyristor Valves, Installation and Maintenance Manual

Table 1 – Theoretical Thyristor Reliability

Component	MTBF (hours)	MTTR (hours)
DC Measurement Shunt	1.752×10^7	14
Earth Switch	1.752×10^7	6
Grading Capacitor	1×10^8	8
Light Guide	1×10^9	8
Thyristor	4.38×10^6	8
HV Surge Arrestor	1.752×10^7	14
Valve Arrestor	1.752×10^7	6
Reactor	5×10^7	8
Star Coupler	9.99998×10^7	8

Table 2 – CIGRÉ Thyristor Valve Equipment Expected Lifetimes

Component	Lifetime (years)
Thyristor Valves	35
Thyristors	35
Valve Reactors	30
Tubing	25
Fibre Optics	35
Damping Capacitor	30
Damping Resistor	30

The CIGRÉ life extension information[5] indicates the thyristor valve cooling tubing has a limited life and will require monitoring.

A total of 6 thyristor failures has been experienced out of the 1440 units in 13 years of operation across both converter stations as individual unrelated events. The thyristors were replaced during the next suitable scheduled outage.

Table 3 – Basslink Theoretical vs Historical Thyristor Failure Rate

OEM theoretical failure rate per year	Basslink current failure rate per year
0.2 %	0.032 %

Viewing table 3, the Basslink failure rate is well below the theoretical failure rate.

[5] CIGRÉ, Technical Brochure,649, Guidelines for life extension of existing HVDC systems, WG B4.54, 2016

CONSEQUENCE OF FAILURE:

RISK RATING:

The Thyristor Valves & Associated Equipment system is a single point of failure, failure of this system will result in the loss of availability.

HIGH TRIP RISK

CONTROL MEASURES:

- Two thyristor circuits are redundant in each group of 60, that is up to two thyristor circuits can fail within a group of 60 thyristors for them to only be replaced on the next scheduled outage.
- Very low failure rate of thyristors.
- Manufacturer's recommended maintenance performed.
- Spares holding increased beyond manufacturer's recommendation (6 thyristors per station) to one electrical group per station (15 thyristors per station) following a review of an event that occurred on Estlink 2 HVDC scheme.

MEDIUM TRIP RISK

6.1.1 Manufacturers Replacement Information

The first HVDC converter valves suspended from the ceiling were installed in 1985-1989 in China and are still in service, without refurbishment.

Virginia Smith Converter Station in Nebraska commenced operation in 1988 and is still in service, without any refurbishments on controls, converter valves or Valve Based Electronics (VBE).

The field experience above indicates the 40-year life is achievable.

In additional the new system maintenance manuals recommend changing sealing rings installed in the valve cooling pipe work at 10-year intervals.

6.1.2 Conclusion

There is no major capital expenditure envisaged for the Thyristor Valves & Associated Equipment for the next 15 years.

6.2 112 – Valve Base Electronics

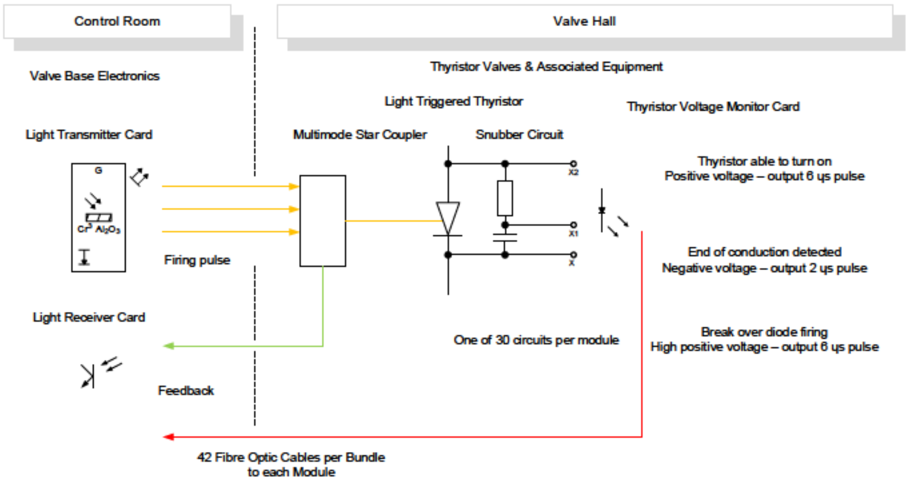

Figure 4. Valve Base Electronics Overview

The Valve Base Electronics system converts the electrical firing signals from pole control to the LASER[6] energy required for the light triggered thyristors and converts all the optical feedback signals to be transmitted to pole control as depicted in figure 4.

The hardware configuration and software are specific to the Basslink asset.

Table 4 – Theoretical Valve Base Electronics Reliability

Component	MTBF (hours)	MTTR (hours)
Valve Base Electronics	1.752×10^7	8

Table 5 – CIGRÉ Valve Base Electronics Expected Lifetimes

Component	Lifetime (years)
Electronic cards	25 - 30

A total of 1 light emitter card failure of 20 installed in 13 years of operation.

The failure did not result in a forced outage and the card was changed during a scheduled outage, restoring redundancy.

The failure was within the power supply section of the card, a switch mode DC/DC converter module failed, resulting in damage to the in-line inductor and no 5V DC to the remainder of the card.

[6] Light Amplification by Stimulated Emission of Radiation (LASER)

CONSEQUENCE OF FAILURE:

The Valve Base Electronics system is a single point of failure, failure of this system will result in the loss of availability.

RISK RATING:

HIGH TRIP RISK

CONTROL MEASURES:

- Redundant processors and power supply.
- One light emitter card is redundant in a group of 3, that is if one light emitter card fails it can be replaced on the next scheduled outage.
- Very low failure rate of components.
- Manufacturer's recommended maintenance performed.
- Spares holding as per manufacturer's recommendation.

MEDIUM TRIP RISK

6.2.1 Manufacturers Replacement Information

The valve base electronics is seen as a part of the converter valves more than a part of the control & protection system. Therefore, replacement of this equipment as a "stand alone system" is not recommended.

The light triggered VBE system, as installed at Basslink has shown quite good performance within the Siemens Classic HVDC fleet.

It is recommended to evaluate if replacement of the VBE would be a prudent decision, at the same stage as planning for a control & protection replacement.

6.2.2 Conclusion

Control system upgrade is forecast in 2028 there may be an upgrade required for VBE for communications with the control & protection system.

6.3 120 – Valve Cooling System

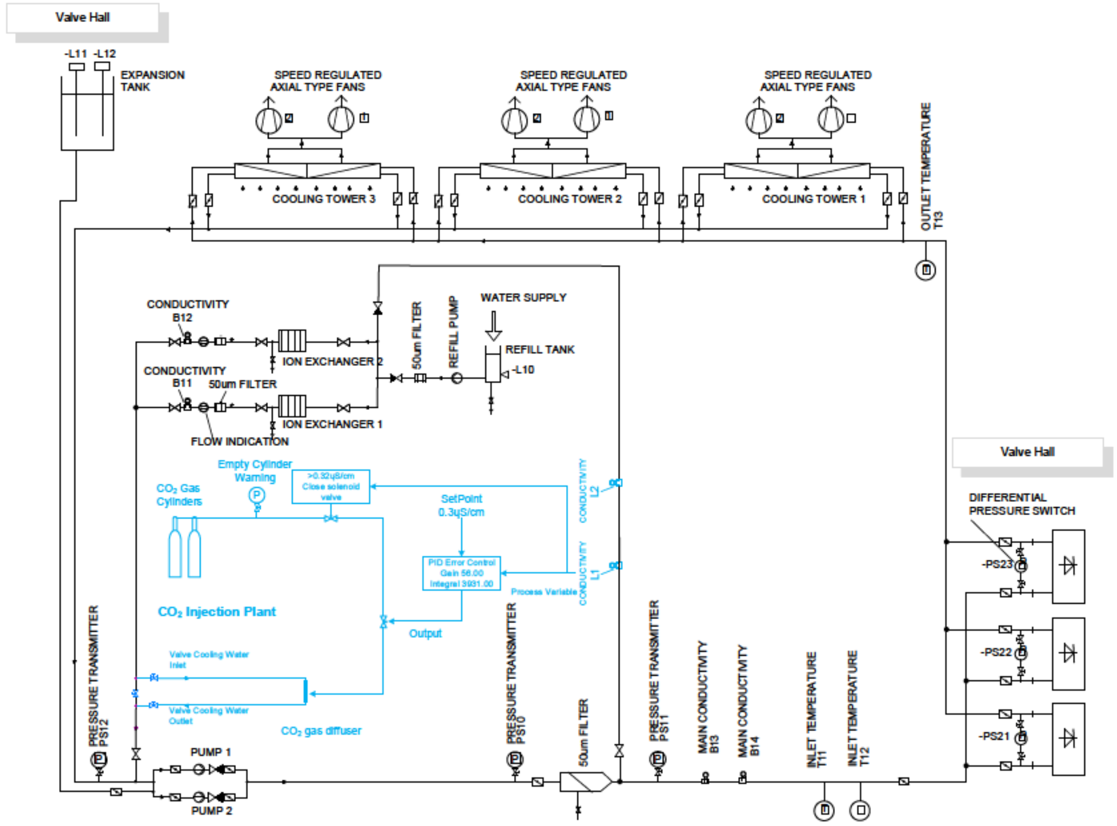

Figure 5. Valve Cooling System Overview

The Valve Cooling System is a closed loop system that circulates deionised water from the thyristor valves to the external heat exchangers to remove heat losses from the thyristor valves.

A CO2 injection trial (blue modification in figure 5) is in progress to control the pH of the water to minimise the formation of aluminium hydroxide on the grading electrodes.

Table 6 - Theoretical Valve Cooling System Reliability

Component	MTBF (hours)	MTTR (hours)
Auxiliary Power	87600	6
Cooling Fan	20000	8
Cooling Control	262800	6
Conductivity Transmitter	350400	6
Pressure Transmitter	586920	6
Water Flow Meter	586920	6
Water Level Meter	586920	8

Table 7 - CIGRÉ Valve Cooling System Expected Lifetimes

Component	Lifetime (years)
Coolers	25
Electronic cards	25 - 30

The valve cooling system consists of stainless-steel piping and heat exchangers.

The following component failures have been experienced:

- one transducer fault resulting in an expansion tank low level trip.
- one undervoltage relay resulting in a trip.
- the system was subsequently modified to prevent a trip from a single device.

CONSEQUENCE OF FAILURE:

The Valve Cooling system is a single point of failure, failure of this system will result in the loss of availability.

RISK RATING:

HIGH TRIP RISK

CONTROL MEASURES:

- The system consists of the following redundant components:
  - cooler group
  - cooling pump
  - ion exchanger
  - controls
- Very low failure rate of components.
- Manufacturer's recommended maintenance performed.
- Spares holding as per manufacturer's recommendation.

MEDIUM TRIP RISK

6.3.1 Manufacturers Replacement Information

The system is controlled by a SIMATIC S7 System, which is still currently available.

For moving parts like pumps the market has changed over the years and manufacturers have merged or disappeared but alternative replacement parts are available.

6.3.2 Conclusion

The following is the major capital expenditure envisaged for the valve cooling system for the next 15 years:

- Control system upgrade is forecast in 2028 with the control and protection upgrade at least for communications with the control & protection system.

6.4 130 – DC Switchyard

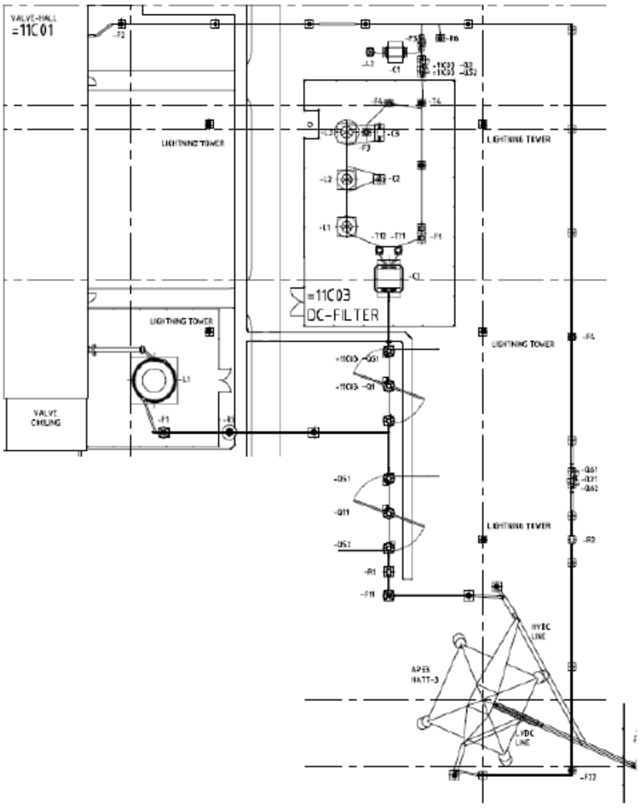

Figure 6. DC Switchyard Overview

The DC switchyard connects the output of the valve hall to the overhead line and provides a means of disconnection for isolations during an outage.

The DC Switchyard components include the following:

- Disconnects
- Earth switches
- Buswork
- Measurement devices
- Surge arrestors

Table 8 - Theoretical DC Switchyard Reliability

Component	MTBF (hours)	MTTR (hours)
Neutral bus capacitor	4.38 x 10^6	6
Disconnector	1.752 x 10^7	6
Earthing switch	1.752 x 10^7	6
Surge Arrestor	1.752 x 10^7	14
DC shunt	1.752 x 10^7	14
DC voltage divider	4.38 x 10^6	14

Table 9 - CIGRÉ DC Switchyard Expected Lifetimes

Component	Lifetime (years)
DC Switching Equipment	35
DC Bus work, structures	50

The Basslink DC switchyard has a design life of 40 years and has experienced a total of 1 HVDC coupling capacitor failure damaging other components.

CONSEQUENCE OF FAILURE:

All components within the DC switchyard are a single point of failure, failure of this system will result in the loss of availability.

RISK RATING:

HIGH TRIP RISK

CONTROL MEASURES:

- The disconnectors & earth switches only operate during an outage.
- Very low failure rate of components.
- Manufacturer's recommended maintenance performed.
- Spares holding as per manufacturer's recommendation.

MEDIUM TRIP RISK

6.4.1 Manufacturers Replacement Information

Wear and tear of the DC switchyard components would not be significant.

The Berlin Factory is still in the position to provide most of the spare parts.

6.4.2 Conclusion

There is no major capital expenditure envisaged for the DC switchyard for the next 15 years.

6.5 138 – DC Wall Bushings

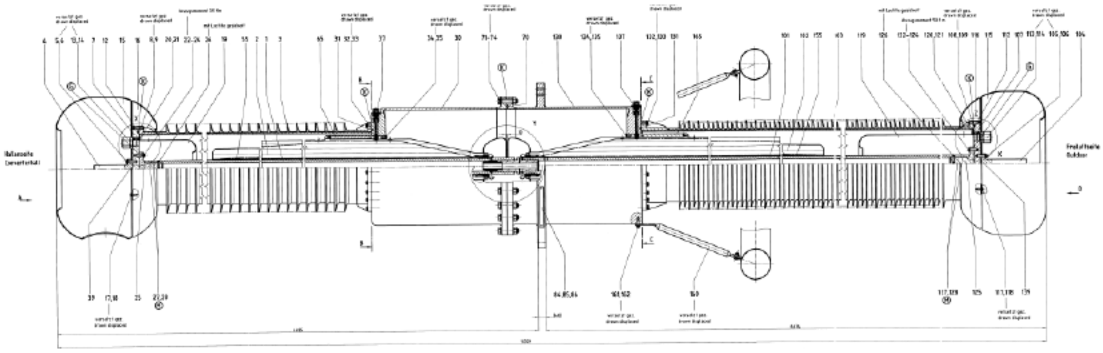

Figure 7. DC Wall Bushings Overview

The DC wall bushing connects the output of the valve hall to the DC switchyard and provides insulation for the conductor through the valve hall wall penetration.

The wall bushing consists of two Resin Impregnated Paper (RIP) bushings, connected with an SF6 insulated section that provides the insulation through the valve hall wall penetration.

Table 10 - Theoretical DC Bushing Reliability

Component	MTBF (hours)	MTTR (hours)
DC Wall Bushing	8.76×10^6	14

Table 11 - CIGRÉ DC Bushing Expected Lifetimes

Component	Lifetime (years)
DC Wall Bushings	35

A total of 1 DC wall bushing failure has been experienced and an additional spare was purchased in 2014 to reduce the return to service time should a similar event occur.

CONSEQUENCE OF FAILURE:

The DC Wall Bushing is a single point of failure, failure of this system will result in the loss of availability.

RISK RATING:

HIGH TRIP RISK

CONTROL MEASURES:

- Very low failure rate of components.
- Manufacturer's recommended maintenance performed.
- Spares holding as per manufacturer's recommendation.

MEDIUM TRIP RISK

6.5.1 Manufacturers Replacement Information

The HVDC Wall bushing failure, as Basslink has experienced, is quite unusual after that many years of operation.

The failure experienced was a single event and was not a result of wear and tear or aging.

The recommended dielectric loss angle measurement and SF6 Gas analysis will provide valuable condition assessment information to determine a replacement timeline.

6.5.2 Conclusion

There is no major capital expenditure envisaged for the DC wall bushing for the next 15 years.

6.6 150 – AC Filter

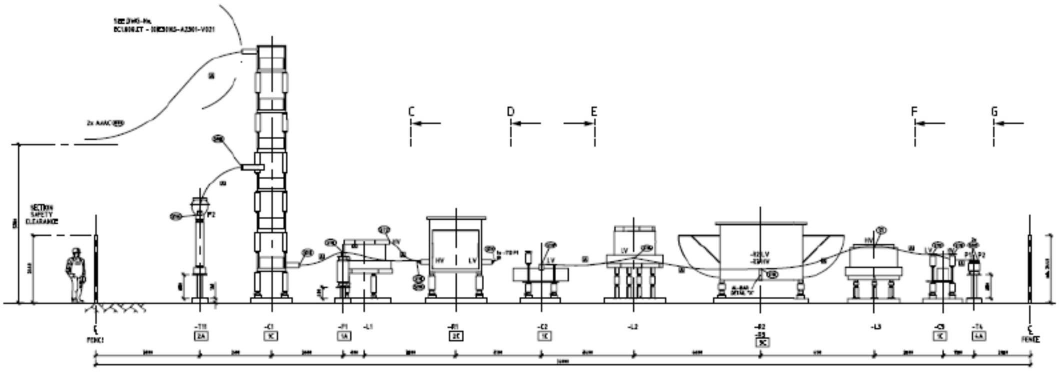

Figure 8. AC Filter Overview

The AC Harmonic Filters (HF) select the non-sinusoidal components from the AC transmission system waveform and shunt to ground to remove harmonics, while providing shunt reactive compensation for the converter transformer.

The AC filters consist of the following components:

- Capacitors
- Reactors
- Resistors
- Current transformers

Table 12 - Theoretical AC Filter Reliability

Component	MTBF (hours)	MTTR (hours)
Capacitor can	4.38 x 106	6
Current transformer	2.46 x 107	6
Reactor	5.58012 x 107	14
Resistor	8760000	14
Surge arrestor	1.752 x 107	14

Table 13 - AC Filter Ratings

<table>
<tr><th colspan="6">George Town AC Filters</th></tr>
<tr><td>=10D01</td><td>=10D02</td><td>=10D03</td><td>=10D05</td><td>=10D06</td><td>=10D07</td></tr>
<tr><td>43MVAr</td><td>43MVAr</td><td>43MVAr</td><td>43MVAr</td><td>43MVAr</td><td>98MVAr</td></tr>
<tr><td>7 12 24 HF</td><td>7 12 24 HF</td><td>5 12 24 HF</td><td>5 12 24 HF</td><td>5 12 24 HF</td><td>5 HF</td></tr>
<tr><th colspan="6">Loy Yang AC Filters</th></tr>
<tr><td>=20B01</td><td>=20B02</td><td>=20B03</td><td>=20B05</td><td colspan="2">=20B06</td></tr>
<tr><td>105MVAr</td><td>105MVAr</td><td>105MVAr</td><td>105MVAr</td><td colspan="2">105MVAr</td></tr>
<tr><td>7 12 24 HF</td><td>7 12 24 HF</td><td>7 12 24 HF</td><td>5 12 24 HF</td><td colspan="2">5 12 24 HF</td></tr>
</table>

There is no CIGRÉ expected lifetime data for the AC filters.

A total of 2 AC capacitor failures has been experienced, replacing the components with the filter out of service.

The AC filter capacitor cans are an active component with a limited dielectric life dependent on temperature and ripple magnitude.

The capacitor cans are internally fused, and the protection system indicates when an internal element has failed initiating replacement.

CONSEQUENCE OF FAILURE:

The AC filters are not a single point of failure.

A reduction of maximum capacity is applied if only two AC filters are in service at any site.

RISK RATING:

LOW TRIP RISK

CONTROL MEASURES:

- Very low failure rate of components.
- Manufacturer's recommended maintenance performed.
- Spares holding as per manufacturer's recommendation.

LOW TRIP RISK

6.6.1 Manufacturers Replacement Information

The main components of the AC filters consist of a Trench reactors, Schniewindt resistors and Cooper Capacitors.

These components have shown good performance in the past. Reactors and Resistors would have shown weak points already if there were any.

Basslink was the first HVDC Siemens that was equipped with Cooper capacitors. This was done because at that time the FACTS colleagues had collected quite good experience with this manufacturer. The Basslink experience to date seems to prove that this decision was not wrong.

It needs to be mentioned that all of these components are long lead items and cannot be made available on short notice. Sufficient spares are therefore kept on site and no reason to believe spares holdings need to increase.

6.6.2 Conclusion

APA will continue to change the capacitor cans when internal elements fail. At this stage APA forecasts to carry out significant refurbishment after around 20 years of operation due to expected increased failure rate as the units age and possibly future component obsolescence Should the forecast failure rates not materialise this date will be extended. Any significant refurbishment program will be carried out in a staggered approach.

6.7 161 – AC Circuit Breakers

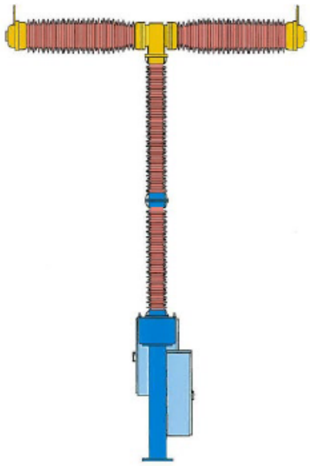

Figure 9. AC Circuit Breaker Overview

The AC circuit breakers connect the AC filters on increasing harmonic requirement and disconnect on increasing reactive exchange when no longer required.

The 7th harmonic filters are connected on initial power flow and the 5th harmonic filters are connected at higher power flow, resulting in the 5th harmonic filter circuit breakers having a higher operations count due to the changes in power flow.

The single tuned 5th at George Town is for voltage support and contingency for the unavailability of a triple tuned filter.

Table 14 - Theoretical AC Circuit Breaker Reliability

Component	MTBF (hours)	MTTR (hours)
Major failure	3.1536×10^6	14
Minor failure	543120	6

There is no CIGRÉ expected lifetime data for the AC circuit breakers. However, the AC circuit breaker have been type tested to 10,000 operational cycles.

Table 15 - AC Circuit Breakers

George Town AC Circuit Breakers						
=10D01-Q0	=10D02-Q0	=10D03-Q0	=10D05-Q0	10D04-Q0	=10D06-Q0	=10D07-Q0
7 12 24 HF	7 12 24 HF	5 12 24 HF	5 12 24 HF	Line	5 12 24 HF	5 HF

Loy Yang AC Circuit Breakers					
=20B01-Q0	=20B02-Q0	=20B03-Q0	=20B04-Q0	=20B05-Q0	=20B06-Q0
7 12 24 HF	7 12 24 HF	7 12 24 HF	Line	5 12 24 HF	5 12 24 HF

The following circuit breaker failures have been experienced:

- Loy Yang - ABB HPL 550
  - 9 events, including repeat operating mechanism failures
  - The ABB circuit breakers were replaced with Siemens 3AP2's due to operating history
- George Town - Siemens 3AP2FI 245
  - No events, additional spares were purchased in 2009

CONSEQUENCE OF FAILURE:

The AC filter circuit breakers are not a single point of failure.

The AC converter circuit breakers is a single point of failure, failure of this breaker will result in the loss of availability.

RISK RATING:

HIGH TRIP RISK

CONTROL MEASURES:

- Very low failure rate of components.
- Manufacturer's recommended maintenance performed.
- Spares holding as per manufacturer's recommendation.

MEDIUM TRIP RISK

The AC line circuit breakers are a single point of failure while the AC filters circuit breakers are not a single point of failure. However, a failure in an intermediate position will result in an outage from breaker fail protection.

A current limit is applied if only two AC filters are in service at any site.

6.7.1 Method of Performance Monitoring

Table 16 - AC Circuit Breaker Maintenance Requirements

Siemens 3AP2FI 245/550	
Description	**Service Interval**
Checks	3, 000 Operations Cycles
Maintenance	6, 000 Operations Cycles
Type Testing (end of life)	10, 000 Operations Cycles
ABB HPL2 550 (=20B04-Q0)	
Description	**Service Interval**
Visual Inspection	1 to 2 years
Visual inspection and lubrication	2, 000 Operations
Service, main contact resistance checks for circuit breakers >100 operations per year	2, 500 Operations
Service, main contact resistance checks	5, 000 Operations
Complete Overhaul	10, 000 Operations

APA will monitor circuit breaker operations to predict the next service interval and replacement dates.

Table 17 - AC Circuit Breaker Average Operations per Day

George Town					
=10D01-Q0	=10D02-Q0	=10D03-Q0	=10D05-Q0	=10D06-Q0	=10D07-Q0
2.65	2.6	4.57	4.46	4.21	1.64

Loy Yang				
=20B01-Q0	=20B02-Q0	=20B03-Q0	=20B05-Q0	=20B06-Q0
2.12	2.26	2.26	1.02	1.11

Table 18 - AC Circuit Breaker Forecast Replacement

George Town projected replacement 10,000 operation cycles (year)					
=10D01-Q0	=10D02-Q0	=10D03-Q0	=10D05-Q0	=10D06-Q0	=10D07-Q0
2026	2027	2034	2034	2035	2039

Loy Yang projected replacement 10,000 operation cycles (year)				
=20B01-Q0	=20B02-Q0	=20B03-Q0	=20B05-Q0	=20B06-Q0
2045	2044	2044	2073	2069

Applying current daily operations count in table 11, provides the bases for forecasting expected AC circuit breaker replacement time frame in Table 12. There is a possibility that as the AC networks in Tasmania and Victoria will weaken due to higher penetration on of non-synchronous generation. This will increase the daily operations of the AC circuit breakers reducing the life expectancy indicated in Table 12.

Additional circuit breaker T head spares purchased at George Town converter, as only one phase was originally supplied as a spare.

Replacements of circuit breakers are forecast as:

- 2 replacement AC filter circuit breakers forecast for 2026 for the Tasmanian converter
- 2 replacement AC line circuit breakers forecast for 2035 for both converters

6.7.2 Manufacturers Replacement Information

Replacement is under execution.

6.7.3 Conclusion

All circuit breakers will be maintained according to the manufactures recommendations and replaced at 10,000 operations cycles to ensure the availability of Basslink.

6.8 165 – AC Disconnectors and Grounding Switches

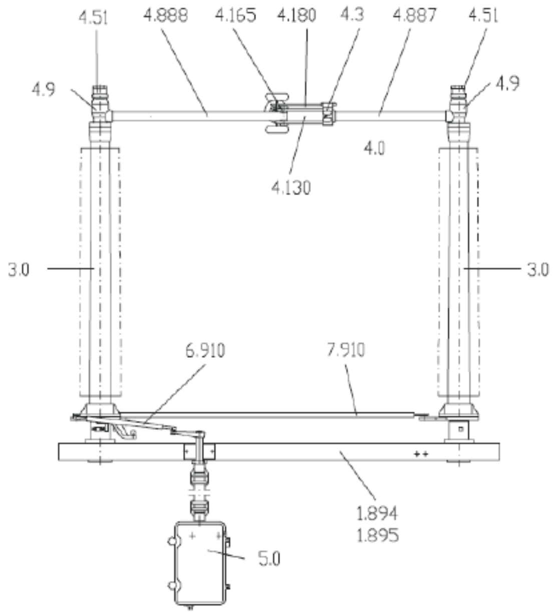

Figure 10. AC Disconnectors Overview

The AC disconnectors & grounding switches connects the filters, transformer and the overhead line to the bus and provides a means of disconnection for isolations during an outage.

Table 19 - Theoretical AC Switching Equipment Reliability

Component	MTBF (hours)	MTTR (hours)
Disconnector	1.752×10^7	6
Earthing switch	1.752×10^7	6

There is no CIGRÉ expected lifetime data for the AC switching equipment.

The Basslink AC switchyard has a design life of 40 years and has not experienced switchgear failure

CONSEQUENCE OF FAILURE:

The AC disconnectors & grounding switches are connected to the converter bus, an electrical failure of on the converter bus will result in the loss of availability.

RISK RATING:

HIGH TRIP RISK

CONTROL MEASURES:

- The units are only used during an outage for isolation.
- Very low failure rate of components.
- Manufacturer's recommended maintenance performed.
- Spares holding as per manufacturer's recommendation.

MEDIUM TRIP RISK

6.8.1 Manufacturers Replacement Information

The brand name Ruhrtal still exists within Siemens, but the factory is in China, which provides the main manufacturing location for Siemens HV AC equipment.

6.8.2 Conclusion

There is no major capital expenditure envisaged for the DC switchyard for the next 15 years.

6.9 171 – Converter Transformers

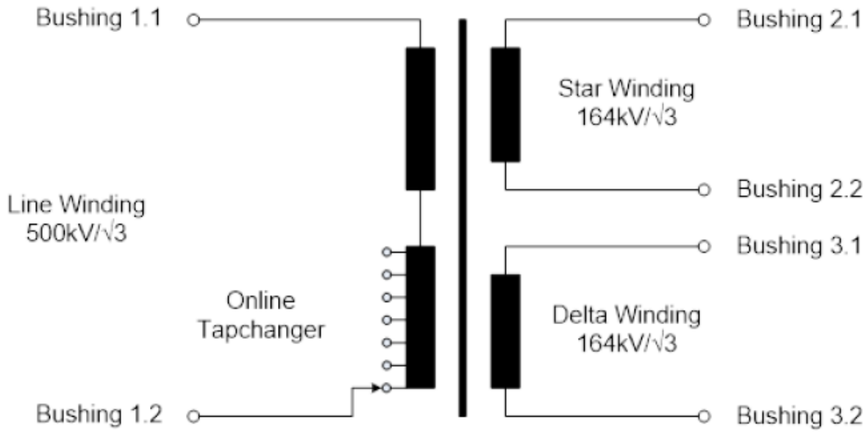

Figure 11. Single Phase Converter Transformer Overview

Three single Ø transformers are externally connected in vector group Y0y0d11.

The converter transformer, displayed in figure 11 transform the voltage of the 500kV or 220kV AC busbar to the required AC voltage of the 12-pulse graetz bridge, with the Y and Δ secondary windings providing a separation of 30 electrical degrees, decreasing DC ripple, and reducing harmonic content.

The converter transformers are equipped with an On-Load Tap-Changer (OLTC) to provide coarse firing angle control during power transfer.

Table 20 - Theoretical Converter Transformer Reliability

Component	MTBF (hours)	MTTR (hours)
AC Bushing	8.76×10^{6}	48
Valve Bushing	8.76×10^{6}	48
Cooling Control	175200	8
AC Bushing CT	2.64×10^{6}	48
Valve Bushing CT	2.64×10^{6}	48
Fan	20000	8
Cooling Pump	50000	12
Diverter	1576800	8
Tap Selector	8.103×10^{6}	7300
Winding	1.04×10^{7}	7300

Table 21 - CIGRÉ Converter Transformer Expected Lifetimes

Component	Lifetime (years)
Converter Transformer	40
AC Bushings	30
DC Bushings	35
Tap changer	30
Coolers	25

The Basslink design life of 40 years aligns with the CIGRÉ expected lifetime for power transformers. However, the indicated tap changer lifetime is generic and conflicts with the Reinhausen service requirements detailed in the methods of monitoring.

One failure has been experienced requiring a converter transformer to be replaced with the spare.

The failure was due to a mechanical stress fracture originating at the step change in diameter of the resin impregnated paper core behind the oil flange in the Delta 3.1 bushing, from the initial angle of the fracture this is understood to have been due to incorrect transportation or installation.

6.9.1 Method of Performance Monitoring

Each converter transformer contains 80,000 litres of mineral oil in the main tank that is used as an insulation and heat transfer medium, with the general cause of deterioration of the mineral oil is due to the formation of acids and sludge due to oxidation, this process normally occurs slowly and continuously but is accelerated rapidly under conditions of prolonged high temperature operation. Sufficient deterioration of the mineral oil will lead to material failure of the transformer.

Monitoring the dissolved gasses in mineral oil provides a condition monitoring tool for the transformers. Gas evolution from an incipient fault is documented in standards and the temperature required for the evolution of each gas is known, ensuring the interpretation of fault conditions are assessed against IEC 60599.

Table 22 – Tap Changer Service Intervals

Description	Service Interval
Service Diverter Switch Insert	100,000 Operations or 7 years
Replace Diverter Switch Insert	800,000 Operations
Replace Tap Selectors	1,000,000 Operations

There is a spare set of 3 diverter switch inserts at each converter station and exchange the inserts during a scheduled outage. Refurbishment of the removed diverters extends the asset life and reduces outage duration.

OF100 oil filters were retrofitted to the diverter switches in 2009, increasing the service interval from 60,000 to 100,000 operations, reducing the outage frequency requirements, the oil filters must be replaced when the filter pressure exceeds 3.5 Bar, otherwise the service interval reverts to 60, 000 operations.

Table 22 – Tap Changer Average Operations per Day

Description	George Town	Loy Yang
Average Operations per day	63.94	3.59
Forecast diverter insert replacement	20.87 Yrs. (18/5/2040)	51.41 Yrs. (5/12/2070)
Forecast tap selector replacement	29.43 Yrs. (20/12/2048)	67.71 Yrs. (25/3/2087)

The forecast diverter insert replacement is for one unit, however there is spare unit per transformer to share this duty extending the life of the asset.

CONSEQUENCE OF FAILURE:

The Converter Transformers are a single point of failure, failure of this system will result in the loss of availability.

Operating the OLTC beyond manufacturer's service intervals will likely result in catastrophic transformer damage.

RISK RATING:

HIGH TRIP RISK

CONTROL MEASURES:

- Very low failure rate of components.
- Manufacturer's recommended maintenance performed.
- Spares holding as per manufacturer's recommendation.

MEDIUM TRIP RISK

6.9.2 Manufacturers Replacement Information

Expected lifetime is 40 years if overload limitations are not exceeded.

6.9.3 Conclusion

No major capital expenditure is envisaged for the converter transformers, however operating expenditure is envisaged in 2048 to replace the tap selectors to ensure the continued safe operation of the tap changers.

6.10 181 – Smoothing Reactor

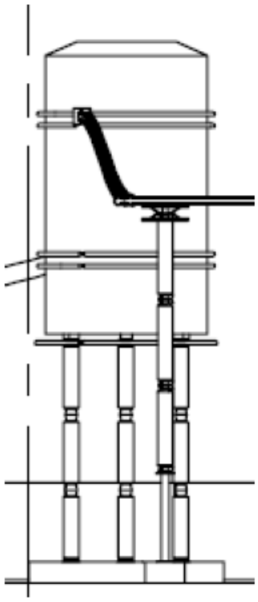

Figure 12. DC Smoothing Reactor

The DC smoothing reactor connects the DC valve hall wall bushing to the DC bus and limits the rate of change of current during a transient.

Table 23 - Theoretical Smoothing Reactor Reliability

Component	MTBF (hours)	MTTR (hours)
Smoothing Reactor	981120	30

Table 24 - CIGRÉ Smoothing Reactor Expected Lifetimes

Component	Lifetime (years)
Smoothing Reactor	35

For air core SR's, the support insulators are critical for mechanical support and dielectric support. Shed profile, such as long short or anti-fog, is important. After 25 to 30 years, two of the insulators should be removed from service and tested both mechanically and electrically. Failure of the grout between the metal flange and the porcelain is a common cause of problems.

For an air core smoothing reactor, the most critical area is the outer coating of paint or silicone RTV. This coating must be refurbished every 10 years (more or less) to protect the SR insulation and applies to both outdoor and indoor installations as most indoor lights emit ultra-violet (UV) radiation. Owners of the air core SR's may not be aware of this requirement. This coating keeps out UV radiation and moisture which if not refurbished will result in insulation failure, corrosion of the winding and require replacement.

A smoothing reactor failure has not been experienced.

CONSEQUENCE OF FAILURE:

The smoothing reactors are connected to the converter DC bus, an electrical failure of on the converter DC bus will result in the loss of availability.

RISK RATING:

HIGH TRIP RISK

CONTROL MEASURES:

- Very low failure rate of component.
- Manufacturer’s recommended maintenance performed.
- Spares holding as per manufacturer’s recommendation.

MEDIUM TRIP RISK

6.10.1 Manufacturers Replacement Information

The brand name Trench still exists within Siemens, with an air-cooled reactor installed in 1980 still in operation.

6.10.2 Conclusion

Capital expenditure is forecast for 2026 to refurbish the smoothing reactor.

6.11 251 – DC Distribution and Chargers

Figure 13. DC Distribution and Charger Overview

The DC Distribution and Charger charges the 110V station batteries and provides DC supply to the switchgear and the inverter provides AC power from the batteries to the HVDC control and protection systems.

Table 25 - Theoretical DC Distribution and Charger Reliability

Component	MTBF (hours)	MTTR (hours)
Inverter	4.38×10^6	6
Isolator	1.752×10^7	6
Miniature circuit breaker	87600	6
Switch	6×10^6	6
Rectifier	6.132×10^6	6
Static Switch	6×10^7	6
Battery Charger	6×10^6	8

There is no CIGRÉ expected lifetime data for the DC Distribution and Chargers.

Only minor issues have been experienced within the statistical failure rates.

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CONSEQUENCE OF FAILURE: **RISK RATING:**

The DC Distribution and Chargers are not a single point of failure.

LOW TRIP RISK

CONTROL MEASURES:

- DC Distribution and Chargers are installed with N+1 redundancy.
- Both systems can be run off a single battery bank.
- Very low failure rate of components.
- Manufacturer's recommended maintenance performed.
- Spares holding as per manufacturer's recommendation.

LOW TRIP RISK

6.11.1 Conclusion

Major capital expenditure is forecast for the DC Distribution and Chargers in 2037.

6.12 261 – 110V Battery

Figure 14. 110V Battery Overview

The 110V station batteries provide DC supply to operate the switchgear and the inverters to provide AC power to the HVDC control and protection systems.

Table 26 - Theoretical 110V Battery Reliability

Component	MTBF (hours)	MTTR (hours)
Battery	87600	6

There is no CIGRÉ expected lifetime data for the 110V Battery, however typical industry lifetime is 10 years.

All the station 110V batteries were replaced in 2019.

CONSEQUENCE OF FAILURE:

RISK RATING:

The 110V station batteries are not a single point of failure.

LOW TRIP RISK

CONTROL MEASURES:

- 110V station batteries are installed with N+1 redundancy.
- The system can be supplied from one battery bank.
- Both systems can be run off a single battery bank.
- Very low failure rate of components.
- Manufacturer’s recommended maintenance performed.

LOW TRIP RISK

6.12.1 Manufacturers Replacement Information

Period replacement of Batteries is expected.

6.12.2 Conclusion

Major capital expenditure is forecast for the 110V batteries at around 10-year intervals from 2019, however the results of regular battery testing will indicate a precise replacement frame required to ensure the availability of Basslink.

6.13 281 – Diesel Generator

Figure 15. DC Switchyard Overview

The diesel generators provide continuity of auxiliary supply during a 22kV supply outage and consist of the following:

- Converter Stations
    - Two 500KVA three phase units
- Transition Stations
    - One 40 KVA single phase unit

Table 27 - Theoretical Diesel Generator Reliability

Component	MTBF (hours)	MTTR (hours)
Diesel prime mover	500	30
Generator control	175200	8
Generator	3.132×10^6	24

There is no CIGRÉ expected lifetime data for the diesel generator.

Major generator failures have not been experienced; however, a transition station generator was replaced in George Town due to the corroded sound enclosure condition from the coastal operating environments.

CONSEQUENCE OF FAILURE:

The diesel generators are not a single point of failure.

RISK RATING:

LOW TRIP RISK

CONTROL MEASURES:

- converter station are diesel generators installed with N+1 redundancy.
- The system can be supplied from one generator.
- Very low failure rate.
- DC batteries at the transition station providing backup to the single generator of components.
- Manufacturer's recommended maintenance performed.
- Spares holding as per manufacturer's recommendation.

LOW TRIP RISK

6.13.1 Conclusion

Based on the current assets condition major capital expenditure is forecast in 2022 and 2032 due to expected unavailability of spare parts for the current systems and forecast at 25-year intervals, to ensure the availability of Basslink.

6.14 300 – Control and Protection

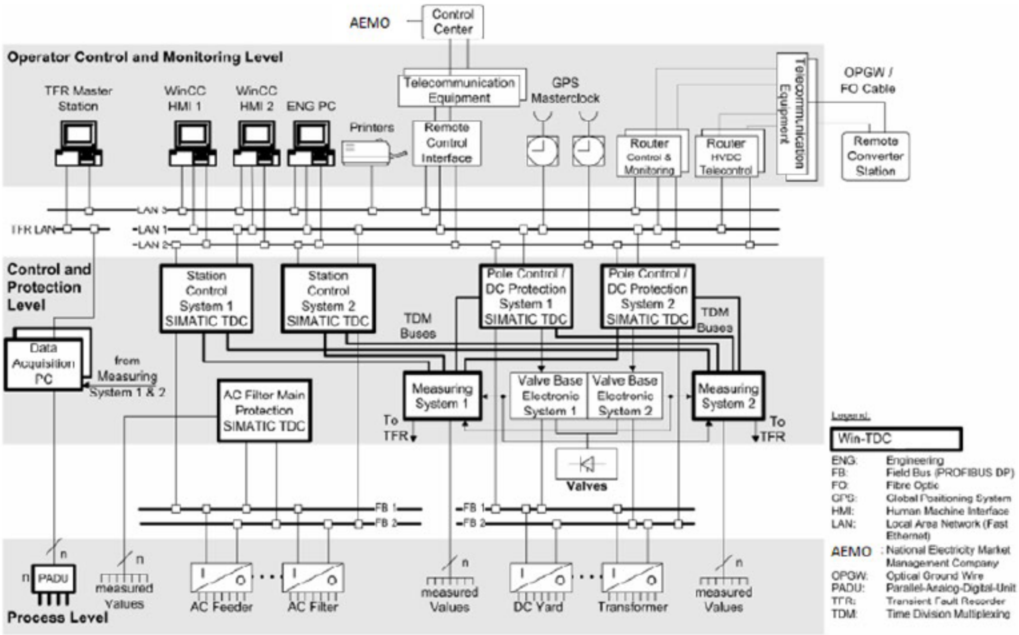

Figure 16. Control & Protection Overview

The HVDC control system, represented in figure 16 by the Control and Protection Level consists of interconnected sub systems with differing design life spans, the design life of the products used in the sub systems need to be regularly monitored for planning to ensure continued operation of the Basslink interconnector.

Table 28 - Theoretical Control & Protection Reliability

Component	MTBF (hours)	MTTR (hours)
CP 50 M0	182208	6
CPU 551	184836	6
FBG _ICH_PCM	1.24392×10^6	6
FBG _ITH	367044	6
GER _LT2002_COL	1.95348×10^6	6
GER _LT2002_LFM_1_OF_2	1.93596×10^6	6
SM 500	164688	6
Rack, Power Supply	130524	12

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Table 29 - CIGRÉ Control & Protection Expected Lifetimes

Component	Lifetime (years)
HVDC Controls	12-15

While CIGRÉ[7] and the manufacturer[8] have nominated a typical 15-year control system life, Siemens have not yet nominated a Simatic TDC platform replacement and the latest HVDC projects are still being commissioned with Simatic TDC, however the manufacture is working on a replacement platform.

Table 30 - Control & Protection Failures Experienced

Component	Hardware Failure History	Comment
SIMATIC TDC CPU551	6DD1600-0BA1 =11VR02+VR2: 10/06/2015 - D02P02 replaced (module failure) 25/09/2017 - D01P01 replaced (module failure)	6DD1600-0BA2 & 6DD1600-0BA3 are a direct replacement, spares are a mix of versions 1 & 2
SIMATIC TDC SUBRACK UR5213	6DD1682-0CH0: 5/10/2009 =21XJ02+XJ2, =21VR01+VR1 & =21VR02+VR2 failure following reprogramming =11VR02+VR2: 15/11/2012 - replaced with 6DD1682-0CH2 (indicating multiple module failure on restart) 9/7/2015 - replaced with 6DD1682-0CH2 (internal power supply fault)	6DD1682-0CH3 is a direct replacement with superior antistatic shielding

[7] CIGRÉ, Technical Brochure,649, Guidelines for life extension of existing HVDC systems, WG B4.54, 2016

[8] Siemens Major Refurbishment or Replacement on HVDC Classic

CONSEQUENCE OF FAILURE:

The control and protection system in a monopole HVDC system is a critical component, but is designed with redundancy and backup mechanisms to minimise the risk of being a single point of failure. However, if these redundancies fail or are improperly maintained, the control and protection system will be a single point of failure leading to a loss of availability

RISK RATING:

CONTROL MEASURES:

- HVDC control & protection system installed with N+1 redundancy
- low failure rate.
- Manufacturer’s recommended maintenance performed.
- Spares holding as per manufacturer’s recommendation while still available.
- Replacement at Manufacturer’s recommended interval

If the hardware is not replaced when recommended the risk rating will increase as redundant components will need to be consumed to maintain availability.

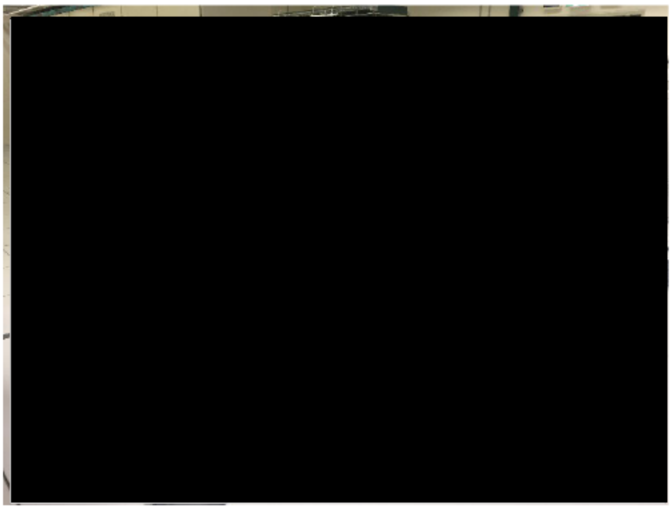
6.14.1 Manufacturers Replacement Information

A C&P refurbishment is recommended after 15 to 20 years.

6.14.2 Conclusion

Major capital expenditure is forecast to replace the system in 2028 to 2030, when the replacement platform is forecast to be available due to the expected unavailability of spare parts for the current system to ensure the availability of Basslink.

[redacted]



[redacted]

The computer hardware, represented in figure 16 in the Control and Monitoring level provides the operator interface to the control system and engineering tools consisting of the following systems:

- Human machine interface
  - Operator workstations
  - Engineering workstation
- Simatic TDC engineering workstation
- Transient fault recorder
  - Data acquisition PC
  - Analysis PC
- Remote control interface
- Terminal server

There are no Siemens failure rates for the computer hardware equipment.

Table 31 - CIGRÉ Computer Hardware Expected Lifetimes

Component	Lifetime (years)
Human Machine Interface	7

[redacted]

CONSEQUENCE OF FAILURE:

RISK RATING:

Redundancy in the Human-Machine Interface (HMI) minimises single points of failure in control systems, but improper maintenance could make the HMI a point of failure leading to a loss of availability.

HIGH TRIP RISK

CONTROL MEASURES:

- computers for the control system interface installed with N+1 redundancy.
- the computers only provide the "window" into the control system, short term loss of the computers will not stop power transfer but stop the ability to view and make changes.
- Very low failure rate.
- Manufacturer's recommended maintenance performed.
- Spares holding as per manufacturer's recommendation while available
- *If the hardware is not replaced when recommended the risk rating will increase as redundant components will need to be consumed to maintain availability.*

LOW TRIP RISK

6.15.1 Manufacturers Replacement Information

As provided in Figure 1, HMI Level Infrastructure related refurbishment is recommended after 7-8 years.

6.15.2 Conclusion

Major capital expenditure is forecast upgrade the Human Machine Interface computers with the manufacture's current design to lift cybersecurity maturity in 2026.
If the hardware is not replaced in 2026 the risk rating will increase as redundant components will need to be consumed to maintain availability.

6.16 400 – Telecommunications

Figure 18. Telecommunications Overview

The telecommunications systems marshal the control and protection signals and transports to the required destinations using the OPGW and submarine fibres.

There are no Siemens failure rates for the telecommunications equipment.

Table 32 - CIGRÉ Telecommunications Expected Lifetimes

Component	Lifetime (years)
Communications Systems	15

Table 33 - Telecommunications Failures Experienced

Description	Parts in Stock per station (EA2)	Hardware Failure History
FP1 hit 7050 subrack	1	Nil
MFP1 Main Board	1	=30XX31+X31 – 26/05/2017
2Mb Card, 1200 ohm p1 -21	1	Nil
STM-1 Board(O155-2) hit	2	Nil
Fan Unit	1	Nil
S-1.1 SFP	1	Nil
L-1.2/3 SFP	2	Nil
SNU Shelf	2	=40XX31+X31 – 4/04/2007 (rodent)
SUE	2	
CUD	2	=30XX32+X32 - 30/01/2007 40XX31+X31 – 15/05/2007
CUC	1	=30XX32+X32 - 1/03/2006 =40XX32+X32 - 30/03/2007

Description	Parts in Stock per station (EA2)	Hardware Failure History
		=40XX31+X31 – 4/04/2007 (2 units due to rodent)
PU16	1	
Sub 102	2	
SLX102E	2	
CPF2	2	
CIM24	3	
X.21	2	

Basslink has experienced a low failure rate of components, however the technology platform is end of design life and no longer supported by the OEM. This is managed by a service contract to provide appropriate technical support and component repairs under OPEX.

CONSEQUENCE OF FAILURE:

RISK RATING:

The telecommunications systems are not a single point of failure.

LOW TRIP RISK

CONTROL MEASURES:

- telecommunications systems installed with N+1 redundancy.
- Very low failure rate.
- Manufacturer's recommended maintenance performed.
- Spares holding as per manufacturer's recommendation.
- Extending asset life by using local technical support

LOW TRIP RISK

6.16.1 Conclusion

Basslink is extending the life of this asset set by using a local specialist support service provider. The duration of this life extension will depend on the service providers ability to supply and repair spare parts and the failure rate of the various components.

HVDC Telecommunications systems are typically replaced with the control system upgrade due to redundant control system timing requirements as it is an integral part of the control system therefore major capital expenditure is forecast in 2028 to coordinate with the control and protection upgrade.

6.17 700 – Auxiliary Systems

Figure 19. HVAC System Overview

The HVAC system provides air cooling for the Valve Hall, Valve Cooling Room, Control Room and. auxiliary supply rooms.

There are no Siemens failure rates for the HVAC equipment.

There is no CIGRÉ expected lifetime data for the HVAC equipment.

Basslink has replaced the control room HVAC system at both converter stations.

CONSEQUENCE OF FAILURE:

RISK RATING:

The Valve Hall, Valve Cooling Room and Control Room systems are not a single point of failure.

LOW TRIP RISK

CONTROL MEASURES:

- Valve Hall, Valve Cooling Room and Control Room systems installed with N+1 redundancy.
- Very low failure rate.
- Manufacturer's recommended maintenance performed.
- Spares holding as per manufacturer's recommendation.

LOW TRIP RISK

6.17.1 Conclusion

Capital expenditure is envisaged for replacement of the Valve Hall Air handling unit at Loy Yang in 2023 due to deterioration and in 2033 for George Town.

6.18 1000 – Overhead Lines

Figure 20. Overhead line Overview

The Overhead Lines connects the stations to provide the conductors for power transfer and interstation communication consisting of:

- Victoria
    - 3.2km of 500kV AC line, strung on 9 towers
    - 57.4km of 400kV DC line, strung on 133 towers
- Tasmania
    - 8.9km of 400kV DC line, strung on 23 towers
    - 2.1km of 220kV AC line, strung on 7 towers

Table 34 - Theoretical Overhead Line Reliability

Component	MTBF (hours)	MTTR (hours)
AC Overhead Line Tasmania	69524	3
AC Overhead Line Victoria	39818	3
DC Overhead Line per km	5×10^6	13
HVDC Overhead Line Transient Failure	4380	
MR Overhead Line Transient Failure	26280	

There is no CIGRÉ expected lifetime data for the overhead lines, however overhead line experience in Victoria and NSW supports a 65-year life.

CONSEQUENCE OF FAILURE:

The Overhead Lines and towers are a single point of failure, failure of this system will result in the loss of availability.

RISK RATING:

HIGH TRIP RISK

CONTROL MEASURES:

- Very low failure rate of components.
- Maintenance performed in accordance with Energy Safe Victoria requirements.
- Spares holding as per manufacturer's recommendation.

MEDIUM TRIP RISK

6.18.1 Conclusion

Condition assessments of the transmission towers will continue to be performed at 3-year intervals to determine maintenance requirements.

6.19 2010 – Cable

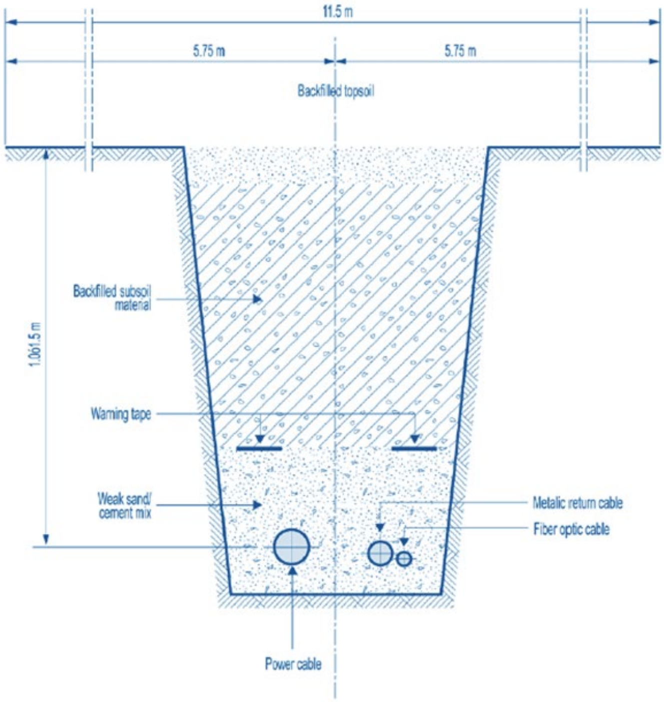


Figure 21. Basslink Land Cable Burial Depth and Easement Width

The cables are a single DC system, buried at around 1 metre below the surface and consists of.

- 400kV DC high voltage cable
- 12kVdc/20kVac metallic return cable
- The fibre optic cable has 12 fibres, the fibre is used for communication for control and protection functions of the Victorian and Tasmanian stations.

The cables connect the transition stations to provide the conductors for power transfer and interstation communication consisting of:

- Victoria
  - 6.4km of cable, buried
- Bass Strait
  - 290km of submarine cable
- Tasmania
  - 1.7km cable, buried

The Basslink interconnector has a design life of 40 years and has experienced one HVDC submarine cable failure and one failure in the land section of the metallic return cable.

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APA has invested in cable and hardware to ensure timely repair of cable faults including:

- jointing kits
- cable
- jointing equipment

CONSEQUENCE OF FAILURE:

The DC Cables are a single point of failure are a single point of failure, failure of this system will result in the loss of availability.

RISK RATING:

HIGH TRIP RISK

CONTROL MEASURES:

- Very low failure rate of components.
- Spares holding as per manufacturer's recommendation.

MEDIUM TRIP RISK

6.19.1 Conclusion

Major capital expenditure is envisaged when the contracted cable repair vessel is changed.

7 Basslink Historical Performance Statistics

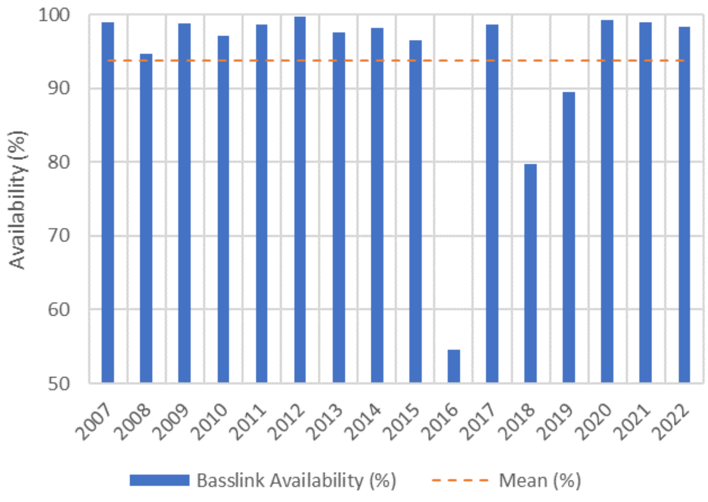

Figure 22. Basslink CIGRÉ Performance Summary

Figure 22 displays the Basslink historical performance, assessed against the CIGRÉ benchmarking criteria, indicating annual availability (blue bars) and the mean availability (red dashed line) at 93.69% from 2007 to 2022.

The same information is presented statistically below, using both graphical and tabular summaries. Figure 22a displays the normal distribution including all outages, while figure 22b represents the normal distribution of availability on the Siemens HVDC plant only.

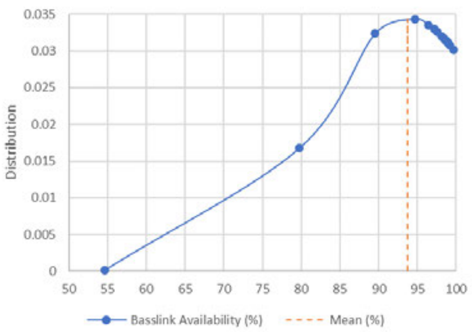

Figure 22a. Availability including Cable Outages

	Availability
Minimum	54.64(%)
Mean	93.69(%)
Maximum	99.71(%)
Standard Deviation	11.57(%)
Kurtosis	9.47
Skewness	3.00

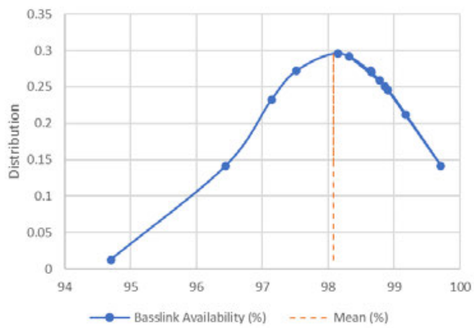

Figure 22b. Availability excluding Cable Outages

	Availability
Minimum	94.70(%)
Mean	98.08(%)
Maximum	99.71(%)
Standard Deviation	1.34(%)
Kurtosis	2.33
Skewness	-1.48

7.1 Basslink Performance Summary

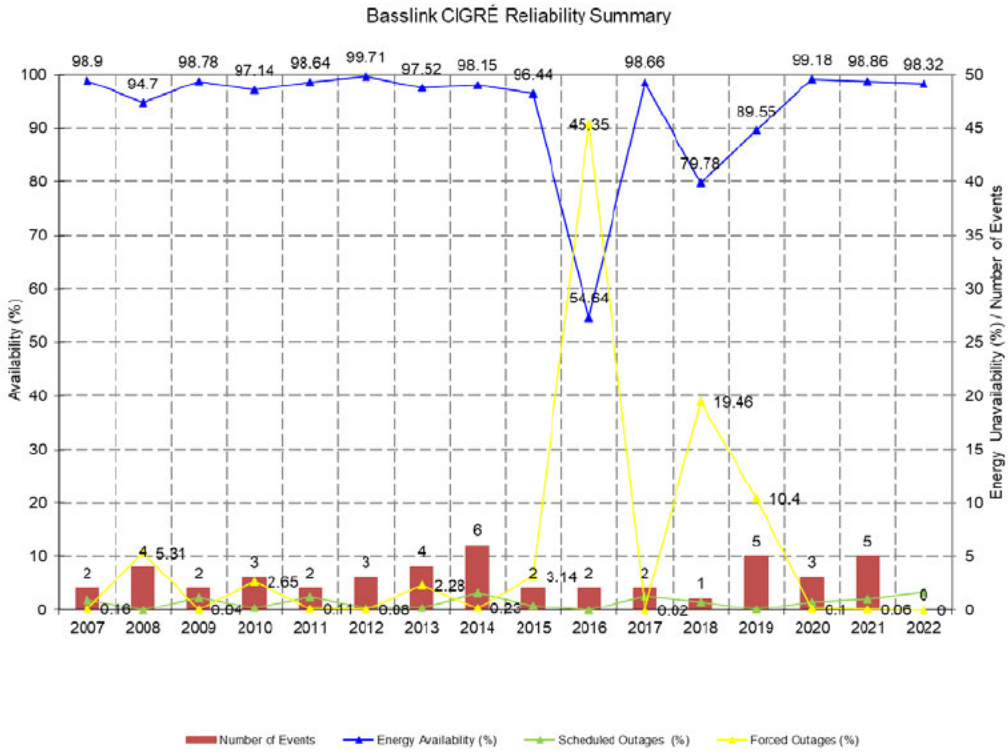

Figure 23. Basslink CIGRÉ Reliability Summary

Figure 23 displays the energy availability (blue trace), scheduled outage unavailability (green trace), forced outage unavailability (yellow trace) and number of outage events (brown bar), the notable performance excursions are summarised below:

Start Date	Duration (hrs)	Description
20/12/2015	4221.79	Fault in HVDC cable protection zone. Submarine cable repaired by Prysmian in 70 meters of water.
26/03/2018	1704.85	HVDC Cable sealing end low pressure, accidental pipework contact by contractor. Cable sealing end compound refilled by Prysmian
24/08/2019	864.16	Fault in LVDC cable protection zone Metallic return cable jointed by Prysmian and sealing end replaced.

All the events in the tabular summary above required specialist equipment and personnel from Prysmian.

7.2 Basslink Individual Style Performance

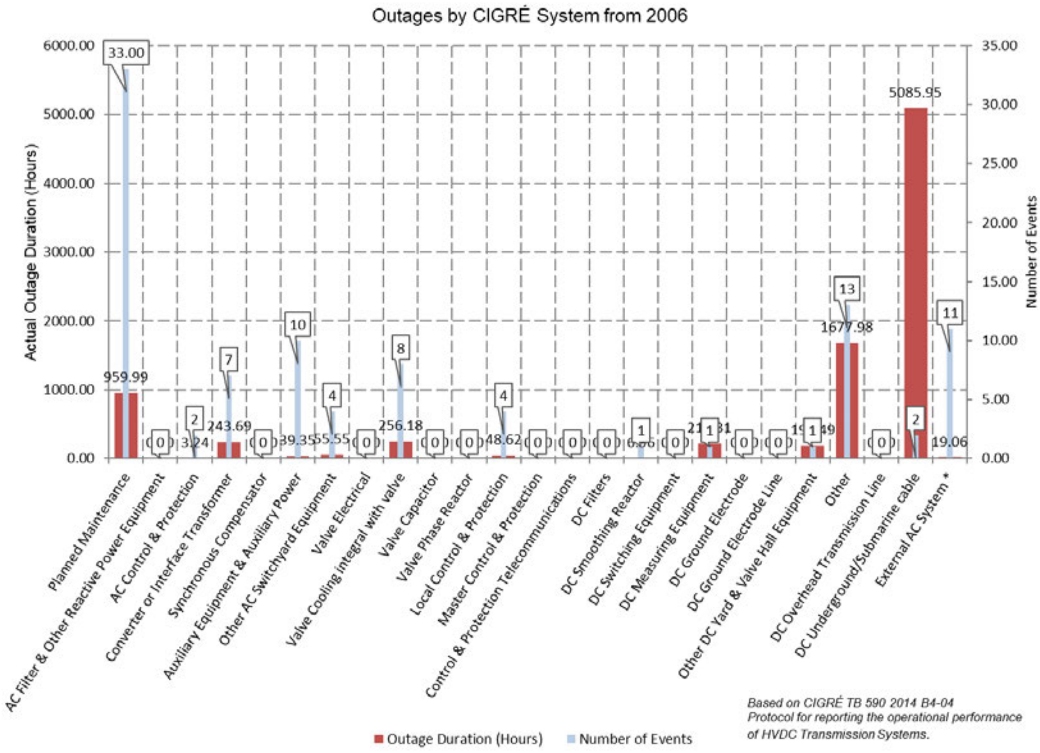

Figure 24. Basslink CIGRÉ System Performance

Figure 24 displays the outage hours (brown bar) and number of outage events (grey bar) attributable by each system from unplanned events or to planned maintenance events for the Basslink interconnector, and the outages are summarised below:

- Planned Maintenance has the highest number of events which accumulating 959.99 outage hours.
- The system with the second highest number of occurrences is Valve Cooling, there have been several process improvements to reduce these events:
  - Modified Valve Cooling PLC FC7 to enable trip function of thyristor differential pressure for the first 5 minutes after deblocking to ensure manual valves open.
  - Modified Valve Cooling PLC FC7 to ensure no single device can cause a trip, with a valid redundant signal.
  - Added surge arrestors to incoming and local supplies, modified Valve cooling PLC to automatically reset VSD 3 times before latching fault to prevent external auxiliary AC transient causing an outage.
- The system with the highest number of outage hours is DC Underground/Submarine Cable. This system requires specialist equipment and personnel to remediate failures.

8 CIGRÉ Benchmarking Comparison

CIGRÉ advisory group B4.04, was formed specifically to assemble and publish data on the reliability and operational experience of similar HVDC systems, using a standard protocol for collecting and compiling the data.

The data in the CIGRÉ reports, provides a record of reliability performance for the majority of HVDC systems in the world, reporting to CIGRÉ, since they first went into operation for the years 1968 to 2020, however, only the data following 2001 has been utilised in this review, to represent the performance of relatively similar modern plant.

Information is collected annually from HVDC system operators and is published at two yearly intervals.

8.1 CIGRÉ Availability

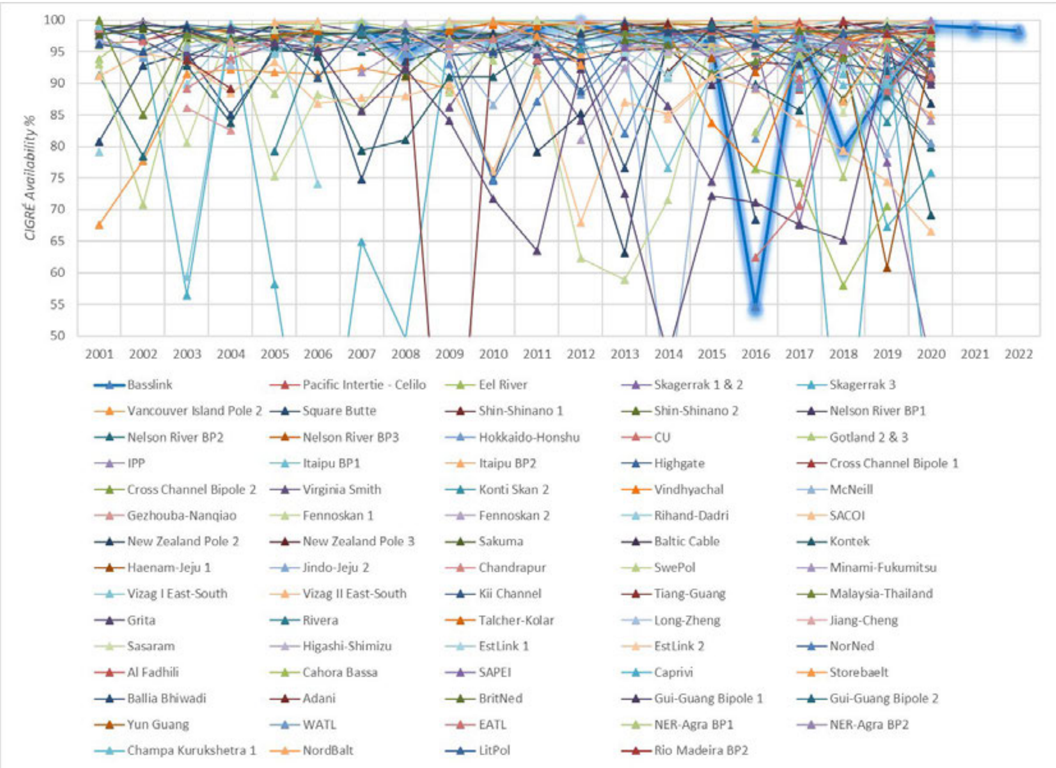

Figure 25. CIGRÉ Yearly Availability

Figure 25 displays the historical performance of Basslink (blue trace) compared with the performance of all HVDC thyristor systems reporting to CIGRÉ.

While the data display is congested, the legend shows the number of systems against which, Basslink's performance is being compared. There is no information on the performance of other systems post 2020. As the latest published data available for comparison, is from CIGRÉ 2022 B4_11135 - A Survey of the Reliability of HVDC Systems throughout the World During 2019-2020. The issuing of the next CIGRÉ reliability report is scheduled for 2024.

Figure 25 comparison includes monopole, bipole and back-to-back systems, while Basslink is a monopole system.

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8.2 CIGRÉ Monopole Availability

The tabular summary below, compares the main parameters of the systems identified in the CIGRÉ reports as monopoles (two terminals with one converter per pole). These systems are from different suppliers but similar capacities.

Monopole Main Parameter Comparison					
System/Project	Supplier	Year Commissioned	Maximum Continuous Capacity (MW)	DC Voltage (kV)	Line/Cable (km)
Baltic Cable	ABB	1994	600	450	261
Basslink	Siemens	2006	500	400	350
EstLink 2	Siemens	2014	670	450	171
Fennoskan 1	ABB	1990	500	400	33+200
Fennoskan 2	ABB	2011	830	500	200
Grita	ABB	2001	500	400	316
Konit Skan 2	ABB	1998	300	285	150
Kontek	ABB	1998	600	400	171
Malaysia-Thailand	Siemens	2001	300	300	110
Skagerrak 3	ABB	1993	500	350	240
Storebælt	Siemens	2010	600	400	58
SwePol	ABB	2000	600	450	254

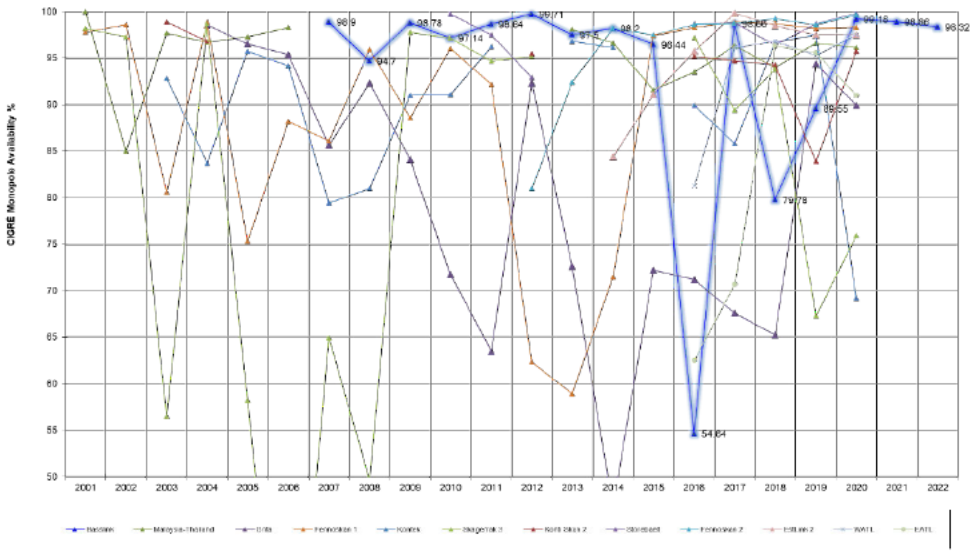

Figure 26. CIGRÉ Monopole Yearly Availability

Figure 26 displays the historical performance of Basslink (blue trace) compared with the performance of other monopole HVDC thyristor systems reporting to CIGRÉ.

Viewing figure 26, it is evident the performance of the Basslink interconnector (blue trace) is one of the leading performers for comparable systems, with three exceptions:

- 2016 - HVDC Submarine cable fault
- 2018 - Contractor damaged cable sealing end
- 2019 – LV Land Cable Fault

Though the 2018 and 2019 availability were not as high as previous years, it still compares relatively well to the performance of other systems.

8.3 CIGRÉ Monopole Availability Statistics

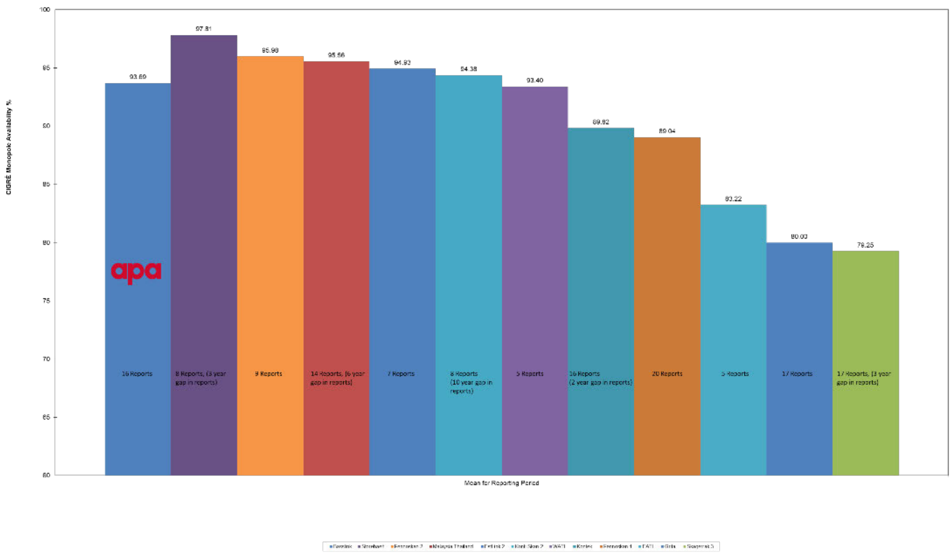

Figure 27. CIGRÉ Monopole Average Availability

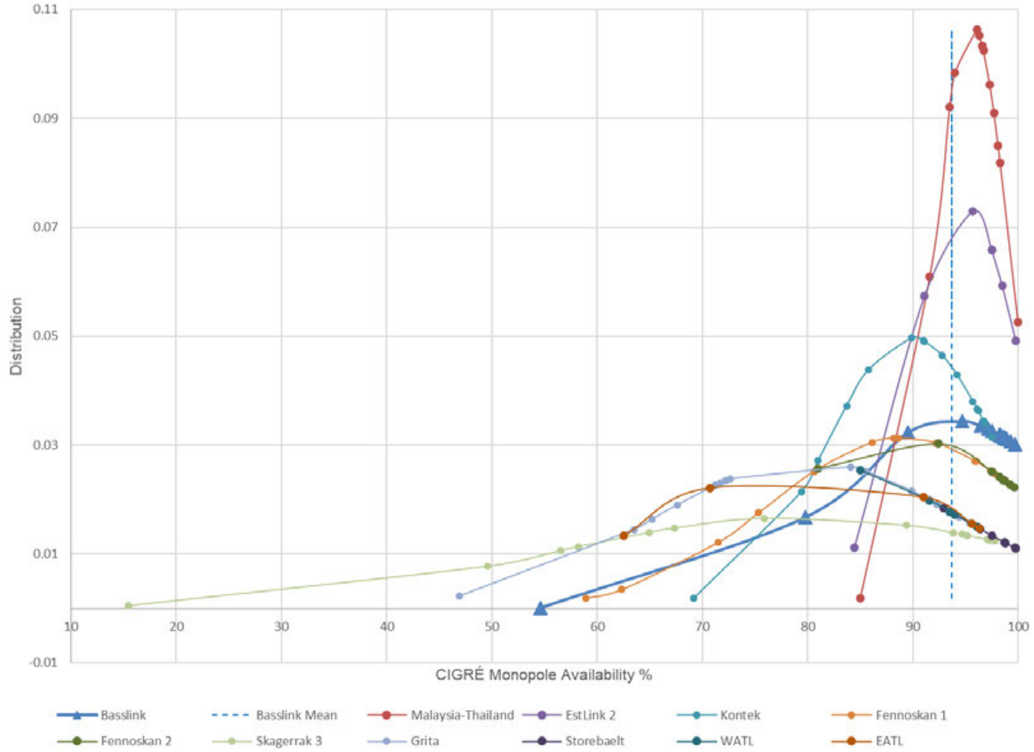

Figure 28. CIGRÉ Monopole Availability Distribution

Figure 27 displays the mean availability for the report period of Basslink (blue bar) while figure 28 displays the distribution (blue trace) compared with the performance of other monopole HVDC thyristor systems reporting to CIGRÉ.

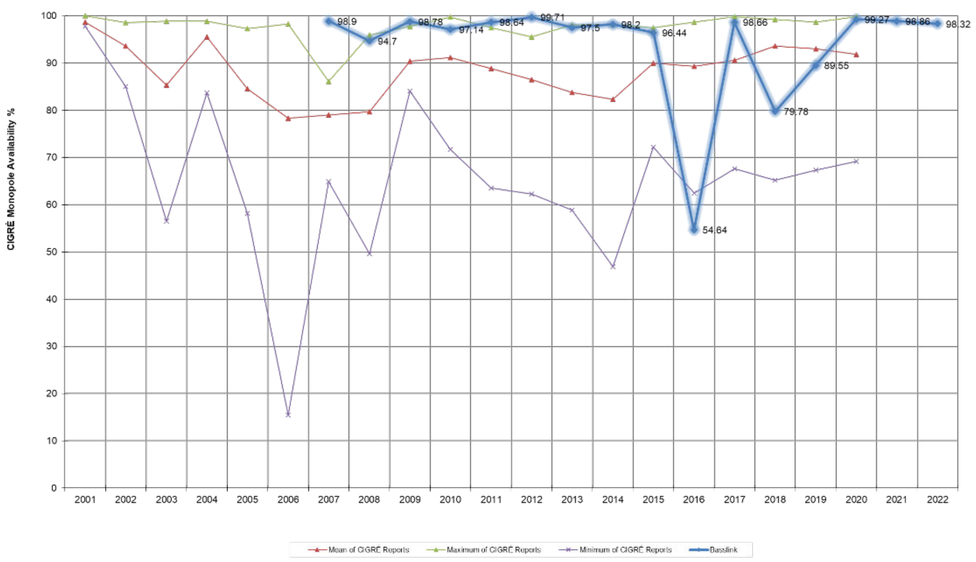

Figure 29. CIGRÉ Monopole Yearly Availability

The comparison in figure 29 displays Basslink availability (blue trace) against each year's best and worst performers (excluding Basslink). In 12 out of the past 15 years Basslink performed at around the best availability performance levels (green trace). In 2 of the remaining 3 years Basslink performed at around the mean performance level (red trace). In the remaining year (2016) availability was at the minimum (violet trace) experienced by the monopoles reporting to CIGRÉ.

9 References

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10 Summary of Changes

Rev	Description	Date	Author
1.0	First Issue	10/08/2020	G. Mather
2.0	Updated with 2021 performance data.	10/01/2022	G. Mather
3.0	Updated with 2022 performance data.	16/02/2023	G. Mather
4.0	Updated to APA template and with forecast data.	18/08/2023	G. Mather