Basslink Condition Assessment

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Executive Summary

Amplitude Consultants Pty Ltd (Amplitude) has been engaged by APA to perform a high-level assessment of the Basslink asset and provide an opinion on the current condition and serviceability of the asset. The engagement was undertaken with a view to identify any condition issues apparent from observation and available documentation which could result in a material cost to rectify in the near future.

For the purpose of this report, we have considered any rectification or replacement of plant and equipment with identified condition issues that are not already planned and budgeted for that will require in excess of $250,000 of work and/or more than 2-3 days of outage as being material.

The assessment was based on a visual inspection of the plant or equipment on site supported by interviews with key operational staff during the inspection. The main categories of plant that were visually inspected included the converter station equipment, AC and DC HV yards, auxiliary systems, AC and HVDC overhead transmission lines and the transition stations. The following transmission line towers were inspected in Victoria and Tasmania:

- **Victoria:** DC: T 95 Monopole, HAT90 AP5, T 5-1, T 5-2, T 5-3, -T 6-4 and MAT60 AP7.
- **Tasmania:** AC: HTT AP227, T 226 and T 223; DC: T 27-1 and HAT90 AP28.

Given the system was energised at the time of the inspection, certain equipment was inspected from the ground or from the safety barrier using binoculars. Due to their installation, the land cables, earthing systems and the subsea cables were not visually inspected.

Due to the limitations described above, the condition assessment was supplemented with a review of the relevant O&M records, engineering reports and previously completed condition reports and failure data available to Amplitude, in order to identify any existing major defects and/or pervasive condition related problems may exist.

For the above ground terrestrial assets, three material findings were found, all related to corrosion, with these being described below:

- **Converter Station Equipment:** The in-service and spare converter transformers at both George Town and Loy Yang display corrosion on the inside bottom of the cooling fins steel header attached oil/air coolers.
- **AC and HVDC overhead transmission lines:** Some of the galvanised steel transmission line towers and hardware, especially those close to the sea, are showing signs of deterioration of the galvanising and minor onset of rust break through. Only some structures are impacted, and the mitigation applied would be specific to each affected tower.
- **Transition Stations:** At the George Town Transition Station, and to lesser extent at the Loy Yang Transition Station, two oil pressure steel tanks for the 400 kV DC cable sealing end, are corroded at their tops where water has accumulated and cannot drain. If corrosion continues and a major oil leak occurs, low oil pressure could initiate a cable and hence total link trip.

To assess the status of the subsea cable system, Amplitude first considered the latest available data on internal subsea cable failures (CIGRE Technical Brochure 815, 2020) to compare Basslink against the operational experience of other subsea cables. Additionally, Amplitude reviewed the investigation reports and expert opinions that have been provided for the cause(s) behind the 2015 failure of the subsea cable. On review of the available data, expert reports and general statistics on HVDC MIND cable performance, the Amplitude opinion regarding the Basslink subsea cable conditions is as follows:

- HVDC cables comparable to the Basslink cable technology (MIND), voltage rating and length have been shown to experience failures as a result of internal causes.
- Basslink was commissioned in 2006 and during the following 17 years of commercial operation, the Basslink subsea HVDC cable suffered one failure in December 2015. The statistical failure rate of the Basslink cable since it was put in service is not considered to be extraordinary or unprecedented for the cable technology used and the length of the subsea cable. Based on the available performance statistics and failure interval calculated, additional failures could be reasonably expected within the remaining commercial life of the Basslink cable.
- The hypothesised existing cable defects coupled with the operational mitigations applied post the 2015 failure have not manifested in additional failures in the last seven years of operation. Given the actions taken by the asset owner, including limiting the continuous rating of the cable, increasing the deionisation time and introducing an improved cable load prediction system, it is considered more probable than not, that future performance will not be impacted by the hypothesised defects under the current operating regime.
- We do not consider it to be economically practical or possible, even when using the latest cable technology and discounting external factors, to guarantee a zero failure rate for a subsea cable of similar length and voltage rating. Cable failures are typically expected, and HVDC subsea cable operators will plan for these events to minimise their impact.
- Based on the historical performance and current operating regime, the condition of the cable is considered typical for its age, technology and voltage rating.

The report that follows discuss in further details the scope of the assessment, methodology followed, condition findings and limitations of our assessment. Only findings identified related to condition are reported on and assessed for materiality.

1. Introduction

Amplitude Consultants PTY LTD (Amplitude) has been engaged by APA to perform a high-level assessment of the Basslink asset and provide an opinion on the current condition and serviceability of the asset.

The engagement was undertaken with a view to identify any condition issues apparent from observation and available documentation which could result in a material cost to rectify in the near future.

This report provides a summary of the methodology and limitations of our assessment and reports “by exception” on the findings of our assessment.

2. Basslink HVDC System Overview

Basslink is a high voltage direct current (HVDC) system that interconnects the electrical networks of the States of Tasmania and Victoria. Basslink was commissioned in 2006 and utilises line commutated converters (LCC) HVDC technology. The underground and subsea cables utilise mass impregnated non-draining (MIND) cable technology for the HVDC cable and XLPE for the metallic return cable.

The Basslink system has a rating of 500 MW in continuous operation and up to 630 MW dynamic rating [1]. The system is connected to the 500 kV Loy Yang Power Station switchyard in Victoria through a short overhead AC 500 kV transmission line, and a longer overhead 400 kV DC overhead transmission line from the Loy Yang Converter Station to the transition station near McGauran Beach. From the transition station, underground and subsea HVDC cables continue to a transition station near Low Head in Tasmania along a route that traverses the Bass Strait. An overhead 400 kV DC transmission line runs from this transition station to the George Town Converter Station, with a short 220 kV overhead line connecting on to the 220 kV switchyard at George Town Substation.

An overview of the Basslink HVDC system, with the lengths of the various overhead, underground and subsea lines/cables is shown diagrammatically in Figure 1. Table 1 provides a summary of the systems and ratings and Table 2 provides a summary of the major plant and equipment associated with the Basslink system.

Figure 1 – Basslink Asset Overview

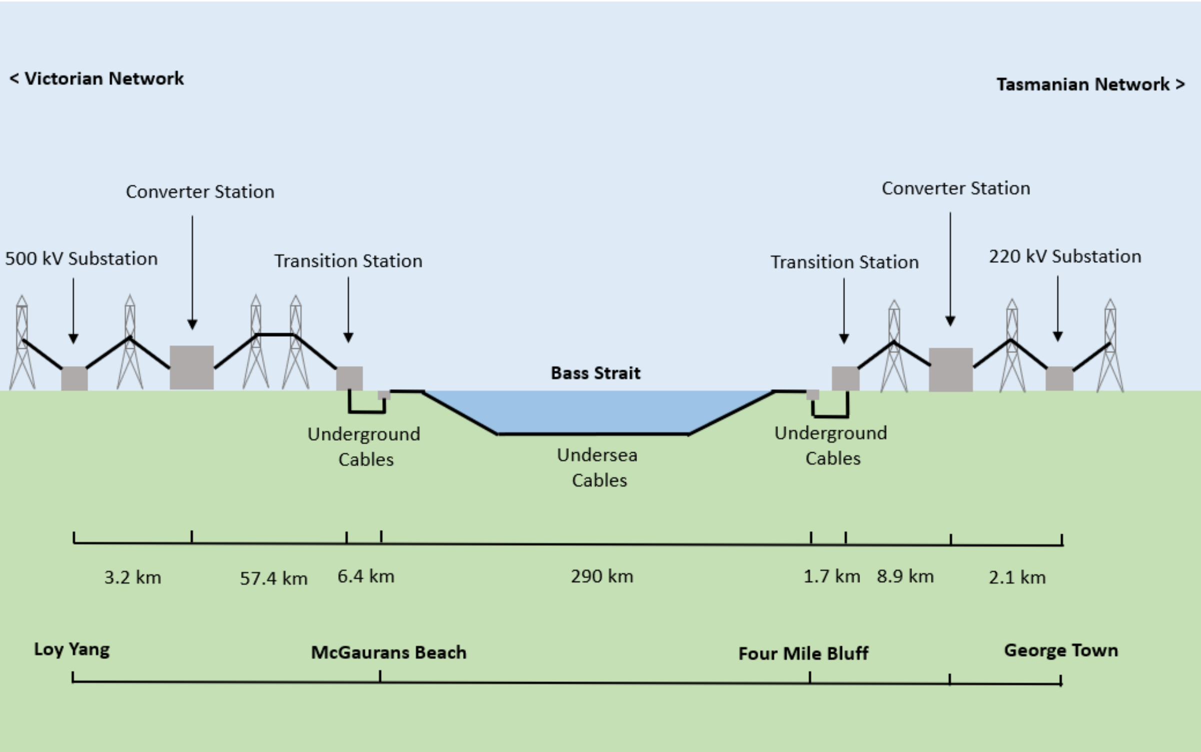


Table 1 – HVDC System Ratings and Technology

System Parameter	Victoria	Tasmania
Grid connection point	Loy Yang Power Station Switchyard	George Town Substation
Grid connection nominal Voltage	500 kV	220 kV
Interfacing TNSP	Ausnet Services	TasNetworks
Nominal DC voltage	400 kV	
Rated DC continuous current	1,250 A	
Rated continuous DC power	500 MW	
Minimum DC power	50 MW	
Maximum dynamic DC rating (infeed)	630 MW	500 MW
HVDC Converter technology	Siemens - LCC	
HVDC Cable Technology	HV: 400 kV DC, MIND Metallic return: MV DC, XLPE Optical fibre cable	
HVDC Overhead Line Technology	Lattice and pole structures with metallic return and OPGW	

Table 2 – Major Plant and Equipment

Major Electrical Assets	Subsystems
Converter Station Equipment	Thyristor valves, HVDC control and protection electronics Valve cooling and related equipment
AC and DC HV Yards	Converter transformers and supporting equipment AC and DC harmonic filters and capacitor banks Smoothing reactor and AC shunt reactor Surge arresters HV measurement equipment (CT, VT, DC) HV wall bushings Switchyard structures, hardware, busbar and connections HV switchgear e.g., breakers, disconnector and earthing switches AC control, protection and telecommunication systems
Auxiliary Systems	Auxiliary systems control and protections Auxiliary AC supply UPS Fire detection and suppression systems e.g., sensors, alarms, water deluge and gas suppression systems
Overhead transmission line	**Victoria:** 3.2 km of 500 kV AC line 57.4 km of 400 kV DC line **Tasmania:** 8.9 km of 400 kV DC line 2.1 km of 220 kV AC line
Underground Cables and Transition Stations	Bundled 400 kV HVDC MIND cable and metallic return XLPE land cable (6.4 km and 1.7 km in Victoria and Tasmania respectively) installed horizontally and spaced apart. Underground to overhead transition stations in Victoria and Tasmania with cable terminations, high voltage switchgear, control and protection equipment and cable monitoring systems
Subsea cables	Bundled 400 kV HVDC MIND cable and metallic XLPE subsea cable (290 km crossing the Bass Strait), installed as a cable bundle.

3. Plant Assessed, Methodology and Approach

In general, where possible, selective visual inspections of the plant or equipment was conducted on site supported by interviews with key operational staff during the inspection. The methodology and approach followed is dependent on the plant or equipment being assessed. The main areas of plant that were visually inspected included the converter station equipment, AC and DC HV yards, auxiliary systems, AC and HVDC overhead transmission lines and the transition stations.

Given the converter stations and transition stations were live at the time of the inspection, certain equipment could not be inspected close up, either due to the equipment being located up high or barriers/fencing preventing access during live operation. These were inspected from the ground or from the barrier using binoculars.

Areas that were not accessible during the site inspection of the converter and transition stations included:

- Equipment within the valve halls of both Loy Yang and George Town Converter Stations
- Panels and doors to energised equipment were not removed during the inspections and therefore the condition of the internal mechanisms of these plant and equipment could not be assessed.

Due to their inherent design and installation, underground infrastructure such as the land cables and the earthing systems together with the subsea cables were not visually inspected.

Given the limitations above, the condition assessment was supplemented with a review of the relevant O&M records, engineering and previously completed condition reports and the failure data available to Amplitude. This was used to identify any existing major defects and/or pervasive condition related problems should they exist.

Table 3 provides an overview of the methodology followed for each area and/or part of the Basslink asset.

Table 3 – Condition Assessment Methodology

Asset Area	High-Level Methodology
Converter Station Equipment AC and DC HV Yards Auxiliary Systems	Site assessment and visual inspection of condition to accessible areas, photograph of any areas of concern. Review of relevant data: • O&M records, including inspection and investigation reports. • Equipment failure reports. • Transformer DGA results. • Previous condition assessment reports/records. Priority placed on critical parts of the asset – e.g., transformers, reactors, thyristor valves and cooling system. Inspection of condition of major spare parts (long lead time items). For inaccessible areas e.g., plant and equipment located inside the valve hall, areas where close up inspection is not possible or where doors/panels cannot be removed while in service, review any previous inspection reports and photographs. Assess areas of concern raised and shortlist to observations that may be material.

Asset Area	High-Level Methodology
AC and HVDC overhead transmission lines	Spot inspection and visual assessment of condition of a sample of transmission towers, and only from ground level (using binoculars and/or camera zoom). Photograph any areas of concern (from ground level). Selected towers will have a balance between tower types and location, with emphasis on towers closer to coastal areas. Review of relevant data: • O&M records, and engineering reports. • Previous transmission line inspection and assessment. Assess areas of concern raised and shortlist to observations that may be material.
Underground Cables and Transition Stations	Site assessment and visual inspection of condition of above ground assets. For inaccessible areas e.g., areas where close up inspection is not possible or doors/panels cannot be removed while in service, e review any previous inspection reports and photographs. Review of relevant data: • Failure and repair reports and any root cause assessment reports. • Review reports and outcomes of any O&M tests undertaken. • Assess areas of concern raised and shortlist to observations that may be material.
Subsea cables	Perform a review of reports relevant to condition of the cables prepared prior to, during and post-arbitration, including the reports of the laboratory dissection and assessment of cables performed by external consultants. Flag any concerns raised regarding the condition of the installed cable and review documentation to assess whether these are material. Provide a high-level failure rate assessment based on CIGRE and other statistics i.e., assess based on statistics the expected failure for a 290 km long cable to understand what should/could normally be expected in terms of failure rate due to internal or incipient faults. Review any other relevant engineering record and O&M tests provided to Amplitude.

4. Condition Assessment Findings

Several condition related findings were observed during the assessment. While we recommend that these be addressed in the short-term, we do note that not all the findings are considered to be material when considering the severity, impact and related techno-economic impact on the remaining life and reliability of the affected plant and equipment.

4.1. Terrestrial Assets

Terrestrial assets include all plant and equipment located within the converter station and transition station sites, all AC and HVDC overhead transmission lines and all underground cables.

Table 4, Table 5 and Table 6 summarise the main findings for the terrestrial assets and where applicable images from the site visit are presented in Appendix B – Site Images.

Condition-related issues identified for the terrestrial assets that Amplitude consider to be material are listed below:

1. **Overhead lines:** Some of the coastal towers and line hardware are displaying signs of corrosion, with this being identified in the 2021 [2] and 2023 [3] line inspection reports. This will require regular inspection and remediation. If not already actioned, it is recommended that a corrosion mitigation/hardware replacement program be initiated. The mitigation would be specific to each affected tower and could include replacement of individual steel members, replacement of bolts and hardware, paint system or application of cathodic protection. In general, it is stated in the 2023 inspection [3] report that the "*Overall condition of structures, insulators and hardware was good, with a few towers where works are recommended*" pp 11.
2. **Transition stations:** The top sides of the steel oil pressure tanks for the 400 kV DC cable sealing ends are corroded. Further deterioration could lead to an outage. If not already actioned, it is recommended that a project be raised to address the risk. The risk being that if the corrosion continues and a major oil leak occurred, low oil pressure could initiate a cable fault. Basslink would be out of service for the time it took to repair the cable sealing end, which could be many months in duration. The long repair time being attributed to the difficulty in obtaining skilled 400 kV DC cable jointers at short notice, from overseas.
3. **Converter Transformer:** The in-service and spare converter transformers at both George Town and Loy Yang display corrosion on attached oil/air coolers. Localised repair options are currently being investigated with indicative costs, as we understand based on site discussions, for full replacement radiators being in order of AUD $2.0 million. If a radiator were to develop an oil leak, it can be individually isolated for repair, while allowing the other three coolers to continue operating. Subject to confirmation, our understanding is that only three of the four cooling circuits are required for rated operation i.e., one is redundant.

Table 4 – Condition Assessment Findings - Converter Stations

Asset Area	Condition Assessment Findings
Converter Station Equipment	The in-service and spare converter transformers at both George Town and Loy Yang display corrosion on the inside bottom of the cooling fins steel header attached oil/air coolers (Appendix B, Image 1). Mitigations are currently being investigated and if one cooler develops an oil leak it can be individually isolated for repair, while allowing the other three coolers to continue operating, Subject to confirmation, our understanding is that only three of the four cooling circuits are required for rated operation i.e., one is redundant. **Finding:** Material
AC and DC HV Yards	The George Town 220 kV circuit breakers are approaching the manufacturer's recommended limited number of operations. We have been advised that they are scheduled for replacement in 2026 (Appendix B, Image 3). The Loy Yang 500 kV circuit breakers have recently been replaced, for the same reason. **Finding:** Not Material (planned maintenance activity)

Asset Area	Condition Assessment Findings
Auxiliary Systems	The Loy Yang valve hall room ventilation plant and outside enclosures are scheduled to be replaced during a planned outage in October 2023. Presently the enclosures are in poor condition, and it is difficult to remove a fan and motor for maintenance, without dismantling the enclosure. **Finding:** Not Material (planned maintenance activity)

Table 5 – Condition Assessment Findings - AC and HVDC Overhead Transmission Lines

Asset Area	Condition Assessment Findings
AC and HVDC overhead transmission lines	Some of the galvanised steel transmission line towers and hardware, especially those close to the sea, are showing signs of deterioration of the galvanising and minor onset of rust break through. It would be in the interests of a long-term asset owner to consider remediation work soon before the issue increases in severity. Only some structures are impacted, and the mitigation applied would be specific to each affected tower. This could include replacement of individual steel members, replacement of bolts and hardware, paint system or application of cathodic protection (Appendix B, Image 4). **Finding:** Material
AC and HVDC overhead transmission lines	• Structure 9_1: The ground erosion around footing of the structure is very critical and may cause unbalance to the structure foundation especially during bad weather conditions. [3]. • Structure 506 and 508: Replacing the earth strap is critical to avoid damage and reliability impacts [3]. • 400 kV DC line: Anti-climb device barbed wire in some structures requires replacement to prevent unauthorized people from climbing for safety purposes. **Finding:** Not Material (considered to be executed as a planned maintenance activity)
Notes: In addition to reviewing the available engineering reports, the following towers were inspected in Victorian and Tasmania: • **Victoria:** DC: T 95 Monopole, HAT90 AP5, T 5-1, T 5-2, T 5-3, -T 6-4 and MAT60 AP7 **Tasmania:** AC: HTT AP227, T 226 and T 223; DC: T 27-1 and HAT90 AP28	

Table 6 – Condition Assessment Findings - Transition Stations

Asset Area	Condition Assessment Findings
Transition Stations	At the George Town Transition Station, and to lesser extent at the Loy Yang Transition Station, two oil pressure steel tanks for the 400 kV DC cable sealing end, are corroded at their tops where water has accumulated and cannot drain (Appendix B, Image 5). If corrosion continues and a major oil leak occurs, low oil pressure could initiate a cable and hence total link trip. The link would be out of service for the time it took to repair the cable sealing end, which could be many months in duration. The long repair time being attributed to the difficulty in obtaining skilled 400 kV DC cable jointers at short notice, from overseas. **Finding:** Material

Table 7 – Condition Assessment Findings - Underground Cables

Asset Area	Condition Assessment Findings
Underground Cables	The underground metallic return cable experienced a failure in 2019 which occurred in the above ground section below the cable termination in the Victorian transition station. The root cause analysis report (ER 1079) by Cable Consulting International Ltd identified incorrect assembly of the termination during construction which led to the premature failure of the metallic return conductor. **Finding:** Not Material (successfully repaired and no condition related findings)

4.2. Subsea Cables

Basslink was commissioned in 2006. During the installation and commissioning period several sections of the cable were repaired due to incidents during installation, and this was presumably identified as part of the quality control measures in place at the time.

During the following 17 years of commercial operation, the Basslink subsea HVDC cable suffered one failure in December 2015 which resulted in an outage duration of approximately 6 months to locate the fault, remove and replace the defective section and effect the repair.

During the arbitration process that followed, various investigations, modelling activities and site surveying activities were performed. The outcomes of these activities were considered in the final determinations from the arbitration, and some activities have continued since. There are varying views and opinions presented by a number of individuals who are experts in their field. These views and opinions are considered here. One thing that is agreed is that the failure was not caused by external interaction and therefore was a fault internal to the cable.

However before discussing the outcomes of those investigations, Amplitude applied the latest available data on internal subsea cable failures to consider what type a failure rate a subsea cable of the same type and length as Basslink could be expected to incur based on operational experience of other subsea cables.

4.2.1. Subsea Cable Failure Rate Comparison

Considering the single failure of the subsea cable in 2015 and with no failures since, the cable failure rate for Basslink has been compared using the latest data and methodology applied in CIGRE Technical Brochure 815 published in 2020 [4].

Table 8 presents three failure rate calculations:

1. Surveyed data from [4] for DC Submarine MIND cables with operational voltages of 315 – 500 kV;
2. Surveyed data from [4] for DC Submarine MIND cables with all surveyed operational voltages 66 - 500+ kV; and
3. Basslink HVDC submarine MIND cable.

Table 8 – Submarine Cable Failure Rate Calculation

DC MIND Cables	CIGRE: 315 kV to 500 kV	CIGRE: All Voltages	Basslink HV Cable
Length (km)	1388	3057	290
Recorded Failures	4[1.]	7[2.]	1
Operational Period (Years)	10	10	17
Calculated Failure Rate (per 100 km/year)	0.029[3]	0.023[3]	0.020

Notes:

1- *CIGRE 315 kV to 500 kV is a data subset of the CIGRE All voltage dataset.*

2- *Four of the recorded faults for DC MIND cables are of unknown origin, meaning that the root cause of the fault could not be identified, or no further data was reported in the CIGRE survey.*

The CIGRE data is derived from a survey of submarine cables within [4] which includes 21 responses from around the world covering a 10-year period of 2006 to 2015, and excludes faults attributed to third party or other external interaction (i.e., is based on internal, unknown or intrinsic cable failures).

From Table 8 it can be seen that the actual Basslink failure rate over its 17 years of operation is lower than the expected failure rate due to internal or intrinsic faults on a notional “new” MIND cable. This means that in terms of failure rate, the Basslink HVDC cable is currently operating better than expected.

Table 9 presents an extract from [4] which shows the breakdown of internal and unknown faults by age of the cable and cable technology. At the time of the cable fault, Basslink was 9 years old, which is within the normal trend seen in the CIGRE data. CIGRE Technical Brochure 815 states that it is “*expected that hidden defects or damages to the cables resulting in internal faults will occur early in the lifetime while failures due to aging would occur late in the lifetime*” pp 54. It is important to note that a large portion of the surveyed cables were at the time relatively young (less than 10 years, like Basslink) and as such the failures for these cables are expected to be internal hidden defects as opposed to the effects of aging.

Table 9 – Failures with Internal and Unknow Cause in Relation to Submarine Cable Type and Age

Reported faults – AC and DC						
Internal/Unknown Faults (Cable faults only)	Age of failed component					
	0-2 years	3-10 years	11-20 years	21-30 years	31+ years	Total
DC – MIND	2	3	1	1	0	7

4.2.2. Discussion on Arbitration Related Condition Assessment Reports

Various investigations have been performed and expert opinions have been provided for the cause(s) behind the 2015 failure of the subsea cable. A listing of the reviewed documents is provided Appendix A- Key Documents Reviewed.

From the information provided, Amplitude has not seen any physical evidence which confirms the root cause of the failure or that suggests that the original un-faulted sections of the cable that are still in-service is in a poor condition or in some way deficient in design.

The Basslink KP199.256 Failure Investigation Findings (Report ER 833) by Cable Consulting International Ltd, makes the following statements on the sections of the cable assessed that were adjacent and/or remote to faulted location:

> *“The insulation adjacent to the failure site was sound and showed no evidence of thermal ageing” pp 25.*
>
> *“A sample of cable remote from the fault site was in sound condition” pp 25.*

The probable hypothesis as described in the DNV GL – Report No. 16-2443 is that the 2015 failure is due to:

> *“the combination of*
>
> - *thermally induced void formation during cooling (with the void formation in the insulation material close to the conductor) and*
> - *the electrical stress enhancement in these voids due to voltage polarity reversals “*
>
> *are very probably the reason why the Basslink power cable failed, where the thermal part is related to the root cause of the failure and the voltage polarity reversal regime is a contributor*.” pp 76- 77.

Regarding time to failure once a void is formed the DNV GL – Report No. 16-2443 states that:

1. *“…the extra electric stress from the voltage polarity reversal just before the failure caused the cable to degrade quickly and break down* “pp 11.
2. *“…the surrounding insulation material will degrade such that a full breakdown of the whole insulation material will follow. It can take minutes to days (or more) in a polymer material environment, but it can take hours to years in a paper insulated environment because the impregnant tends to redistribute, forcing the spark to act on another spot.”* pp 27.

Based on the hypotheses put forward earlier, the DNV GL – Report No. 17-2917 provides mitigating actions to:

1. *“Limit the future cable load such that the cable will not be thermally overstressed anymore. This will prevent that new permanent voids will be created and it will prevent a too high electrical stress (beyond the design limit) on the outside of the insulation “* pp 5.

2. *"Prevent that during cooling down the cable, the already existing voids (from the past thermally overstressed moments) will not be enlarged and that the electric stress during this cooling down stage is reduced "* pp 5.

On review of the available data, expert reports and general statistics on HVDC MIND cable performance, the Amplitude opinion regarding the Basslink subsea cable conditions follows:

- HVDC cables comparable to the Basslink cable technology (MIND), voltage rating and length have been shown to experience failures as a result of internal root causes. Whilst certainly not ideal, cable failures are typically expected, and HVDC subsea cable operators will plan for these events to minimise their impact.
- The statistical failure rate of the Basslink cable since it was put in service is not considered to be extraordinary or unprecedented for the cable technology used and the length of the subsea cable. Based on the available performance statistics and failure interval calculated, additional failures could be reasonably expected within the remaining commercial life of the Basslink cable.
- The hypothesised *"already existing voids"* coupled with the operational mitigations applied post the 2015 failure have not manifested in additional failures in the last seven years of operation. Given the actions taken by the asset owner, including limiting the continuous rating of the cable, increasing the deionisation time and introducing an improved cable load prediction system, it is considered more probable than not, that future performance will not be impacted by the hypothesised *"already existing voids"* under the current operating regime.
- Based on the historical performance and current operating regime, the condition of the cable is considered typical for its age, technology and voltage rating.
- We do not consider it to be economically practical or possible, even when using the latest cable technology and discounting external factors to guarantee a zero failure rate for a subsea cable of similar length and voltage rating.

The above view broadly aligns with the Technical Due Diligence Report undertaken by WSP (July 2021) which considers that:

- The operational history of the cable after the 2015 fault provides confidence in the cable condition.
- The cable system should prove reliable provided if operated within the design limits and using a 5-minute polarity reversal time, though further work is needed in defining the steady state and dynamic loading conditions.
- Future faults are possible and cannot be ruled out.

5. Limitations and Qualifications

Given the limited time for Amplitude to perform the assessment, a methodology was determined based on a combination of site inspection and review of available documentation. As there was no outage on the Basslink assets at the time of the inspections of the terrestrial assets and given the fact that the HVDC land and subsea cables cannot be visually inspected, Amplitude's assessment has had to rely on available documentation and previous inspection and condition assessment reports. This necessarily means that there are some limitations and qualifications to the outcomes of our assessment.

The following limitations and qualifications are applicable to the condition assessment undertaken and the findings within this report:

- The condition assessment performed is limited to assets that were accessible, could be viewed and condition issues that were clearly visible during the site inspections.
- Any plant or equipment could not be inspected close up, either due to the equipment being located up high or barriers/fencing preventing access during live operation, the condition is only what could be assessed from zoom photography or use of binoculars.
- The internal mechanisms of equipment were not inspected. Panels and doors to energised equipment were not removed and therefore the condition of the internal mechanisms of these plant and equipment could not be assessed.
- For parts of the asset that could not be accessed or visually inspected close up, the assessment relied upon information and engineering records provided to Amplitude. A list of the provided and reviewed documents is provided in Appendix A.
- Amplitude cannot comment on any condition issues that, by nature, are identified and severity determined via testing, dissection, disassembling and/or analysis of materials. An exception to this being the following records which were made available and reviewed by Amplitude:
    - Results of the subsea cable material analysis reported on by Cable Consulting International Ltd (Report ER 833);
    - The converter transformer dissolved gas analysis results (Test Report AL-0741-23 and AL-0886-22); and
    - The George Town converter station routine testing report (Report MVTR-9273 Parts 1-5).
- No assessment has been made of anything of a civil or structural nature, including ground conditions, foundations, structures or buildings within the converter stations and transition stations.
- No assessment has been made of any underground plant and equipment, including earthing systems and underground and subsea cables, except as evident from the provided reports.
- No materiality threshold was provided to Amplitude, so our assessment of what is material or not material may be subjective. For the purpose of this report, we have considered any rectification or replacement of plant and equipment with identified condition issues that are

not already planned and budgeted for that will require in excess of $250,000 of work and/or more than 2-3 days of outage as being material.

- This report presents only the condition related material findings identified for major asset types i.e., equipment that if it fails or in the process of being repaired/replaced is likely to impact the reliability of the HVDC system.
- Our assessment only considers condition of the plant or equipment after considering the age and operational environment of the system. We do not comment on plant and equipment that is considered consumable nor on any equipment that typically would be replaced or upgraded as a part of a normal HVDC lifecycle, such as the HVDC control and protection systems, valves and complete valve cooling systems. It is assumed these are already included in any forward forecasting budgets.
- Issues, hazards and risks associated with operation, maintenance, system design, safety, environmental and regulatory compliance were not assessed and are not reported here.

6. Conclusion

Based on the site visits, data available and reports reviewed, Amplitude have identified three main material concerns for the terrestrial assets, namely corrosion occurring on the overhead lines in coastal areas, tops of the steel oil tanks at the transition stations and converter transformer radiators.

Based on the information provided, we have not identified any material findings related to the existing condition of the underground or subsea cables even when considering the recent operational history. We note that the cable system has been subject to operational limitations as a result of findings from the 2015 cable failure and subsequent arbitration.

7. References

[1] Siemens, “Basslink HVDC Interconnector- Overload/Dynamic Rating-ED1.011CTV-A,” 2004.

[2] Beon Energy Solutions, “Basslink Transmission Lines VIC/TAS, Condition Assessment Preliminary Report,” 2021.

[3] TIMCO Transmission Lines Pty Ltd, “3 Yearly Inspections, OHTL – VIC & TAS, Basslink,” 2023.

[4] CIGRE, “TB 815 – Update of service experience of HV underground and submarine cable systems,” 2020.

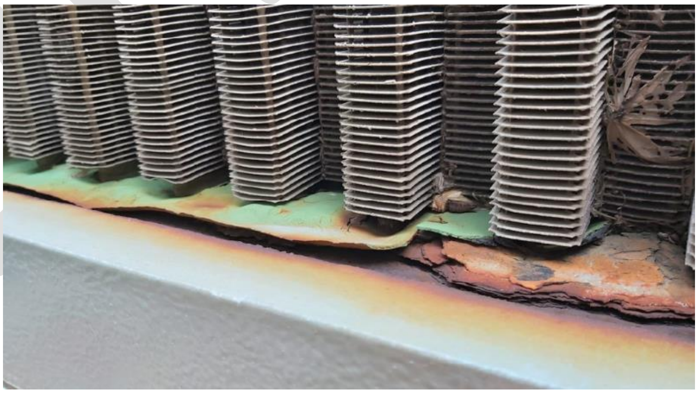
Appendix A- Key Documents Reviewed

Table 10 – Key Documents Reviewed

Topic Area	Title	Author	Date	Revision
AC OHL DC OHL	3 Yearly Inspections, OHTL – VIC & TAS, Basslink 2023	B. Marsh, et.al	2023	-
	Basslink Transmission Lines VIC/TAS	R. Long	16/12/2021	Final
General	Project McGauran Technical Due Diligence	WSP	02/08/2021	D1
	Basslink Interconnector Assessment Report – Phase 2 (Addendum)	K. Walker	04/06/2021	2
	Basslink Interconnector Assessment Report – Phase 2	K. Walker	23/01/2020	F
Subsea Cable	Reply Report Regarding the Basslink Interconnector (Report Number 20-2651)	F.H. de Wild	17/07/2020	0
	Basslink Outage 2015 – Reply to CCI Report ER1112 (Report Number 20-2598)	E.F. Steennis	13/07/2020	0
	Basslink Outage 2015 – Root Cause Analysis of the Failed HVDC Power Cable (Report Number 18/06/2020)	E.F. Steennis	18/06/2020	0
	Basslink Interconnector Outage 2015 Mitigating Actions Report (Report Number 20-2370)	J.M. Wetzer	29/05/2020	-
	Thermal Analysis of the Basslink Interconnector (Report Number 19-3114)	F.H. de Wild	31/01/2020	1
	Basslink Interconnector – Metallic Return Cable Fault Root Cause Analysis (Report ER 1079)	L. Trim	16/01/2020	-
	Basslink Outage 2015 – Root Cause Analysis of the Failed HVDC Power Cable (Report Number 16-2443)	E.F. Steennis	15/12/2017	0
	Basslink Outage 2015 – Mitigating Actions Related to the Failed HVDC Power Cable (Report Number 17-2917)	E.F. Steennis	15/12/2017	0
	Basslink KP199.256 Failure Investigation Findings (Report ER 833)	L. Trim, et.al	02/12/2016	-
	Basslink KP199.256 Failure Examination (Report 808)	L. Trim, et.al	27/06/2016	-

Topic Area	Title	Author	Date	Revision
	Basslink KP199.256 Failure Examination (Report ER 795)	L. Trim, et.al	27/05/2016	-
O&M Records	Test Report – Basslink George Town (Batch 30597, Report AL-0741-23)	Jake Grigorescu	13/04/2023	-
	Test Report – Basslink Tas TX's (Batch 28717, Report AL-0886-22)	Murray Teese	07/05/2022	-
	MVDC Cable – Leaking Prysmian Outdoor Sealing End Repair, George Town.	Darren Brundish	28/03/2022	-
	Test Report – Basslink George Town Converter Station Routine Testing – Red Phase Transformer (Report ID: MVTR-9273.1)	Kyron Fogarty	24/03/2017	-
	Test Report – Basslink George Town Converter Station Routine Testing – White Phase Transformer (Report ID: MVTR-9273.2)	Kyron Fogarty	24/03/2017	-
	Test Report – Basslink George Town Converter Station Routine Testing – Blue Phase Transformer (Report ID: MVTR-9273.3)	Kyron Fogarty	24/03/2017	-
	Test Report – Basslink George Town Converter Station Routine Testing – DC Wall Bushing (Report ID: MVTR-9273.5)	Kyron Fogarty	24/03/2017	-
	Test Report – Basslink George Town Converter Station Routine Testing – Spare Transformer (Report ID: MVTR-9273.4)	Kyron Fogarty	15/02/2017	-

Appendix B – Site Images

Asset Area	Image 1
Converter Station Equipment	Converter transformers attached oil/air coolers  

Asset Area	Image 2
Converter Station Equipment	Air Handling Plant 

Asset Area	Image 3
Converter Station Equipment	220 kV AC Circuit Breaker in AC Yard 

<table>
<tr><th>Asset Area</th><th>Image 4</th></tr>
<tr><td>AC and HVDC Overhead Transmission Lines</td><td>Transmission Tower -Light corrosion
</td></tr>
</table>

<table>
<tr><th>Asset Area</th><th>Image 5</th></tr>
<tr><td>AC and HVDC Overhead Transmission Lines</td><td>Two Oil Pressure Steel Tanks for 400 kV DC Cable Sealing End
</td></tr>
</table>

Appendix C - Authors

Les Brand – Managing Director

Les Brand (FIEAust, CPEng, RPEQ) is an experienced electrical engineer with over 29 years of experience in the transmission and distribution industry in Australia, Asia and the USA. He has held senior and executive roles within the power transmission and distribution sectors, including utilities, consultancies and private companies.

Les has held senior technical roles for a number of HVDC interconnection projects including Directlink (Australia), Murraylink (Australia), Basslink (Australia) and Trans Bay Cable (California, USA). Until late 2019, Les was the convenor of the CIGRE Australian Panel for HVDC and Power Electronics (B4) and was also convenor of the international working group B4.63 “Commissioning of VSC HVDC Systems” which published a technical brochure that is now the standard for commissioning VSC HVDC converter stations. Les is also the convenor of Joint Maintenance Team 7 (JMT 7) of IEC Technical Committee 99 responsible for the revision of IEC TS 61936-2 “Power installations exceeding 1kV AC and 1.5kV DC – Part 2: DC” which defines the safety, maintenance and general installation requirements for HVDC facilities. Les is currently the convenor of the working group B4.90 “Operation and Maintenance of HVDC and FACTS Facilities”. Les is also the lead author of Section 7 “Implementation of HVDC schemes” for the CIGRE Green Book on HVDC which is under development and due for release in 2023. Since Amplitude’s inception, Les has led the HVDC elements of key projects, including a number of HVDC projects under development in Australia, support on a HVDC project in Canada and upgrades on Directlink and Murraylink (Australia) as well as various AC vs HVDC and HVDC framing/scoping studies for proposed projects in Australia and the UK.

Les is a joint recipient of the 2020 National Professional Electrical Engineer of the Year award from Engineers Australia.

Thavenesen Govender – Principal Consultant

Thavenesen (Thavi) Govender (MIEAust, CPEng, RPEQ) is an experienced engineer with over 17 years of experience covering project engineering, commercial and procurement functions as well as research, testing and development in high voltage power transmission. His experience covers a balance between experience in the electrical industry and academia with nine years of experience in the electrical transmission utility environment and five years as a research fellow and lecturer.

Thavi has significant experience in the development of equipment specifications for HVDC converter stations, SVC, STATCOM and AC filter equipment and facilities and also in the operations and maintenance, lifecycle management, asset health appraisals and root cause analysis. He is also experienced in the technical support of and input into commercial and procurement activities including development of tender documentation, undertaking tender evaluations, leading technical aspects of supplier negotiations. Immediately prior to joining Amplitude, Thavi held the role of Chief Engineer – HVDC and FACTS Devices for Eskom in South Africa.

Since joining Amplitude in late 2019, Thavi has been heavily involved in the third-party assessment of the factory system testing and subsequent factory acceptance testing for the control and protection systems for a large HVDC project under development in Canada as well as the development of concept designs and cost estimates for proposed HVDC projects. Thavi was the site lead for the installation, testing and commissioning of the new control and protection systems for the Murraylink HVDC system between Victoria and South Australia and has been involved in various HVDC interference engagements.

Jonathan Faint – Senior Consultant

Jonathan Faint is an experienced electrical engineer with over 19 years of experience in many aspects of high voltage transmission and distribution and project auxiliary systems in a number of countries, including Australia, Singapore, England, New Zealand, Fiji, Papua New Guinea and Indonesia. Jonathan has held key roles in the design, implementation, commissioning and support of various electrical applications, including design, testing and commissioning of protection systems, control and automation systems, SCADA, communications, MV switchgear, auxiliary power systems and fire systems.

Jonathan is an experienced specialist in control and protection systems, having undertaken full project cycle from design, construction, factory tests, commissioning, acceptance testing and documentation for a number of control and protection systems and having led the site commissioning of these systems. He completed Owner’s Engineer activities for control and protection replacement works for Directlink and Murraylink HVDC systems including witnessing of FST testing, site manager duties, and SCADA system interfacing and upgrade works.

Ivan Hunt – Principal Consultant

Ivan's exceptional career as an electrical engineer has left an indelible mark on the power systems landscape, spanning continents and disciplines. His proficiency in High Voltage Direct Current (HVDC) technologies is evident in his pivotal contributions to projects like the Bass Link in Australia and the Pole 3 upgrade in New Zealand. Serving as an Owners Engineer, he meticulously assessed technical documentation, demonstrated his negotiation skills, and managed resources to enhance capacity, reliability, and availability of primary equipment.

Beyond HVDC, Ivan's influence is far-reaching. His role in projects like Islington SVC3's refurbishment and Haywards' multilevel STATCOM showcases his prowess in owner's project engineering. He's been a driving force in substation design, operations, maintenance, and commissioning, ensuring seamless functioning of power systems.

Ivan's versatility is showcased by his involvement in international projects such as the Upper Tamakoshi Hydroelectric Project in Nepal, where he served as Chief Electrical Engineer. His influence extends to various power generation methods, from combined-cycle and thermal to geothermal, wind, and hydro power. This adaptability underscores his ability to excel across diverse energy landscapes.

Beyond technical achievements, Ivan's leadership shines. He's adept at managing teams, mentoring junior engineers, and guiding projects from concept to fruition. His research contributions, presented in conferences globally, reflect his commitment to advancing industry knowledge.

Rajiv Dhillon – Electrical Engineer

Rajiv brings a decade of diverse engineering prowess across multiple sectors, from petrochemicals to renewable energy. His journey has spanned roles as Owner's Engineer, Project Engineer, and more. With a knack for managing complex systems, he's showcased his adeptness by monitoring and controlling New Zealand's national grid assets and power system through real-time SCADA.

As a Project Engineer, Rajiv achieved notable feats, overseeing the simultaneous installation of 4 MW Battery Energy Storage Systems (BESS) and the integration of a new substation for solar farms into Powerlink's network. His contributions extended to enhancing operational management systems and protocols, minimizing errors and optimizing workflows.

Renewable energy took centre stage as Rajiv guided the construction of a utility-scale 50 MW Battery Energy Storage System (BESS) in Rockhampton, Queensland. His responsibilities covered assisting with design reviews, testing, commissioning, and interfacing with stakeholders. Another BESS project involved deploying commercial batteries across five Queensland locations, demonstrating his capabilities in managing multi-site projects.

Rajiv's scope expanded into asset management, where he assisted with developing an Asset Management Plan for two Static Frequency Converters. His expertise in software tools like PI System, Maximo, SCADA, Jira, EDMS, and more, has enabled him to streamline operations and facilitate collaboration. With a strong grasp of real-time systems, Rajiv has become an anchor in ensuring the stability and security of New Zealand's national power grid.