Basslink HVDC Interconnector

Depreciated Optimised Replacement Cost Assessment

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Executive Summary

This report is prepared by Amplitude Consultants Pty Ltd (Amplitude), on behalf of Gilbert and Tobin (the Client), to provide a replacement cost of the Basslink interconnector (Basslink), should it be built today using modern equivalent technology.

In order for Amplitude to develop an estimate of the replacement cost of Basslink, Amplitude has developed the scope for a Basslink Modern Equivalent HVDC system. A summary of the key parameters for the modern equivalent, with the ratings and route length based on the existing system, is shown in the below table.

Parameter	Value	Reasoning and Discussion
Converter Technology	VSC	Voltage source converter (VSC) technology is more suitable for the power transfer capacity and consideration of other factors such as the current and declining system strength of the AC networks in Victoria and Tasmania.
Converter Topology	MMC	Multi-level modular converter (MMC) topology has been selected for the project as it is anticipated to produce a lower level of harmonic emissions, therefore requiring less filtering equipment, less land area, and lower capital cost. MMC topology also results in lower converter losses, closer to those expected from LCC converters, than other VSC topologies.
Configuration	Symmetric Monopole	This configuration provides the same degree of redundancy as the current design of Basslink while allowing for lower DC voltages and reduced current on the cables, resulting in smaller conductors (cross-sectional area) when compared to an asymmetric monopole.
HVDC Cable Technology	Polymeric	This is becoming the more common cable technology used on VSC HVDC systems and provides ease of installation benefits over MI cables as well as other benefits such as lower weight and reduced environmental risks.
Voltage Level	±320 kV	For the required power transfer capacity, this DC voltage represents a reasonable balance between keeping the current at a level to allow for reasonable cable sizing and the cost of the converter stations.
Power – Nominal	500 MW	The system is to be rated to continuously provide up to 500 MW import into Victoria and Tasmania.
Power – Overload	630 MW	The system is to be rated to provide up to 630 MW export from Tasmania for periods up to 4 hours. With losses, this results in ~600 MW delivered into Victoria.
HVDC OHTL Route	VIC 57.4 km TAS 8.9 km	57.4 km of 400 kV DC overhead transmission line from Basslink Loy Yang to McGauran Beach transition station. 8.9 km of 400 kV DC overhead transmission line from Basslink George Town to Four Mile Bluff transition station
AC OHTL Route	VIC 3.4 km TAS 2.1 km	3.4 km of 500 kV AC transmission line from Loy Yang Power Station to Basslink Loy Yang Converter Station. 2.1 km of 220 kV AC transmission line from George Town Substation to Basslink George Town Converter Station.
DC Cable Route	298 km	Victoria: 6.4 km underground. Bass Strait: 290 km subsea. Tasmania: 1.7 km underground.

Based on the parameters above, Amplitude has estimated the Basslink Modern Equivalent cost to be $1,58 billion. A summary of the cost estimate is shown in the table below.

Basslink Modern Equivalent System	Item Cost ($AUD, 2023)
AC Connections and AC Overhead Transmission Lines	$21,101,000
HVDC Overhead Transmission Lines and Transition Stations	$82,800,000
HVDC Converter Stations	$449,532,000
HVDC Cable Systems (Supply and Install)	$757,568,000
Project Development, Planning and Permitting	$270,380,000
Basslink Modern Equivalent Total	**$1,581,381,000**

Amplitude developed three further cost estimates for alternative HVDC systems which include LCC and VSC systems at different power levels, for comparative purposes. A summary of the cost estimates produced are provided in the table below.

Alternative HVDC Systems	System Item Cost ($AUD, 2023)		
Power Level	**150 MW**	**350 MW**	**500 MW**
System Description	**VSC Symmetric Monopole**	**VSC Symmetric Monopole**	**LCC Asymmetric Monopole**
AC Connections and AC Overhead Transmission Lines	$21,101,000	$21,101,000	$21,101,000
HVDC OHTL and Transition Stations	$47,883,000	$63,518,000	$82,799,000
HVDC Converter Stations	$141,826,000	$321,638,000	$356,556,000
HVDC Cable Systems (Supply and Install)	$485,952,000	$633,543,000	$927,329,000
Project Development, Planning and Permitting	$157,844,000	$220,692,000	$284,227,000
Total	**$854,606,000**	**$1,260,492,000**	**$1,672,012,000**

Additionally, an AC technology, 500 MW equivalent system was developed with the parameters and indicative cost estimates shown in the table below.

Alternative 500 MW AC System	Value / Item Cost ($AUD, 2023)
AC Voltage	230 kV
Number of Circuits	4
Onshore AC Connections, Substations, Reactive Compensation	$172,404,000
AC Overhead Transmission Lines	$214,313,000
AC Land and Submarine Cable	$3,495,430,000
Offshore Platform and Reactive Compensation	$337,212,000
Project Development, Planning and Permitting	$805,526,000
TOTAL	**$5,024,885,000**

1 Purpose

This report is prepared by Amplitude Consultants Pty Ltd (Amplitude), on behalf of Gilbert and Tobin (the Client), to develop:

1. A cost estimate for the replacement of the Basslink Interconnector (Basslink) in the case where Basslink is built today using equivalent VSC technology (Basslink Modern Equivalent);
2. A cost estimate for the "as built" system utilising the older LCC technology as well as smaller rated systems (150 MW and 350 MW) using newer VSC technology; and
3. A concept and cost estimate for alternative power transfer solutions not utilising HVDC technology i.e., AC technology.

2 Authors

The primary Amplitude team members that took part in performing this high-level study and authors of this report are Les Brand, Alastair Pinkard, Thavenesen Govender and Alexander Kayrin. A summary of their credentials and industry experience is presented below.

2.1 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.

2.2 Alastair Pinkard – Principal Consultant

Alastair Pinkard (MIEAust, CPEng, RPEQ) is an electrical engineer with over 20 years of experience in transmission and distribution networks. He has extensive experience in network planning in distribution, transmission and at the Australian Energy Market Operator.

Alastair also has experience in the regulatory regime underpinning the National Electricity Rules (NER). He participated in the preparation of a revenue proposal and supporting documentation to support the revenue determination process and has developed supporting documentation for numerous regulatory investment tests for transmission (RIT-T). Since joining Amplitude, Alastair has undertaken analysis and prepared reports for numerous clients supporting the development of generation and transmission projects across Australia and overseas.

2.3 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.

2.4 Alexander Kayrin - Senior Consultant

Alexander Kayrin is an electrical engineer with over ten years of experience in utility distribution networks, industrial high voltage systems, renewable energy projects and HVDC projects. He is a specialist in the application of lightning protection, earthing, power, lighting and high voltage equipment for high voltage substations in Australia.

Alexander also has experience in the design documentation, specifications and calculations for industrial electrical and control systems and in undertaking technical investigations, feasibility studies and network risk assessments. Since joining Amplitude, Alexander has performed as the owner's engineer for the Directlink and Murraylink HVDC control and protection system replacement, including site supervision during installation and commissioning, and participated in the development of the technical specifications for the proposed 600 MW Ceres HVDC project. Alex led HVDC cable failure investigations and is responsible for pre-FEED activities for a long distance AC submarine cable off the Western Australian coast. Alexander was a key member in the performance of the AC vs HVDC assessment for large scale solar in Victoria and in the development of Basis for Transmission and Scoping studies for the Australia – Asia Power Link and other proposed HVDC projects in Australia and overseas.

3 Abbreviations

The terms and abbreviations provided in Table 3-1 are used throughout the document.

Table 3-1 – Definitions and Abbreviations

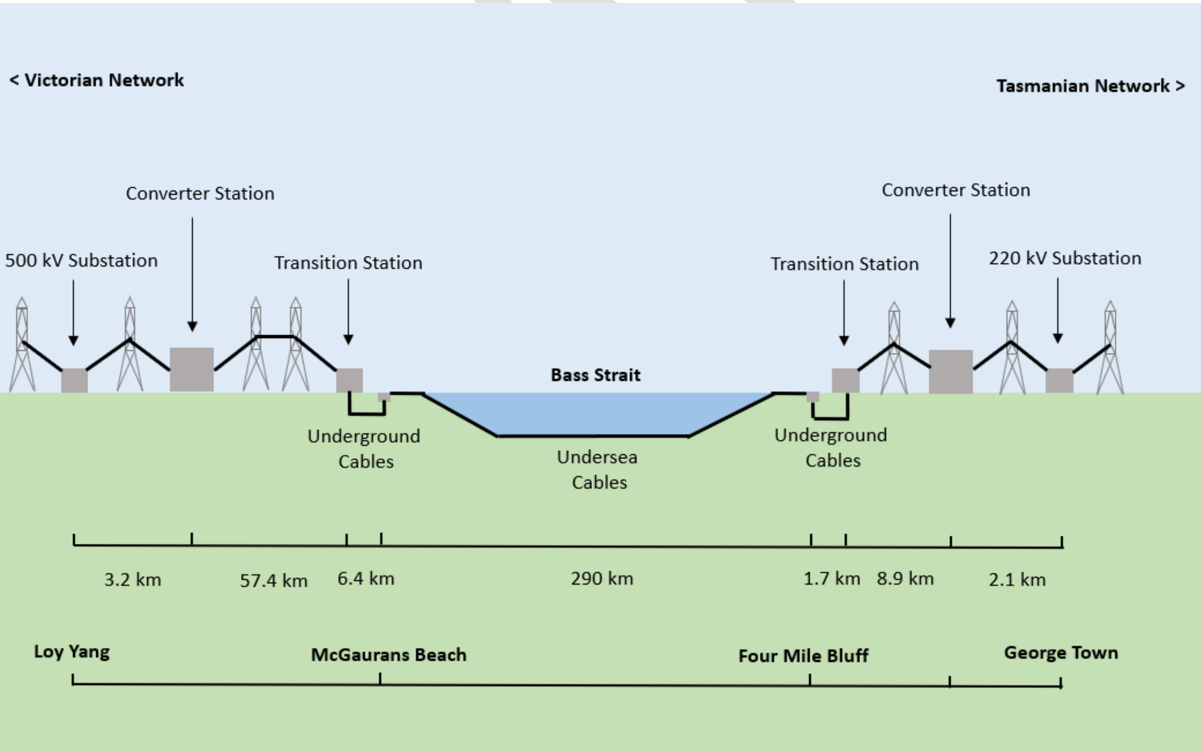
Term / Abbreviation	Definition
A	Amps (measurement of current)
AC	Alternating Current
AEMO	Australian Energy Market Operator
AUD	Australian Dollar
Capex	Capital expenditure
EPC	Engineer, Procure and Construct
FACTS	Flexible AC Transmission Systems (includes SVCs and STATCOMs)
FEED	Front End Engineering and Design
HVDC	High Voltage Direct Current
IGBT	Insulated Gate Bipolar Transistor
kV	Kilovolt (measurement of voltage)
LCC	Line Commutated Converter
MI	Mass Impregnated
MR	Metallic Return
MVA	Mega-Volt-Ampere (measurement of apparent power)
MVAr	Mega-Volt-Ampere reactive (measurement of reactive power)
MW	Mega Watt (measurement of active power)
NEM	National Electricity Market
NER	National Electricity Rules
OHTL	Overhead Transmission Line
PACR	Project Assessment Conclusion Report
PPI	Producer Price Index
RIT-T	Regulatory Investment Test for Transmission
STATCOM	Static Compensator (power electronic reactive power device)
SVC	Static VAr Compensator (power electronic reactive power device)
TAS	Tasmania
TNSP	Transmission Network Service Provider

Term / Abbreviation	Definition
VIC	Victoria
VSC	Voltage Source Converter
WPI	Wage Price Index

4 Introduction and Background

Basslink is a high voltage direct current (HVDC) system that interconnects the electrical networks of the Victorian and Tasmanian States in Australia. The 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. The overview of the assets that Basslink consists of is shown diagrammatically in Figure 4-1.

Figure 4-1 – Basslink Asset Overview



Basslink was commissioned in 2006 and utilises line commutated converters (LCC) and mass impregnated (MI) cable technologies.

5 Scope of Basslink Modern Equivalent

To provide a cost estimate for Basslink as it would be built today, it was necessary for Amplitude to establish the scope of a Basslink Modern Equivalent HVDC system.

5.1 Converter Station Technology

For HVDC transmission, the two major technology options currently available in the market are line commutated converters (LCC) and voltage source converters (VSC).

LCC converters have been in operation since the mid-1950s and are often referred to as "conventional" or "classic" HVDC. In the early years, mercury arc valves were used to perform the commutation. Since 1972, LCC systems exclusively use thyristor valves to commutate the current to create a DC current at the rectifier (sending end) and an AC current at the inverter (receiving end).

VSC technology has been developed more recently than LCC systems, with the first commercial systems commissioned in the late 1990s. VSC technology uses the switching of insulated gate bipolar transistors (IGBTs) to create an AC voltage waveform of sufficient amplitude and phase angle difference to cause both active power and reactive power to flow in either direction. The same IGBTs are used to create a DC voltage to allow active power to flow to or from the other converter. Consequently, VSC systems are capable of bi-directional, four-quadrant power transmission.

VSC technology can be configured either as a two-level or three-level converter or as a modular multi-level converter (MMC).

A two-level or three-level converter uses pulse width modulation (PWM) to derive the required DC and AC waveforms, employing series connected insulated gate bi-polar transistors (IGBT) modules to switch between the positive and negative DC voltages. The very high switching frequency results in significant switching losses, and filters are required on the network side to limit harmonic distortion.

An MMC converter is comprised of a number of submodules, each consisting of a number of IGBTs and an energy storage capacitor. Each submodule is independently switched to build the required DC and AC waveform. As the switching frequency is much lower than a two-level or three-level converter, switching losses are much lower. The construction of the AC waveform using capacitor charging and discharging also minimises harmonic distortion for the MMC, and minimal (if any) filters on the AC network side are required.

In order to determine the appropriate technology, it is necessary to consider not only the HVDC system itself but also the AC networks into which the HVDC system will connect. The following is an explanation of the considerations that go into selecting the appropriate technology and topology for the converter stations.

- **Power Transfer** - Modern LCC systems are constructed for higher power transfers, up to 12 GW, and often for long distance DC overhead transmission lines. VSC systems are generally preferred for lower power transmission levels and are commonly now used for HVDC systems connected with underground or submarine cables.
- **AC Network System Strength** - LCC systems require a minimum level of system strength to avoid instability of the converter due to commutation failure. VSC systems are able to operate

at much lower levels of system strength. System strength in this context refers to the ability of the voltage waveform to withstand disturbances on the network [3].

- **Use of DC Overhead Transmission** - VSC systems must use either a full-bridge topology or DC circuit breakers when considering the use of DC overhead transmission lines. This is required due to the relatively high incidence of intermittent faults experienced with overhead transmission lines (compared to underground or subsea cables) and the need to quickly interrupt the fault current to protect the sensitive power electronics.
    - Full-bridge VSC converters require twice as many IGBTs per sub-module as the (typical) half-bridge topology, which increases the cost of the converters. The additional IGBTs are required to force a reverse voltage during faults, creating an artificial zero-crossing to allow the current to be interrupted.
    - HVDC circuit breakers are still in the development phase, with commercially available products at the DC voltage level anticipated for Basslink not yet available. [4]
    - LCC converters are able to derive an artificial zero-crossing without any modification and their power electronics have a higher tolerance to withstand DC faults, and as such are also appropriate for use with overhead lines.
- **Losses** – Converter losses for LCC systems are lower than those of VSC. Considering the two-level, three-level and MMC VSC technology, the MMC has the lower converter station losses. The converter station losses of MMC VSC technology is slowly getting to the levels of LCC systems, although the use of full bridge converters will serve to increase losses again.
- **Requirement for Harmonic Filters** – LCC converters require the provision of a large amount of reactive power to compensate for reactive power used by the conversion process. LCC converter stations require large and numerous AC filters to provide this reactive power and harmonic filtering of the generated AC waveform. The AC filters require a large footprint to accommodate these filters. VSC systems do not consume reactive power like LCC systems, and the level of AC filtering required will depend on the selected topology. Two-level and three-level VSC converters will require some AC filters to smooth out the AC voltage, although much less than LCC converters. For MMC VSC converters, depending on the design and the connected AC network, some AC filters may be required, although many MMC VSC converter do not require any AC filters at all.
- **AC Voltage Control** – The ability of VSC converters to provide allows the VSC converters to generate or absorb reactive power independently on the magnitude and direction of active power flow (within defined limits). This controllability allows VSC converters to provide smooth AC voltage control to each connected AC network, adjusting reactive power generation or absorption to achieve the desired AC voltage level. Conversely, LLC systems cannot provide this reactive power support, although a rudimentary form is possible through the switching in and out of the AC filters.
- **Site Footprint** – Due to the requirement for AC filters to provide harmonic filtering and reactive support, the site footprint of an LCC converter is significantly larger than that of a VSC converter of equivalent active power rating. This difference in site footprint becomes even

larger when compared to a VSC MMC converter, making the VSC MMC converter more preferred for applications where land and/or space is restricted or of high value.

- **Overload Capability** - The power electronics used in LCC systems (i.e., thyristors) are able to be overloaded for short-periods, within limits. For VSC systems however, which use IGBTs, the submodules cannot be overloaded beyond their rating even for very short periods. That said, VSC submodules are typically offered by suppliers in specified sizes, which means that depending on the levels of current required for the application there may be some 'headroom' in current rating inherent in the design. If this headroom is not sufficient to achieve the desired overload capability, then the next size up must be selected, even for a short-term overload.

A summary of the considerations for selection of the appropriate technology and topology for the Basslink modern equivalent is shown in Table 5-1.

Table 5-1 – Considerations for Converter Selection

Parameter	LCC	MMC VSC	Two-Level or Three-Level VSC
AC Network System Strength Requirements	High	Low - High	Low
Power Transfer Levels	High - Very High	Medium - High	Low - Medium
Use with Overhead Lines	Yes	Yes (Full Bridge only)	No
Converter Losses	Low	Low - Medium	Medium - High
Harmonic Filtering	High	Minimal or Zero	Medium
Voltage Control	Limited	Yes	Yes
Construction Footprint	Large	Smallest	Small
Overload Capacity	Yes	Limited headroom	Limited headroom

The requirement to operate the Basslink interconnector with overhead lines precludes the use of two-level or three-level VSC technology.

To operate an LCC link in a declining system strength network, as well as provide voltage control to the surrounding network, it would be necessary to install synchronous condensers with LCC converters. The inclusion of such synchronous condensers, or alternative system strength remediation measures, will have a cost impact, including additional CAPEX for the installation and then ongoing OPEX during operation.

A recent example is for the North Sea Link, a VSC HVDC system connecting the UK to Norway, that was commissioned in 2021. The project team concluded that to make an LCC converter work on the Norway end, they would require synchronous condensers, and their assessment concluded that the capital cost of a combined LCC and synchronous condenser solution would be higher than for a VSC. They concluded the same in relation to the operational losses and maintenance costs of the combined LCC and synchronous condenser solution. These factors were key to the decision to implement VSC technology for the North Sea Link [5].

On balance, Amplitude recommend MMC VSC technology as the most appropriate for the Basslink Modern Equivalent.

5.2 HVDC Cable Technology

For HVDC systems, the two main types of cable used on the DC side are mass impregnated (MI) and polymeric cables. The key difference between these is the insulating medium, with MI cables using layers of impregnated paper insulation while polymeric cables use extruded polymer-based insulation material.

The selection of cables is dependent on a number of factors, where the first, and often the deciding, consideration is typically the HVDC technology of the converter stations. Polymeric cables cannot withstand the regular polarity reversals which are required in LCC systems to change the direction of active power flow. Therefore, MI cables must be used for LCC HVDC systems. VSC systems do not require this polarity reversal and therefore, MI or polymeric cables can be used. Unless there is a specific requirement for MI cables (such as requiring a voltage level not already type tested), polymeric cables are typically used for VSC systems as they are lighter and easier to transport and install, which results in more cable on a vessel and therefore fewer laying campaigns for subsea cable and are easier to handle during installation for land cables.

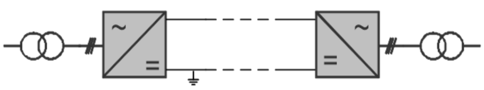
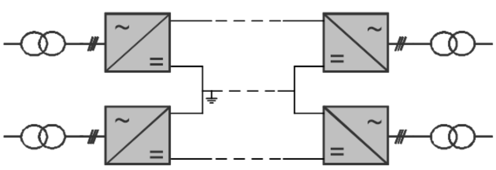
Polymeric cables as also typically designed to be able to operate at higher temperatures than MI cable, 70 - 90 degrees Celsius [6] [7] for polymeric cables compared to 55 degrees for the MI cables [8] used in the existing Basslink interconnector. The actual values depend largely on the cable supplier and the temperature characteristics of their insulation technology. This means that smaller polymeric cables can be used for the same power transfer. Polymeric cables also present a lower environmental risk than MI cables.

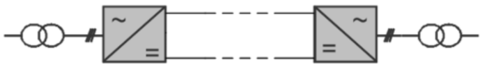
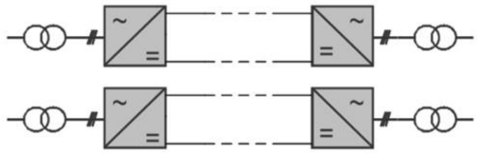
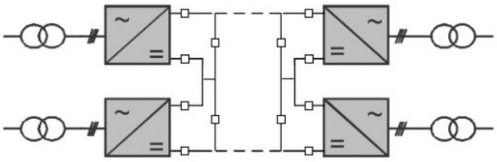
Amplitude considers, given that the converter station is to use MMC VSC technology, and there is no specific requirement to use MI cables, that it is appropriate to select polymeric cables.

5.3 HVDC System Configurations

There are a number of different configurations that can be used for HVDC, each with advantages and disadvantages. The major configurations are summarised in Table 5-2. As Basslink was previously unsuccessful in gaining approval for an earth return via electrodes, earth return configurations are not considered here. Redundancy refers to the remaining capacity of the link for an outage of one of the elements, either a cable or a converter.

Table 5-2 – HVDC System Configurations

Configuration	Diagram	Pros and Cons
Asymmetric Monopole		• Lowest cost. • No redundancy.
Bipole with Metallic Return		• Minimal current in MR during balanced operation. • Min 50% redundancy.

Configuration	Diagram	Pros and Cons
Symmetric Monopole		• Typically, smaller cables for same voltage levels. • No redundancy. • Use of more "standard" transformer technology.
Double Symmetric Monopole		• As for symmetric monopole. • Min 50% redundancy.
Rigid Bipole		• No MR cable or earth return. • Converter fault – min 50% redundancy (with time delay for switching). • Cable fault – no redundancy.

Basslink was initially designed, and is currently operating as, an asymmetric monopole. This means that a fault or failure in the converter station, either of the DC cables or the DC overhead line circuits will result in a complete loss of infeed.

While not offering any additional redundancy, Amplitude considers that a symmetric monopole is appropriate selection as the larger voltage between the positive and negative HVDC cables will reduce the required cable size without significantly increasing the converter requirements.

5.4 Basslink Modern Equivalent HVDC System

For the Basslink Modern Equivalent, Amplitude is of the opinion that the following would be suitable:

- **Voltage Source Converter** – VSC technology is more suitable for the power transfer capacity and other factors such as the current and declining system strength of the AC network in Tasmania and Victoria as well as the ability to provide reactive support and voltage control.
- **Modular Multi-Level Converter** – MMC is selected for the project as it is anticipated to produce a lower level of harmonic emissions, therefore requiring less filtering equipment and a reduced construction footprint. MMC topology also results in converter losses closer to those expected from LCC converters.
- **Polymeric Cables –** Polymeric cable technology is widely adopted and are appropriate for the selected converter technology and voltages.
- **Symmetric Monopole –** Currently there is no redundancy for Basslink, and it is considered that the system that will most closely match the design redundancy of Basslink is an asymmetric monopole. The use of a symmetric monopole is recommended as the larger voltage between the HVDC cables results in a lower current rating requirement for the cables.

- **Voltage Level** – Whilst any voltage level up to the current technology limit for VSC technology can be used, in practice the system voltage is selected from the commonly applied values to take advantage of proven and type tested designs. Typical values are 250 kV, 320 kV, 400 kV and 525 kV. For the proposed topology, power transfer and transmission distances being assessed, ±320 kV is selected as the likely optimum transmission voltage level.

6 Basslink Modern Equivalent Cost Estimate Inputs and Assumptions

6.1 Costs and Escalation

All costs included in this report are in Australian Dollars (AUD) and based on latest 2023 cost inputs, unless otherwise stated. Where Amplitude has utilised costs from other regions and currencies to develop cost estimates, these costs have been converted to AUD in the year of reporting using the reported annual average foreign exchange rate for that year and escalated using the most appropriate producer index available for the region.

The majority of suppliers who offer commercialised VSC converter stations and polymetric HVDC cables are based in, and manufacture their product in Europe. Therefore, where using historical costing information from HVDC converter and cable projects, we have used the index C271 "Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus" for converter stations and electrical equipment, and C2732 for "Manufacture of other electronic and electric wires and cables" for submarine cables, as provided by the Statistical Office of the European Union (Eurostat) [9] to escalate the costs.

Where transmission line labour rates are used, the rate used was $175 per hour, this being based on a 2015 labour rate of $150 per hour reported in the Powerlink – REPEX, Cost Data Review Report [10] and scaled by the latest available Wage Price Index (WPI) from the Australian Bureau of Statistics [11].

Costs provided in AUD are escalated using the producer price index for electrical equipment manufacturing as provided by the Australian Bureau of Statistics [12].

The cost estimates provided in Sections 6.2 to 6.7 are "EPC costs" and are limited to the costs directly relating to the engineering, procurement, manufacturing, construction, installation, testing and commissioning of the HVDC converters for the project. These EPC costs do not include costs for land purchase or easements, environmental studies, permitting or cultural heritage approvals, front end engineering studies and development, grid connections works and AC network reinforcements, financing or insurance or interest during construction.

Cost elements such as insurances, easement and environmental offsets, project management and project development costs are estimated and described in Section 6.8.

The cost components developed in Sections 6.2 to 6.8 are considered baseline costs, to these estimates, risk multipliers are applied to estimate the overall project cost estimate.

6.2 HVDC Converter Stations

VSC technology is still an evolving technology, with each HVDC vendor providing solutions with differing topologies, control philosophies, and concepts for customers for individual projects. Detailed costing information associated with specific projects is often considered proprietary intellectual property and as a result pricing information is either not available or only available at a very high-level. Many of the published project costs that presented in the public domain can include other costs (e.g., environmental, permitting, marine and route studies etc.) which can vary dramatically from project to project, making it difficult to extract out the actual EPC costs. Fortunately, there are some sources which can be used at a high level and, when considered in combination with Amplitude's actual experience in the development and project management of VSC projects, can be developed into useful price indicators, which have been used for the estimate of the EPC costs for the converter stations.

Due to the relatively small number of vendors and each having finite engineering and manufacturing resources, it is our experience that the pricing for VSC HVDC projects can vary from year to year based on the demand for projects. This needs to be considered for any HVDC project pricing. Cost estimates developed based on recent and past projects may differ from actual costs in a competitive tender process, either higher or lower, depending on the overall demand for HVDC projects at the time of the tender. In recent years, the global demand for HVDC converter stations and cables has increased dramatically and stories of a steep increase in these costs during 2021 to 2023 have been widely circulated in the industry. For this reason, we have limited our costing inputs to relatively recently reported projects and applied the scaling indices described in Section 6.1.

6.2.1 Converter Station Cost Inputs

Amplitude has developed the converter costs based on publicly reported EPC contract values for VSC projects reported since 2015. The sample has been limited to those projects where the scope is well known and where the reported contract values exclude other project elements not directly related to the VSC converter stations. The values within the sample have been reduced to a cost, in 2023 AUD, per MW per converter, which is then applied to the required power transfer for the Basslink modern equivalent scope. Published EPC contract values for France/Italy (2015) [13], Eleclink (2017) [14], IFA2 (2017) [15], and ALEGro (2020) [16] were applied to derive an average cost per MW per converter station.

From the information available, a trend analysis of the cost data was undertaken in order to select the appropriate unit rate for the Half Bridge converter station costs. The converter station costs are also scaled depending on the size of the station in terms of power capacity to be representative of economy of scale, while accounting for the commonly fixed components that every project needs to undertake regardless of size and complexity, such as basis engineering, technical studies, FST/FAT, DPS and site commissioning.

Regarding the use of full bridge technology, a full bridge VSC project has not yet been put into service and to the best of our knowledge, there is only one project under construction (although others are under development). The published cost for that project (Ultranet) was shown to be 18% above the average of published costs for other VSC bipole projects. This aligns roughly with a rule of thumb of a 20% uplift on the cost of half-bridge converter stations which has been used by Amplitude on other projects, and initially derived from the Electranix VSC transmission brochure [17]. For the purpose of this cost estimate, the value of 20% has been applied.

6.2.2 MMC Submodule Headroom

MMC VSC submodules come in specific sizes, so to achieve the required rating of any VSC system it is necessary to select the appropriate submodule size. Based on a nominal rating of 500 MW and a DC voltage of ±320 kV, the required current rating of the submodules, including reactive power at 39.5% active power, is estimated at 840 A. At the overload capacity of 630 MW, the required rating including reactive power is estimated at 1,060 A.

Different HVDC vendors have different IGBT sub-module models, which are specified based on current rating and built up to the required voltage level. There are limited sizes of submodules available, particularly in full-bridge VSC configuration. The information we have available is that one vendor offers 580 A, 1,140 A, 1,740 A and 2,610 A submodules for half-bridge systems [18], whilst another vendor offers only 2,000 A submodules for full-bridge VSC systems.

In the case of the first listed vendor, the 580 A rated submodules will not be sufficient for the proposed nominal (continuous) rating, whilst the 1,140 A rated submodules would provide for the continuous rating of 500 MW and the overload rating of 630 MW. The second vendor's 2,000 A submodule will also be sufficient for both the 500 MW continuous rating and 630 MW overload rating. Therefore, the cost of the VSC converters have been determined by multiplying the cost per MW by the required continuous rating (up to 500 MW) for each converter station.

6.2.3 Converter Station Costs

Amplitude has developed a high-level cost estimate for the converter stations based on the information in Section 5.4, combined with the costing inputs and assumptions described in Sections 6.2.1.

The high-level cost estimates for an EPC cost for each VSC converter station, based on full bridge MMC technology and symmetric monopole configuration are presented in Table 6-1.

Table 6-1 – VSC Converter Station Cost Estimates

Continuous MW Rating	Cost Per Converter Station ($AUD, 2023)
500 MW	$189,114,000

Amplitude has used the cost for the 500 MW converter station of $189.15 m in developing the cost estimates in this report.

6.3 HVDC Cable

Amplitude has developed the HVDC cable estimates using the following assumptions when developing the scope and estimates for the HVDC cable component of the Basslink Modern Equivalent:

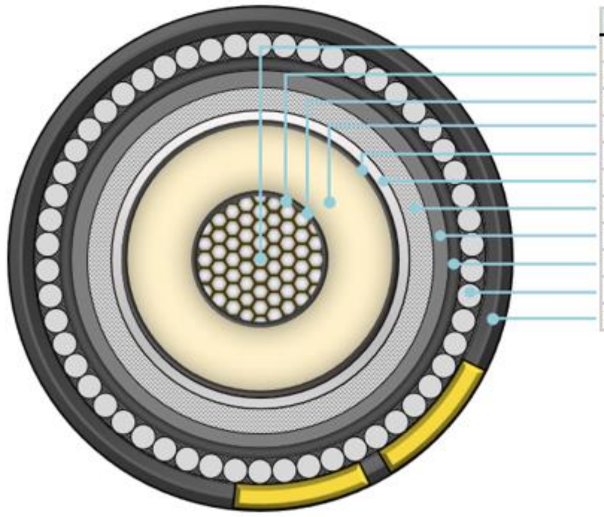
- All cost and size estimates are derived and scaled from publicly available information and are high-level estimates.

- Land cables for a relatively small component of the HVDC cable route (13 approx. 9 km) and therefore it is assumed that the variation in land cables cost will have an insignificant impact on the overall cost of the Basslink Modern Equivalent. The costs for the land cables are included in the cost of the submarine component.
- The fibre optic cable is expected to be imbedded into one of the layers of the actual HVDC per cable (similarly to the NEMO project) [19], and therefore the costs if the fibre optic cable is assumed to be included in the overall supply cost of the submarine cable component.
- The cable estimates have been developed for a power transfer level of 500 MW continuous and an overload of 630 MW. HVDC Cable Sizing.

Amplitude has assessed the approximate size of the HVDC polymeric cables for the required system ratings for a symmetric monopole configuration using cable rating software. An example of the cable model used for this assessment is shown in Figure 6-1. Note that the cable cross-section diagram is not shown to scale.

The design of the cable, including internal cable layer thicknesses, were adapted from the HVDC cable installed on the Caithness Moray project [20].

Figure 6-1 – Cable Model for 800 mm² Submarine Cable



Layer	Material	QTY	Thickness [mm]
Conductor	Al	1	34.20
Conductor Binder	Tape	1	0.55
Conductor Screen	PE	1	1.50
Insulation	PEX	1	27.13
Insulation Screen	PE	1	1.40
Longitudinal Water Bloc	Swellable Tapes	1	0.60
Metallic Sheath	Lead Alloy	1	2.90
Inner Sheath	HDPE	1	2.50
Bedding	Polymeric tapes	1	0.25
Armour	Steel Wire	1	5.00
Serving	Polypropylene yarn	1	4.00

Overall Diameter: 125.87 mm
Cable Weight: 35.66 t/km

Amplitude applied the parameters shown in Table 6-2 as input to this assessment. These were derived from information made available during the investigations that followed the arbitration into the 2015 Basslink cable failure [21].

Table 6-2 – Cable Design Parameters

Parameter	Land	Subsea
Burial depth (to top of cable):	1.0 m	1.0 m
Conductor Spacing	0.5 m	Bundled
Thermal Resistivity (TR) of soil:	1.2 K.m/W	1.0 K.m/W
Soil/Seabed Temperature	20^{O}C	19^{O}C

Parameter	Land	Subsea
Operating Voltage	320 kV	320 kV
Conductor/Insulation Max. Operating Temperature	80 ^{o}C	80 ^{o}C

Using the parameters in Table 6-2, the resultant estimated ratings for different cable size and conductor material options are shown in Table 6-3.

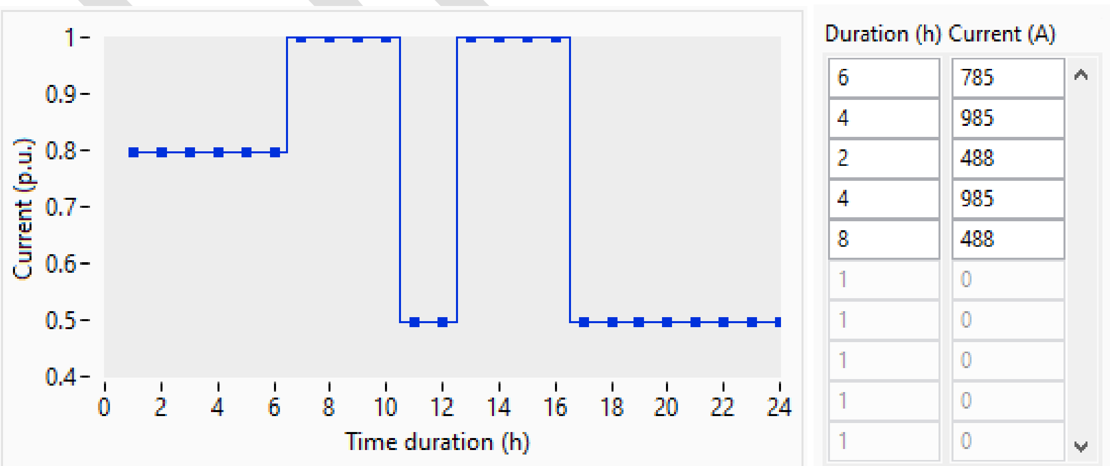
Table 6-3 – HVDC System Cable Sizing Options

Cable Size	Core Material	Continuous Cable Ratings	
		Estimated Current Rating (A)	Estimated Power Rating (MW)
400 mm^2	Cu	763	488
500 mm^2	Cu	881	564
630 mm^2	Cu	1013	648
630 mm^2	Al	785	502
800 mm^2	Al	905	579

In Table 6-3, all of the cable options at and above 500 mm^2 are able to meet the continuous rating of 500 MW.

In addition to being able to operate at a 500 MW in continuous steady state, the Basslink cable system is also designed to meet several overload conditions which are both time and power transfer orientated. The condition that is more onerous on the HVDC cable system requires the cables to be able to operate (in a 24-hour period, starting from a continuous steady state of 500 MW) at 630 MW for four hours, then cooling at 312 MW for two hours, then for a further 630 MW for four hours, and finally for a minimum of 312 MW for the remainder of the 24-hour period [1]. This condition is shown in Figure 6-2, where a current of 1 p.u. equates to 985 A, or 630 MW at ±320 kV.

Figure 6-2 – Overload Condition Illustration



While it is understood that the equivalent system will use a cable load prediction system instead of set profiles, these profiles have been used to determine like for like cable sizing. Using the profile in Figure 6-2, Amplitude assessed the overload capability of this cable. This assessment looked to determine how long the cable would be able to operate in overload conditions (630 MW) before breaching the maximum cable temperature of 80°C.

Based on this high-level assessment, Amplitude is of the view that the 800 mm^2 Al cable should be able to operate continuously at 630 MW for more than the required durations before reaching the maximum operating temperature of the cable (assumed to be 80°C).

6.3.1 HVDC Cable Supply Cost Inputs

In a similar way to converter station costing, as described in Section 6.2, HVDC polymeric cable technology is also an evolving technology with detailed costing information difficult to find in the public domain. Without the direct involvement of cable vendors, preliminary costs for HVDC cables have been determined through a combination of available public information and the knowledge and experience of those who have been involved in the implementation of HVDC projects.

Amplitude reviewed the information that is available in the public domain for similar types of projects that have been implemented around the world in recent years. The foreign exchange and scaling assumptions described in Section 6.1 were applied to this information to raw extract cable costs and these costs were adjusted and scaled for a range of cable sizes.

The project information found in the public domain is summarised in Table 6-4.

Table 6-4 – Similar HVDC Cable Project Details and Cost Information

Item	NEMO Project	Caithness Moray Project	IFA2 Project
Contract Award Amount	**EUR €225 M**	**USD $360 M**	**EUR €350 M**
Voltage [kV]	400	320	320
Conductor Size [mm^2]	1,100	2,200	1,600
Route Length (km)	141.5	160	240
Number of cables	2	2	2
Contract Award Year	2018	2014	2017
Exchange Rate to $AUD (Contract Year)	1.58	1.11	1.47
Scaling from Contract Award Year to March 2023	1.354	1.385	1.374
Reference	[19], [22]	[20], [23]	[24], [25]

The supply per km costs of cables in 2023 Australian dollars were derived from the published supply-only contract costs of these projects and scaled for 320 kV, 800 mm^2 aluminium and 630 mm^2 copper conductor polymeric cables, which were found to be suitable for the Basslink Modern Equivalent HVDC system based on their ratings. The derived costs for these cables are shown in Table 6-5.

Table 6-5 – HVDC Cable Supply Project Costs

Cable Size (mm^2)	Conductor Material	Voltage	NEMO Base (AUD $/km)	Caithness Moray Base (AUD $/km)	IFA2 Base (AUD $/km)	Average (AUD $/km)
630	Copper	320 kV	$775,000	$731,000	$669,000	$725,000
800	Aluminium	320 kV	$643,000	$678,000	$613,000	$645,000

Notes:

1. *All per km costs shown are per km of manufactured cable.*
2. *All costs are for supply only, no install included.*
3. *Basslink Equivalent **$**AUD costs include estimated scaling from the date of the contract award to March **202**3.*
4. *Cost of Copper and Aluminium was obtained from the London Market Exchange, cash per tonne in USD**$**, as of the year of Contract Award. These costs were used for cost conversion and scaling of the different cables from copper to aluminium conductor types.*

The average of the scaled project costs, in AUD$/km, for the selected cable/conductor size are used in this report as the cost for HVDC cable supply.

As the supply of the 630 mm² Cu cable is expected to cost more than the 800 mm² Al cable, Amplitude consider that the 800 mm² Al core polymeric cable is suitable for the Basslink modern equivalent at a supply cost of $646,200 per km.

6.3.2 HVDC Subsea Cable Installation

The installation of the subsea portion of the HVDC cable requires the use of specialised cable laying vessels and equipment. The cable is typically loaded onto vessel at a port close to the manufacturing plant, a process that can take several weeks. Once loaded, the vessel then travels to the cable laying location. Once laying is complete, the vessel returns to port. This process, from loading to return to port, is referred to as a "campaign".

The size and type of the cable is a key factor in determining the number of campaigns required to complete the full cable installation program. For the proposed 800 mm² Al cable, the weight is estimated to be approximately 27.5 tonnes per km [26], requiring circa 17,500 tonnes for the total project. The 630 mm² Cu cable weighs slightly more (30 tonnes/km, 19,000 tonnes total), and therefore is not expected to significantly influence the installation cost of the subsea component of the Basslink Modern Equivalent. While the installation of the cable may not have much of an impact, the supply of the cable is still more expensive for the copper cable, and so the decision of considering the 800 mm² Al cable for the Basslink Modern Equivalent still remains. The max load capacity of the majority of cable laying vessels ranges between 5,000 and 10,000 tonnes. Higher load capacities are also possible, with vessels such as Leonardo da Vinci able to take up to approximately 17,000 tonnes, noting that there is also likely to be physical size restrictions of the storage on the vessel may be reached before the maximum tonnage is achieved.

Amplitude is of the view that undertaking the installation of the cable for the Basslink Modern Equivalent would most likely have to be done in two, or potentially three campaigns, depending on the selection of cable manufacturing contractor and availability of vessels. Adding a third campaign will significantly increase the time and cost of the installation as many of the cable manufacturing facilities are located in the northern hemisphere, and as such there will be a significant cost associated with additional campaigns due to travel time to and from the factory for cable loadout. Amplitude is of the view that it is likely that a third campaign can be avoided during the design optimisation and planning stages of the project and therefore has assumed that two laying campaigns will be required.

Amplitude has estimated the installation portion of this project based on the following assumptions:

- The cables will be installed in a bundle and simultaneously laid on the seabed.
- The survey of the cable route prior to installation is done at 3 km per day.
- Loadout of the cable from the factory onto the cable laying vessel is expected to take approximately 27-30 days.
- The selected cable manufacturing facility for HVDC cables was selected to be located in China. Average speed for the cable laying vessel of 12 knots, from an origin in Northern China to a nearby port in Victoria for circa 22 days (i.e., one way trip) with a 10% allowance for delays and standing. Selection of a manufacturing facility that is located in Europe e.g., Sweden or Italy, is estimated to increase the cost of the installation campaign by approximately 25-30% as the cable laying vessel travel time would increase significantly.
- Cable lay rate of 0.5 km per hour with a 24-hour operation, and an increase of duration by 30% to account for inclement weather and other delays.
- Trenching rate for burial of cable assumed as 0.2 km per hour with a 24-hour operation and an increase of duration by 30% to account for inclement weather and other delays.
- No cable or other services crossings are required.
- Six joints in total will be required, which includes the two pairs of sea-land joints and one pair of rigid subsea joints.

The rates for vessels and trenching equipment were taken from the case study for the Australian – Singapore HVDC cable [8], whilst the Contractor Project Management and Overheads is taken from Table 6-9. An estimate of the costs for laying and burial of the cables is presented in Table 6-6.

Table 6-6 – Subsea Cable Installation Cost Estimate Breakdown

Install Items	Cost $AUD 2023
Total Survey Cost	$14,954,000
Loadout and Transit Cost	$62,038,000
Cable Installation Total	$13,113,000
Cable Trenching Total	$19,669,000
Landfall Cost	$64,988,000
Joints Total Cost	$3,098,000
Total Install	$177,860,000
Contractor Project Management and Overheads (16.5%)	$29,347,000
Total Cable Install Cost + Overheads	**$207,207,000**
Per km of route	**$695,500**

6.3.3 Summary of HVDC Cable Costs

The summarised high-level cost estimate of the cable system is presented in Table 6-4.

Table 6-7 – Basslink Modern Equivalent Cable Cost Estimate Summary

Item	Cost $AUD 2023
Cable Supply Cost	$422,765,000
Total Cable Install Cost + Overheads	$207,207,000
Total	**$629,972,000**

6.4 HVDC Overhead Line

6.4.1 HVDC Overhead Line Cost Inputs

As is the case with the converter stations and HVDC cables, the information in the public domain on HVDC overhead lines is limited. Amplitude has developed the HVDC overhead line costs based on publicly available estimating sources such as the ElectraNet Transmission Line Cost Review [27] and the AEMO Transmission Cost Database [28].

Amplitude have developed the cost estimate based on a review of published reference costs for overhead lines of similar voltage and rating, as well as undertaking a bottom-up cost exercise to provide an internal reference for the estimates.

The ElectraNet Transmission Line Cost Review [27], undertaken by Jacobs in 2019, seeks to establish appropriate costs for the establishment of a 400 kV, 1,450 km long HVDC line from South Australia to Queensland via NSW, with these estimates shown in Table 6-8.

Table 6-8 – 400 kV HVDC Transmission Line Amended Price Estimate (2019) [27]

Vendor	Cost Estimate ($/km)	Weighting	Designation
Powerlink	$469,480	1	Optimistic
Vendor one	$726,530	3	Most likely
Vendor two	$639,346	2	Likely
Vendor three	$655,565	3	Most likely
Adjusted value	**$654,940**		

The line design parameters for the ElectraNet cost estimates included a combination of chainette and self-supporting towers. Chainette towers, whilst requiring less steel, have a much larger "footprint" due to the use of guy wires to support the towers, and are suited mostly to remote areas with little or no vegetation and land cultivation. These structures are not considered appropriate for the Basslink overhead line transmission route. Amplitude has amended these cost estimates to better reflect the establishment of a 320 kV symmetric monopole using all self-supporting towers.

The AEMO Transmission Cost Database provides a cost for a 320 kV, asymmetrical, 750 MW monopole of $1.22 m per km excluding easement, property and environmental offset costs. This number includes $0.39 m in contractor project management and overheads, which is a 46% uplift on the costs elements as listed. Amplitude believes a more reasonable value for contractor project management and overheads would be in the order of 16.5%, as presented in Table 6-9.

Table 6-9 – Contractor Project Management and Overheads

Cost Item	Value	Source
Contractor contingencies	3.0 %	CIGRE Technical Brochure 388 [29]
Administration and supervision	6.8 %	
Contractor profit margins	6.7 %	NERA Economic Consulting, Benchmark Study of Contractor Profit margins (2002-2011) (Network Infrastructure Sub-Set) [30]
Total	**16.5%**	

Shorter lines, such as the Basslink overhead line sections, are typically more expensive to construct, the AEMO scaling values for transmission lines between 10 km and 100 km indicate a 5% uplift is required, however it is also worth noting that the AEMO estimate is rating of 750 MW which leads to comparatively higher cost for the Basslink 500 MW equivalent. Applying only the 16.5% uplift for Contractor Project Management and Overheads yields a value of $0.97 m per km.

6.4.2 Bottom-up Cost Estimates

Amplitude has carried out the bottom-up costing exercise using two approaches; using the latest data from the USA based Midwest Independent System Operator (MISO) Transmission Cost Estimating Guide [31] and using Australian values for materials, equipment and labour from the 2023 Rawlinson's Construction Handbook [32]. This approach was supplemented with specific cost data from the MISO guide and conservative assumptions where these are not readily available, as well as applying the contractor project management and overheads derived in Table 6-9.

Using the MISO Guide, a cost estimate of $0.88 m per km was determined. Analysis of the MISO assumptions indicate that a lower average tower weight is used when compared to the Jacobs and AEMO values.

Using input from the 2023 Rawlinson's Construction Handbook [32] yielded a value of $0.84 m per km. The predominant suspension tower weight assumed in the cost estimate was 18 tons, from the ElectraNet assessment which found this to be a suitable value for a 400-year wind return period. No assessment has been made for the required reliability metrics for the Basslink DC overhead transmission line and corresponding wind return period. Increasing the design to factor in a 2000 wind return period is estimated to require an increase in the estimated tower weight to 22 tons, this increases the line cost estimate to $0.99 m per km.

6.4.3 Summary of DC Overhead Line Cost Inputs

The cost estimating exercise yielded a transmission line cost range of between $0.77 m and $0.97 m per km, as shown in Table 6-10.

Table 6-10 – Cost Estimate Summary

Estimate Source	$/km (AUD 2023)
Amplitude bottom-up - MISO Transmission Cost Estimating Guide	$877,000
ElectraNet Transmission Line Cost Review, adjusted for inflation using PPI	$769,000
Amplitude bottom-up - Rawlinson's Construction Handbook values supported by MISO Cost Guide and assumptions	$837,000
AEMO Transmission Cost Database, adjusted for contractor project management and overheads	$972,000
ElectraNet Transmission Line Cost Review, adjusted for comparison to 320 kV symmetrical monopole, self-supporting towers	$973,000
Average	**$885,000**

Based on Amplitude's experience and the available data, Amplitude estimates that EPC cost of the 66.3 km, ± 320 kV HVDC overhead line to be circa $59 m noting that this value could change significantly, given the relatively short route and dependence of overhead line costs on route conditions, final design and reliability level selected.

6.5 HVDC Transition Stations

HVDC transition stations are required to connect the HVDC overhead transmission line to the DC land cable components both in Victoria and Tasmania. Transitions stations are typically unique to each particular HVDC system or project, and there is limited information available for the cost of these stations.

Amplitude has reviewed published reference costs, identifying only one applicable source published by Central Maine Power in the USA [33]. Amplitude has also developed a high-level bottom-up cost using the latest substation component data from the Midwest Independent System Operator (MISO) Transmission Cost Estimating Guide [31].

The published estimates in the Central Main Power report [33] indicates an approximate EPC cost of when scaled to 2023 rates of $9.7 m per station. The bottom-up approach using the MISO Transmission Cost Estimating guide for unit costs of similar rated AC equipment together with contractor margins and contingencies yielded a value of $6 m per station. The variance between the two estimates can be attributed to the site improvement work in the Central Maine Power report, where a value of approximately $3.7 m per station has been included, likely reflecting local site conditions and constraints, whereas the Amplitude estimate has assumed the site will require minimal improvements.

Amplitude estimates that the EPC cost for the two HVDC transition stations to be approximately $12 m.

6.6 Overhead AC Transmission Line

The AC overhead line portion of Basslink is made up of approximately 3.4 km of 500 kV overhead line in Victoria and approximately 2.1 km of 220 kV overhead line in Tasmania. The cost estimate has been based on the following assumptions:

- A single 3-phase circuit is constructed at both ends.
- Self-supporting towers are used for the entire length of the line.
- Permitting for the works do not cause significant delays to the construction programme.
- Geological conditions and constraints along the line route do not require abnormally large foundations, line crossings or special earthing arrangements.

Amplitude's cost estimate is based primarily on the AEMO Transmission Cost Database [28] yielding a cost to construct the AC overhead transmission line of approximately $2.1 m per km and $1.4 m per km for the 500 kV and 220 kV transmission lines respectively. These costs are relatively more expensive on a per kilometre basis due to the lack of economy of scale achieved in larger projects, with the costs increased using the appropriate adjustment factors from the AEMO Transmission Cost Database.

Amplitude estimates the EPC cost for the AC transmission lines to be $7.1 m and $3.0 m for the 500 kV and 220 kV transmission lines respectively.

6.7 AC Connection Assets

Basslink is connected to the 220 KV transmission network at the George Town Substation in Tasmania via a 220 kV double breaker bay. In Victoria, the connection to the Loy Yang Substation is via a 500 kV breaker and a half diameter, populated with two circuit breaker bays (a full breaker and a half diameter has three circuit breaker bays for two network elements, so called as each element is connected by one and a half circuit breaker bays). The cost estimate has been based on the following assumptions:

- No expansion of the switchyard is required at either George Town Substation or Loy Yang Substation.
- Permitting for the works do not cause significant delays to the construction programme.
- Geological conditions and constraints do not require abnormally large foundations or special earthing arrangements.

Using the AEMO Transmission Cost Database [28] and applying adjustments for the project scale and brownfield nature of the work, Amplitude estimates that the 500 kV and 220 kV EPC costs for the AC connection assets would be approximately $5.5 m and $3.1 m respectively.

6.8 Other Costs

The cost estimates presented in the previous sections for the individual elements are the Engineering, Procurement and Construction (EPC) costs. In addition to these costs, there are a number of other costs involved in setting up a project of this magnitude. These costs have been established based on Amplitude's experience and information available on similar projects to date.

6.8.1 Insurances

Insurances for the project include protection against cargo damage, acts of terrorism, defective design, loss of revenue and damage to wet assets. In the Basslink Project Cost Summary [34], the actual cost forecast for insurances for the Basslink Project amount to circa $48.5 m AUD, in 2005. This represented 7.3% of the total EPC cost at the time.

Whilst higher than estimates for insurance from sources such as the Independent Verification and Assessment Report for Project EnergyConnect and the AEMO Transmission Cost Database [28], this reported cost is likely higher due to the risks associated with the transportation and installation of the subsea cable. Subsea cables also attract additional levies, such as a Terrorism Levy and Emergency Services Levy [35].

The Independent Verification and Assessment Report for Project EnergyConnect [36] estimates insurances as approximately $8.6 m, noting that this is a corporate and network overhead, and is considered to represent the increase in insurance coverage to support the project. Amplitude is of the view that this does not accurately represent the insurances that would be required for a standalone project of this magnitude, nor is it representative of the coverage required for subsea installations.

Amplitude considers that insurance of 7.3% of the total EPC cost is appropriate for the project as it is consistent with the rates incurred at the time of construction.

6.8.2 Easements and Environmental

Amplitude has reviewed costing information available in the public domain for a number of major Australian projects to obtain the costs for easement acquisition and environmental offsets and approvals.

The AEMO Transmission Cost Database [28] puts the cost of easement acquisition and environmental offsets at approximately $0.45 m/km. The GHD Project EnergyConnect report [36] estimates the costs at $0.19 m/km for easement acquisition and $0.18 m/km for environmental offsets. The Marinus Link Cost Estimate Report [35] estimates the costs for easement acquisition at $0.22 m/km. The HumeLink Early Works Contingent Project Application (CPA) [37] includes the purchase of a substation site and options for easement acquisition, at a cost of $0.17 m/km. That the estimate makes note that these are options for easement acquisition indicates that full compensation is not included, however it is considered in the development of the cost estimates, resulting in an average cost for easement acquisition of $0.17 m/km.

It is important to note that the environmental offset cost and the easement acquisition costs vary greatly depending on the land use and jurisdiction in which the project is being carried out. This can be observed by comparing the Humelink project and the New South Wales component of Project EnergyConnect. The Humelink Project Assessment Conclusions Report (PACR) [38] includes a cost of over $2.8 m/km for environmental offsets in New South Wales, whilst the TransGrid Contingent Project Application [39] for the New South Wales component of Project EnergyConnect includes a cost of $0.29 m/km for environmental offsets. At the other end of the scale, the ElectraNet Contingent Project Application [40] for the South Australian component of Project EnergyConnect includes a cost of less than $0.02 m/km for environmental offsets. Including the Humelink estimate, the average cost for environmental offsets is circa $1 m/km, however Amplitude have excluded the Humelink costs and used an average of $0.16 m/km for environmental offsets.

Amplitude estimates the cost of easement acquisition for the HVDC overhead line in Victoria and Tasmania, the 220 kV overhead line in Tasmania and the 500 kV overhead line in Victoria at $0.17 m/km, for a total cost of $12.5 m. Environmental offsets for the same portion are estimated to cost $0.16 m/km, for a total of $11.2 m.

6.8.3 Other Capex

Other capex includes motor vehicles, IT equipment, leasehold Improvements, furniture and fittings, spares and tools as well as spare marine cable. The Basslink Project Cost Summary [34] includes an amount of 0.4% of EPC costs for other capex. Amplitude has used the same value in the assessment.

6.8.4 Project Management

Project Management includes the costs and overheads associated with delivery of a project of this magnitude. This typically includes the owner's or project developer's personnel, advisors and consultants, including project management and coordination, management or superintendence of the EPC contracts and owner's engineer services.

The Basslink Project Cost Summary [34] puts this cost at $65.2 m, which represents 9.8% of EPC costs at the time of delivery.

The Midwest Independent System Operator Transmission Cost Estimation Guide MTEP23 [31] provides a reference of approximately 5.5% for project management.

A report published in 2014 provides a cost breakdown of the East West Interconnector project between Ireland and Britain, with cost of EUR 40.1 m included for project management, which represents 9.2% of the EPC costs at the time [41].

For the purpose of this cost estimate, Amplitude has considered these benchmarks and assumed a value of 8.2% of the EPC costs for project management.

6.8.5 Project Development

The development cost of the project was calculated as a percentage of the total cost of the original Basslink project, which calculated as 8% of the EPC costs from the Basslink Final Schedule of Costs [42].

The GHD PEC report [36] places the project development of Project Energy Connect (NSW to South Australia) at $39.4 m AUD, which is circa 2.7% of the PEC plant cost estimate. Similarly, the AEMO Transmission Cost Database [28] estimates project development costs at 3.2% for a $500-1000 m project, and 2.8% for a $1000-$1500 m project.

The project development for Humelink Early Works [37], including procurement costs, represents 17% of the early works capital expenditure forecast, and 2.5% of the total project cost. As this is only the early works capex forecast, it is not clear how much of the project development for the entire project is captured in the early works forecast.

The report on the East West Interconnector project between Ireland and Britain includes a cost for project development of $17.2 m, which represents 4.0% of the EPC costs at the time [41].

When compared to these projects, the Basslink Modern Equivalent project would incur similar or the same development for the land aspects (e.g. overhead transmission lines, underground cables), however there is a significant difference in the amount of work required for the development of the subsea component (for example, marine surveys, fishing and shipping studies and investigation, marine permitting processes etc.) and significantly more technical development (for example, the development of detailed technical specifications for the HVDC converter stations and the HVDC cables). Based on this we anticipate that the amount of project development required is expected to be significantly higher than that required for AC substations utilising AC overhead transmission lines.

Considering the above, Amplitude considers the reported 8% to be a high value whereas the reported 2.7% to 3.2% reported for the overhead line projects to not take into account the additional project development complexities related to the subsea and HVDC converter components of the project. For the purpose of this cost estimate, Amplitude has assumed a value of 5% of the EPC costs for project development.

6.9 Risk Adjustments

For this exercise we have selected the AEMO cost database [28] as a guide to select risk multipliers on which to increment the base cost estimates described earlier in the report. In applying the AEMO risk categories we have assumed that the AC equipment cost data used [28] is relatively more accurate than the HVDC cost data. The application of the risk categories is shown in Table 6-11 and summarised below:

- For all cost elements we have applied cultural heritage together with scope and technology risk multipliers.
- For the HVDC OHL we have included the project complexity risk multiplier due to the differences in the electrical performance and additional design scope which has to be taken into account. HVDC OHL subcomponents and civil scope are similar in most aspects to AC OHL, hence no additional risks factors have been applied.
- For the HVDC converter station and cable systems, as there are no local suppliers or comparable systems being commissioned in recent years, we have included productivity and labour, project complexity, overhead and plant procurement cost risks multipliers.
- For the easement and environmental offsets we applied the average of the station and OHL scope and technology together with overhead risk multipliers.
- The applicable AEMO underground cable system risk multipliers are used for the subsea cable as there is no specific risk multipliers for subsea cables.
- The same risk multipliers as used for the HVDC converter stations are assumed for the transition station.

Table 6-11 – Application of AEMO Risk Categories

Applied Risk Categories	Asset Category	Classification used	Justification
Scope and technology risks	All	Class 5a	High- level screening. Assumed similar route to existing systems
Cultural heritage	All terrestrial assets	BAU	It is not known at this stage if the risk is low or high.
Productivity and labour cost risks	HVDC converter stations, OHL and subsea cable	Class 5a	Limited Australian benchmark cost data.
Plant procurement cost risks		Class 5a	Limited Australian benchmark cost data.
Project overhead risks		Class 5a	Limited Australian benchmark cost data.
Project complexity	HVDC converter stations, OHL and subsea cable	Partly complex	Additional requirements and time to develop, study, design and deliver the project. No recent projects in Australia.

The weighting of each risk multiplier was assessed and the aggregated value to be applied to the base cost estimate was calculated. Table 6-12 presents the calculated risk multipliers that were applied to the base cost estimates for each asset category.

Table 6-12 – Risk Multipliers Applied

Applied Risk Categories	Classification	Increment
AC Connection Assets		
Scope and technology risks	Class 5a	10.60%
Cultural heritage	BAU	0.40%
Total Risk Adjustment		**11%**
AC OHL		
Scope and technology risks	Class 5a	12.93%
Cultural heritage	BAU	1.69%
Total Risk Adjustment		**15%**
HVDC OHL		
Scope and technology risks	Class 5a	9.67%
Cultural heritage	BAU	1.73%
Project overhead risks	Class 5a	1.24%
Project complexity	Partly complex	4.00%
Total Risk Adjustment		**17%**
Subsea Cable System		
Scope and technology risks	Class 5a	12.25%
Plant procurement cost risks	Class 5a	2.64%
Project complexity	Partly complex	4.00%
Productivity and labour cost risks	Class 5a	1.13%

Applied Risk Categories	Classification	Increment
Project overhead risks	Class 5a	0.23%
Total Risk Adjustment		**20%**
HVDC Converter and Transition Stations		
Scope and technology risks	Class 5a	10.55%
Cultural heritage	BAU	0.30%
Project complexity	Partly complex	4.00%
Productivity and labour cost risks	Class 5a	1.33%
Plant procurement cost risks	Class 5a	2.19%
Project overhead risks	Class 5a	0.48%
Total Risk Adjustment		**19%**
Easement		
Scope and technology risks	Class 5a	13.00%
Project overhead risks	Class 5a	15.00%
Total Risk Adjustment		**28.00%**
Environmental Offsets		
Scope and technology risks	Class 5a	13.00%
Project overhead risks	Class 5a	15.00%
Total Risk Adjustment		**28.00%**

7 Cost Estimate

Amplitude has used the information presented in Chapters 5 and 6 of this report to develop a high-level cost estimate for the replacement of the Basslink Modern Equivalent. This estimate has been prepared as described in the preceding chapters.

The detailed cost estimate is shown in Table 7-1.

Table 7-1 – Basslink Modern Equivalent Cost Estimate

#	Item	Qty	Cost ($AUD, 2023)
1	**System Overview**		
1.02	Station	**Loy Yang, VIC - George Town, TAS**	
1.04	Grid Connection Voltage	220 kV (TAS) and 500 kV (VIC)	
1.01	Transmission Voltage		±320 kV DC
1.03	System Capacity MW (nominal)		500
2	**Connection Bays**		
2.01	500 kV Connection Bays (VIC)	1	$6,152,000
2.02	220 kV Connection Bays (TAS)	1	$3,391,000
3	**OHTL System: Loy Yang (VIC)**		
3.01	AC 500 kV Single Circuit OHTL	3.4	$8,172,000
3.02	HVDC ±320 kV Symmetric Monopole OHTL	57.4	$59,282,000
4	**OHTL System: George Town (VIC)**		

#	Item	Qty	Cost ($AUD, 2023)
4.01	AC 220 kV Single Circuit OHTL	2.1	$3,386,000
4.02	HVDC ±320 kV Symmetric Monopole OHTL	8.9	$9,192,000
5	**Cable System**		
5.01	Supply DC Cable 320 kV DC (2x 800 mm^2 AL PEX)	298	$508,393,000
5.02	Installation of 320 kV HVDC Subsea Cable	298	$249,175,000
6	**HVDC Transition Stations**		
6.01	OHTL to UG cable transition station	2	$14,326,000
7	**HVDC Converter Stations**		
7.01	**VIC Terminal:** 500 MW continuous, 630 MW overload	1	$224,766,000
7.02	**TAS Terminal:** 500 MW continuous, 630 MW overload	1	$224,766,000
8	**TOTALS**		
8.01	Subtotal Estimated EPC Construction Costs		$1,311,001,000
8.02	Allowance for Project Planning, Permitting, Overheads, Contingency		$204,830,000
8.03	Development Cost	5%	$65,550,000
8.04	**TOTAL**		**$1,581,381,000**
9	**Breakdown Summary**		
9.01	AC Connections and AC Overhead Transmission Lines		$21,101,000
9.02	HVDC Overhead Transmission Lines and Transition Stations		$82,800,000
9.03	HVDC Converter Stations		$449,532,000
9.04	HVDC Cable Systems (Supply and Install)		$757,568,000
9.05	Project Development, Planning and Permitting		$270,380,000
9.06	**TOTAL**		**$1,581,381,000**

8 Alternative HVDC Power Transfer Options

Two further solutions and cost estimates were developed by Amplitude for smaller rated HVDC systems, this being 150 MW and 350 MW. In addition, a cost estimate of an equivalent LCC system was also developed.

Amplitude applied a similar approach to that detailed in Section 6 of this report with adjustments to accommodate for voltage, power transfer and differences in reference cost inputs

8.1 HVDC 150 MW System

Amplitude has developed a high-level cost estimate for the converter stations based on the information in Section 5.4, combined with the costing inputs and assumptions described in Sections 6.2.1. The system was scoped considering a lower voltage of ±80 kV, which is more suitable for this level of power transmission.

There are limited public references for the design and costs for overhead HVDC transmission lines constructed at this voltage and power level. To estimate these costs, Amplitude developed EPC unit cost rates using trend analysis of the HVDC overhead line data in the latest AEMO cost database [28]. The cost for a 150 MW, 80 kV overhead transmission line is estimated at $502,200 per km. For comparison, the EPC costs for high voltage AC overhead lines with similar voltage and power transfer reported in AEMO database are in the region of $650,000-$750,000 per km. The HVDC transition stations are estimated to cost $3.81 m each.

The AC assets, and therefore the cost estimates, would be the same for the 150 MW option as for the larger options, including connection at 500 kV in Victoria. There is a single 500/220 kV transformer that serves as the connection assets for Valley Power Station, however the ratings and ownership of that transformer is not publicly available. Project development and other costs, including acquisition of easements are defined as a percentage of the overall EPC cost, and therefore reduce with the reduction in capacity. The reduction in these costs potentially overstates the savings of a lower rated project, however there is insufficient evidence on projects at this size to provide alternative values.

The high-level cost estimates for an EPC cost for each VSC converter station, based on full bridge MMC technology and symmetric monopole configuration are presented in Table 8-1.

Table 8-1 – VSC Converter Station Cost Estimates

Continuous MW Rating	Voltage	Current	Cost Per Converter Station ($AUD, 2023)
150 MW	±80 kV	940 A	$59,665,000

Using the environmental parameters defined in Section ⍰, the resultant estimated ratings for different cable size and conductor material options are shown in Table 8-2.

Table 8-2 – HVDC System Cable Sizing Options

Cable Size	Core Material	Continuous Cable Ratings		Cable Costs ($AUD, 2023)	
		Estimated Current Rating (A)	Estimated Power Rating (MW)	Supply Cost per km	Installation Cost per km
630 mm²	Cu	1050	168	$348,000	$695,500
1,000 mm²	Al	1074	171.5	$300,500	$695,500

Based on the ratings and costs in Table 8-2 both the Cu and Al core cables are able to meet the required continuous power rating. The 1,000 mm² Al core cables were selected for this solution as they are cheaper than the Cu alternative with an added advantage of a slightly higher power rating.

Installation costs of the cables were estimated using the same assumptions and methodology as described in Section 6.3.2, with the resultant cost of $695,500 per km of route.

8.2 HVDC 350 MW System

Amplitude has developed a high-level cost estimate for the converter stations based on the information in Section 5.4, combined with the costing inputs and assumptions described in Sections 6.2.1. The system was scoped considering a lower voltage of ±150 kV, which is more suitable for this level of power transmission.

Similar to the previous 80 kV scenario, there are limited public references for the design and costs for 150 kV overhead HVDC transmission lines. To estimate these costs, Amplitude developed EPC unit cost rates using trend analysis of the HVDC overhead line data in the latest AEMO cost database [28]. The cost for a 350 MW, 150 kV overhead transmission line is estimated at $678,300 per km. For comparison, the EPC costs for high voltage AC overhead lines with similar voltage and power transfer reported in AEMO database are in the region of $950,000-$1050,000 per km. The HVDC transition stations are estimated to cost $4.65 m each.

The high-level cost estimates for an EPC cost for each VSC converter station, based on full bridge MMC technology and symmetric monopole configuration are presented in Table 8-3.

Table 8-3 – VSC Converter Station Cost Estimates

Continuous MW Rating	Voltage	Current	Cost Per Converter Station ($AUD, 2023)
350 MW	±150 kV	1,170 A	$135,311,000

Using the environmental parameters defined in Section ⍰, the resultant estimated ratings for different cable size and conductor material options are shown in Table 8-4.

Table 8-4 – HVDC System Cable Sizing Options

Cable Size	Core Material	Continuous Cable Ratings		Cable Costs ($AUD, 2023)	
		Estimated Current Rating (A)	Estimated Power Rating (MW)	Supply Cost per km	Installation Cost per km
800 mm²	Cu	1180	354	$560,000	$695,500
1,400 mm²	Al	1255	376.5	$488,500	$695,500

Based on the ratings and costs in Table 8-4 both the Cu and Al core cables are able to meet the required continuous power rating. The 1,400 mm² Al core cables were selected for this solution as they are cheaper than the Cu alternative with an added advantage of a slightly higher power rating.

Installation costs of the cables were estimated using the same assumptions and methodology as described in Section 6.3.2, with the resultant cost of $695,500 per km of route.

The AC assets, and therefore the cost estimates, are assumed to be the same for the 350 MW option as for the larger options, including connection at 500 kV in Victoria. Project development and other costs, including acquisition of easements are defined as a percentage of the overall EPC cost, and therefore reduce with the reduction in capacity. The reduction in these costs potentially overstates the savings of a lower rated project, however there is insufficient evidence on projects at this size to provide alternative values.

8.3 Basslink LCC Equivalent

Amplitude has developed an equivalent cost for Basslink using LCC technology. It is unlikely for the reasons discussed earlier that LCC technology will be chosen due reducing system strength and consequential HVDC system performance and reliability impacts. The cost of additional synchronous condensers to improve the LCC HVDC system resiliency and to bring performance to the same level as a VSC equivalent has not been estimated.

Costs for the overhead transmission lines and AC connections are assumed to be same as that developed for the modern VSC Basslink equivalent with main differences being attributed to costs of the LCC converter stations and mass impregnated submarine cables. The estimate excludes the cost of land needed for the converter station sites.

There are few HVDC LCC system being built at present and at a similar scale of the Basslink system. As such, there are few public cost references that can be relied upon and older. available cost reference values skewed to much larger HVDC projects where LCC technology is more commonly used.

Using the equivalent unit rate from the AEMO Transmission Cost Database [28] and modified to account for the additional costs for overloading capability up to 630 MW, the EPC cost for each LCC converter station is estimated at $76 m. We believe that this value is too low and whilst we do not know the reference cost data or scaling applied in developing the AEMO Transmission Cost Database we believe the EPC cost for each LCC converter station is between $150-160 m. We have used $150 m in the developing the total cost estimate of the LCC equivalent system.

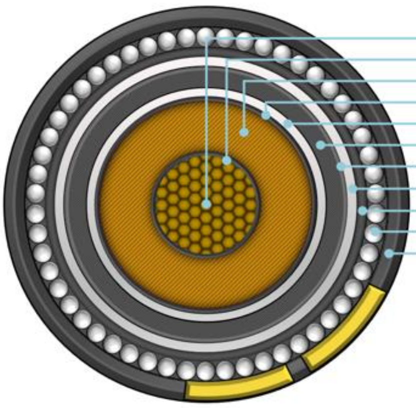
Based on the information presented in this Section ▯ in terms of the environmental, installation and cable design parameters, the subsea cable ratings are estimated to be as shown in Table 8-5.

Table 8-5 – Summary of MI Cable Ratings

Rating Description	Value
Power Rating (Nominal)	500 MW
Min. Required Current Rating	1,250 A
Selected Cable Size	1600 mm^2
Modelled Current Rating	1,310 A

A HVDC submarine cable with MI insulation was modelled in Amplitude's internal cable rating software using the cable data obtained from the original Basslink HVDC land cable design [43]. Design details for the land cable are shown in Figure 8-1.

Figure 8-1 – MI Submarine Power Cable Design Parameters



Layer	Material	QTY	Thickness [mm]
Conductor	Cu.	1	48.50
Conductor Screen		1	0.30
Insulation	MI	1	18.98
Insulation Screen		1	0.30
Metallic Sheath	Lead	1	3.30
Sheath	PE	1	3.50
Tapes	Polyester	1	0.00
Reinforcing Tapes	Steel	2	0.40
Bedding		1	1.40
Armour	Steel Wire	2	5.00
Serving	Jute	1	4.40

Overall Diameter: 123.38 mm
Cable Weight: 46.39 t/km

Amplitude reviewed similar projects that have been implemented around the world in recent years which are available in the public domain. HVDC projects that closely resemble the design of the cable proposed in this section, being of mass impregnated design, were selected for developing the cost estimate for the Basslink submarine MI cables.

The cable costs were derived from information from these project using Amplitudes internally developed cable design and estimation tool. The parameters and corresponding costs were scaled to match the voltage level and cable size that was chosen for this project.

The per km cost of cables in Australian dollars was derived from contract award costs which are shown in Table 8-6.

Table 8-6 – Similar HVDC Cable Project Costs

Project	Fenno-Skan 2	Neptune Cable	Western HVDC Link	BritNed
Voltage [kV]	500	500	600	450
Power Capacity [MW]	800	660	2,200	1,000
Conductor Size [mm²]	2000	2,100	2,400	1,430
Route Length [km]	100	105	420	256
Project Cable Contract Cost	€ 150 M	£ 170 M	€ 800 M	€ 600 M
Year of Contract Award	2008	2005	2012	2007
Exchange Rate (in Year of Contract)	1.74	1.63	1.24	1.63
Manufacturing Price Adjustment	30%	55%	33%	33%
Reference	[44]	[45]	[46]	[47]
400 kV 1,600 mm² Basslink Equivalent $AUD/km	$730,000	$924,000	$749,000	$881,000
400 kV Average Cost $AUD/km	**$821,000**			

Notes:

1. *All per km costs shown are per km of the manufactured cable.*
2. *Contract costs are for supply and install, turn-key solution.*
3. *Route lengths shown include both the land and subsea portion of the route.*
4. *Cable cost of manufacture and supply was scaled using the Eurostat Data from year of reference project cable supplier contract announcement to year March 2023* [48].

Installation costs of the cables were estimated using the same assumptions and methodology as described in Section 6.3.2, with the resultant cost of $0.83 million per km of route. The increased cost is due to the size and weight of the cables, which require additional delivery and installation campaigns.

8.4 Cost Summary of Alternative Options

Using the base cost estimates presented in the above sections, the risk multipliers in Table 6 12 are assumed to be similar and applied to calculate the overall cost estimate of the alternative HVDC systems. The cost summary of alternative options is presented in Table 8-7.

Table 8-7 – Alternative HVDC Options Cost Summary

#	Item	Qty	Cost ($AUD, 2023)		
	System Overview		**150 MW (VSC)**	**350 MW (VSC)**	**500 MW (LCC)**
1.01	Station		**Loy Yang, VIC - George Town, TAS**		
1.02	Grid Connection Voltage		**220 kV (TAS) and 500 kV (VIC)**		
1.03	System Type		**Symmetric Monopole**	**Symmetric Monopole**	**Asymmetric Monopole**
1.04	Transmission Voltage		**±80 kV DC**	**±150 kV DC**	**400 kV DC**
1.05	System Capacity MW (nominal)		**150 MW**	**350 MW**	**500 MW**
2	**Connection Bays**				
2.01	500 kV Connection Bays (VIC)	1	$6,152,000	$6,152,000	$6,152,000
2.02	220 kV Connection Bays (TAS)	1	$3,391,000	$3,391,000	$3,391,000
3	OHTL System: Loy Yang (VIC)				
3.01	AC 500 kV Single Circuit OHTL	3.4	$8,172,000	$8,172,000	$8,172,000
3.02	HVDC ±150 kV Symmetric Monopole OHTL	57.4		$45,413,000	
3.04	HVDC ± 80 kV Symmetric Monopole OHTL	57.4	$33,623,000		
3.05	HVDC 400 kV Asymmetric Monopole OHTL	57.4			$59,282,000
4	**OHTL System: George Town (VIC)**				
4.01	AC 220 kV Single Circuit OHTL	2.1	$3,386,000	$3,386,000	$3,386,000
4.02	HVDC ± 150 kV Symmetric Monopole OHTL	8.9		$7,041,000	
4.03	HVDC ± 80 kV Symmetric Monopole OHTL	8.9	$5,213,000		
4.04	HVDC 400 kV Asymmetric Monopole OHTL	8.9			$9,191,000
5	**Cable System**				
5.01	Supply DC Cable 80kV DC (2x 1,000 mm² AL PEX)	298	$236,777,000		
5.02	Supply DC Cable 150kV DC (2x 1,400 mm² AL PEX)	298		$384,368,000	
5.03	Supply DC Cable 400kV DC (2x 1,600 mm² Cu MI)	298			$631,017,000
5.04	Installation of 80 kV/150 kV HVDC Subsea Cable	298	$249,175,000	$249,175,000	
5.05	Installation of 400kV MI HVDC Subsea Cable	298			$296,312,000
6	**HVDC Transition Stations**				
6.01	150 kV OHTL to UG Cable Transition Station	2		$11,064,000	
6.02	80 kV OHTL to UG Cable Transition Station	2	$9,047,000		
6.03	400 kV OHTL to UG Cable Transition Station	2			$14,326,000
7	**HVDC Converter Stations**				
7.01	**VIC Terminal:** 150 MW continuous (VSC)	1	$70,913,000		
7.02	**VIC Terminal:** 350 MW continuous (VSC)	1		$160,819,000	
7.03	**VIC Terminal:** 500 MW continuous (LCC)	1			$178,278,000
7.04	**TAS Terminal:** 150 MW continuous (VSC)	1	$70,913,000		
7.05	**TAS Terminal:** 350 MW continuous (VSC)	1		$160,819,000	
7.06	**TAS Terminal:** 500 MW continuous (LCC)	1			$178,278,000
8	**TOTALS**				

#	Item	Qty	Cost ($AUD, 2023)		
	System Overview		**150 MW (VSC)**	**350 MW (VSC)**	**500 MW (LCC)**
8.01	Subtotal Estimated EPC Construction Costs		$696,762,000	$1,039,800,000	$1,387,785,000
8.02	Project Planning, Permitting, Overheads, Contingency		$123,006,000	$168,702,000	$214,838,000
8.03	Development Cost	5%	$51,990,000	$69,389,000	$58,029,000
8.04	**TOTAL**		**$854,606,000**	**$1,260,492,000**	**$1,672,012,000**
9	**Breakdown Summary**				
9.01	AC Connections and AC Overhead Transmission Lines		$21,101,000	$21,101,000	$21,101,000
9.02	HVDC OHTL and Transition Compounds		$47,883,000	$63,518,000	$82,799,000
9.03	HVDC Converter Stations		$141,826,000	$321,638,000	$356,556,000
9.04	HVDC Cable Systems (Supply and Install)		$485,952,000	$633,543,000	$927,329,000
9.05	Project Development, Planning and Permitting		$157,844,000	$220,692,000	$284,227,000
9.06	**TOTAL**		**$854,606,000**	**$1,260,492,000**	**$1,672,012,000**

We note that the LCC equivalent system cost estimate is higher than the equivalent VSC system. This is mainly due to larger cables being needed due to the asymmetric configuration. The mass impregnated cables for the LCC system utilise copper, which is more expensive and heavier than the aluminium cables considered for equivalent VSC system, this leading to larger supply and installation costs.

9 Alternative AC power transfer options

9.1 AC System Scope and Overview

It is expected that for the required submarine cable route length and power transferred, HVDC technology will be the most cost-efficient solution as well as being preferred due to having other beneficial features such as directional power transfer control over AC transmission. For comparative purposes, a concept AC submarine solution for 500 MW transfer has been developed.

The scope of the concept AC solution was developed using high-level considerations for optimal AC cable cross-sectional areas, maintaining operating voltage limits, losses and reactive compensation requirement.

Cables due to their construction are highly capacitive with the total capacitance being proportionate to the length of the cable. Under AC energisation a capacitive charging current is drawn for each half-cycle of the 50 Hz waveform, this capacitive current reduces the power transfer capacity of the cable to the load and introduce challenges such as managing inrush currents and energising the cable without breaching voltage limits. This phenomenon inherently reduces the practical transmission length that an AC cable can be used. Shunt reactors are used to reduce the capacitive charging current drawn and depending on the length of the cable circuit are required at different position along the cable route. The quantity of shunt reactors needed depends on the total cable capacitance and network performance requirements and this impacts the economic transmission distance of AC cable projects.

At a high level, the selected system will consist of four AC submarine cable circuits together with a midpoint offshore platform housing reactive compensation equipment as well as onshore substations and additional reactive compensation in Victoria and Tasmania.

The estimated reactive compensation required for each circuit is shown in Table 9-1. A schematic of the AC concept developed is shown in Figure 9-1 together with a high-level single line diagram in Figure 9-2.

Table 9-1 – Estimated Reactive Compensation per Circuit

Reactive Compensation Location	MVAr Required
Onshore -Loy Yang	300 MVAr
Offshore- Bass Strait	500 MVAr
Onshore -George Town	250 MVAr

Figure 9-1 – Basslink AC Transmission Concept

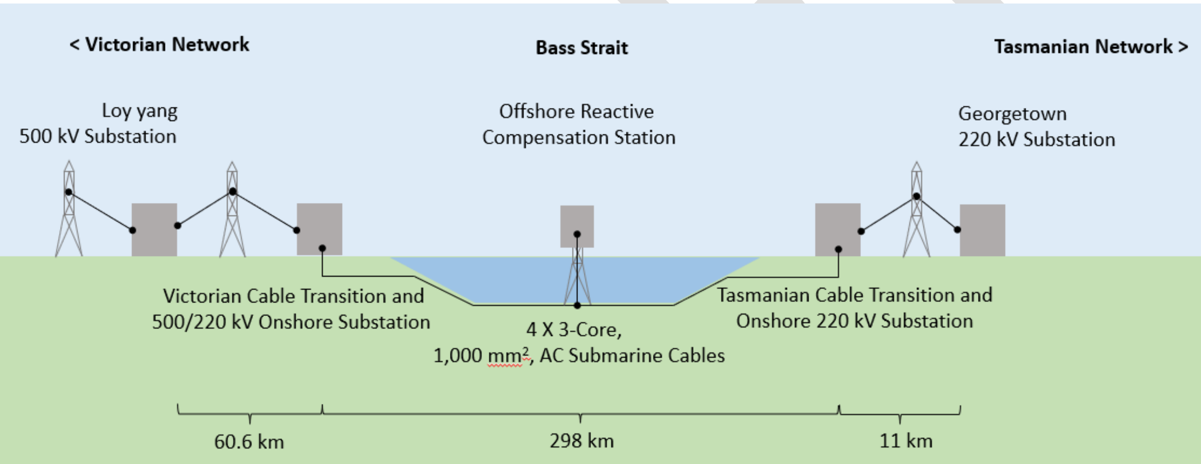
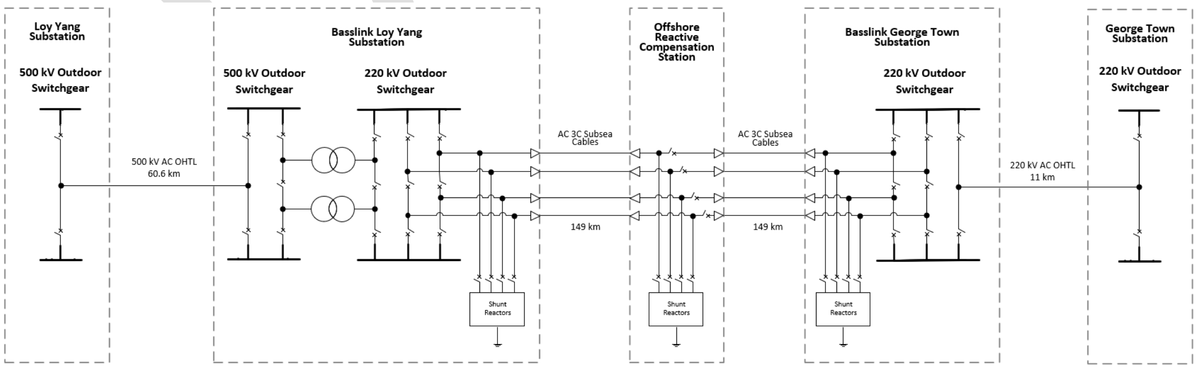


Figure 9-2 – Single Line Diagram for Basslink AC Transmission Concept



The onshore assets and reactive plant costs were estimated using the latest AEMO cost database, except for the project development costs for which a 5% allowance was used in line with our earlier estimates.

There are limited public references for the cost of offshore reactive compensation stations. The only recent reference offering technical information on which we have based our estimate is the Hornsea Wind Farm in the North Sea. The first phase of the Hornsea Wind Farm was commissioned in 2020 and includes a 3x 240 MVAr offshore reactive compensation station.

We estimated the cost of the offshore reactive compensation station platform using our internal unit costs for HVDC platforms derived from published costs of these projects. This was then linearly scaled for the lower weight of the Basslink concept offshore reactive compensation station, which is based on the published weight of the Hornsea reactive compensation station [49].

Amplitude reviewed the information that is available in the public domain for similar types of AC submarine cable transmission projects that have been implemented around the world in recent years. The foreign exchange and scaling assumptions described in Section 6.1 were applied to this information to raw extract cable costs and these costs were adjusted and scaled for a range of cable sizes.

The project information found in the public domain is summarised in Table 9-2.

Table 9-2 – Similar AC Cable Project Details and Cost Information

Item	Malta-Sicily Link	Little Belt	Hornsea One
Contract Award Amount	**EUR €178 M**	**USD $30 M**	**EUR €139 M**
Voltage [kV]	230	420	220
Conductor Size [mm²]	630	1,400	1,000
Route Length (km)	138.6	28	120
Number of cables	1	1	1
Contract Award Year	2010	2012	2016
Exchange Rate to $AUD (Contract Year)	1.45	0.97	1.49
Scaling from Contract Award Year to March 2023	1.421	1.304	1.413
Reference	[50]	[51]	[52]

The supply per km costs of cables in 2023 Australian dollars were derived from the published supply-only contract costs of these projects and scaled for 220 kV, 1,000 mm² copper conductor XLPE cables, which were found to be suitable for the Basslink Modern Equivalent Concept AC system based on its ratings. This cable would be capable of transferring 125 MW of power with adequate reactive compensation at the three points along the transmission line, as described in Table 9-1.

Using the environmental parameters defined in Section 5, the resultant estimated ratings for different cable size and conductor material options are shown in Table 9-3.

Table 9-3 – AC System Cable Sizing

Conductor Size	Core Material	Estimated Continuous Current Rating (A)	Cable Costs ($AUD, 2023)	
			Supply Cost per km of Cable	Installation Cost per km of Route
1,000 mm²	Cu	785	$1,516,567	$2,801,000

Installation costs of the cables were estimated using the same assumptions and methodology as described in Section 6.3.2, with the resultant cost of $2.801 million per km of route for four circuits.

9.2 Cost Summary of Alternative AC Option

Using the base cost estimates presented in the above sections, the risk multipliers in Table 6 12 are assumed to be similar and applied to calculate the overall cost of the alternative AC system. The cost summary of the alternative AC option is presented in Table 9-4.

Table 9-4 – Alternative AC Options Cost Summary

#	Item	Qty.	AC System 500 MW
1	**System Overview**		
1.01	Transmission Voltage		220 kV AC
1.02	Station	**Loy Yang, VIC - George Town, TAS**	
1.04	Grid Connection Voltage	220 kV (TAS) and 500 kV (VIC)	
1.03	System Capacity MW (sending)		500
2	**Connection Bays**		
2.01	500 kV Conn. Bays/Ccts (VIC)	1	$6,152,000
2.02	220 kV Conn. Bays/Ccts (TAS)	1	$3,391,000
3	**OHTL System: Loy Yang (VIC)**		
3.01	AC 500 kV Single Circuit OHTL	60.6	$193,676,000
4	**OHTL System: George Town (TAS)**		
4.01	AC 220 kV Single Circuit OHTL	11.0	$20,637,000
5	**Loy Yang (VIC) Substation**		
5.01	500 kV Substation + Reactive Plant	1	$115,815,000
6	**George Town (TAS) Switching Station**		
6.01	220 kV Switching Station + Reactive Plant	1	$47,046,000
7	**Cable System**		
7.01	Supply 1,000 mm^2 Cu AC XLPE Cable 220kV 3-Core Submarine	298	$2,391,281,000
7.02	Installation AC Subsea Cable (4x circuits)	298	$1,104,149,000
8	**Bass Strait - Reactive Compensation Platform**		
8.01	Platform	1	$208,158,000
8.02	Reactive Compensation	1	$129,054,000
9	TOTALS		
9.01	Subtotal Estimated EPC Construction Costs		$4,219,359,000
9.02	Allowance for Project Planning, Permitting, Overheads, Contingency		$594,558,000
9.03	Development Cost	5%	$238,662,000
9.04	**TOTAL**		**$5,024,885,000**
10	Breakdown Summary		

#	Item	Qty.	AC System 500 MW
10.01	Onshore AC Connections, Substations, Reactive Compensation		$172,404,000
10.02	AC Overhead Transmission Lines		$214,313,000
10.03	AC Land and Submarine Cable		$3,495,430,000
10.04	Offshore Platform and Reactive Compensation		$337,212,000
10.05	Project Development, Planning and Permitting		$805,526,000
10.05	**TOTAL**		**$5,024,885,000**

10 Conclusion

Amplitude has, based on publicly available reference sources and our own industry knowledge, developed the cost estimate for replacement of the Basslink interconnector with modern equivalent technology. The estimated cost for the Basslink Modern Equivalent, which would comprise a symmetric monopole VSC system using polymeric cables, is approximately $1,581 m AUD in 2023.

Cost estimates developed for the alternative systems are as follows:

- AC technology (220 kV, 500 MW system): $5,025 m
- HVDC LCC technology (400 kV, 500 MW system): $1,672 m
- HVDC VSC technology (150 kV, 350 MW system): $1,260 m
- HVDC VSC technology (80 kV, 150 MW system): $855 m

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