

TECHNICAL MEMO



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HVDC Converter Station and Cable Cost Estimate Development

This technical memo presents a high-level cost estimate developed by Amplitude Consultants for North Projects of a concept 2 GW double symmetric monopole ± 525 kV high voltage direct current (HVDC) system, with underground transmission cables.

1. Introduction

VicGrid is developing transmission infrastructure to coordinate offshore wind (OSW) connections in Gippsland and Portland (subject to the Commonwealth offshore wind zone declaration process). These works involve the development and assessment of project options for each region.

North Projects has engaged Amplitude to develop a HVDC cable and converter station cost estimate based on pre-selected technical parameters to meet the needs of the specific power transfer capacity.

The high-level scope, brief discussion and estimates of the concept HVDC system and underground cable transmission line are presented in the following sections.

2. HVDC System General Information for Costing Inputs

2.1. Converter Station Technology

Amplitude considers multi-level modular voltage sourced converter (MMC VSC) technology as the most appropriate for this HVDC application. This is due to the required power transfer level, relatively lower losses and some considerations that are given to the connecting AC system strength that may be expected to be reduced over time due to increasing renewable generation penetration.

2.2. HVDC System Configuration

North Projects has advised Amplitude that the double symmetric monopole configuration was selected for this application and therefore will be the focus for the cost estimate of this concept HVDC system.

A single symmetric monopole is comprised of a single converter at each end (referred more broadly as a "converter station") with fixed HVDC "poles" at positive and negative on the DC side and operated as a standalone system.

Having a single converter at each end of the transmission line means that there is no redundancy in this configuration, therefore a fault on one cable or converter will cause both converters and the DC lines to trip. Any outage in the VSC converters or on either HVDC cable will result in the complete loss of the HVDC transmission system.

Two symmetric monopoles (double symmetric monopole configuration) can be built in parallel to provide redundancy for the HVDC system and also to facilitate higher power transfer capacities which will be required for this application.

A double symmetric monopole configuration can share the load between the two HVDC systems. The double symmetric monopole will require two HVDC cables per system (a total of four cables).

2.3. Converter Station Footprint

The converter station layout for a VSC converter in a double symmetric monopole configuration requires the following major components at each end:

- Two converter halls, each rated at ± 525 kV.
- Two sets of converter transformers (assumed 3x single phase units per pole) typically enclosed within containment walls.
- Converter AC side HV switchgear including the AC circuit breaker and associated instrument transformers.
- Connection to the station HV AC bus work for interconnection to the wider AC network.
- HVDC reactor and switchyard for connection to the underground HV cables.

An indicative converter station footprint dimension for a 2.8 GW double symmetric monopole converter station is expected to be in the range of approximately 250 m x 250 m, i.e. circa 62,500 m². If additional AC harmonic filters are required (based on the outcome of technical studies performed during the design and engineering phase) this will require a larger footprint for the converter station.

The AC switchyard dimensions will depend on the configuration and operating voltages on the interconnected AC networks, number of bays/circuits etc. and are not considered in detail here.

2.4. HVDC System Ratings Considering the Loss of Largest Infeed

North Projects advised Amplitude that the costing of the converters is to be based on a rating of 1,433 MW per symmetric monopole. This will mean that the HVDC system will only be able to transmit 2 GW under normal operating conditions, based on an assumption that a loss of no more than 600 MW is allowed for a single credible contingency.

In this case, the loss of any single pole (converter or cable) the “healthy” system will be able to ramp up and facilitate the transmission of an additional 400 MW, meeting the loss of infeed requirement without any need for overloading.

For the converter transformers, the ratings are dependent on the maximum power transfer requirement of each symmetrical monopole and the reactive power. The converter transformer ratings are assumed to be based on 1,433 MW of active power and power factor of 0.93 based on the AEMO’s automatic access standard requirement. With three single phase transformers per symmetric monopole at one end, this would give a rating of approximately 515 MVA per transformer.

2.5. HVDC Cable Technology

2.5.1. HVDC Cable Types

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 insulation made of layers of paper impregnated with high viscosity fluid while polymeric cables use extruded polymer-based insulation material.

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 assume polymeric cables. These cables tend to have a higher allowable insulation temperature than MI cables, with the added benefit that polymer cables will be lighter and easier to install.

2.5.2. HVDC Cable Ratings and Capabilities

The electrical characteristics of the HVDC cables and accessories are designed to meet the required DC current levels, the switching impulse withstand levels, lightning impulse withstand levels and short circuit levels determined during the technical studies performed for the project. The design of the HVDC cables should also take into account the maximum allowable losses determined during the optimisation of the transmission system.

The key factors that impact the design of the HVDC cables include:

- The required current carrying capacity, which is driven by:
 - the continuous active power transfer capability of the HVDC scheme.
 - the rated DC voltage.
 - any required additional short-time ratings and the frequency and duration of the additional loading cycles.
 - the number of HVDC cables required by the selected HVDC configuration.
- The thermal resistivity (TR) of the surrounding medium (soil types) along the cable route.
- The expected ambient temperature of the soil.
- The maximum conductor temperature allowed by the insulation.
 - Typical maximum conductor temperature of up to 70°C, but higher temperatures can be considered (for example 90°C) subject to cable type testing, prequalification testing and contract experience.
 - For this assessment, a temperature of up to 70°C for the HVDC cables is assumed.
- Layers for water blocking and mechanical protection.

2.6. Summary HVDC System

A summary of the key parameters selected for the concept HVDC system for the North Project application, for the purpose of developing a cost estimate, is provided in Table 1.

Table 1 – North Project Concept HVDC System Key Parameters

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 the region.
Converter Topology	MMC	Multi-level modular converter (MMC) topology 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 than other VSC topologies.
Configuration	Double symmetric monopole	This configuration provides a degree of redundancy required to be able to handle the loss of one system element (credible contingency) while not losing more than the allowable limit for largest loss of infeed of 600 MW. It also significantly reduces the likelihood of a “bipole” trip caused by the HVDC system.
Voltage Level	±525 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.
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 higher allowable insulation temperature, lower weight and reduced environmental risks.

These inputs are used to further develop the HVDC system in terms of sizing, ratings and cost estimation for the converters and cables.

2.7. Indicative Lead Times and Installation Durations

There is a high demand for HVDC at the present driven by a number of factors such as high renewable energy targets set by many countries, application of HVDC technology in connecting large renewable energy sources, a limited number of HVDC suppliers and a worldwide shortage of experienced people to be able to deliver these projects. The actual project schedule for a HVDC system depends on many factors, including:

- Available manufacturing capacity.
- Availability of HVDC and cable vendor engineering and design personnel.
- Quantity of HVDC cable required.
- Equipment transit times.

- The need for type and pre-qualification testing.
- The need to commission remote wind after HVDC completion may result in a much longer commissioning period.

In 2025, from the point of contractor engagement the expected schedule and delivery time for a typical HVDC system is expected to be in the order of 6 - 8 years from engagement with the HVDC supplier. Figure 1 provides a high-level view on what a typical delivery schedule would look like for the converter stations for a VSC HVDC system. Note that this schedule assumes that the HVDC cables can be designed, manufactured, delivered and installed within this timeframe, which needs to be clarified during project development as there is significant demand currently on the HVDC cable suppliers.

Figure 1 – Example of a VSC HVDC Project Schedule

	Est. Duration (Months)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Contract and Engagement	18								
Design and Manufacture	48								
Construction	30								
Commissioning	3								
Trial Period, Documentation and Close Out	3								

Another impact of the high demand is a very significant increase in the capital cost of HVDC converter and HVDC cable technology. Based on our various cost estimating activities, we have observed the cost of HVDC converters to have increased between 40% and 70% (depending on size and configuration) over the past 3-4 years. These increases have been accounted for in our cost estimates for this study.

3. High-Level Capital Cost Estimates

Amplitude's scope included development of a high-level EPC (engineer, procure and construct) capital cost estimate for a HVDC solution based on HVDC converter unit and cable rates derived from publicly available information.

The HVDC converter and HVDC cable supply costing used for this assessment is based on "per/MW" and "per/km" rates respectively, derived from selected publicly available cost sources. These estimates are suited for the comparison of projects and are to be considered to be informed but high-level estimates.

The next phase after this high-level assessment should include additional engineering and the engagement of HVDC converter and cable suppliers to determine a more accurate cost estimate for the proposed HVDC system transmission solution.

3.1. Costing Assumptions

The following assumptions were applied for the development of the cost estimates presented in this memo.

1. This high-level estimate (AUD, June 2025) has been developed for the purpose of presenting a cost for the selected HVDC system as discussed in this memo.

2. The capital cost estimates are limited to the costs directly related to the engineering, procurement, manufacture, construction, installation, testing and commissioning of the selected HVDC solution.
3. Other assumptions, exclusions, and details of the level of accuracy of the cost estimates are as described in this memo.

The cost estimates for this high-level assessment have been based on unit rates for the converters (per MW) and for underground cable (per km), which have been derived from costing information from publicly available sources, which may include:

1. Published feasibility and technology reports.
2. Announcements and press releases from HVDC converter and HVDC cable suppliers.
3. CIGRE technical brochures and papers.
4. Unit rates from Rawlinson's 2025 Construction Guide.

3.2. HVDC Converter Station Costs

There is a high degree of confidentiality associated with the cost of VSC HVDC converter stations from known suppliers, and this is even more so for the unit cost of individual components making it challenging to develop bottom-up cost estimates of any reasonable level of accuracy. Further, HVDC converter costs can vary over time and are greatly dependent on the level of global demand for HVDC projects at any point in time. At present, there is significant global demand for HVDC projects, and HVDC vendors have the opportunity to be quite selective in what projects that pursue.

In Amplitude's experience, initial costing assessments for early feasibility can be done using publicly available sources if these sources are carefully assessed and selected. However, more accurate cost estimates can only be achieved through engagement with HVDC converter station suppliers, the majority of which are located in Europe.

The high-level EPC cost estimates for the HVDC converter stations developed by Amplitude are presented in Table 2.

Table 2 – Concept HVDC Converter Station Capital Cost Estimate

Total MW Rating (Per Station)	DC Voltage	Converter Qty.	Cost /MW/Converter	Converter Estimate (\$AUD, 2025)
2,866 MW	±525 kV	4 ^A	\$627,000	\$3.594 Bn
Notes: A: There are two converters in one symmetric monopole system (one at each end) and therefore a double symmetric monopole system would have four converters. This would be constructed as two converters within a single converter station at each end of the double symmetric monopole system.				

From the values presented in Table 2, the overall capital cost estimate for two converter stations to make up the double symmetric monopole configuration rated at 2,866 MW (2,000 MW transfer in normal operation), is circa \$3.594 billion (\$AUD, 2025). The transmission component cost, being

underground cables for the complete length of the route, is described and presented in the following section.

3.3. HVDC Cable Costs

3.3.1. HVDC Cable Selection

Amplitude has reviewed the cable size provided by North Projects and assumed a suitable cable configuration and spacing to meet the required current carrying capacity for the HVDC system, considering a nominal operating voltage level of ± 525 kV as well as the anticipated maximum DC current. The environmental parameters assumed are as shown in Table 3.

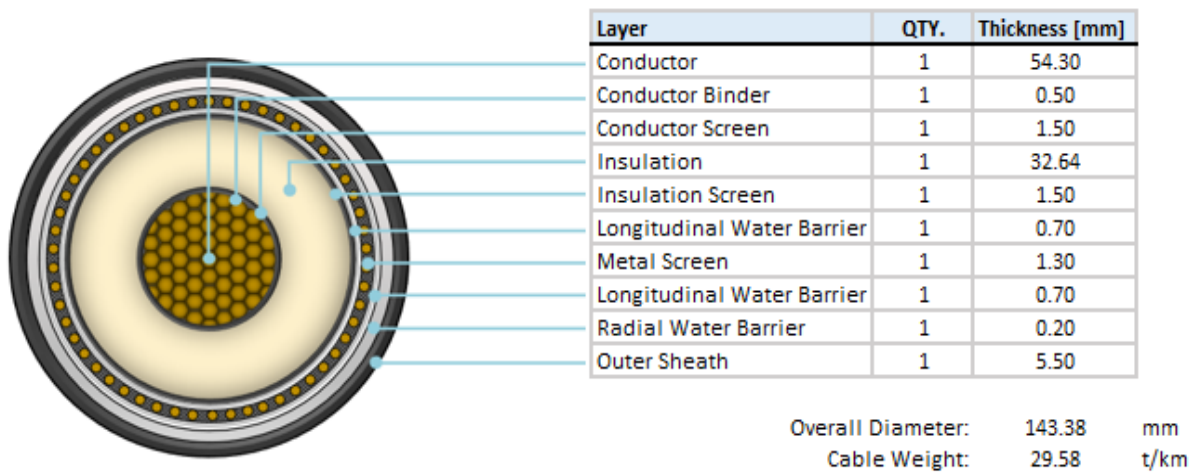
Table 3 – Land Cable Assumed Environmental Parameters

Parameter	Value	Unit
Thermal Resistivity of Soil	1.2	K.m/W
Temperature	30	°C
Burial Depth to Top of Cable	1	m
Conductor/Insulation Max. Operating Temperature	70	°C

It is possible that the thermal resistivity and temperature may be greater than the value shown in Table 3, particularly in some localised areas. Amplitude expects that this will be managed by measurement of the thermal resistivity prior to and during installation and the application of mitigation strategies in the event higher values are experienced, including importing known thermal resistivity backfill or spacing the cables further apart. For the purpose of this high-level cost estimate, Amplitude have limited the environmental parameters to the ones shown in Table 3 and have assumed that the additional cost of any localised higher thermal resistivity values will be well within the accuracy of the capital cost estimates developed in this assessment.

The concept HVDC cable design shown in Figure 2 has been determined for the purpose of developing the cost estimate based on Amplitude's experience and publicly available sources. The final cable design will depend on the actual environmental parameters and the selected cable supplier which may also influence the cost of the cable.

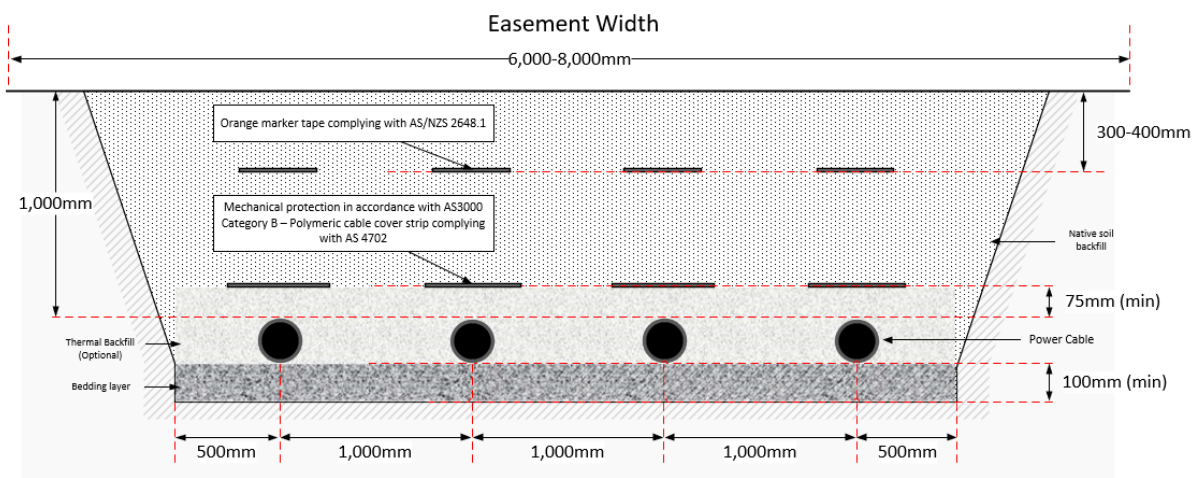
Amplitude has estimated the HVDC cable size proposed by North Projects of 2,000 mm². The cable model used for this assessment is shown in Figure 2. Note that the cable cross-section diagram is not shown to scale.

Figure 2 – Cable Model for 2,000 mm² Land Cable

Fibre optic cables (FOC) can provide a number of benefits such as improved coordination and control of the HVDC control systems, underground cable condition monitoring fault identification and improved voice and visual communication between the converter station sites. For the purpose of this assessment, Amplitude have assumed that the FOC cable will be integrated into the overall construction of the main HVDC power cables similar to modern HVDC long distance transmission projects such as SuedLink (Prysmian, 2020) and SuedOstLink (Prysmian, 2022).

3.3.2. HVDC Cable Installation

For underground cable installation, the cable trench profile assumed for this assessment is as shown in Figure 3. Each set of power cables (two per symmetric monopole system) will be laid and buried in a single trench with separation distances of a minimum of 1.0 m between each cable to maintain thermal and current cable ratings.

Figure 3 – Concept Cable Trench Profile

The minimum required current carrying capacity of the cables for this system is 1.4 kA so that each HVDC monopole is able to transmit 1,433 MW at ± 525 kV. Based on the environmental parameters,

installation configuration and cable design, the maximum cable current carrying capacity has been modelled to be 1.63 kA for a HVDC 2,000 mm² Cu polymer cable (refer to Figure 2), which is above the required 1.4 kA for the system but provides a reasonable level of margin to account for variations in environmental and cable design parameters at a later stage.

While the cable spacings shown in Figure 3 is to determine the minimum requirements to maintain cable ratings, Amplitude acknowledges that the spacing may need to be increased for practicality reasons for installation, repairs or operations and maintenance purposes.

HVDC cables are typically direct buried without installation of cable conduits, with examples of this existing in Australian long distance HVDC cable projects. This installation method provides a cost saving on materials and installation of the cables while at the same time improving the cable thermal rating and giving the cables a higher power transfer capability. Therefore, conduits have not been considered in the cost estimation of this report. The project may decide to use conduits (at a later stage) for other reasons, such as for constructability benefits or project staging.

Also, unlike HV AC power cables, HVDC cables do not require access to the joints for maintenance purposes and therefore typically do not require the installation of joint pits. The HVDC cable joint construction is therefore fully sealed and can be buried directly in the ground, without the need for accessible joint pits. For this reason, joint pits are omitted from cost estimates presented in this technical memo.

3.3.3. Cost Estimate Inputs and Assumptions

Amplitude has developed the HVDC cable estimates using the following assumptions:

- Amplitude has excluded costs associated with any civil works such as clearing, trenching, land remediation, or HDD requirements at North Project's request. Therefore, the estimates reflect only supply, delivery, installation and jointing of the cables.
- The cable estimates have been developed for a power transfer level of 1,433 MW continuous.
- The cost of cable termination is based on Amplitude's industry experience.

An estimate for the cost of the ± 525 kV 2,000 mm² Cu XLPE cable was developed, and determined to be \$891,000 per kilometre (AUD, June 2025). The overall installed cable cost is estimated to be \$716,000 per kilometre of route (see Table 4 below), meaning the installation of four cables in one trench.

3.4. Cost Estimate

Amplitude's high-level cost estimate for the North Projects concept HVDC system, which excludes costs associated with any civil works for the underground cables such as clearing, trenching, land remediation, or HDD requirements and also excludes any "non EPC" costs for the converter stations. The overall cost estimate comes to circa \$3.93Bn with the details of the estimate shown in Table 4.

Table 4 – Concept HVDC System Cost Estimate

PARAMETER		VALUE	UNITS
Circuit configuration		Double Symmetrical Monopole	
Converter Stations		2	
Voltage		±525	kV
Power Rating (Per Station)		2,866	MW
Cable Size		2,000	mm ²
Route Length		60	km
Number of Cables		4	
CONVERTER COST			
Converters supply cost		\$627,000	\$AUD/MW/Converter
Subtotal		\$3,594,000,000	\$AUD
CAPITAL COST – CABLE SUPPLY			
Cable supply cost per km of manufactured cable		\$891,000	\$AUD/km
Cable supply cost per km of route (four cables)		\$3,564,000	\$AUD/km
Subtotal		\$235,224,000	\$AUD
CAPITAL COST – CABLE INSTALLATION			
Cable terminations (total of 8)		\$660,000	\$AUD
Civil works – excavation, trenching, etc.		\$0 (Excluded)	\$AUD
Electrical works – cable laying, jointing, etc.		\$716,000	\$AUD/km
Subtotal		\$43,620,000	\$AUD
OTHER (Cable Related Non-EPC Cost)			
Engineering & PM	20%	\$55,000,000	\$AUD
Contractor PM	10%	\$27,500,000	\$AUD
Mobilisation & De-mobilisation	\$5M	\$5,000,000	\$AUD
Testing & Commissioning	1.5%	\$4,125,000	\$AUD
Subtotal		\$91,625,000	\$AUD
COST SUMMARY			
Converters		\$3,594,000,000	\$AUD
Cables (Supply, Install, Other, excl. Civils)		\$366,625,000	\$AUD
Total Cost:		\$3,960,625,000	\$AUD

3.4.1. Cable Cost Estimate Optimisation

Amplitude has also assessed 1,600 mm² and 1,800 mm² conductor sizes for the underground cables. Based on the environmental parameters provided in Table 4 and the cable spacings in Figure 3, the

maximum current-carrying capacity calculated is approximately 1.53 kA for the 1,800 mm² cable and 1.43 kA for the 1,600 mm² cable, both of which are greater than the system requirement of 1.4 kA. This could reduce the overall cost estimate for the complete HVDC system. A detailed cable rating study and system performance analysis is recommended to confirm the technical suitability of the smaller conductor size and ensure compliance with operational requirements.

4. Conclusion

In this report, Amplitude has presented a high-level cost estimate for the HVDC system as specified by North Projects.

Amplitude's cost estimate of the 2,866 MW $\pm$ 525 kV HVDC converter station costs and 2,000 mm² Polymer HVDC underground cable cost and installation in Australia for a transmission route of 60 km, has resulted in an overall cost of approximately \$3.96Bn (excluding cable civil works and any "non EPC" costs for the converter stations).