High Voltage Alternating Current (HVAC) and High Voltage Direct Current (HVDC) Technical notes

Jacobs

TasNetworks | Powering a Bright Future

(Prepared by Jacobs. Jacobs are contracted to provide technical engineering and project management advice for Project Marinus, which includes the HVDC Marinus Link cables and converter stations and the HVAC North West Transmission Developments)

Project Description

Australia's transition from coal-fired power to renewables is occurring quickly. The National Electricity Market (NEM) needs access to affordable, 'on-demand' dispatchable energy and long duration deep storage to ensure the lights stay on and power bills stay low. Project Marinus, covering Marinus Link and Tasmania's North West Transmission Developments, enables access to Tasmania's latent hydro capacity, high quality wind resources, and deep energy storage capability. Tapping into such low cost / high volume dispatchable energy resources means the benefits of Project Marinus outweigh the estimated $3.5 billion dollar cost. Project Marinus will be a significant contributor to Australia's emissions reduction ambitions, being a cost-effective way to rapidly cut emissions, helping to save at least 140 million tonnes of CO2 equivalent by 2050.

The Australian Energy Market Operator (AEMO) and the Australian Government have declared Project Marinus a national priority project. The Tasmanian Government through TasNetworks is progressing Project Marinus in partnership with the Australian Government. The project is currently in the Design & Approvals phase.

Project Marinus involves large and sophisticated infrastructure. It will support an undersea and underground 1500MW HVDC connection between Tasmania and mainland Australia, and will also increase Optic Fibre capacity across Bass Strait leading to increased opportunities in telecommunications.

Significant job opportunities and regional benefits will flow from the construction of Marinus Link and Tasmania's overhead HVAC North West Transmission Developments.

Independent analysis shows these developments could unlock significant existing and potential renewable energy and storage projects, thousands more jobs, and billions more in regional investment.

What is HVAC?

The power in your home is known as Alternating Current or AC power. It can be generated by different types of power generators and transmitted to your home via the transmission and distribution networks. AC power forms the backbone of transmission and distribution networks in Australia and around the world.

This form of electrical power provides various advantages:

- The voltage levels can be changed in a simple, proven and cost effective manner with the use of transformers and substations.
- AC networks, compared to the DC alternative, are easily augmented, expanded and upgraded.
- Three phase and single phase systems allows for effective connection of consumers with variable consumption needs.

There are however some limitations of AC power which include:

- When compared to DC, electrical losses are high for long transmission lines, both overhead and underground.
- AC cables have high electrical capacitance which reduces the amount of power they can carry and requires compensation equipment.
- All assets on the network must be synchronised to the same voltage and frequency. Stability of both voltage and frequency can become a problem for regional areas connected by long transmission lines.

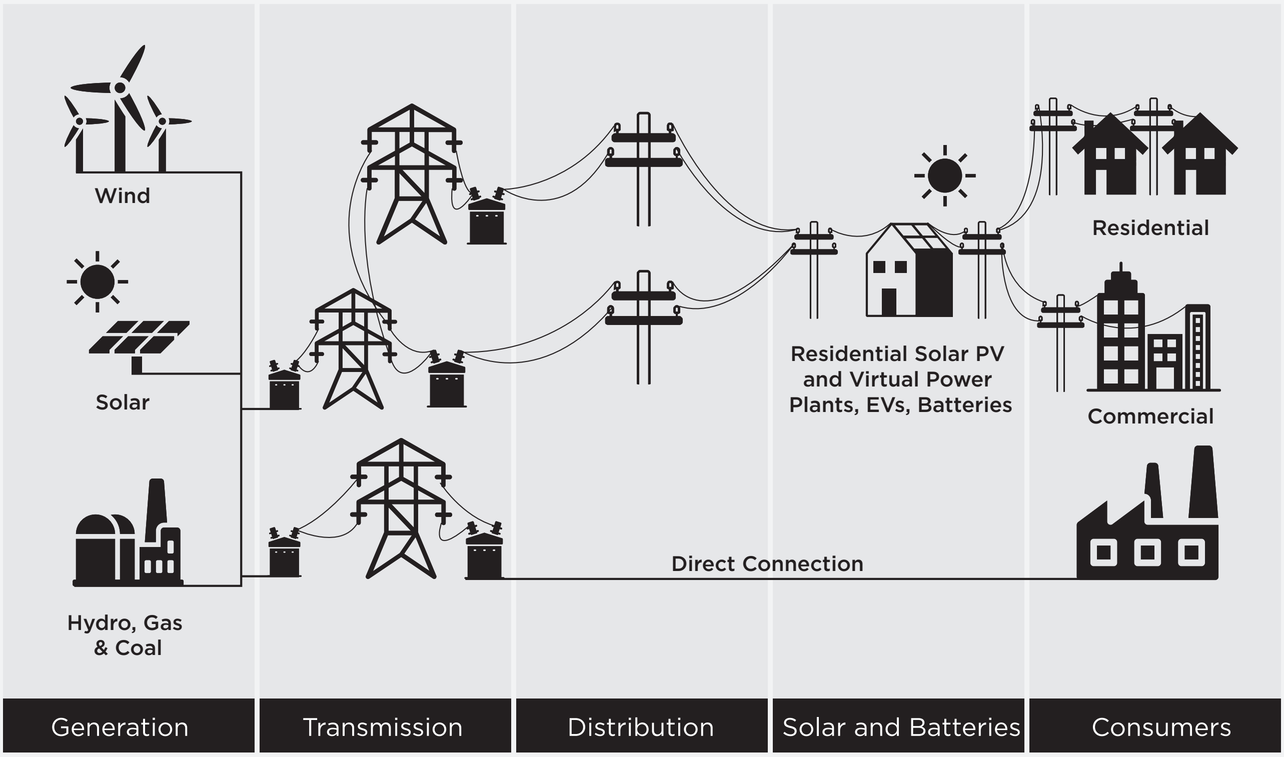


Figure 1 General Power Networks

What is HVDC?

HVDC transmission lines are used for bulk transmission of electricity where the connection requirement is usually between two points only. Unlike HVAC overhead transmission lines, connection to HVDC transmission lines cannot simply be done with a transformer or a substation. HVDC connections require the use of complex, sizable and costly converter stations at each end of the line to connect back into the HVAC network, in this case one in North West Tasmania and the other in the Latrobe Valley in Victoria. Marinus Link is a good example of a proposed HVDC connection with two converters located close to suitable connection points in the HVAC network.

When seeking to connect to the strongest parts of the Victorian and Tasmanian power systems HVDC transmission systems like Marinus Link have advantages over traditional HVAC transmission systems including:

- HVDC interconnectors can connect HVAC networks operating at different voltages or/and frequencies together, such as Tasmania's 220 kV network and Victoria's 500 kV network.
- They avoid the capacitance issue that HVAC cables cause and therefore can be used over longer distances for high capacity energy transfer.
- They typically have lower losses compared to HVAC systems over long distances.
- HVDC is the only technically feasible option to transfer energy across open water.
- Undergrounding the HVDC cables reduces the risk and cost related to lightning strikes on HVDC overhead lines.

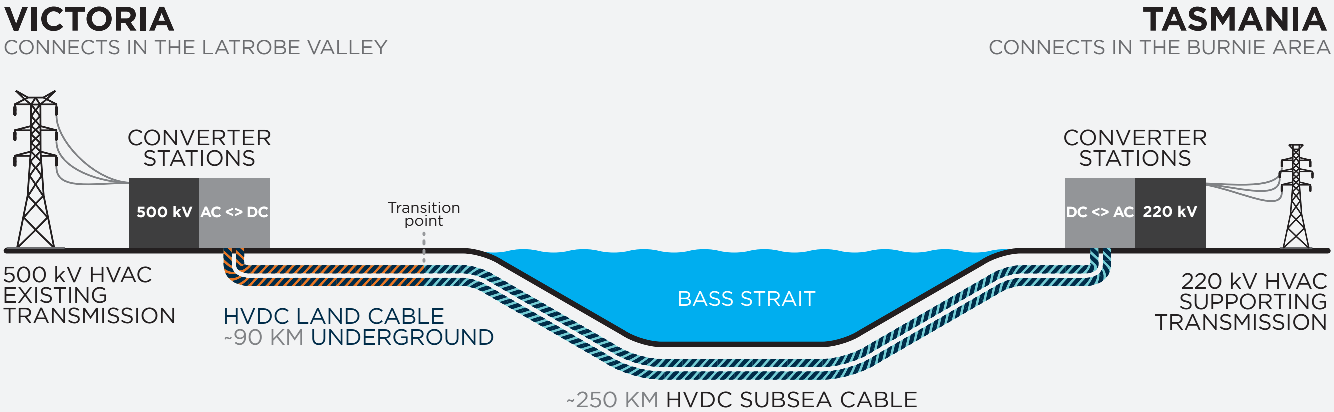


Figure 2 Marinus Link connection configuration

Technical Terms

Alternating Current (AC)

AC is the flow of electric charge that periodically reverses direction and continuously changes magnitude with respect to time.

Direct Current (DC)

DC is the flow of electric charge that maintains a single direction flow, from the positive pole to the negative pole, without any magnitude change for a specific load.

Voltage

Voltage is the force from an electrical power source that pushes electric charge through a conductor, resulting in a current.

Power

Power is a measure of the rate that electrical energy is transferred, or work that is done, along a conductor.

Electromagnetic Fields (EMFs)

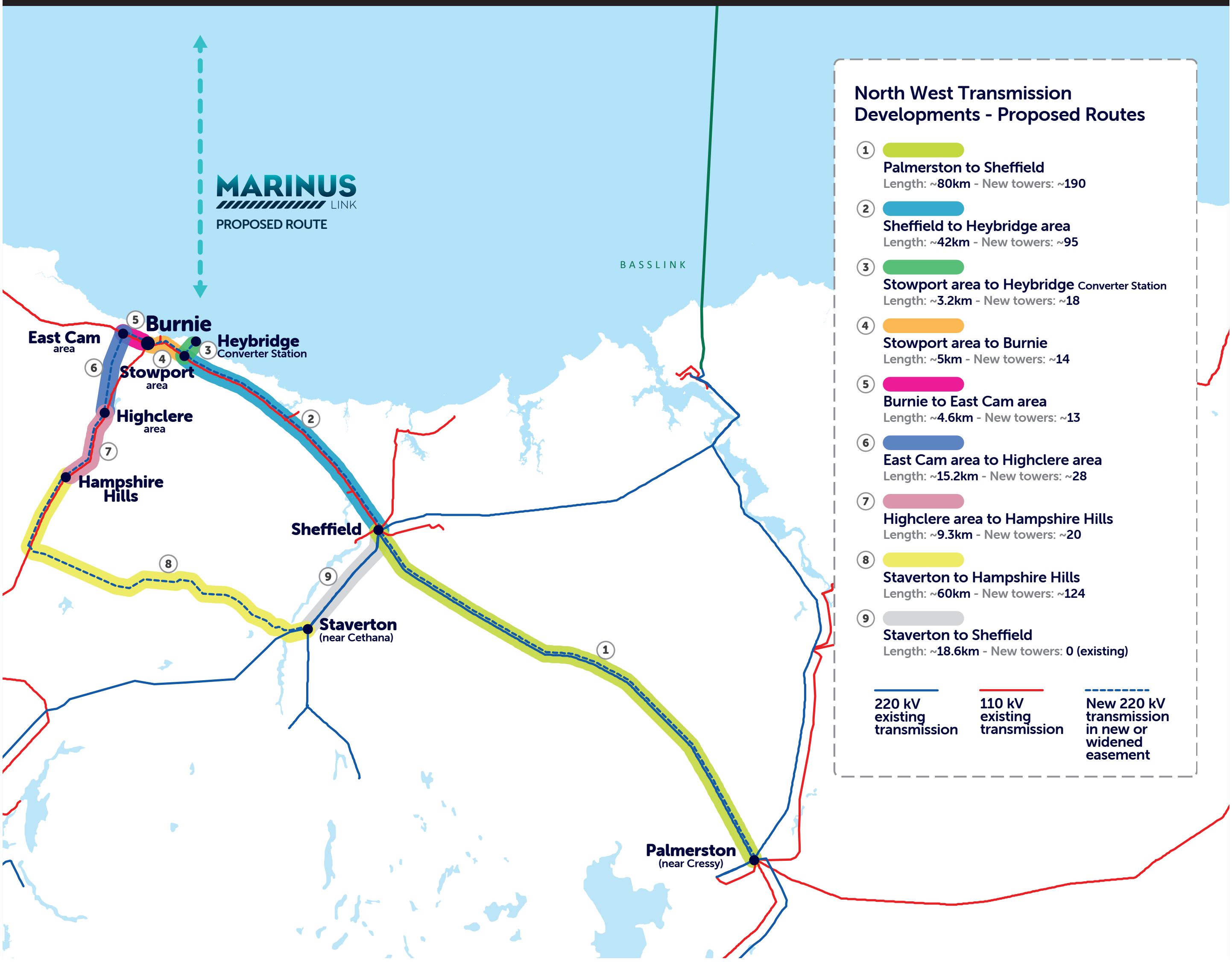
Electromagnetic fields are produced by accelerating electric charges in a conductor and are a combination of electric and magnetic fields. The magnitude of the field is proportional to the current. Such fields can excite an electric charge in nearby conductors through the principle of electrical induction.

The North West Transmission Developments

To support the electricity transmission developments in North West Tasmania, the network will need to undergo significant changes over the coming years. These changes include building new transmission lines and switching stations and with upgrades to existing lines and substations to increase the capacity of the network. These developments will also help to improve the reliability of Tasmania's power system.

The connection point for Marinus Link at Heybridge, near Burnie, was chosen as an optimal location; proximal to the coast and within an area of Tasmania's existing HVAC transmission network which connects numerous renewable energy assets and substations, including the area known as the North West Renewable Energy Zone. By upgrading the existing HVAC network, energy transfer via Marinus Link will be possible to its full design capability, while ensuring resilience and capacity within the Tasmanian transmission network. The map below shows the proposed works to be completed.

Figure 3 The proposed North West Transmission Developments



What Works Are Required?

Can we upgrade the NWTD with underground cables rather than overhead lines?

While development of underground cable technology is advancing, there still exists some significant limitations for underground cables to replace long distance overhead transmission line networks.

Underground HVAC is not feasible in Tasmania because:

- It takes much longer to construct;
- It is 7-10 times more expensive to construct;
- There are still impacts to landowners like farmers;
- Specialist skills sets are needed from mainland/internationally;
- There are greater environmental impacts from vegetation clearance and trenching; and
- It is harder to find and repair faults on underground assets.

Cost

Palmerston to Sheffield case study:

Jacobs were commissioned to undertake a class 5 cost estimate for undergrounding one section of the proposed North West Transmission Developments (NWTD). The section between Palmerston and Sheffield is ~80km long and traverses rural farmland, with terrain that is relatively flat and accessible from a construction perspective compared to other more mountainous rocky sections of the NWTD.

The cost to develop this route underground utilising HVAC cable technologies as an alternative to HVAC overhead transmission infrastructure was estimated to cost 7-8 times more ($1 billion vs $144 million) and take 2.5-3 times longer to construct (5 years vs 1.6 years). An underground HVDC option is almost 10 times more expensive ($1.4 billion vs $144 million) mainly due to the requirement to build converter stations at either end of the connection at a cost of up-to $500 million for a pair.

Palmerston to Sheffield transmission option cost comparison summary

Option	Notes	Total cost $'M	Factor of Baseline
Overhead Line Cost (Baseline)	220kV Double Circuit, twin conductor. Including contractor direct and indirect costs. Excluding cost for removal of existing 220kV single circuit line.	$144.5	1.0
HVAC Buried Cable Option	Based on 3 circuit 220kV design. Including reactive compensation.	$1,064.5	7.37
HVDC Cable Option	Based on 2 circuits # 320kV with a single pair of converter stations. Prices factored to suit 900MVA continuous operation.	$1,411.0	9.77

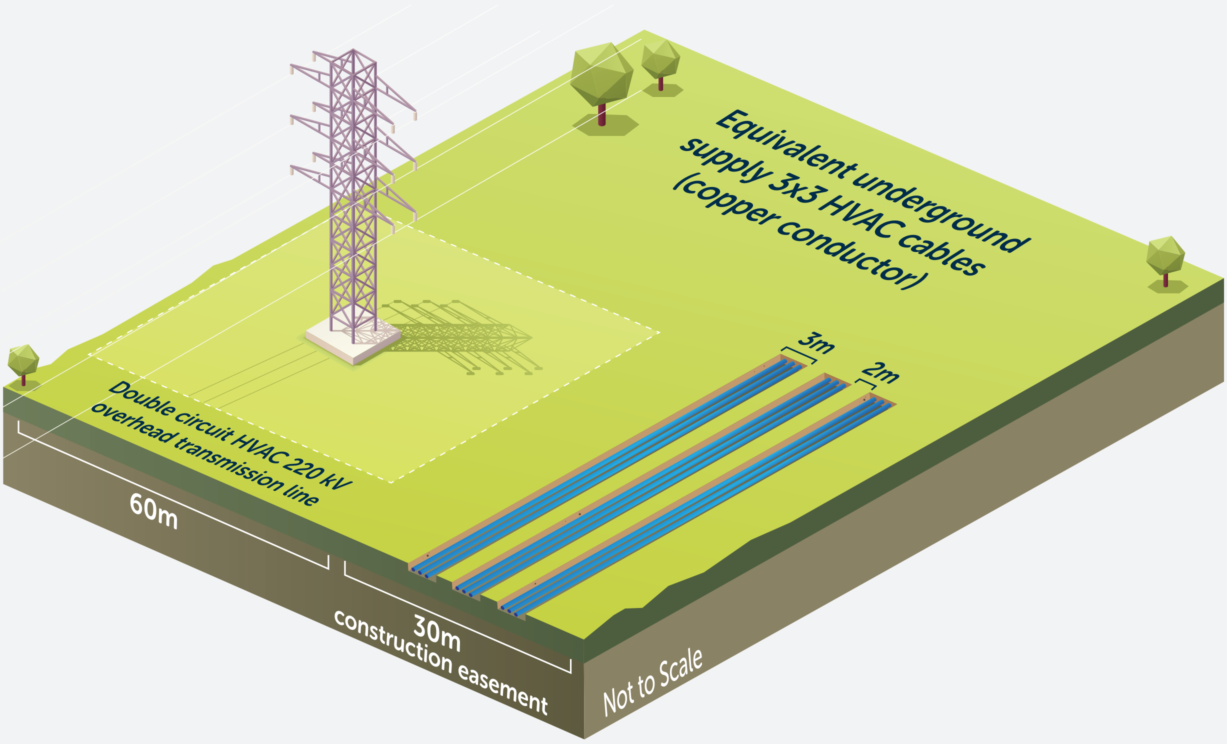


Figure 4 Overhead lines with the equivalent underground cable configuration comparison. (copper conductor configuration)

Power

Overhead lines and underground cables cannot transmit the same amount of electrical energy using the same size conductor. This is mainly because the flow of electricity generates heat within a conductor. Overhead lines can easily dissipate this heat due to air flow around the conductors, while underground cables cannot. Underground lines must typically be larger in size and greater in number in order to transmit the equivalent electrical energy of their overhead counterparts. For the overhead lines proposed for the North West Transmission Developments, up to four sets of three cables could be required if it was installed underground.

Vegetation Clearance and Management

Both underground cables and overhead lines require vegetation clearance to allow for installation and ongoing maintenance. Burial of underground cables results in ground disturbances along the entire length of the route; while those associated with overhead installation are localised to the tower sites.

In both cases, large tree growth is discouraged with the preference being for low level vegetation such as grasses and small shrubs. Cable joint bays must be accessible at all times in the event of a fault.

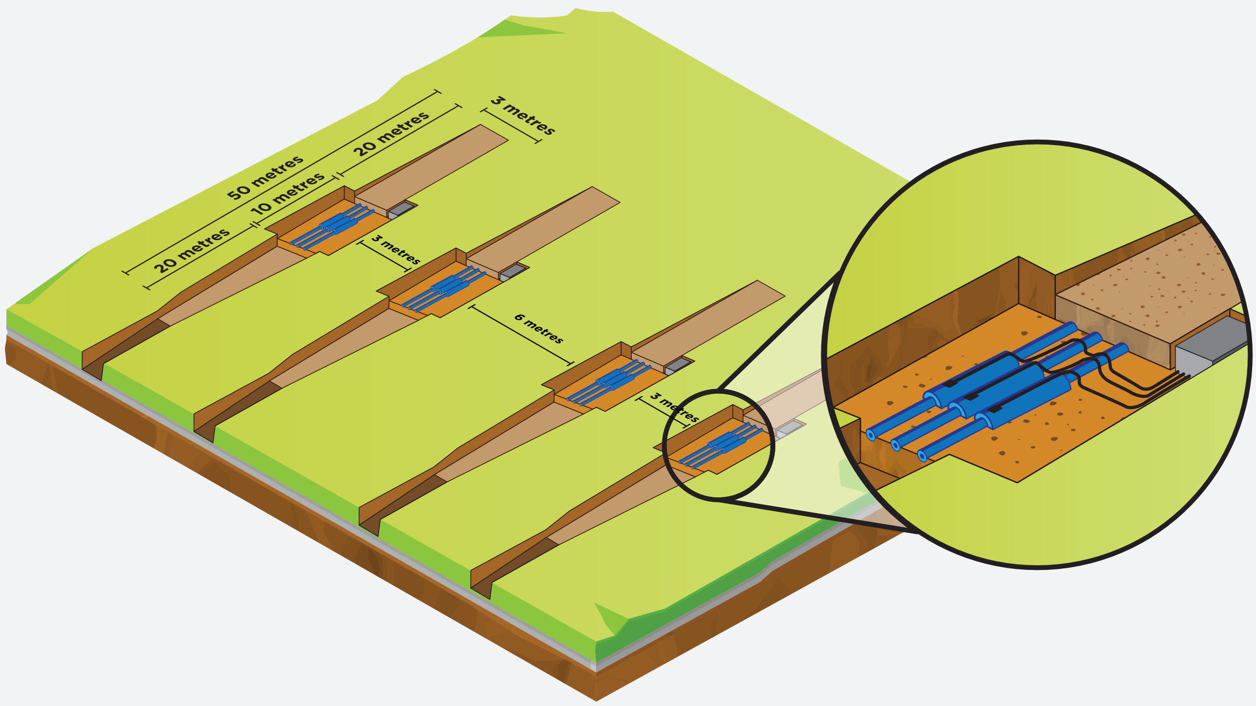


Figure 5 There are up-to 4 cable joint bays for HVAC including 12 joints every 1000 metres (aluminium conductor configuration)

Cable Joints

Underground cables are typically transported on cable drums up to 1000 m in length. This requires joints between sections of cables to be made in what are called jointing bays. The jointing process for 220 kV HVAC cables is complicated and each individual cable joint can take a number of days, performed by highly skilled international resources in high global demand. To underground the overhead lines in North West Tasmania with the resources available would require years of jointing activities. Overhead line conductors can have much longer drum lengths and the jointing process only takes hours. Cable jointing requires a clean room to be constructed along with other auxiliary underground equipment such as link boxes. Each joint bay is typically 10 m long and 3 m wide.

Difficult Terrain

Installing underground cables in undulating terrain can be difficult and introduce major risk and complexities during construction and maintenance activities. This is normally due to cable-pulling activities, installation of trenches, and horizontal directional drilling. Typically complex and difficult terrains are technically better traversed by overhead lines. Multiple underground route sections would be technically challenging for cable installation, as well as economically unfeasible. This approach would leave the asset unreliable (due to the multitude of joints) and difficult to maintain considering the high levels of availability required for these networks.

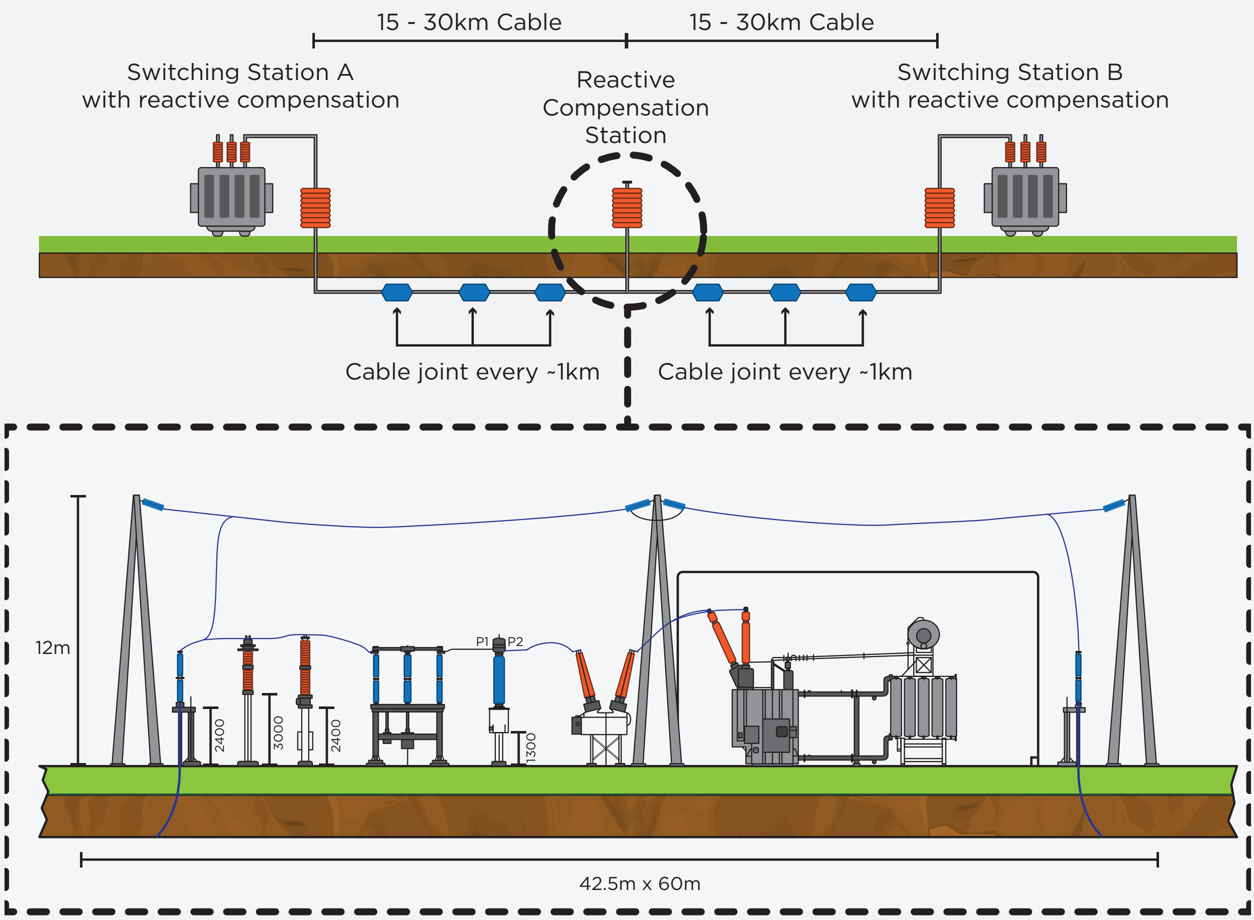


Figure 6 Reactive compensation

Capacitance

Underground cables introduce higher capacitance onto the network due to the large electrical field contained between the cable conductor and the metallic sheath. This capacitance reduces the amount of power which can be safely transferred by the circuit. To compensate for this, electrical equipment which provides reactive compensation is typically installed either at one end or both ends of the circuit or, as would be the case with the North West Transmission Developments, at multiple points along the various route sections.

This results in larger substations and an increased number of electrical yards and compensation assets along the route.

Capacitance limits the length of long distance high capacity submarine AC cables as it is impractical to install compensation stations along the cable.

Why HVDC instead of HVAC for Marinus Link?

Marinus link is an HVDC interconnection, a type of electrical system very different from the HVAC systems found in the existing electrical network and the AC power used in 240 volt household mains. HVDC cable systems have very little losses and are used to transmit large amounts of power at high voltages over long distances, usually between two connection points only. They are not suitable to replace the existing AC network as they require a large, complex and costly converter station at each end.

Due to the long length of the submarine cable, Marinus Link can only be built using HVDC cables. As such the system design already caters for the two converter stations, which makes the option of going underground instead of overhead in Victoria less costly than it would be to go underground for the NTWD.

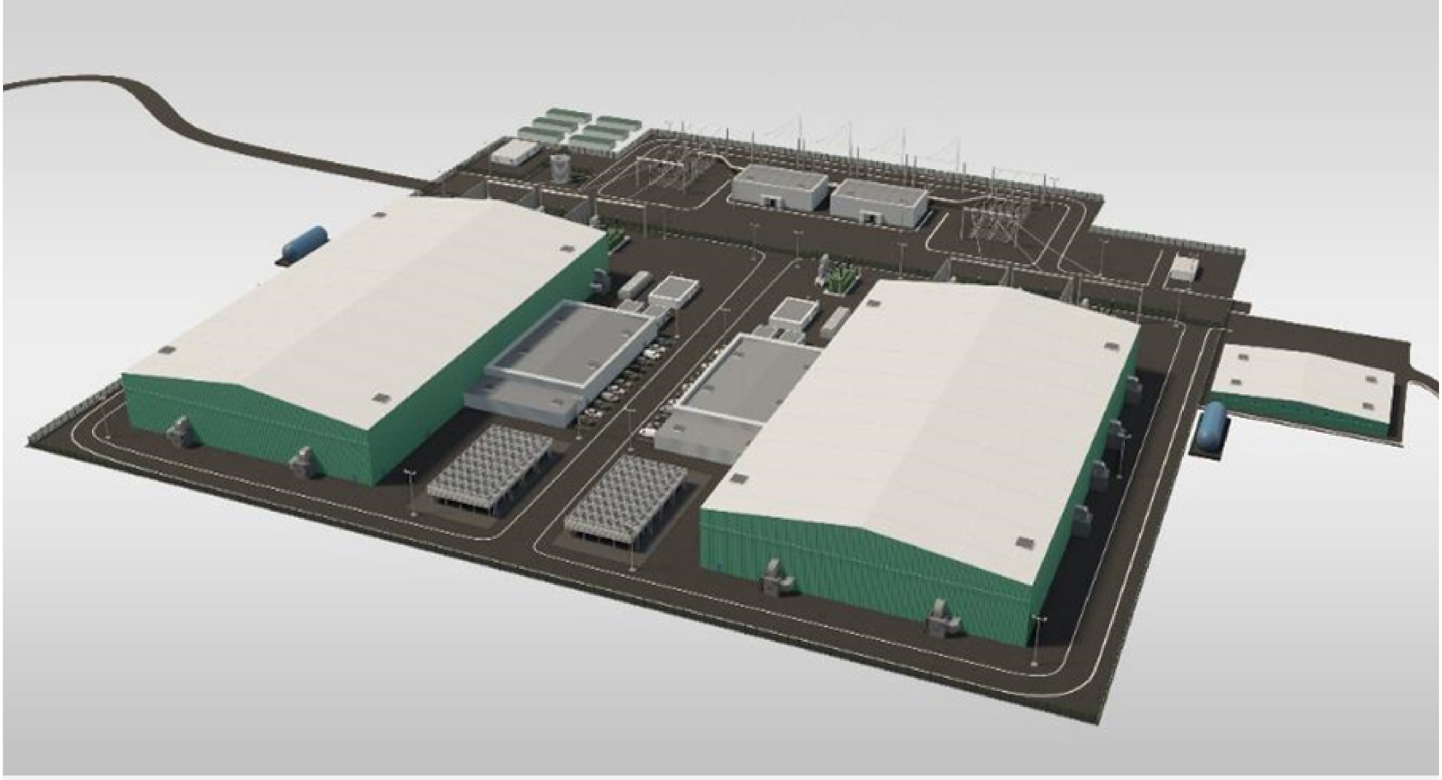


Figure 7 A pair of converter stations

What Is A Converter Station?

While HVDC excels at transporting large amounts of energy between two points over long distances, DC power must be converted back to AC in order to be distributed for end use. Converter stations are therefore required at each end of an HVDC link in order to convert electric power from AC to DC and vice versa. Converter stations contain the HVDC cable terminations, as well as a place called a "valve hall" which converts electricity from AC to DC, and transformers, which connect the converter station to the AC grid. Converter stations also accommodate differences in voltage frequency at each end, so that power transferred from Tasmania can be synchronized to the power system in Victoria and vice versa.

Staying Informed About The Northwest Transmission Developments

NWTD Version:

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