INDEPENDENT ANALYSIS OVERVIEW

Comparing high voltage overhead and underground transmission infrastructure

About the review

The University of Queensland and Curtin University have completed an independent analysis of the benefits and trade-offs between overhead and underground transmission line infrastructure.

The review, called 'Comparing High Voltage Overhead and Underground Transmission Infrastructure', seeks to establish a clear and consistent approach to evaluate overhead transmission lines and underground transmission cables, including the consideration of community concerns around the need for new transmission infrastructure to connect large renewable energy generation projects.

It has demonstrated this through systematic reviews of Australian and international studies and literature, as well as incorporating experiences of Transmission Network Service Providers (TNSPs) in Australia and overseas. The purpose of the report was not to identify a preferred technology, but rather outline the considerations and trade-offs associated with both overhead transmission lines and underground transmission cables.

Subject matter experts were engaged to undertake a peer review of the research. This inclusive approach aimed to address a broad range of technical, economic, environmental, social and cultural factors linked to the challenges of expanding Australia's electricity grid to support the energy transformation currently underway.

The review's Summary Report and associated Comparison Table are available online on the University of Queensland and Curtin University websites. This brochure provides an overview of key research findings, examining the different perspectives between overhead transmission lines and underground transmission cables.

The research was commissioned by Powerlink, the Government Owned Corporation that develops, operates and maintains the high voltage electricity transmission network in Queensland.

Curtin University

THE UNIVERSITY OF QUEENSLAND AUSTRALIA

Powerlink QUEENSLAND

High voltage transmission technologies

There are two types of high voltage transmission technologies - alternating current (AC) and direct current (DC). This section of the brochure explores their key features.

AC sees the flow of electrons switching from positive to negative at regular cycles or frequency. In Australia, the frequency of AC is 50 hertz or 50 cycles per second. On an AC transmission line, power is transferred via three phases per circuit. In comparison, DC has no cycles or frequency and transfers power with two phases or polarities, one being positive and the other negative. AC is easier to generate and transmit over long distances, as it can be stepped up or down using transformers. Normal household electricity that comes from a wall outlet is AC.

High voltage alternating current (HVAC)

For years, HVAC overhead transmission lines have been the most common form of transmission line infrastructure, providing the lowest cost system for connecting multiple generators and providing electricity to customers. They are designed to meet high-performance standards for safety and reliability with proven technologies for structures, conductors and insulators that, with good maintenance practices, have a service life of between 60 to 80 years.

Transmission lines are typically constructed at 132kV, 275kV, 330kV and 500kV in Australia, with the higher voltages affording greater power transfer along a single transmission line. As the voltage increases, the size of the transmission tower increases as shown in the comparison table within this brochure.

In high density urban areas where there is congestion of overhead lines, infrastructure constraints or in areas of environmental sensitivity and natural beauty, HVAC underground transmission cables have been used. The application of HVAC underground cables is limited to much shorter route lengths, for example around 50km for 500kV, due to associated energy losses when compared to an overhead transmission line of the same voltage. HVAC underground cables are expected to have a service life greater than 40 years.

Powerlink works to install a 132kV underground cable to connect Vena Energy's Wandoan South Battery Energy Storage System to the transmission network.

High voltage direct current (HVDC)

HVDC is an alternative to the HVAC system, and involves overhead transmission towers and underground transmission cables designed to transfer power over very long distances (hundreds of kilometres) with lower energy losses than HVAC. HVDC transmission generally becomes more economic for longer route interconnector transmission lines.

HVDC requires large and costly AC/DC converter stations to provide connection points to the existing HVAC transmission grid and any generators and loads along the route.

For example, the AC/DC converter station site for the Marinus Link project (a proposed undersea and underground electricity and telecommunications interconnector between Tasmania and Victoria), will be up to 16 hectares in size[1], which is almost 30 football fields. Noise levels from equipment at converter stations can also be an environmental issue.

Until now, HVDC has been used predominantly for inter-regional transmission connectors and submarine cables – like the connections between Tasmania and Victoria.

Transmission line easements

Transmission lines are typically located within easements, for both overhead and underground infrastructure. Easements provide a legal 'right of way' over a portion of land to safely build, operate and maintain transmission lines. Easement widths for overhead transmission lines are typically 40m for a 132kV double circuit and around 70m for a 500kV double circuit. Underground transmission cables still require an easement or corridor depending on location. These may be a relatively small footprint when installed in tunnels and ducts, but when installed in open ground (mainly in rural areas), the easement footprint can be considerable – typically around 10m for a 132kV HVAC underground cable and 40m for a 500kV HVAC underground cable (noting this width is still less than an overhead lines easement).

[1] The Victorian Converter Station Fact Sheet, Marinus Link, March 2003, marinuslink.com.au

HVAC overhead transmission lines are the most common form of transmission line infrastructure, providing the lowest cost system for connecting multiple generators and providing electricity to customers.

Economic considerations

When you compare the cost of HVAC overhead versus HVAC underground cable transmission, the cost of undergrounding is generally in the range of 3 to 20 times more expensive depending upon type of construction, route length and other route specific factors.

HVDC overhead transmission lines generally become more economic for longer route interconnector transmission lines. Project costs for HVDC were not examined in this review, however the break-even cost point for HVDC overhead transmission is expected to be at a route length of around 600km to 650km when compared to an equivalent 500kV HVAC overhead line. The break-even distance will depend on project specific parameters such as power transfer capacity, number of circuits, system voltage, converter technology, installation conditions and environmental factors.

Environmental considerations

There is the potential for environmental impacts with both overhead and underground transmission lines. Clearing vegetation for easements can impact on wildlife habitats, with overhead lines potentially causing a barrier effect leading to changes in bird migration patterns. The use of underground transmission lines with a smaller easement footprint can somewhat mitigate this impact.

In contrast, underground transmission lines may cause soil degradation and hydrological alterations throughout the lifetime of underground cables.

To minimise the environmental impacts from any transmission project, there are strict legislative requirements in place at both Federal and State levels. These approval processes require detailed assessment and surveys to comprehensively examine social, environmental and economic aspects of a project.

Social considerations

In the studies reviewed, overhead transmission lines and towers were viewed negatively because of their visual impact on the landscape. This impact was not mentioned in relation to underground cables. Perceptions surrounding the impact of overhead transmission lines on property values is also mostly negative.

Powerlink's goal is to identify the location for our infrastructure that has the least overall impact from a social, environmental and economic perspective. For more information, please view our Transmission Easement Engagement Process.

Construction work underway to install a 132kV underground cable as part of the Wandoan South Battery Energy Storage System Connection Project, delivered for Vena Energy.

Factors examined

The following table summarises some of the technical, economic and environmental factors examined in the review in more detail. Please refer to the review's full Comparison Table on the University of Queensland and Curtin University websites for additional information on a range of factors.

Factor	HVAC Overhead	HVAC Underground	HVDC Overhead	HVDC Underground
TECHNICAL FACTORS				
Feasible maximum line route lengths	Overhead transmission lines can traverse long routes up to 1,000km.	Up to 60km (≥ 275kV).	Feasible route length for comparable HVAC transmission lines is currently up to 1,000km for both HVDC overhead lines and HVDC underground cables.	
	To maintain voltage control at transmission voltages typically above 275kV, specialised equipment such as shunt reactors or static var compensators are required at intervals along overhead and underground transmission.			
Power conversion equipment required	Not applicable.	Not applicable.	AC/DC power conversion equipment is required at each end of the transmission line. This is a major cost factor for HVDC systems and can have other impacts such as land disturbance, noise and additional system losses.	
Above ground impacts and construction requirements	Typical lattice tower height and conductor span lengths for double circuit lines: • 500kV: 60m to 80m high, spans 300m to 500m • 330kV: 50m to 60m high, spans 300m to 400m • 275kV: 40m to 50m high, spans 300m to 400m • 132kV: 30m to 40m high, spans 200m to 300m. Alternative tower designs may have lower heights.	Transition structures and fenced ground terminations are required for connection to an overhead transmission line.	Structure heights will typically be less than the equivalent HVAC overhead transmission line. Structures will be more compact as less conductors will be needed. HVAC lines can be converted to HVDC application.	Transition structures and fenced ground terminations are required for connection to an overhead transmission line or substation.

Factor	HVAC Overhead	HVAC Underground	HVDC Overhead	HVDC Underground
TECHNICAL FACTORS continued				
Below ground impacts and construction requirements	Tower foundations and earthing conductors.	Cable trenching to lay conduits or cables – typically 1m to 2m deep. Trench widths vary depending on the number of cables and power transfer rating per circuit: • 500kV: 4m to 5m • 330kV: 1.5m to 2m • 275kV: 1.5m to 2m • 132kV: 1m to 1.5m Horizontal direction drilling or micro-tunnelling may be required at some locations e.g. under waterways, rail corridors or busy roads. Cable tunnels may be required in high density urban areas.	Tower foundations and earthing conductors.	Similar to HVAC underground transmission lines, however trench widths may be less as fewer cables will generally be required for the same power transfer capacity.
Vehicle access tracks	Access tracks are required for construction (heavy vehicles) and ongoing maintenance (light vehicles). Primary requirement is access to structure location for construction and an ongoing requirement for vegetation management along the route.	Access tracks along the cable route are normally required for construction and ongoing routine inspection and maintenance. The impact will vary depending upon the route, terrain and installation methods.	Access tracks are required for construction (heavy vehicles) and ongoing maintenance (light vehicles). Primary requirement is access to structure location for construction and an ongoing requirement for vegetation management along the route.	Access tracks along the cable route are normally required for construction and ongoing routine inspection and maintenance. The impact will vary depending upon the route, terrain and installation methods.

Factor	HVAC Overhead	HVAC Underground	HVDC Overhead	HVDC Underground
TECHNICAL FACTORS continued				
Future connection capability	HVAC overhead transmission lines provide the most economic and flexible capability for future connections to the line.	HVAC underground transmission lines provide some economic and flexible capability for future connections to the line. Costs will be greater than overhead lines however with more expensive underground works to extend, joint and terminate cables.	HVDC lines provide the least economic and flexible capability for future connections due to the requirement for additional converter stations. HVDC is more suited to applications for direct power transfer between two distant locations.	
Reliability and return to service times	Typical outage rate of 0.5 to 1.0 outage per 100km per year. Structural failure rate is around 1 in 150,000 per annum. Overhead lines are exposed to severe weather including lightning strikes. Repair time for faults is a much shorter duration compared to underground cables.	Outage rates are typically lower than equivalent overhead lines. Repair time for underground cable faults is a much longer duration than overhead lines due to excavation, cable jointing and electrical testing work required e.g. up to four weeks per circuit but may be longer.	Limited data is available however outage rates are expected to be similar to HVAC overhead transmission lines. The lesser number of conductors in a HVDC line would result in less exposure to faults compared to HVAC, noting return to service times may be extended if the fault is located at a converter station.	Limited data is available however outage rates are expected to be like HVAC underground transmission lines. The lesser number of conductors, joints and terminations in a HVDC line would result in less exposure to faults compared to HVAC.

Transmission network service providers work with landholders to minimise the impacts of overhead transmission lines on their farming operations.

Factor	HVAC Overhead	HVAC Underground	HVDC Overhead	HVDC Underground
TECHNICAL FACTORS continued				
Electromagnetic Fields (EMF) (all transmission technologies are designed to comply with standard limits)	Magnetic field levels are maximum under the centreline of the transmission line and decrease less gradually with distance from the line, compared to a similar voltage transmission underground line. Magnetic field levels at 40m from overhead transmission line are similar to levels from typical appliances found within a home.	Magnetic field levels are highest above the centreline of the underground transmission cable and decrease more rapidly with distance from the cable compared to an overhead line. Electric fields are contained within a cable with an outer earth bonded metallic sheath. However, the typical magnetic field levels at 1m above ground level at the centreline of an underground cable will be greater compared to an equivalent overhead line. Magnetic field levels at 4m from underground transmission line are similar to levels from typical appliances found within a home.	DC magnetic fields are static and subject to higher reference limits (i.e. less onerous) compared to AC. HVDC overhead line design needs to control and minimise the occurrence of charged ion particles being produced and accumulating in areas around lines.	DC magnetic fields are static and subject to higher reference limits (i.e. less onerous) compared to AC.
Noise	Audible noise can occur due to: • corona discharge on the transmission line conductors • dirt or pollution build-up on insulators • wind effects on transmission structures and associated fittings. These effects need to be considered in the design process and maintenance measures employed to ensure noise is within compliance limits.	No audible noise from underground AC cables.	Audible noise is similar to HVAC overhead transmission lines. Design measures are applied to ensure noise levels are within compliance limits. Audible noise from HVDC converter stations will occur. This needs to be considered in the design and location of converter stations to minimise impact.	No audible noise from underground cables. Audible noise from HVDC converter stations will occur. This needs to be considered in the design and location of converter stations to minimise impact.

Factor	HVAC Overhead	HVAC Underground	HVDC Overhead	HVDC Underground
TECHNICAL FACTORS continued				
Corridor and easement width requirements (depending on route specific factors including technical, safety, construction and maintenance requirements)	For double circuit typically around: 500kV AC ~ 70m 330kV AC ~ 60m 275kV AC ~ 60m 132kV AC ~ 40m	For double circuit, rural: 500kV AC ~ 30m to 40m 330kV AC ~ 10m to 20m 275kV AC ~ 10m to 20m 132kV AC ~ 5m to 10m Urban installation corridor width depends on the availability of suitable public road corridors or if there is a requirement for a tunnel. Land is also required for underground to overhead transition equipment.	Corridor widths for HVDC overhead lines are similar to HVAC overhead lines. Buffer zones required for EMF reduction or prudent avoidance would be less.	Corridor widths for HVDC underground lines will be generally less than HVAC underground transmission lines. This is due to a lesser number of cables and reduced trench widths required for installation.
Lifespan	60 to 80 years.	Greater than 40 years.	60 to 80 years.	Greater than 40 years.
Construction timeframes (depending on route length, topography and other route specific factors)	Two years.	Four to six years.	Two years.	Four to six years.
Bushfire risk	Overhead transmission lines can cause bushfires in extremely rare circumstances. Overhead structures and components may be exposed to bushfire damage, but are generally resilient except in extreme bushfires.	Underground transmission lines have limited exposure to bushfire damage risks. Above ground equipment including cable terminations at overhead to underground transitions would be exposed.	Overhead transmission lines can cause bushfires in extremely rare circumstances. Overhead structures and components may be exposed to bushfire damage, but are generally resilient except in extreme bushfires.	Underground transmission lines have limited exposure to bushfire damage risks. Above ground equipment including cable terminations at overhead to underground transitions would be exposed.

Factor	HVAC Overhead	HVAC Underground	HVDC Overhead	HVDC Underground
ECONOMIC FACTORS				
Cost	The cost of undergrounding is generally in the range of 3 to 20 times more expensive, depending upon the type of construction, route length and other route specific factors.		Project costs for HVDC were not in the scope of this study. 'Break even' distance for HVDC overhead lines compared to HVAC overhead lines is around 600km to 650km.	
ENVIRONMENTAL FACTORS				
Overall environmental impacts	Likely overall negative impacts on local biodiversity.			
Habitat loss	Both overhead and underground transmission infrastructure requires vegetation clearance.			
Soil degradation	Impacts are mostly associated with the construction and removal phases of overhead transmission line infrastructure.	Impacts would be markedly different compared to overhead transmission lines and likely more significant for underground cables for the lifecycle of the infrastructure.	Impacts are mostly associated with the construction and removal phases of overhead transmission line infrastructure.	Impacts would be markedly different compared to overhead transmission lines and likely more significant for underground cables for the lifecycle of the infrastructure.

A cross-section view of an underground cable prior to installation.

Glossary

Converter station	Electrical stations (a specialised substation) required for HVDC systems that convert alternating current (AC) to direct current (DC) or the reverse of this.
Easement	A defined area that facilitates building, operating and maintaining transmission lines. While the easement is registered on the land title, the landholder continues to own the land over which the easement exists and retains most of the rights and responsibilities of ownership.
Electromagnetic Fields or Electric and Magnetic Fields (EMF)	EMF are found everywhere electricity or electrical equipment is used, including in the home, office, work sites and around transmission lines. EMF associated with the use of electricity are independent quantities associated with the electric field (a function of the system voltage) and magnetic field (a function of the amount of current flow in the system).
High voltage alternating current (HVAC)	Alternating current (AC) sees electrons flowing from positive to negative at regular cycles or frequency. On an AC transmission line, power is transferred by three phases per circuit.
High voltage direct current (HVDC)	Direct current (DC) involves electrons flowing unidirectionally (with no cycles or frequency), with power transfer most commonly over two poles (polarities) – one being positive and the other negative.
Overhead transmission line	A transmission line located above ground, where the powerline wires are strung between transmission towers or poles along an easement.
Shunt reactor	A piece of equipment used for reactive power compensation and contributing to system voltage control. They are required at intervals along long overhead line and underground cable routes to counteract the high capacitance of transmission lines and underground cables at transmission voltages typically above 275kV.
Static var compensator	A piece of equipment connected to the high voltage transmission network that automatically regulates voltage, and enables the transmission system to deliver more power when it's needed. These provide capacitive or inductive compensation dynamically for the power system as required.
Substation	They manage the flow and voltage levels of electricity around the transmission network and help keep the network stable to provide a reliable electricity supply. Electricity enters and leaves the substation via transmission lines – electricity is not generated at a substation. Substations allow switching of the connected circuits, the step-up or step-down of voltages and facilitate the connection of bulk supply loads for distribution or industrial customers.
Transmission line	A powerline capable of efficiently transferring power at high voltages (e.g. 132kV, 275kV, 330kV and 500kV), with lower losses in the system. Transmission lines are larger and taller than the everyday distribution powerlines that deliver electricity to homes and businesses. Transmission lines are normally built on steel lattice towers or concrete and steel poles.
Underground transmission cable	A transmission cable buried in the ground, normally in conduit or ducts in trenches around 1.2m to 1.5m deep.

An overhead transmission line easement adjacent to Powerlink's Kaban Green Power Hub Connection Project, completed for Neoen.

Further information

For more information on comparing high voltage overhead and underground transmission infrastructure please contact:

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Powerlink acknowledges the Traditional Owners and their custodianship of the lands and waters of Queensland and in particular, the lands on which we operate. We pay our respect to their Ancestors, Elders and knowledge holders and recognise their deep history and ongoing connection to Country.