

High Voltage Overhead vs Underground Transmission Infrastructure (330kV and 500kV)



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As Australia rapidly transitions towards its net zero targets, a number of new significant transmission infrastructure projects are needed to support the increased demands on the electricity grid. The question to place new infrastructure overhead or underground is considered early in the design process, and the outcome is based on a range of technical, financial and other factors. This is a complex and sensitive issue as we work towards net zero targets at the same time as minimising the community impacts of transmission infrastructure. This white paper compares the impacts and technical aspects of overhead and underground high voltage (330kV-500kV) transmission infrastructure.

Comparison of disruptions from overhead and underground infrastructure across lifetime

Sources of disruption for overhead infrastructure include:

Aspect of disruption	Community Level of disruption to landowners and wider community		
	Relative degree of disruption	Duration of disruption	Frequency of disruption
CONSTRUCTION & ENVIRONMENTAL IMPACT: Excavation at tower footings (approx. every 300-500m); joints simple and quick to construct	●●○	●●○	●○○
NORMAL OPERATION: Greater visual impact; lesser impact on land use (no vehicle restrictions, fewer vegetation restrictions); less frequent reactive compensation infrastructure needed. Ongoing visual impact. Perceived impacts on health, livestock and crops. Potential fire risk.	●○○	●○○	●○○
MAINTENANCE: Faults slightly more frequent; much easier and faster to locate and fix faults and damage; shorter outages (typically 1-2 days)	●○○	●○○	●●○

See page 3 for more detail

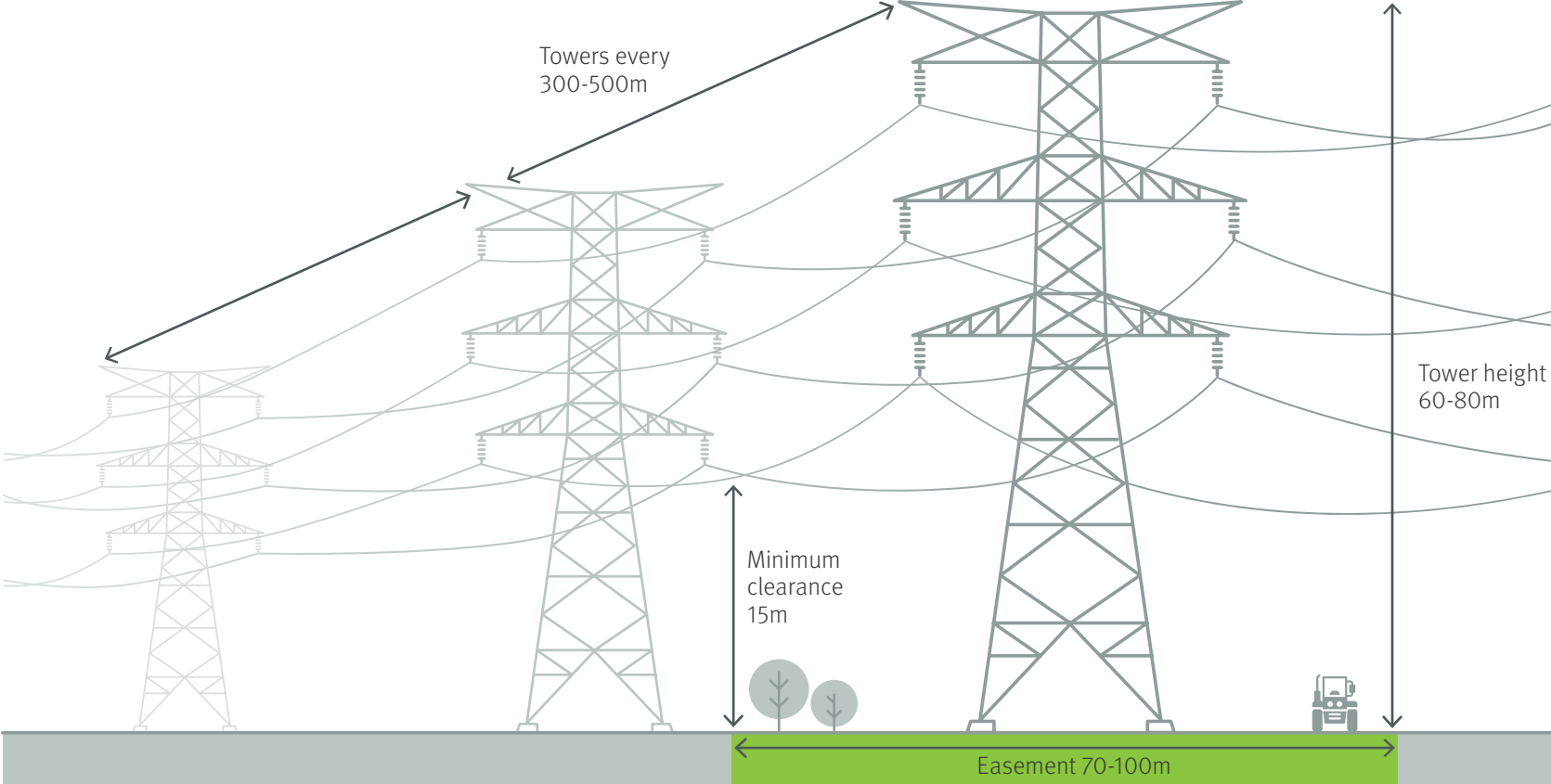
Sources of disruption for underground infrastructure include:

Aspect of Disruption	Community Level of disruption to landowners and wider community		
	Relative degree of disruption	Duration of disruption	Frequency of disruption
CONSTRUCTION & ENVIRONMENTAL IMPACT: Excavation along entire route; joints challenging and time-consuming to construct. Rehabilitation of disturbed ground takes significant time.	●●●	●●●	●○○
NORMAL OPERATION: Lesser visual impact; much greater impact on land use ie restrictions on vehicle use, vegetation and farming; more frequent reactive compensation infrastructure needed. Limited visual impacts or perceived health impacts. Some impact on land use.	●●●	●○○	●○○
MAINTENANCE: Faults less frequent; takes much longer to find and fix faults and damage because excavation is needed; longer outages (typically 5-9 days)	●●●	●●●	●○○

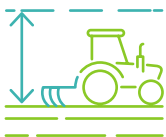
See page 5 for more detail



Typical high voltage overhead transmission line



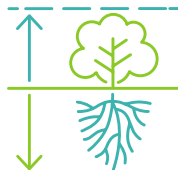
High voltage overhead transmission infrastructure are typically 8 - 10 times less expensive compared to underground cable infrastructure.



Farming practices such as excavation, deep ploughing, use of heavy machinery allowed with height restriction of approximately 4.3m



Crews present for relatively short time during construction and fault maintenance



Height restrictions on trees and other vegetation under conductor, no restrictions on deep roots



Impacts on geology, soils, natural drainage mostly limited to tower footing areas

When do we use overhead transmission lines?



Terrain: in many cases, the terrain of the proposed route precludes underground infrastructure. In particular, if the route needs to cross hilly or mountainous terrain, overhead transmission lines are the best option. While there are still challenges associated with overhead construction in steep areas, the need for trenching or drilling makes underground transmission infrastructure prohibitively more difficult to construct than overhead.



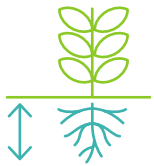
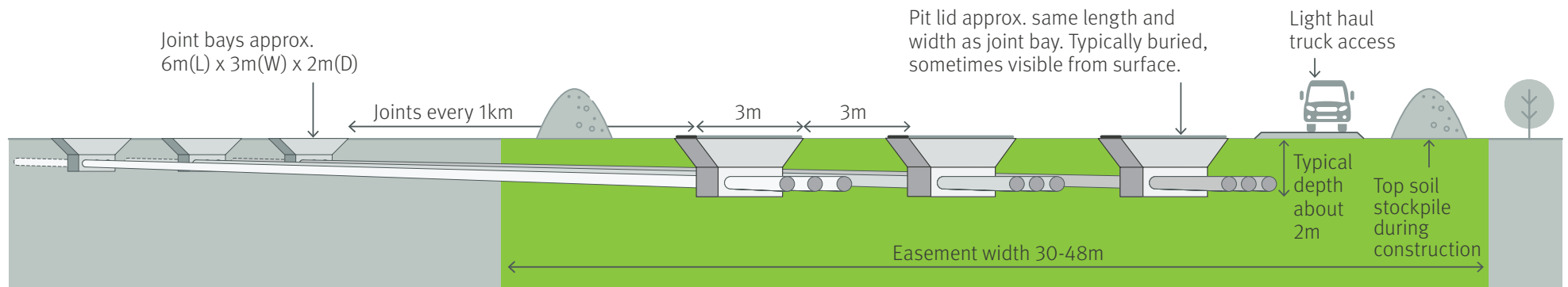
Joints: joints in overhead systems are easier and less costly to install, which means they cause less disruption to landowners during the installation process. Underground cable joints are technically difficult to construct, meaning they require specialised skills which are in short supply. They are also required more frequently along a line, because underground cables are bulky and heavy, and can only be transported on cable drums in shorter segments (about 1km) than thinner overhead conductors. Overall, the complexity and frequency of underground joints make the installation process longer, more costly and more disruptive for landowners.



Line length: In alternating current (AC) infrastructure, reactance and reactive power can cause the system voltage to deviate from its nominal value, requiring reactive power compensation and control to maintain voltage stability. Due to their physical configuration, cables used in underground transmission have a higher reactance per unit length compared to overhead lines. This higher reactance causes underground cables to affect the system voltage over a shorter distance than overhead lines, necessitating reactive power compensation more frequently along the length of the underground cable installation. Reactive power compensation increases the cost, construction time, and disruption associated with alternating current (AC) underground infrastructure, as large reactive compensation stations (often greater than 3000m²) must be built along the transmission corridor where compensation is required.



Typical high voltage underground cables



Selected crops allowed in easement, no vegetation with deep roots



Crews present for significant time during construction and fault maintenance



No excavation, deep ploughing or heavy machinery in easement



Frequent reactive compensation along length of line for HVAC



Possible impacts on geology, soils and natural drainage due to excavation along whole length of line

When do we use high voltage underground cables?

There are several examples of high voltage underground cable infrastructure installations across Europe and in Australia, which means that the costs and challenges associated with underground cables are sometimes justified. The presence of a few key factors can make undergrounding preferable:

- **No intermediate connections:** in rare cases where no intermediate connections are required, the challenge associated with connecting to the existing electricity grid is significantly reduced and underground cables may become feasible.
- **Short length:** there are very few examples of long (more than 100km) HVAC underground cables worldwide. This is due to the increasing need for reactive compensation to control voltage as cable length increases.
- **Terrain:** it is not always possible to install overhead infrastructure across large bodies of water or in urban areas. Underground cables may then be utilised for underwater transmission and in urban areas.

What about High Voltage Direct Current (HVDC)? Does it make undergrounding possible?

High voltage direct current (HVDC) is sometimes preferred as an alternative to high voltage alternating current (HVAC), particularly when considering underground transmission infrastructure. This is because using DC transmission generally overcomes the challenges associated with line length (see page 2) for AC transmission. In many recent projects, HVDC has been mostly used for subsea transmission exactly for this reason.

To date, DC transmission is only feasible for point-to-point connections, because it cannot easily accommodate intermediate connections.

This is because when transmission is done in direct current (DC), connecting to the predominantly alternating current (AC) grid becomes more expensive and challenging. AC-DC connections require power converter stations, which are large and technically complex systems. In contrast, AC-AC connections only require a switching station or substation, which are more commonplace installations. The majority of new transmission projects have to facilitate intermediate connections as a key requirement from the electrical network, which makes HVDC (underground or overhead) unfeasible.

Some Australian examples of underground cable installation, where overhead transmission was not feasible due to the factors explored above, are shown in the table below.

Project	Infrastructure type	Voltage and length	Rationale
Murray Link (2002)	HVDC underground	150kV, 176km	Point-to-point with no intermediate connections. Low voltage and flat terrain.
Basslink (2006)	HVDC underground, subsea and overhead sections.	400kV, underground section is 290km, overhead 95km.	Subsea, overhead is not feasible. Point-to-point with no intermediate connections. A 8km landfall segment was undergrounded to protect the landscape.
Victorian Desalination Project (2012)	HVAC underground	220kV, 88km	Single load with no intermediate connections, short length.
Marinus Link (proposed)	HVDC underground	325kV, 340km (subsea)	Subsea, overhead is not feasible. DC chosen to avoid voltage regulation issues associated with line length. On-land segment will be undergrounded because it simplifies DC/AC converter design in this case.
Powering Sydney's Future	HVAC underground	330kV, 20km	Urban area, overhead obstacles preclude overhead transmission. AC needed to integrate with existing grid at several locations.
DirectLink	HVDC underground cables (primarily buried, some mounted above ground) with short HVAC overhead section.	Approx. 63km long. Underground sections are 80kV, overhead section is 110kV.	Point-to-point with no intermediate connections, low voltage and relatively short length.



What does this all mean?

High voltage transmission infrastructure is essential to achieving Australia's energy transition. The solution for any individual project depends on multiple factors and needs to be done with sensitivity and empathy for the directly impacted landowners and communities.

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