

Engineering Victoria's Future Electricity Grid



An abstract graphic at the top of the page features several overlapping geometric shapes. On the left, there is a red triangle pointing downwards and a larger cyan triangle pointing to the right. On the right side, there is a blue triangle pointing downwards. In the center-right, there is a stylized logo consisting of a grey circle with a white 'S' shape inside it, which is further overlaid by a light blue arrow-like shape pointing towards the top-left.

The transition to renewable energy generation must be harmonised with broader environmental goals to enable the exploitation of co-benefits and minimise negative socioeconomic and environmental impacts.

Developing Victoria's Renewable Energy Future

Victoria's electricity system is transforming at a rapid rate. We need a reliable power system that keeps the lights on around the clock, especially during extreme weather events when Victorians need it most.

Investing in transmission networks that are reliable, resilient, secure and efficient will support the connection of new wind, solar and hydro generation and smart storage solutions that are waiting to be commissioned.

Augmenting existing assets with smart High-Voltage Direct Current (HVDC) keeps lifetime costs down and speeds up delivery of renewable generator connections, powering new and exciting industries. HVDC will modernise Victoria's electricity grid in alignment with global trends¹.

Where there is a need for new transmission, underground options should be deployed, using existing rights-of-way where technically feasible. This will eliminate risks from extreme weather and bushfire related events and significantly reduce socioeconomic and environmental impact.

According to analysis by world-leading transmission cable manufacturers, ABB², by optimising design solutions that minimise the number of overhead transmission links needed and undergrounding HVDC, it is possible to cut hundreds of millions of tonnes of carbon emissions by reducing the volume of construction materials required.

By working together, with smart thinking and technology, we can engineer resilience, safeguard reliability, reduce carbon emissions, encourage renewable generation investment, create new and exciting jobs, and avoid unnecessary impacts on our economy and environment.





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We must strive to achieve decarbonisation targets whilst maintaining environmental standards.

Background

The transition from coal-based to renewable energy is one of the key challenges of the 21st century. Conversion of the energy supply system must, however, be designed to minimise the impact on the environment and landscape and take account of human needs. The strong incentive mechanisms over recent years have led to a dynamic expansion in renewable energies and in order to harmonise climate change objectives with the conservation of biodiversity, the interests of nature conservation and landscape management must be fully considered.

This raises the question of what consequences will arise for the environment and society if Victorian renewable energies are gradually expanded until the State Government's legislated climate goals are reached? The Victorian Government has set ambitious targets to reduce greenhouse gas emissions from 2005 levels by increasing the Victorian Renewable Energy Target (VRET) to 50 per cent by 2030⁵.

Economic models and financial mechanisms should be developed and deployed to provide transparency around environmental, social, and economic trade-offs. This will ensure that the full impacts of decarbonisation are recognised, and the societal and environmental benefits are maximised.

HVDC has experienced a dramatic global expansion in use over recent years, as well as putting cables underground rather than stringing lines overhead. Historically, the higher cost of HVDC and undergrounding was a significant deterrent to its use. However, with lower cost production methods, improved technologies and increased reliability, the cost differential between underground HVDC cables and overhead lines is rapidly narrowing.

Globally, transmission network developers are more frequently turning to underground HVDC as an economically viable and environmentally sensitive way of providing redundancy, resilience and reliability in transmission networks.

Leadership is required to address the interdependencies between achieving decarbonisation and non-climate related environmental degradation and harmonise environmental policies with decarbonisation strategies, with respective bodies working together at state, national and international levels.

State Government, local government, businesses and individuals have an obligation to reduce greenhouse gas emissions and prepare Victoria for the impacts of climate change. We must strive to achieve decarbonisation targets whilst maintaining environmental standards.

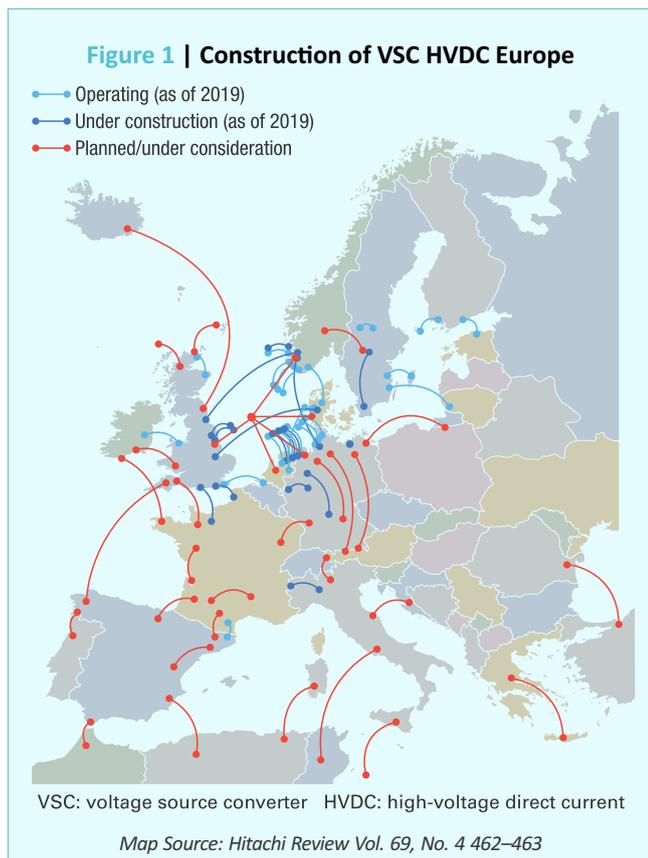
Global Rise of HVDC Transmission

Historically, comparisons of high-voltage alternating current (HVAC) with high-voltage direct current (HVDC) transmission as a means of providing grid connections have tended to opt for the HVAC option.

However, around the world, the installation of HVDC systems is now increasing at a rapid pace. Examples include Europe, North and South America, and China etc., and the trend is accelerating. (see Figure 1).

Australia appears to be lagging behind the world trend but is now catching up. HVDC has historically been viewed as a last resort under special conditions, such as frequency conversion, interconnectors or subsea transmission, however, a number of HVDC projects are now under development to facilitate the long-distance transmission of renewable energy sources.

Another factor behind the global rise in popularity of HVDC, in addition to increases in renewable energy capacity, growth of cross-regional electricity trading, and rising demand for a more reliable electricity supply, is the economic justification for using HVDC to strengthen grid connections. This has been demonstrated by numerous HVDC projects, as well as cost-benefit analysis (CBA) conducted by the European Network for Transmission System Operators - Electricity (ENTSO-E)¹.



Rapid technical progress in voltage source converter HVDC (VSC HVDC) has also contributed significantly to this outcome. VSC technology is a recent advancement, with the first commercial systems commissioned in the late 1990s. VSC technology uses the switching of Insulated Gate Bipolar Transistors (IGBTs) in a Converter Station to create an AC voltage waveform 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 another Converter Station. The maturing of VSC HVDC technology offers a variety of benefits to power grids that have made HVDC an effective option for strengthening grid connections.

In the past, HVDC connections tended to be used to connect different AC power grids, in many cases by subsea cables, however, a notable development in recent years has been that there is growing number of cases where HVDC is installed within a single synchronous grid—where the AC option was usually chosen in the past—or where HVDC systems have been built to operate in parallel with existing AC grids as high capacity shunts or 'bypass' connections.

This indicates that HVDC can solve a variety of electricity grid challenges and in a growing number of cases HVDC has a competitive edge over AC options.

Globally, rather than only being used for a limited range of applications, where special conditions apply, HVDC has become a widely used option for a diverse range of situations.

Some key observations on international trends in HVDC projects include:

- An increased preference for VSC technology
- Increasing power capacity requirements for VSC projects
- Increased instances of multi-terminal VSC HVDC systems
- More HVDC projects with long-distance underground land cables being developed and installed
- More VSC HVDC systems using long distance HVDC overhead transmission lines
- Increased interest in the conversion of existing HVAC transmission lines to HVDC.

The increased rate of HVDC use is a result of how rapidly VSC HVDC technology has advanced over the past 20 years.

VSC HVDC can now provide capacities up to 3 or 4 GW and typically use voltages between 100kV and 800kV. Technological progress is also reducing the required land area for transmission and the electrical losses of AC-to-DC Converter Stations, thereby improving the overall economics of HVDC. This means the technology can meet most application needs.

VSC HVDC has a major role to play in increasing the penetration of renewable energy around the world while also helping to improve grid stability.



Technical Considerations

High-Voltage direct current (HVDC) transmission uses direct current (DC) for the bulk transmission of electricity, in contrast to the more common high-voltage alternating current (HVAC) systems. The reason HVAC systems are more common than HVDC is historical. National Grids have been evolving for over 100 years. Solid-state power electronics for cost effective HVDC Systems did not become available until the early 1970's.

Technical Advantages of HVDC vs HVAC

- An HVDC line has lower power losses than an HVAC line of the same capacity in practically all cases, which means more power is reaching its destination
- For long-distance transmission, HVDC systems are less expensive and have lower electrical losses
- HVDC avoids the heavy currents required for AC to charge and discharge the cable capacitance each cycle when placed underwater or underground, this allows cables to be buried rather than suspended on towers
- For shorter distances, the higher cost of DC conversion equipment compared to an AC system may still be justified, due to other benefits of direct current links.

HVDC has experienced a dramatic global expansion in use over recent years due to the following benefits:

- Undersea-cable transmission schemes between land masses and from offshore renewable energy generation
- Point-to-point long-haul bulk power transmission without intermediate 'taps,' usually to connect a remote generating plant to the main grid
- Increasing the capacity of an existing power grid in situations where additional lines are difficult or expensive to install
- Power transmission and stabilisation between unsynchronised AC networks. An example being the ability to transfer power between countries that use AC at different frequencies. Power transfer can occur in either direction, which increases the stability of both networks by allowing them to draw on each other in emergencies and failures
- VSC HVDC systems can relax operational constraints imposed on AC grids by voltage stability considerations and can be used for damping control to suppress power swings that might occur on the AC grid
- VSC HVDC can contribute to the transient stability of existing AC grids through supply of reactive current during a grid fault to minimise the voltage drop and the suppression or damping of power swings after the fault is cleared
- VSC HVDC can be utilised to support restoration after blackouts.

Technical Disadvantages of HVDC vs HVAC

The disadvantages of HVDC are in conversion, switching, control, availability, and maintenance.

- Because of the additional conversion equipment HVDC is statistically less reliable and has lower availability than alternating current (AC) systems
- Converter Stations are expensive to build and have limited overload capacity
- At smaller transmission distances, power losses in the Converter Stations may be greater than in an AC transmission line (which does not require a Converter Station) for the same distance
- For shorter distances, cost of Converters may not be offset by reductions in line construction cost and lower line loss
- Operating an HVDC system requires many spare parts to be kept, often exclusively for one system, as HVDC systems are less standardized than HVAC systems and technology changes faster
- In contrast to AC systems, realising multi-terminal systems is complex, as is expanding existing systems to multi-terminal systems.

Table 1 - Pros and Cons of VSC HVDC and HVAC Technology³

Parameter	HVAC	VSC HVDC
Controllability	No	High
Losses – Substation/Converters	Lower	Higher
Losses – Lines/Cables	Higher	Lower
Inherent Voltage Support Capability	Not Available	Available
Inherent Damping Control Capability	Not Available	Available
Overhead Line	Larger Conductors, More Conductors, Larger Towers	Smaller Conductors, Fewer Conductors, Smaller Towers
Underground Cable Capability	At a distance >50km and at higher voltage, requires substantial reactive compensation	No Practical Limit on Distance, Fewer Cables
Tap Off Points Along Route	Unlimited, relatively low cost	Limited to a few, preferably known in advance, high cost
Substation/Converter Station Footprint	Smaller	Larger
Easement Width for Overhead Lines	Larger	Smaller
Trench Width for Underground Lines	Larger (up to 45m)	Smaller (2-4m)
Visual Impact of Overhead Lines	Greater	Lesser
Visual Impact of Underground Lines	Greater	Negligible



Socioeconomic Considerations

VSC HVDC transmission has several technical advantages over HVAC transmission, including controllability, lower losses on the transmission lines, voltage support and damping control capability. Conversely, HVAC transmission has lower losses in the terminals (substations) than a HVDC Converter Station.

For the same power transfer level, the VSC HVDC transmission can be superior in terms of environmental impact and aesthetics where the use of underground cables becomes more viable.

Historically, the higher cost of underground HVDC was a significant detractor for its use. However, with lower cost production methods, improved technologies and increased reliability, the cost differential between underground cables and overhead lines is rapidly narrowing.

Transmission project developers are more frequently turning to underground HVDC as an economically viable and environmentally sensitive way of providing redundancy, resilience and reliability in transmission networks.

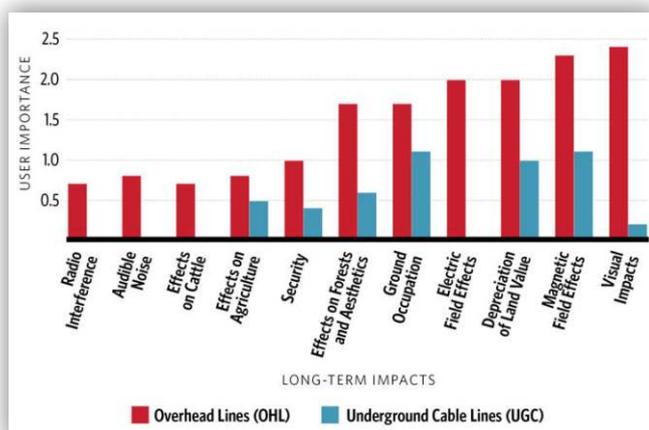
To realise the true net benefit of underground HVDC over the life of a project, a Triple Bottom Line (TBL) analysis is required to consider profit, people and the planet. Not just profit.

The International Council on Large Electrical Systems (CIGRÉ), compared the impacts of greatest environmental concern for overhead lines (OHL) and underground cable lines (UGC)⁴. (See Figure 2)

Compared to overhead HVAC, underground HVDC transmission provides significant socioeconomic benefits:

- Little to no risk of underground cables causing fire or being affected by severe weather events
- Infrastructure resilience to extreme weather-related events such as bushfires, storm damage, interruptions, costs of storm damage surveys and precautionary storm shutdowns
- Little to no impact to access e.g., for emergency services and aviation operations
- No avian or bat mortalities due to transmission line collisions
- No impact to Aboriginal cultural heritage and historic cultural heritage as areas can be avoided
- Minimal impact on private land or current land-use once construction is completed as easements can be designed to fit within an existing right-of-way
- Significantly reduced land-use conflict with easements typically ranging from 2-4m wide
- Protects agricultural values including irrigation infrastructure and avoids potential for loss of prime production agricultural land
- While a larger volume of soil excavation may be required, compared to an overhead line, vegetation is typically restored within a few years
- Minimises impact to endangered or threatened and protected species, biodiversity and native vegetation
- Protects landscape values and visual amenity
- Equivalent or reduced visual and land-use impact from Converter Stations as they would be expected to occupy a similar area as a typical HVAC terminal station with much of the equipment being housed indoors
- No audible noise
- Little to no electromagnetic field impacts
- Lower maintenance costs than overhead lines
- Opportunity costs from lengthy planning delays are reduced and the expense and complexity of public legal battles are minimised
- Less impacted by planning zones, overlays, and buffers.

Figure 2 | User Importance of Long-term Impacts





Environment Considerations

The transition from coal-based to renewable energy is one of the key challenges of the 21st century. Conversion of the energy supply system must, however, be designed to minimise the impact on the environment and landscape and take account of human needs. The strong incentive mechanisms over recent years have led to a dynamic expansion in renewable energies. To achieve a harmonisation of the climate change objectives with those of conserving biodiversity, the interests of nature conservation and landscape management must be fully considered.

While the output of renewable energy generation thus far has only met a relatively minor proportion of the total energy requirement in Victoria, in places this has come at the cost of significant changes to the landscape and impacts on the natural environment. This raises the question of what consequences will arise for nature, landscape and society if renewable energies are gradually expanded until the Victorian Government's legislated climate goals are reached? The Victorian Government has set ambitious targets to reduce greenhouse gas emissions from 2005 levels by increasing the Victorian Renewable Energy Target (VRET) to 50 per cent by 2030⁵.

According to the Climate Change Act 2017⁶, everyone — State Government, local government, businesses, individuals — has a role to play in reducing greenhouse gas emissions and preparing Victoria for the impacts of climate change. This means considering the benefits to the environment of emission reduction strategies. Whilst ambition for rapid decarbonisation is commendable it is recognised that it risks a wide range of unintended negative environmental consequences, both locally and across the world. We must strive to achieve decarbonisation targets whilst maintaining environmental standards.

Decarbonisation must be harmonised with broader environmental goals to enable the exploitation of co-benefits and minimise negative impacts. This coupled approach was demonstrated at COP26 where efforts to reduce fossil fuel use were set alongside the Glasgow Leaders' Declaration on Forests and Land Use⁷, with 141 countries agreeing to halt and reverse forest loss and land degradation by 2030.

Economic models and financial mechanisms should be developed and deployed to provide transparency around environmental, social, and economic trade-offs. This will ensure that the full impacts of decarbonisation are recognised, and the societal and environmental benefits are maximised. Underground transmission answers many of the requirements that stakeholders now expect.

The construction and operation of overhead transmission infrastructure can lead to significant land use changes in the transmission right-of-way and on the grounds of associated facilities. The priority when planning transmission lines routes should be to avoid environment and land use conflict in the first place.

The impact of new overhead transmission infrastructure on an area may depend on the topography, land cover, and existing land uses. In forested areas for example, the entire right-of-way width is cleared and maintained free of tall-growing trees for the life of the transmission line. The result is a permanent change to the land cover resulting in habitat fragmentation.

Agriculture can be affected, by the elimination of cropland, the temporary loss of crop production due to construction, and the incompatibility of certain crops and agricultural activities with transmission facilities. Transportation can be affected by the placement of transmission lines and towers near airports, roads, and waterways.

Where transmission lines are routed through areas that are valued for their scenic qualities, or close to materially populated towns, the visual impacts of the line may extend well beyond the right-of-way.

Underground HVDC provides a superior transmission solution that minimises degradation of the broader environment by mitigating the likelihood, extent and/or duration of potential effects. Transmission network planners must apply the following mitigation hierarchy in order to maximise environmental benefits.

- **1. Avoidance:** measures taken to avoid creating adverse effects on the environment from the outset, such as careful spatial or temporal placement of infrastructure or disturbance, e.g., undergrounding
- **2. Minimisation:** measures taken to reduce the duration, intensity and extent of impacts that cannot be avoided
- **3. Rehabilitation/restoration:** measures taken to improve a degraded environment following exposure to impacts that cannot be completely avoided or minimised
- **4. Offsets:** measures taken to compensate for any residual, adverse impacts after full implementation of the previous three steps of the mitigation hierarchy



Concept Application HVDC Transmission Superhighways

Although the location of generation sources is becoming more diverse, system demand remains relatively localised, and power still needs to get to the same locations. The NEM Renewable Energy Zones (REZ) are maturing, incentivising generation to cluster where fuel resource is favourable and in locations where high-capacity network augmentation between the REZ and the bulk transmission system could be economic. This is not without its challenges though, as the bulk transmission system can then become the bottleneck, requiring extensive and costly augmentation with long lead times and considerable regulatory uncertainty.

Injecting REZ generation capacity directly into major demand centres seems a sensible option to explore, providing a bypass of existing and emerging bottlenecks in the transmission where management of future congestion risk is of major concern or in other words, creating a high-capacity parallel path to “shunt” power and offload the parallel transmission network.

HVDC can make this possible

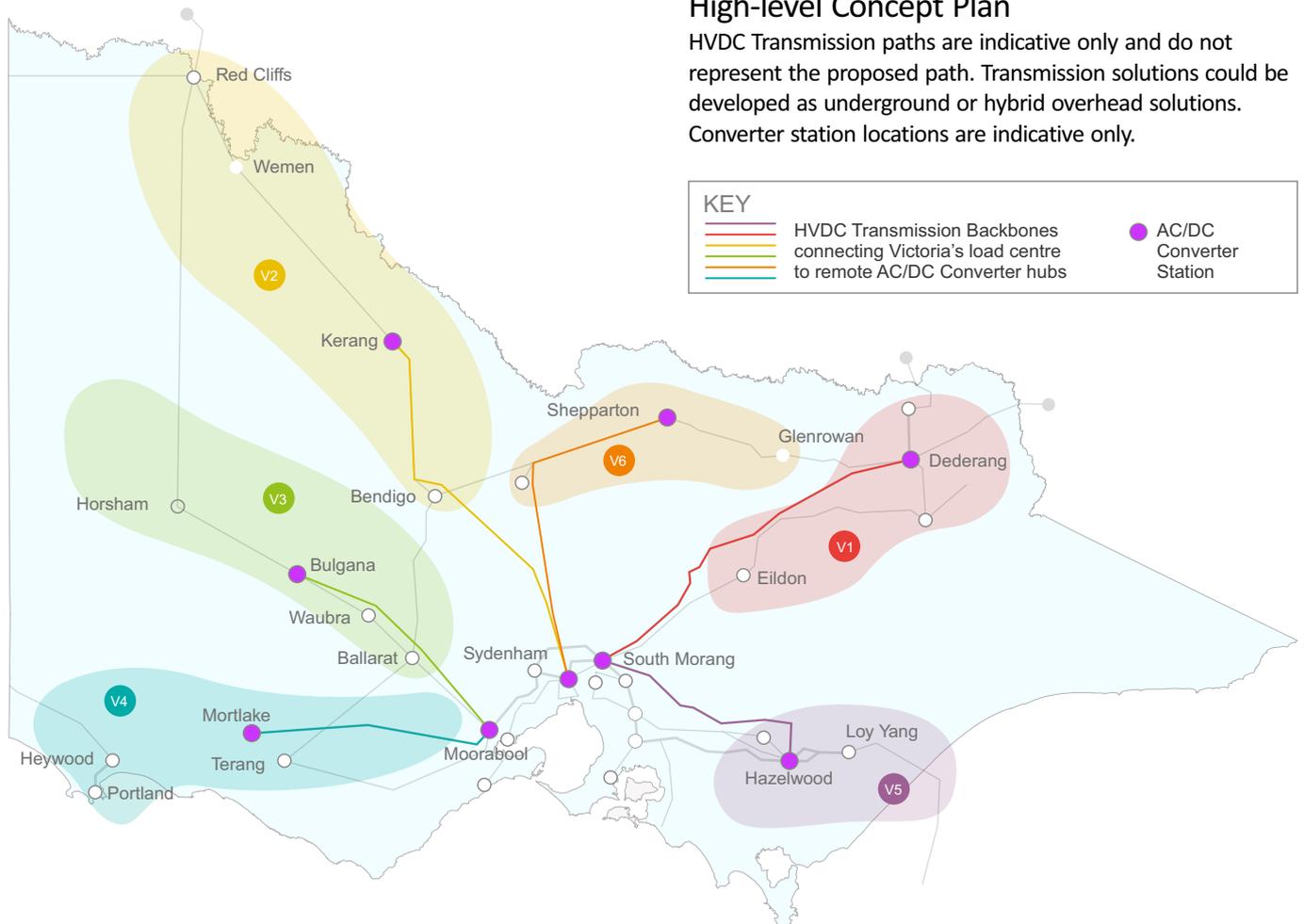
Other countries are exploring and implementing the conversion of AC transmission lines to HVDC systems to benefit from the higher power transfers possible without installing new transmission towers⁸. One HVDC transmission system deployed overhead can prove to be more reliable than a double circuit AC transmission line⁹.

The implementation of such “transmission superhighways” could allow the bulk of the generation to get to the major load centres directly with lower losses, while leaving the parallel AC transmission network with less congestion to allow generation and loads to “tap in” along the way.

This solution can be visualised as a highway bypass, allowing the bulk of traffic to bypass the area while still keeping the roads in and within the bypassed area available for local traffic to enter and leave with less congestion.

High-level Concept Plan

HVDC Transmission paths are indicative only and do not represent the proposed path. Transmission solutions could be developed as underground or hybrid overhead solutions. Converter station locations are indicative only.



Victorian Renewable Energy Zones (REZs)
Adapted from the Victorian Renewable Energy Zones Development Plan

Case Study

Underground HVDC Transmission

- ▶ **Capacity**
525kV
- ▶ **Length**
536km, underground
- ▶ **Underground Benefit**
Avoids or minimises the typical impacts of overhead transmission line construction on sensitive environmental areas, including wetlands and forested areas.

1. SOO Green HVDC Link, USA

SOO Green is a first of its kind underground HVDC transmission line located primarily in the Canadian Pacific rail corridor between Iowa and Illinois in the US, that will connect the MISO and PJM regional energy markets, enabling the delivery of 2,100 MW of renewable energy from the upper Midwest to eastern markets. The innovative 350-mile project will use state-of-the-art 525KV class underground cable and Siemens' modern Voltage Sourced Converter (VSC) technology.

As the first link in a national clean energy grid, SOO Green's innovative underground rail co-location development model can be replicated to accelerate decarbonization and enhance grid reliability and resilience. Installing transmission cables safely underground within railroad rights-of-way protects landowners by avoiding using eminent domain to secure the project route. In addition, installing cables underground enables faster permitting by avoiding environmental and visual impacts associated with traditional overhead transmission lines.

The project will use two 5-inch diameter (about the size of a wine bottle), 525KV extruded cross link polyethylene (XLPE) insulated cables installed in a 2 ½' wide x 5' deep trench.



Converter Station



Underground rail co-location development

HVDC

The SOO Green HVDC Link will provide a number of significant benefits. Notably it will reinforce the transmission grid as an inter-regional 'backbone' transmission facility linking the transmission systems and increase the transfer capacity on the existing grid. The project will reduce viewshed and environmental impact through underground co-location within an existing pre-disturbed, privately owned railroad right-of-way, which not only avoids impacts to neighbouring landowners and the need for extensive use of eminent domain to secure real estate rights, but also avoids or minimises the typical impacts of overhead transmission line construction on sensitive environmental areas, including wetlands and forested areas.

The project represents an additional economic output in the state of Iowa of almost \$1.0 billion, and over \$1.1 billion the state of Illinois from transmission construction. The project will result in thousands of construction, operations and maintenance jobs, and additional economic activity throughout the Midwest.

REFERENCES

Images: SOO Green
SOO Green - <https://www.soogreenrr.com/>
SOO Green Explainer Video - <https://vimeo.com/385593848>
SOO Green Information Session - <https://vimeo.com/456744497>

Case Study

Underground HVDC Transmission



► Capacity

525kV

► Length

750km, underground

► Underground Benefit

Underground HVDC was selected mainly due to resistance from residents towards building overhead lines.

2. SuedLink, Germany

SuedLink was initially proposed as an overhead transmission line, however switched to HVDC underground cables following new legislation introduced by the German Government.

Under the new law, underground cables have been made the standard for new high voltage direct current (HVDC) projects while overhead lines will now become an exception. Further, overhead lines close to residential areas in general have been disallowed.

The project will deliver new underground cable connections to transport wind power from northern Germany to Bavaria and Baden-Württemberg.



Installation of underground HVDC cable



525kV HVDC cable trench

At a length of 750 kilometres, at 525kV and delivering 4000MW via two 2000MW circuits, SuedLink will be the largest transmission cable in the network and the longest underground power cable in the world .

SuedLink will help to better integrate renewable sources, such as wind and solar power, into Germany's electricity grid, and also link with interconnectors to provide cross-border energy resilience.

The project will be constructed using cable lengths of approximately 1200m. The number of trenches and the cable voltage is still to be optimised.

HVDC

REFERENCES

Images: SuedLink

Germany's Underground Cable Law: New rules aims to accelerate grid expansion - <https://www.globaltransmission.info/archive.php?id=25738>

SuedLink - <https://www.jacobs.com/projects/Germany-SuedLink>

SuedLink Fact Sheet - https://www.jacobs.com/sites/default/files/content/article/attachments/Suedlink%20comms%20release_191216_new%20logo.pdf

Case Study

Underground HVDC Transmission

Capacity

Two 320kV 750MW links

Length

90km, underground (Victoria)
250km, subsea

Underground Benefit

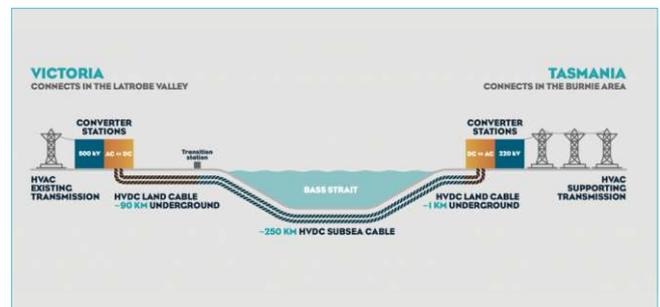
Underground HVDC is more technically feasible, economically viable, more efficient, and more beneficial to the project.

3. Marinus Link, Australia

Marinus Link involves laying approximately 250 km of subsea HVDC cables and approximately 90 km of underground HVDC cables to provide a second transmission connection between Tasmania and mainland Australia's electricity grid.

A set of HVDC cables between Heybridge in North West Tasmania and Hazelwood in the Latrobe Valley Victoria, with a converter station site at each end, has been identified as best suited to manage the energy transfer capacity of Marinus Link. It is proposed that the link is built in two 750 MW capacity stages, and that the land cables for each stage are located in a common easement.

The Marinus Link business case determined that, not only is underground HVDC technically feasible it was more economically viable, more efficient, and more beneficial to them; particularly so, when social licence, environmental and climate risks to overhead infrastructure were considered.



Schematic indicating underground, subsea and overhead transmission

Underground cables have been selected for the sea and Victorian land sections of Marinus Link due to a range of factors, including:

- HVDC uses fewer and more compact cables to transfer large volumes of energy over long distances of land and sea, compared to HVAC cables. HVDC cables therefore tend to be used to transport energy from 'point to point' at high volume over long distances.
- HVDC is the only viable technology for the approximately 250 km of subsea cable required for the Bass Strait crossing. It is viable to use on land as well, however a choice needs to be made as to where the converter stations connect it to the HVAC transmission network.
- It is more efficient to transport energy at HVDC from the Victorian coast right into the Latrobe Valley, and convert to HVAC there, as this represents the best balance between energy transfer, and connection of forecast new generation and load.
- For the Victorian HVDC land section, use of overhead HVDC transmission lines was considered, however would require more expensive VSC converter lightning protection schemes, and wider easements. Analysis therefore shows that underground HVDC cables, rather than overhead cable, is the preferred option for this section of the route.



Map showing approximate land based underground cable route

HVDC

REFERENCES

Images: Marinus Link

Marinus Link - <https://www.marinuslink.com.au/>

Marinus Link Overview - <https://www.marinuslink.com.au/wp-content/uploads/2020/12/Proposed-route-overview-to-support-community-input-Marinus-Link.pdf>

Marinus Link PACR - <https://www.marinuslink.com.au/wp-content/uploads/2021/06/Project-Marinus-RIT-T-PACR.pdf>

Case Study

Underground HVDC Transmission



▶ Capacity

150kV 220MW

▶ Length

178km, underground

▶ Underground Benefit

The Murraylink project earned several Australian state and national awards for both environmental and engineering excellence.

4. Murraylink, Australia

Murraylink is a 178km, 220 MW, 150 kV HVDC bipolar interconnector underground power transmission system, connecting the Riverland region in South Australia and Sunraysia region in Victoria through converter stations at Red Cliffs in Victoria and Berri in South Australia.

The controllable interconnection allows power to be traded in either direction between the two States and provides enough electricity to meet the needs of around 200,000 households. The HVDC transmission system comprises extruded cables buried in the ground and an HVDC converter station at each end of the link. Cables were laid and backfilled into the trench automatically using a Vermeer T755 Chain Trencher.

Network reliability is improved in terms of power supply and system voltage control, as the converter stations can both transmit power and support the AC voltage of surrounding networks, an important feature for the weak Berri network at the edge of the South Australian system.



Installation of underground HVDC cable



Underground co-location development using a Vermeer T755 Chain Trencher

From its near tri-state border site, Murraylink can deliver power from South Australia, Victoria, NSW and the Snowy River generation in either South Australia or Victoria, using existing corridors.

The Murraylink project earned several Australian state and national awards for both environmental and engineering excellence. The project won the 2002 Case EARTH Award for Environmental Excellence for best practice and innovation in the environmental management of civil construction projects.

These awards demonstrate that a high level of environmental sensitivity is possible in large scale transmission infrastructure projects when an underground HVDC solution is selected.

HVDC

REFERENCES

Images: ABB

ABB power transmission project wins national environmental award in Australia - <https://new.abb.com/news/detail/13669/abb-power-transmission-project-wins-national-environmental-award-in-australia>

Murraylink, Australia - <https://www.nkt.com/references/murraylink-australia>

Murraylink Fact Sheet - https://library.e.abb.com/public/1456d376d330bbeac1256f4100489126/PT_MurrayLink.pdf

Case Study

Underground HVDC Transmission

- ▶ **Capacity**
80kV 180MW
- ▶ **Length**
65km, underground
- ▶ **Underground Benefit**
Underground installation on existing rights of way, easing permit processes and reducing environmental impacts.

5. Directlink (Terranora), Australia

Directlink interconnector (Also known as Terranora interconnector) is a 180 MW underground HVDC Light® transmission link connecting the New South Wales and Queensland electrical grids in Australia, allowing power to be traded between the two states.

The 65-km long link was built by TransÉnergie Australia, a subsidiary of the Canadian utility Hydro Québec and Country Energy. TransÉnergie US supplied its technical expertise for the construction and operation of the interconnection, as well as its expertise in marketing transmission services. The transmission system is now owned by Energy Infrastructure Investments consortium and operated by the APA Group. The Directlink interconnector comprises three HVDC Light® independent links of 60 MVA each operating at 80 kV. Three pairs of underground polymeric insulated HVDC Light® cables operate at ±80 kV and transmit 60 MW each, linking the regional electricity markets of New South Wales and Queensland.



Underground HVDC Trench



Underground HVDC Trench

The interconnection links the 132 kV AC grid in New South Wales with Queensland's 110 kV AC grid, and solves capacity shortage problem in southern Queensland, and a surplus capacity issue in New South Wales.

HVDC Light® technology provides numerous advantages for power market projects like this, including mostly underground installation on existing rights of way, easing permit processes and reducing environmental impacts; precisely defined and controlled power flow that matches power need and/or controls network voltage; support for weak power networks connected to the link; modularity, standardized design reducing construction and commissioning periods – the Directlink interconnector HVDC Light® link was delivered in 12 months. These features mean that HVDC Light® facilities can be installed quickly in response to competitive market signals.

HVDC

REFERENCES

Images: Directlink

Directlink interconnector - <https://www.hitachienergy.com/references/hvdc/terradora-interconnector>

Case Study

Overhead Retrofit HVDC Transmission

► Capacity

80kV 180MW

► Length

340km, overhead retrofit

► Project Benefit

Spatial constraints in existing right-of-way does not allow for undergrounding. Retrofitting existing infrastructure increases throughput and reduces further impact on the environment.

6. Ultranet, Germany

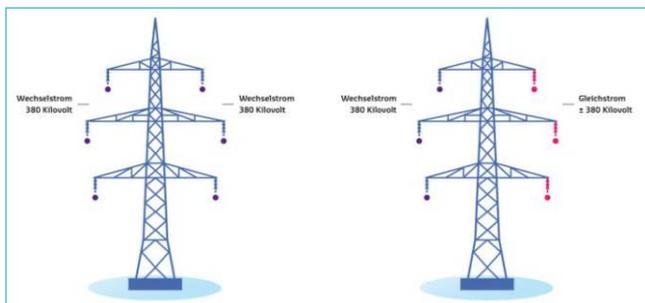
A project currently under construction in Germany is Ultranet, a new DC link between North Rhine-Westphalia and Baden-Württemberg. The 340-kilometre-long line will transmit 2,000 megawatts of electricity and is due for commissioning in 2023.

The innovative hybrid approach will for the first time, transmit direct and alternating current – both with a voltage of 380 kilovolts – over the same pylons. By using existing routes to do so, Ultranet will increase the capacity of the network in an efficient, resource and environmentally friendly way.

The project contributes significantly to security of supply and grid stability through the widespread integration of renewable energies in northern (wind offshore and onshore) and southern Germany (wind onshore). In particular, the system flexibility is increased by the use of HVDC converter.

Figure 3 shows how Ultranet will utilise one of the two 380kV circuits on the existing transmission line to convert to a bipole with metallic return arrangement.

Figure 3 | Conversion of Existing HVAC circuit to HVDC



Installation of HVDC cable on existing HVAC overhead infrastructure

There is an increased interest in the conversion of existing HVAC transmission lines to HVDC. The benefits are clear – significant increase in power transmission capacity could be obtained without having to install any new transmission lines or cables. The work required to achieve this will include, as a minimum, the installation of the HVDC converter stations at each end and likely the replacement of the insulators on the existing AC transmission line.

There have been studies performed looking closely at various conversion scenarios, with some reports concluding that active power transmission capacity levels of between 50% and 150% may be possible, depending on the design of the existing AC transmission line to be converted.

Retrofitting existing HVAC infrastructure with HVDC increases throughput and reduces further impact on the environment.

HVDC

REFERENCES

Images: ENTSO-E

B. P. Lionel O., *The Future of Transmission Technology*, Pittsburgh, P.A., 2004.

Ultranet, Germany Retrofit HVDC to overhead HCAV towers - <https://www.amprion.net/Grid-expansion/Our-Projects/Ultranet/>

ENTSO-E, Project 254 - Ultranet HVDC Osterath to Philippsburg, ENTSO-E - <https://tyndp.entsoe.eu/tyndp2018/projects/projects/254>

Case Study

Underground HVAC Transmission

- **Capacity**
2.2 GW of new capacity
- **Length**
75km, mostly underground
- **Underground Benefit**
The project proponent believes undergrounding provides benefits for the community, the landscape, and the environment.

6. Star of the South, Australia

Star of the South is Australia's first offshore wind project. The project includes a HVAC transmission network of undersea and underground cables and substations to connect the offshore wind farm to Hazelwood in the Latrobe Valley. The project will connect into one of the strongest grid connection points in the National Electricity Market, making use of existing infrastructure and skills in the region.

Star of the South is committed to using underground HVAC cables unless it's not technically feasible or where overhead lines would have lower impacts. While it's more costly to construct underground cables, the project proponent believes there are many other benefits for the community, the landscape, and the environment.



HVAC Transmission investigation area



Installation following Basslink – an existing, high voltage overhead transmission line

The 75 km land route passes through mostly agricultural and plantation land. Around 35 km of this route may follow Basslink – an existing, high voltage overhead transmission line, and where possible share some of the existing easement.

The scheme is planning for up to four power-load compensating sub-stations on the water, and another four along the 75km land route.

HVAC

REFERENCES

Images: Star of the South

Star of the South - <https://www.starofthesouth.com.au/project-overview>

Star of the South Fact Sheet - <https://static1.squarespace.com/static/5eb3699d1492806f7759caf4/t/604fb87b18e42328c8a8c6bf/1615837311371/SOTS+Transmission+factsheet+March+2021.pdf>

Case Study

Underground HVAC Transmission



- **Capacity**
220kV
- **Length**
87km, underground
- **Underground Benefit**
Underground power was the preferred solution for the project as it has the least impact on landowners and people living and working in the area.

7. Aquasure - Desal Plant, Victoria

The Victorian Desalination Plant is powered by an underground 220kV High Voltage Alternating Current (HVAC) power cable. Interestingly, this project set the record at the time for the world's longest high voltage AC underground cable link.

Community consultation played an important part in developing the project. Underground power was the preferred solution for the project as it has the least impact on landowners and people living and working in the area. The power supply was placed underground, rather than overhead, at the request of communities and landowners.

The underground transmission route is 87-kilometres long and provides a dedicated supply for the desalination plant. The cables are located in the same easement as the pipeline (in separate trenches), sharing the same alignment except for a 9-kilometre section where it diverts at Clyde North to Cranbourne Terminal Station. Much of the transmission corridor was located along roadside easements where possible.

The HVAC design uses power-load compensating equipment, which is co-located with the pipeline booster pump station at Clyde North and at a point south of Lang Lang. Each of these installations occupies a small area and has landscaping to minimise visual impacts.



Much of the transmission corridor located was along roadside easements where possible



Underground transmission, rather than overhead, at the request of communities and landowners.

HVAC

REFERENCES
 Images: Aquasure
 Victorian Desalination Plant - <https://aquasure.com.au/pipeline-powerline>
 Victorian Desalination Plant Fact Sheet - https://aquasure.com.au/uploads/files/OTDV-FS-0004-02_W%20PipePower.pdf

References

- 1) entso-e, Ten Year Network Development Plan - <https://tyndp.entsoe.eu/>
 - 2) ABB Underground transmission with HVDC Light - <https://library.e.abb.com/public/15896c343f126852c1257488003ee14e/ABB%20Review%20April%202005%20-%20Underground%20transmission%20with%20HVDC%20Light.pdf>
 - 3) WVTNP High-Level HVDC Alternative scoping report, Amplitude Consultants, 17 June 2021 - <https://www.moorabool.vic.gov.au/files/content/public/about-council/large-projects-impacting-moorabool/western-victoria-transmission-network-project/wvtnp-high-level-hvdc-alternative-scoping-report.pdf>
 - 4) The International Council on Large Electrical Systems (CIGRÉ) - <https://www.cigre.org/>
 - 5) Victoria's Climate Change Strategy - <https://www.climatechange.vic.gov.au/victorias-climate-change-strategy>
 - 6) Climate Change Act 2017 - <https://www.climatechange.vic.gov.au/legislation/climate-change-act-2017>
 - 7) COP26. Glasgow Leaders' Declaration on Forests and Land Use - <https://ukcop26.org/glasgow-leaders-declaration-on-forests-and-land-use/>
 - 8) Hybrid AC/DC OHL - <https://www.entsoe.eu/Technopedia/techsheets/hybrid-ac-dc-ohl>
 - 9) GE Grid Solutions (pp 2) - https://www.gegridsolutions.com/products/brochures/powerd_vtf/hvdc-systems_ges-31971_lr.pdf
- SOO Green - <https://www.soogreenr.com/>
- SOO Green Explainer Video - <https://vimeo.com/385593848>
- SOO Green Information Session - <https://vimeo.com/456744497>
- SuedLink - <https://www.jacobs.com/projects/Germany-SuedLink>
- SuedLink HVDC Power Transmission Project, NS Energy - <https://www.nsenerybusiness.com/projects/suedlink-hvdc-power-transmission-project/>
- SuedLink Fact Sheet - https://www.jacobs.com/sites/default/files/content/article/attachments/Suedlink%20comms%20release_191216_new%20logo.pdf
- Marinus Link - <https://www.marinuslink.com.au/>
- Marinus Link Overview - <https://www.marinuslink.com.au/wp-content/uploads/2020/12/Proposed-route-overview-to-support-community-input-Marinus-Link.pdf>
- Marinus Link PACR - <https://www.marinuslink.com.au/wp-content/uploads/2021/06/Project-Marinus-RIT-T-PACR.pdf>
- Marinus Link, ABB power transmission project wins national environmental award in Australia - <https://new.abb.com/news/detail/13669/abb-power-transmission-project-wins-national-environmental-award-in-australia>
- Murraylink, Australia - <https://www.nkt.com/references/murraylink-australia>
- Murraylink Fact Sheet - https://library.e.abb.com/public/1456d376d330bbeac1256f4100489126/PT_MurrayLink.pdf
- Directlink interconnector - <https://www.hitachienergy.com/references/hvdc/terranora-interconnector>
- Star of the South - <https://www.starofthesouth.com.au/project-overview>
- Star of the South Fact Sheet - <https://static1.squarespace.com/static/5eb3699d1492806f7759caf4/t/604fb87b18e42328c8a8c6bf/1615837311371/SOTS+Transmission+factsheet+March+2021.pdf>
- Aquasure - Desal Plant, Victoria - <https://aquasure.com.au/pipeline-powerline>
- Aquasure - Desal Plant, Victoria Fact Sheet - https://aquasure.com.au/uploads/files/OTDV-FS-0004-02_W%20PipePower.pdf
- Ultranet, Germany Retrofit HVDC to overhead HCAV towers - <https://www.amprion.net/Grid-expansion/Our-Projects/Ultranet/>
- ENTSO-E, Project 254 - Ultranet HVDC Osterath to Philippsburg, ENTSO-E - <https://tyndp.entsoe.eu/tyndp2018/projects/projects/254>
- Comparison Between HVDC and HVAC Transmission System - <https://www.electricaldeck.com/2021/08/comparison-between-hvdc-and-hvac-transmission-system.html>
- Comparison of 500kV Overhead Lines with 500kV Underground Cables, Moorabool Shire Council, September 2020 - <https://www.moorabool.vic.gov.au/files/assets/public/orphans/documents/20200924-msc-transmission-comparison-overhead-with-underground.pdf>
- CIGRE, Characteristics of system and parameter design on key equipment for Zhangbei DC Grid, CIGRE, Paris, 2021.
- CIGRE, Design and Operational Experience of the Worlds First Three-Terminal VSC HVDC System for Wind Power Integration and its Upgrade with DCCBs, Paris, CIGRE, 2019.
- CIGRE, Zambezi Link HVDC Interconnector: Review of Operational Performance in the First Years, CIGRE, Paris, 2016.
- HITACHI, Caithness Moray HVDC Link - <https://www.hitachiabb-powergrids.com/au/en/references/hvdc/caithness-moray-hvdc-link>
- HITACHI, Maritime Link, HITACHI, 2020 - <https://www.hitachiabb-powergrids.com/au/en/references/hvdc/maritime-link>
- Svenska Kraftnat, The South West Link - <https://www.svk.se/en/grid-development/grid-projects/the-south-west-link/>
- Modern Power Systems, TenneT opts for 525 kV HVDC, onshore and offshore, 09 July 2020 - <https://www.modernpowersystems.com/features/featuretennet-opts-for-525-kv-hvdc-onshore-and-offshore-8019642/>
- B. P. Lionel O., The Future of Transmission Technology, Pittsburgh, P.A., 2004.
- Germany's Underground Cable Law: New rules aims to accelerate grid expansion - <https://www.globaltransmission.info/archive.php?id=25738>
- Global Rise of HVDC and Its Background - https://www.hitachi.com/rev/archive/2020/r2020_04/pdf/gir.pdf
- Top 5 Reasons to Use Underground Transmission Lines - <https://www.hdrinc.com/insights/top-5-reasons-use-underground-transmission-lines>
- The Future Electric Grid: How HVDC Could Transform the U.S. Power System - <https://www.powermag.com/the-future-electric-grid-how-hvdc-could-transform-the-u-s-power-system/>
- High Voltage Direct Current Electricity – technical information (NationalGrid) - <https://www.nationalgrid.com/sites/default/files/documents/13784-High%20Voltage%20Direct%20Current%20Electricity%20%E2%80%93%20technical%20information.pdf>
- Review of Energy Policy 2021 (UKERC) - https://d2e1qxpswcpz.cloudfront.net/uploads/2021/12/UKERC_Review-of-Energy-Policy-2021-1.pdf
- RE100 IN PRACTICE – ENVIRONMENTALLY COMPATIBLE ENERGY TRANSITION - <https://www.natur-und-erneuerbare.de/en/project-database/re100-in-practice-environmentally-compatible-energy-transition/>
- Use of New Technologies to Mitigate Visual Impact and Public Concerns Related to Siting of Transmission Lines - https://www.energy.gov/sites/prod/files/2018/12/f58/11-20-2018_Use%20of%20New%20Technology%20to%20Mitigate%20Visual%20Impact%20and%20Public%20Co....pdf



Energy Grid Alliance was established with the purpose of engaging with energy transmission companies, industry regulators, market operators, relevant peak bodies, government and communities to establish best planning practices for new energy transmission infrastructure and to inform on the benefits of working with communities to acquire and maintain social license.