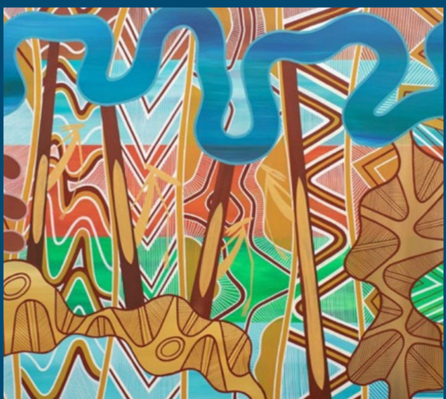
Summary of transmission infrastructure

VicGrid
August 2023

energy.vic.gov.au

VICTORIA State Government | Energy, Environment and Climate Action

Contents



Acknowledgment of Traditional Owners

We acknowledge and respect Victoria's Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond.

Introduction

As Victoria's ageing and increasingly unreliable coal-fired power stations retire, more and more renewables – paired with battery storage - will provide the state's electricity as part of our renewable energy transition.

New transmission is critical to our renewable energy transition

Victoria's grid is historically strongest in the Latrobe Valley, where our coal-fired power is based. However, our renewable resources are dispersed across Victoria – from our windy coastlines to our sunny plains.

That's why we are working on transmission and network upgrades across the state. This will improve and modernise the grid in the areas where sun and wind are abundant so more renewables can flow through Victoria. This will deliver a cleaner, cheaper, stronger energy system for all Victorians.

Work to upgrade our grid will eventually unlock more than 10,000 megawatts of capacity across our renewable energy zones.

This will:

- prepare our grid for the unprecedented volume of renewable energy in the pipeline
- make it easier for new projects to connect to the grid
- ensure the ongoing security and reliability of the grid, particularly as coal-fired generation ends.

Victoria's 6,500 kilometre high voltage transmission network is the backbone of our electricity system

It moves electricity from where it is generated to homes and businesses across the state. It powers our houses, our hospitals, our manufacturing and business sectors, and even parts of our transport system.

There are a range of transmission types that suit different situations. They have different designs and uses, different costs and impacts. As Victoria transitions to renewable energy it is important that communities have access to information about transmission infrastructure.

This summary provides communities with information on available transmission technology and the important issues that are considered when planning and developing transmission infrastructure.

This summary should not be inferred as the list of transmission options VicGrid is considering for transmission projects.

Transmission networks

Transmission networks transport large amounts of energy over long distances from where it is generated to where it is needed.

Generators use energy sources like coal, wind or solar to produce electricity. The electricity is converted to a higher voltage at terminal stations at the beginning of the network and transported over long distances. The electricity is then converted to a lower voltage at terminal stations at the end of the transmission network. From here electricity is transported to homes and businesses across the state by the distribution network. These are the poles and wires that we see along our streets.

Transmission networks are built to carry different voltages. Voltage is the pressure that pushes charged electrons through a circuit. Voltage is measured in volts (V) – from the 1.5 V battery in a TV remote, to the 230 V wires running through street poles to our houses.

In a transmission network, much larger amounts of pressure are needed to keep the electricity flowing and ensure energy is not lost. This voltage is measured in thousands of volts, or kilovolts (kV). High voltage transmission lines can range between 11 kV and 1,000 kV depending on how far they need to carry power.

Higher voltages are better at transmitting large amounts of power over long distances.

Transmission networks use equipment called transformers. Transformers increase and decrease the voltage of electricity so that it can be efficiently and safely transported.

FIGURE 1 Key parts of a transmission network

Generation

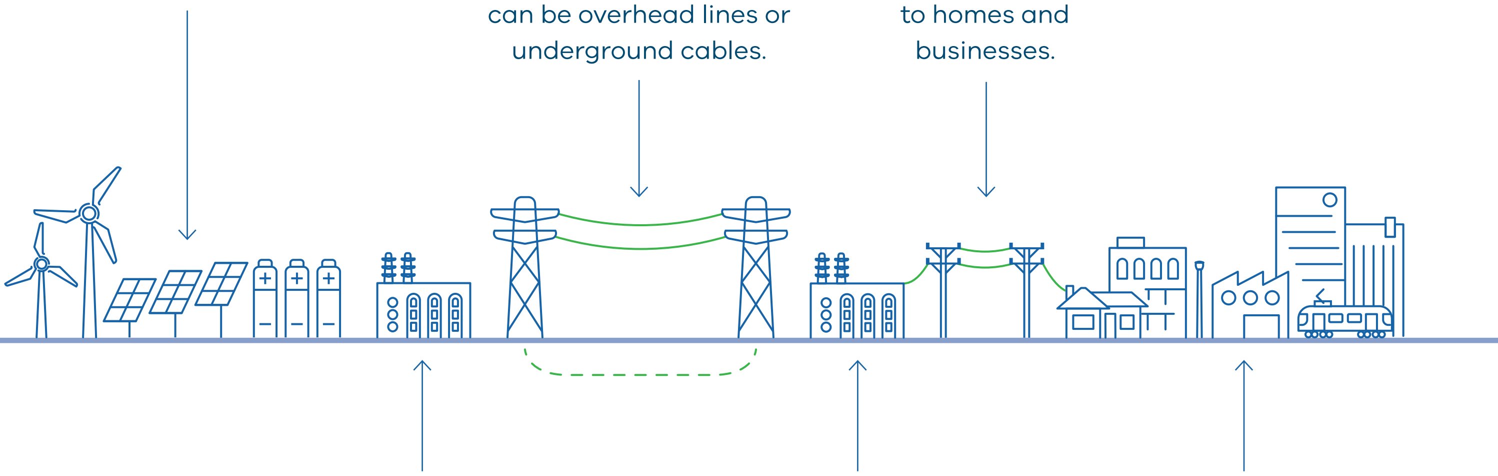
Generators use energy sources to produce electricity.

Transmission

Transmission lines carry high voltages of electricity over long distances. These can be overhead lines or underground cables.

Distribution

Distribution lines carry lower voltages of electricity to homes and businesses.



Step-up voltage transformer

Transformers at terminal stations increase the voltage ready for transmission. Higher voltages mean more electricity can be transmitted over long distances.

Step-down voltage transformer

Transformers at terminal stations decrease the voltage ready for distribution lines.

Homes and businesses

Use the electricity.

Transmission in Victoria

We need to upgrade Victoria's transmission network, or 'energy grid', to accommodate renewable energy.

Victoria's current energy grid

Victoria's current energy grid was built last century. It was designed to connect electricity from coal-fired power generators in the Latrobe Valley to Victorian homes and businesses.

Most of Victoria's transmission network is made up of high voltage overhead lines to transmit energy from generators to consumers. The transmission voltages used in Victoria are 220 kV, 330 kV and 500 kV.

Victoria's first 220 kV overhead lines were built in the 1950s, and the first 500 kV overhead line was built in the 1970s. This line connected the coal-fired power stations in the Latrobe Valley to Melbourne. Today Victoria's transmission network is made up of 6,500 kilometres of overhead lines and 50 terminal stations.

Energy sources and generation mix

In Victoria, we currently generate electricity through energy sources like coal, gas, solar, hydro, and wind power.

In 2022, 65 per cent of our electricity was produced by coal-fired power stations in the Latrobe Valley. These coal-fired power stations are coming to the end of their economic life and are set to close in the coming decades. This means that we need to change where we get our energy from. At the same time, the electrification of vehicles, homes, offices and industries means there will be more demand for electricity in the future.

We need new energy generation sources to keep the lights on. Victoria is replacing its ageing coal-fired power generators with renewable energy sources like solar and wind. These renewable energy sources are spread across Victoria. They are not always located close to existing transmission infrastructure. We need to build new high voltage transmission to connect new renewable energy sources to the grid.

Transmission infrastructure types

There are a range of different transmission types available. They all have different characteristics.

These differences include:

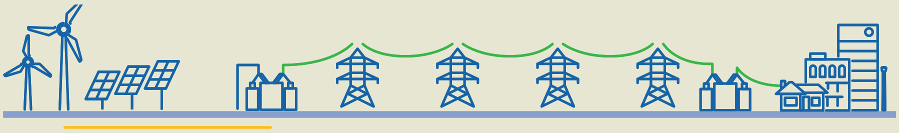
- construction methods
- operation and maintenance needs
- impacts on the environment and existing land uses.

Onshore transmission infrastructure can be above ground with overhead lines, or underground with cables. Offshore transmission infrastructure involves subsea cables and substations out at sea.

Overhead lines and underground cables can carry alternating current (AC) or direct current (DC) voltages.

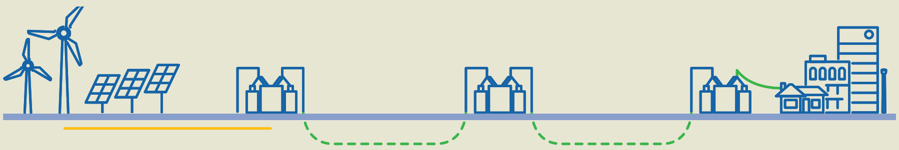
FIGURE 2 Transmission infrastructure types

High Voltage Alternating Current – Overhead



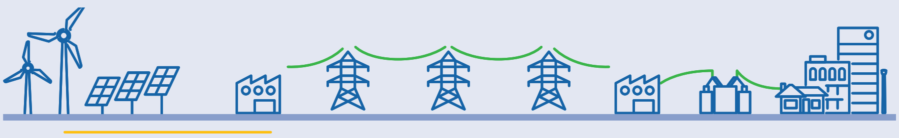
- Large amounts of power over long distances
- Higher current carrying capacity

High Voltage Alternating Current – Underground



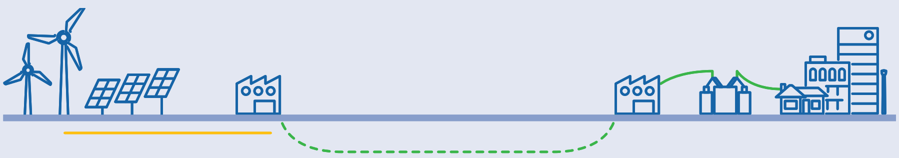
- Lower current carrying capacity
- Requires shunt reactors to remove excess reactive power to increase the amount of electricity that can be transmitted and used

High Voltage Direct Current – Overhead



- Used for bulk power between AC systems
- Requires converters at both ends
- Requires converter stations along the line to connect generators

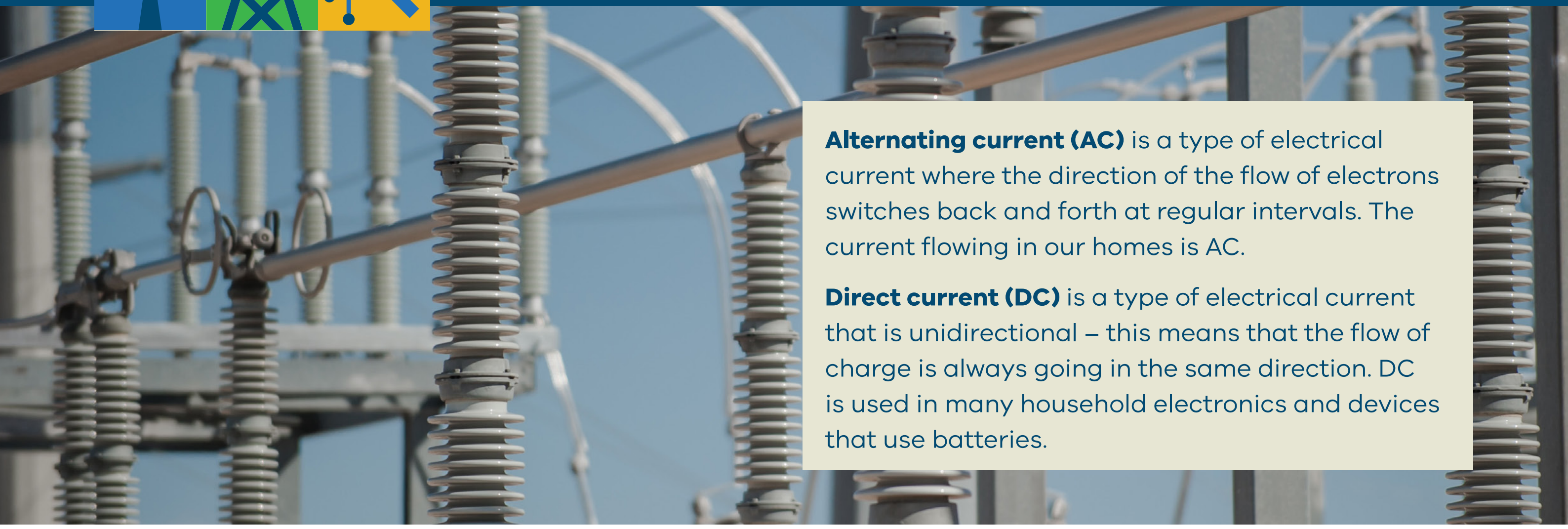
High Voltage Direct Current – Underground



- Used for bulk power between AC systems
- Requires converters at both ends
- Requires converter stations along the line to connect generators

Transmission tower · Supporting infrastructure · Converter station

Overhead line · Underground cable · Generation connection



Alternating current (AC) is a type of electrical current where the direction of the flow of electrons switches back and forth at regular intervals. The current flowing in our homes is AC.

Direct current (DC) is a type of electrical current that is unidirectional – this means that the flow of charge is always going in the same direction. DC is used in many household electronics and devices that use batteries.

AC and DC transmission types have some differences:

- The size of the infrastructure they need.
- The way the land around it can be used.
- The equipment needed at the start and end of the network to connect them into the existing energy grid.

All standard power systems in Australia use AC. DC is used for transporting large amounts of energy over long distances when point-to-point transmission of power is needed and connecting generation along the line is not important.

High voltage alternating current overhead lines

Most transmission infrastructure around the world using high voltage alternating current (HVAC) systems uses overhead lines to transmit electricity over long distances.

In Victoria, most transmission infrastructure uses HVAC overhead lines at 220 kV, 330 kV and 500 kV.

High voltage alternating current underground cables

There are HVAC systems that use underground cables to move electricity instead of overhead lines. These systems are generally used for shorter distances due to high costs and the requirement for shunt reactors. Along the cable shunt reactors remove excess reactive power. Excess reactive power is a phenomenon which causes voltages to rise and reduces the efficiency of moving electricity using underground HVAC.

In Victoria, the most significant underground cables are:

- the 10 km Richmond – Brunswick 220 kV underground cable
- the 88 km Victorian Desalination 220 kV underground cable, with two shunt reactors installed along the cable route.

High voltage direct current overhead lines

High voltage direct current (HVDC) moves power between separate AC networks. HVDC is a common way to transmit bulk power point-to-point over very long distances, or to connect offshore wind projects to onshore grids through undersea cables. A HVDC network uses two or more converter stations. A converter at the start of the network converts the AC power to DC. A converter at the end of the network converts the DC power into AC.

Many HVDC examples moving large amounts of power over long distances (of approximately 600 km or more) use overhead lines.

In Australia, Basslink is a 290 km undersea cable and a 60 km overhead line HVDC network connecting the Tasmanian and Victorian AC networks.

High voltage direct current underground cables

A HVDC network can use underground cables to move power. A converter at the start of the network converts the AC power to DC. A converter at the end of the network converts the DC power into AC.

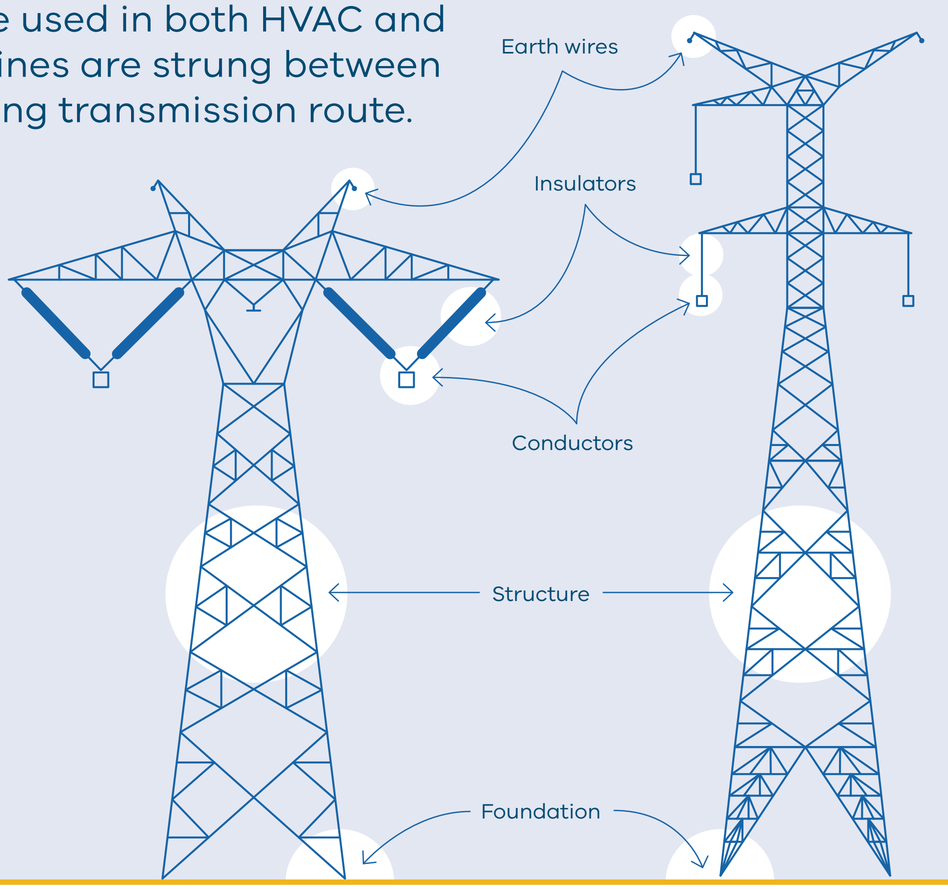
In Australia, there are two HVDC underground cable networks:

- the 180 km Murraylink
- the 63 km Directlink.

Overhead lines

Most of the transmission infrastructure around the world uses overhead lines at voltages of 110 kV and above. Overhead lines are used in both HVAC and HVDC transmission. The lines are strung between towers or poles along a long transmission route.

HVAC overhead lines can handle more than one million volts (1000 kV) of electricity and HVDC overhead lines can carry voltages of up to ±640 kV. Both HVAC and HVDC overhead lines can carry large amounts of electricity over long distances without losing a lot of power.



HVDC Bipole Tower

HVAC Single Circuit Tower

FIGURE 3 **Typical parts of an overhead line**

Structure

The structure of an overhead line is a tall steel tower made up of a central tower with cross-arms that hold and carry the lines long distances. They can be lattice cages or tall steel poles.

Conductors

These are the wires that carry the electricity. They are made from steel, aluminium or carbon fibres.

Insulators

Insulators are mounted on the tower or pole to stop electricity from escaping through the conductors towards the ground.

Foundations

Steel or concrete foundations provide a solid base for the tower to stand on.

Earth wires

The earth wires intercept lightning strikes before they can hit the conductors. This protects them from damage and power surges. Separate to the earth wire, for safety each steel tower is connected to the ground via buried earth wires.

Transmission towers for illustrative purposes only.

Overhead line structure types

There are many standard and alternative overhead line structure types used in Australia and around the world.

FIGURE 4 Overhead line structure types and easement widths

Steel poles

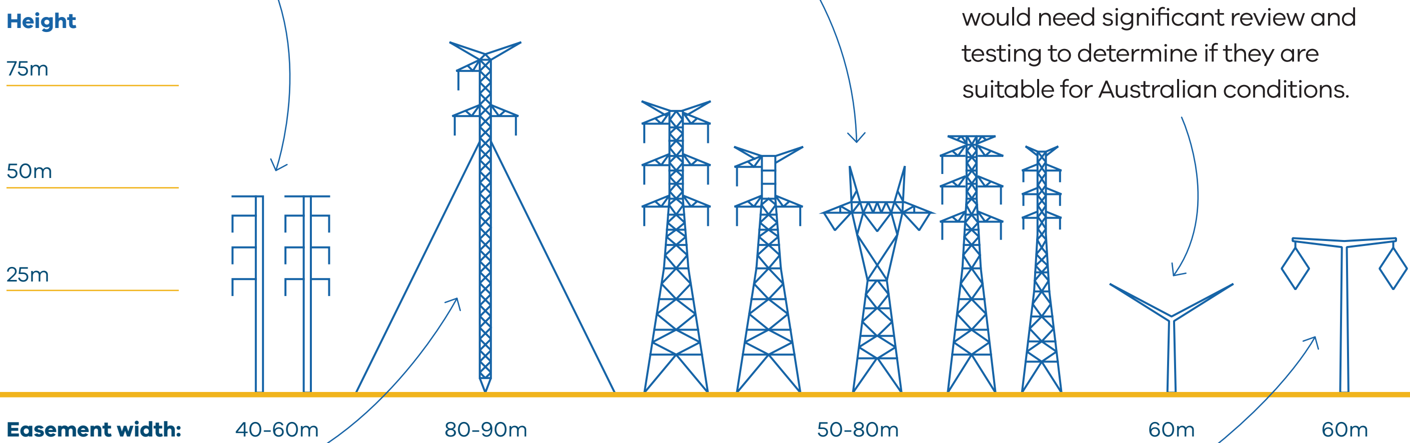
Steel poles are normally used at lower voltages and across shorter distances. They can be used for HVAC overhead lines up to 330 kV. The poles and their foundations can be quite large for voltages over 300 kV so they are more commonly used on lower voltages.

Lattice towers

Steel lattice towers have been used in overhead line transmission infrastructure for over 100 years. They are the accepted industry practice for HVAC voltages of 330 kV and above.

European Composite Pylon

The European Composite Pylon, piloted in Denmark, uses three pylons to carry a 400 kV double circuit over 4 km. It uses a simple and lightweight design that allows it to be easily transported and quickly installed. With its shorter height, it may be an option for sections of overhead line where there is a need to minimise visual impact. These towers have never been used in Australia and would need significant review and testing to determine if they are suitable for Australian conditions.



Guyed towers

Guyed towers stay upright using guy wires. They use less materials than lattice towers and are quicker and easier to install. Guyed towers are well suited to flat land but are not always appropriate for agricultural land, built-up areas or within forests or bushland. This is because they have a large footprint which can restrict access or the use of machinery. Guyed towers are often used in emergencies when replacement towers are needed urgently, because they can be constructed quickly.

T-Pylon

The T-Pylon has been used in the United Kingdom where the pylons carry a 400 kV double circuit over more than 40 km. Like the European Composite Pylon, it uses a simple and lightweight design and may be an option for minimising visual impact. These towers have never been used in Australia and would need significant review and testing to determine if they are suitable for Australian conditions.

Easements

The land transmission infrastructure occupies is called an easement. It provides a clear and safe corridor for people to build, operate and maintain the infrastructure. They act as safe zones to protect people living, working or playing near the infrastructure.

Easement width changes depending on the voltage, and design of the infrastructure. Easement width also depends on the choice of underground or overhead infrastructure. In Australia, the higher the voltage, the wider the easement generally needs to be. Figure 4 shows the typical easement sizes needed for different overhead line types of voltages 220 kV, 330 kV, 400 kV, 500 kV and ±525 kV.

Figure not to scale. Typical easement widths shown only.

Construction

The construction of an overhead line involves several steps. These include:

- removing trees and vegetation
- putting in access tracks
- excavating earth
- installing foundations
- erecting the structures
- stringing conductors.

It is possible to use helicopters to pull and string the lines to avoid removing trees and vegetation in sensitive areas.

Operation and maintenance

Regular inspections of overhead lines take place by plane, helicopter, car, foot or by climbing the structures. These inspections help maintenance staff check the conditions of the overhead lines.

A big part of maintaining overhead lines is clearing trees and vegetation around the line to ensure minimum clearance spaces are maintained. This is done to protect against fire risk.

Differences between AC and DC overhead lines

Overhead lines can either carry AC or DC electricity, and while they may look similar, they have some differences.

	HVAC overhead lines	HVDC overhead lines
Line losses (the amount of power that is lost during transmission)	Higher line losses.	Lower line losses.
Conductors	Larger and more conductors are needed.	Smaller and less conductors are needed.
Tower size	Often larger than HVDC for the same power transfer.	Often smaller than HVAC for the same power transfer.
Electric and magnetic fields	HVAC overhead lines will produce electric and magnetic fields (EMF). HVAC overhead lines are always designed to ensure EMF levels are safe for public exposure.	HVDC overhead lines will produce a static magnetic field. Static magnetic fields have a higher acceptable limit for safe public exposure, as they are considered safer than AC fields.
Terminal stations	Needed at each end of the HVAC transmission.	Needed at each end of the HVDC transmission.
Converter stations	Not needed.	Needed at each end of the HVDC transmission.
Reactors	Needed in the terminal station at each end of long HVAC overhead lines.	Not needed.
Generator connections	Does not need converter stations to connect generators into the network.	Needs converter stations to connect generators into the network.

Impacts

There are many environmental considerations and potential impacts during the construction, operation and maintenance of overhead lines. This table provides a summary of potential high-level impacts – specific impacts in different locations may change based on detailed investigation and studies.

Impact	Potential construction and operation impacts
Aboriginal cultural heritage	In long overhead line routes, Aboriginal cultural heritage sites may be impacted by construction activities when the ground is disturbed. It may be possible to avoid some culturally significant areas by changing the route. Overhead lines can also impact intangible cultural heritage through their visual impact.
Aviation	Overhead lines pose a hazard to aviation activities as they take up airspace that may be used by planes and helicopters. Overhead lines should avoid infringing upon airspace by considering distances to airports and landing strips. Consultation with state aviation authorities is needed to determine safe flying distances from towers.
Biodiversity	During construction of overhead lines, trees and vegetation may need clearing to build access tracks, laydown areas and foundations. The removal of habitat may have an impact on local fauna. The easement may also create a barrier, affecting some local fauna from moving between neighbouring habitats. Only grasses or shallow rooted vegetation are permitted to grow in the easement. Overhead lines can also pose a risk to some birds.
Bushfire and other natural disasters	Extreme weather events like bushfires or storms can damage the towers. In Victoria, firefighters are trained to manage fires near transmission lines. When managed and maintained, transmission lines pose a very low risk of starting a fire.
Historic heritage	In long overhead line routes, historic heritage sites may be present. It may be possible to avoid some historically significant areas by changing the route.
Landscape and visual	Overhead lines may have a high visual impact in sensitive landscapes.
Land use, including impacts on farming	During construction, partial or entire occupation of land by the project temporarily limits the land being used for other activities. An overhead line easement would change the planning conditions of that land, including introducing restrictions on land use. This means that there may be changes to the way that the land can be used for housing, farming activities and tree planting. The land can no longer be used for forest plantations. Grazing and cropping is permitted.
Noise	During construction, there will be some noise and vibration from machinery. During operation, overhead lines make some noise that can sound like crackling or hissing.

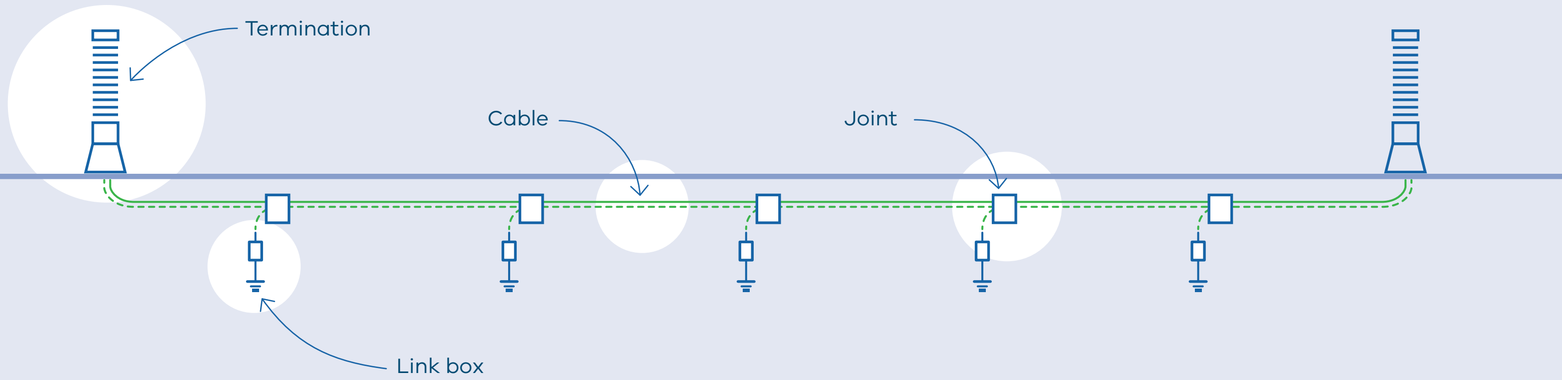
Underground cables

HVAC and HVDC transmission can use underground cables. They can either be directly buried in the ground or installed in ducts along the bottom of a trench.

HVAC underground cables are being installed with voltages from 110 kV and up to 500 kV. HVDC underground cables have been, or are being, installed with voltages of up to ± 525 kV.

Underground cables are installed in sections and joined together. The cable system consists of cables, terminations, joints, link boxes and remote monitoring systems.

FIGURE 5 Key parts of an underground cable system



Terminations

These are a type of connector that allow the cables to connect with the equipment at each end of the system. They are often filled with oil.

Cables

These are the wires that carry the electricity. They are made from copper or aluminium. For a HVDC single circuit system, there are two cables and for a HVAC single circuit, there are three cables.

Joints

These are the points where two sections of cable connect along a route.

Link boxes

These are the points where cable sheaths (the surrounding layer of a cable) are bonded and connected to the earth. This eliminates sheath currents and limits voltages for safety.

Remote monitoring systems

There is remote monitoring of underground systems. A fibre optic cable runs next to the underground cable to measure its performance and detect any failures, if they occur.

Operation and maintenance

There are measures in place to ensure the smooth operation and protection of underground cables. Databases detail the location of any underground cables to help excavation planning. Above ground markers, warning tape and strip covers help locate underground cables.

Regular monitoring of cable systems ensures the circuit is operating effectively.

If the cables are damaged, excavation works are required to open the trench. A new and larger trench is needed to repair the fault.

Construction

Constructing an underground cable involves:

- removing trees and vegetation
- putting in access tracks
- excavating earth to create a trench
- pulling and jointing the cables
- backfilling the trench.

FIGURE 6 Underground cable installation

A trench is dug and secured.

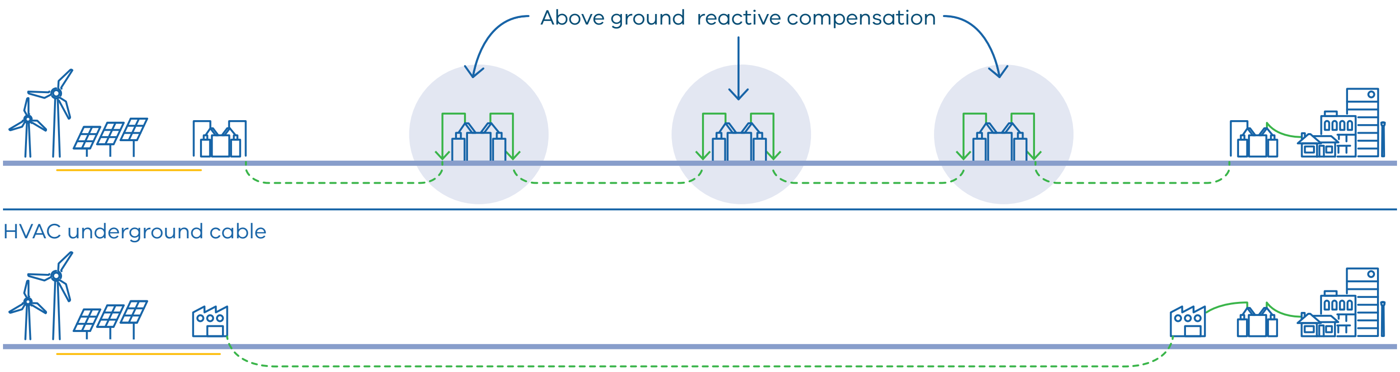
The ground is compacted. Bedding material is placed for the cable ducts to run along. Ducts are placed in the trench.

Concrete or a thermal backfill, like sand, is placed in the trench. A protective slab, warning tapes and the top layer of soil is then placed in the trench. Cables are then pulled through the ducts.

Reactors

Reactors remove reactive power – a type of wasted energy – that is present in HVAC underground cables. A cable's ability to move electricity depends on several electrical factors that contribute to the real power and reactive power. Real power is the power that continuously flows from a source to load. Reactive power is power that continuously flows from source to load and returns back to the source. It is essential that reactive power is managed and it must be removed to protect the cable from overloading. To do this, we need to bring HVAC underground cables back above ground at regular intervals in large stations to connect them to reactors.

HVDC underground cables do not need to be brought back out of the ground to reactors.



Differences between AC and DC underground cables

Underground cables can either carry AC or DC electricity, and while they may look similar, they have some differences.

	HVAC underground cables	HVDC underground cables
Cable losses (the amount of power that is lost during transmission)	Higher cable losses.	Lower cable losses.
Cables	Larger and more cables needed.	Smaller and less cables needed.
Electric and magnetic fields	HVAC underground cables generate EMF. Electric fields are screened by the metallic sheath built into the cable. Underground cables are always designed to ensure magnetic field levels are safe for public exposure. Underground cables are surrounded by plastic insulation which eliminates electrical discharge and will not interfere with radio, television and mobile communication signals nearby. EMF can interfere with nearby metal infrastructure like fences or pipelines. Assessments are undertaken to determine the EMF interference and if it can be mitigated through a minimum distance between infrastructure.	HVDC underground cables produce a static magnetic field. Static magnetic fields have a higher acceptable limit for safe public exposure, as they are considered safer than AC fields.
Terminal stations	Needed at each end of a HVAC transmission.	Needed at each end of a HVDC transmission.
Converter stations	Not needed.	Needed at each end of a HVDC transmission.
Shunt reactors	Needed at intervals along the cable route.	Not needed.
Generator connections	Does not need converter stations to connect generators into the network.	Needs converter stations to connect generators into the network.

Impacts

There are many environmental considerations and potential impacts during the construction, operation and maintenance of underground cables. This table provides a summary of potential high-level impacts – specific impacts in different locations may change based on detailed investigation and studies.

Impact	Potential construction and operation impacts
Aboriginal cultural heritage	In long underground cable routes, Aboriginal cultural heritage sites may be impacted by construction activities when the ground is disturbed. It may be possible to avoid some culturally significant areas by changing the route. Underground cables may not pose significant impact to intangible cultural heritage through their visual impact, but some above ground equipment will still be visible.
Aviation	Underground cables do not impact aviation activities.
Biodiversity	During construction of underground cable routes, trees and vegetation may need to be cleared to build access tracks, laydown areas, foundations and trenches. The removal of habitat may have an impact on local fauna. The easement may also create a barrier, affecting some local fauna from moving between adjacent habitats. Only grasses or shallow rooted vegetation is permitted to grow in the easement. Underground cables pose no risk to birds.
Bushfire and other natural disasters	Underground cables aren't affected by bushfires or storms and don't prevent aerial firefighting, although firefighters on the ground need to be aware of the constraints around using heavy machinery over easements.
Historic heritage	In long underground cable routes, historic heritage sites may be impacted by construction activities when the ground is disturbed. It may be possible to avoid some historically significant areas by changing the route.
Landscape and visual amenity	Underground cables are not visible once buried, posing limited visual impact on the landscape. While underground cables are buried, they require above ground equipment which has the potential for high visual impact. As only grasses or shallow rooted vegetation is permitted to grow in the easement, the removal of trees also has the potenital for high visual impact.
Land use, including impacts on farming	During construction, partial or entire occupation of land by the project temporarily limits the land being used for other activities. There are restrictions on heavy machinery and equipment that can be used over underground cable easements, which may impact farming activities. Sheds and houses cannot be placed over easements. Grazing is permitted, but generally cropping is not permitted.
Noise	During construction, there will be some noise and vibration from machinery. During operation, underground cables make no or minimal noise.

Superconducting cables

Superconducting cables use a type of material called high temperature superconductors. These cables need to be kept very cold, even colder than minus 200 degrees Celsius. To achieve this, the cables have a jacket, which keeps them insulated. Inside this jacket, liquid nitrogen cools the cables to maintain their temperature.

AC superconducting cables can carry far higher currents than conventional copper or aluminium cables. This makes it possible to move more electricity at lower voltages. A project in Europe has used superconducting cables to transmit up to 3.2 GW of power, however only over a short distance. The longest superconducting cables currently being used are around one kilometre long. There are several challenges when considering superconducting cables for long distances such as the required cooling systems and how to detect faults.

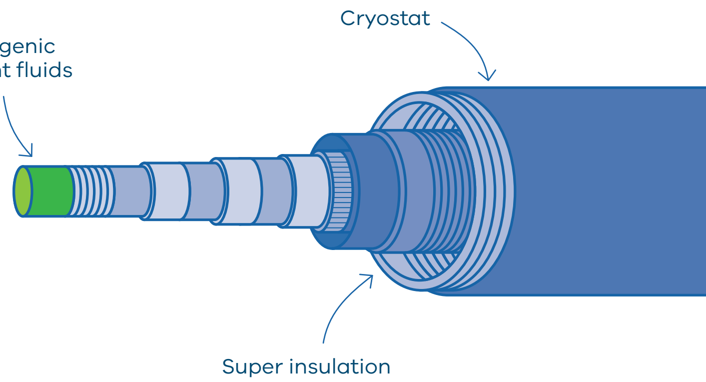
Superconducting cables use both AC and DC voltages over short distances (up to 2.5 km). To be reliably used over long distances superconducting cables require the availability of liquid nitrogen and multiple cooling systems which can be expensive. They are usually used in large cities or busy urban areas with limited space for easements. In Australia this technology is not in use.

FIGURE 7 Key parts of a superconducting cable

Cryostat
This is a metallic tube filled with liquid nitrogen.

Super insulation
This is a material that in low temperatures does not conduct electricity.

Cryogenic coolant fluids
This is a refrigerant like liquid nitrogen that keeps the temperature below minus 200 degrees Celsius.



Cooling systems and above ground infrastructure

Superconducting cables cannot operate without cooling systems. The cooling system has a few parts. These include:

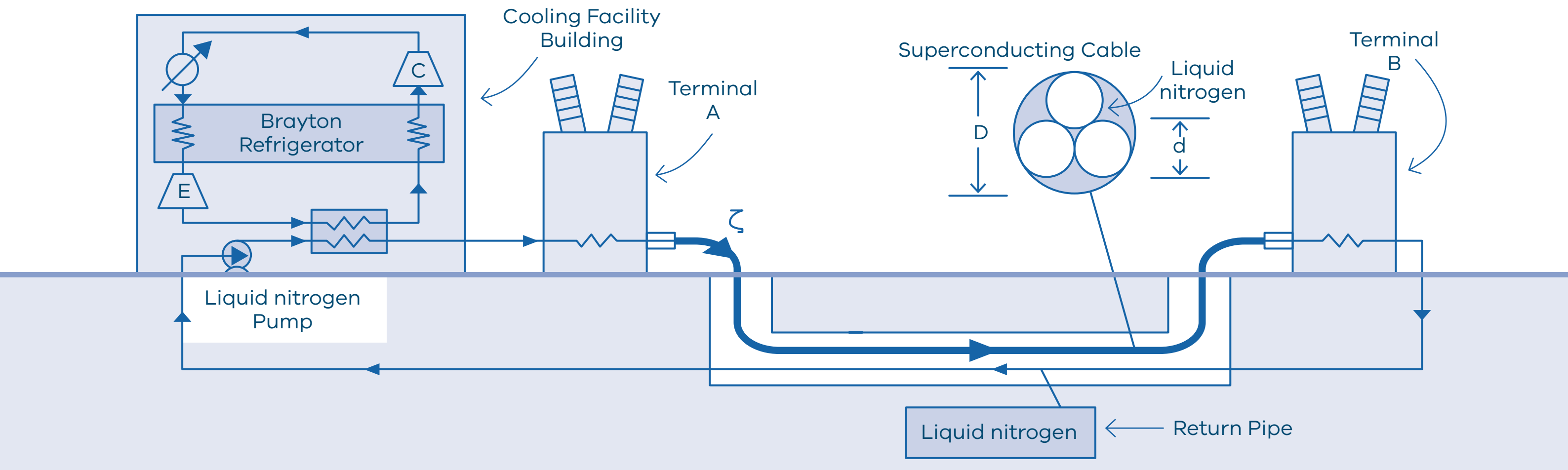
- a coolant tank holding the liquid nitrogen
- pumps and compressors
- cooling system controllers
- a reservoir unit
- a buffer tank
- a heating unit
- a cryocooler – or refrigerator.

The longest superconducting cables are around one kilometre long. A cooling station is at one end only.

Superconducting cable installations greater than one kilometre commonly need a cooling return pipe.

At larger distances, additional intermediate cooling and pumping stations maintain the temperature. The SuperLink project in Germany uses this type of cooling system.

FIGURE 8 Example of Superconductor Cable Cooling System



Superconducting Fault Current Limiters (SFCLs) protect the superconductor. They sit in container units above ground next to the cable route.

In normal operation, the SFCL allows current to flow. During a fault, a superconductor heats up and shifts from perfect conductor to a powerful resistor. A SFCL limits the fault current until the fault clears, the superconductor cools. Then the SFCL can return to normal operation.

Construction

Underground superconducting cables are installed in similar ways to other underground cables. The main differences are:

- they have smaller easements
- often less ground disturbance
- are quickly installed.

Superconducting cables require liquid nitrogen and the installation of a cooling system. Liquid nitrogen boils rapidly when exposed to heat so it is stored at extremely low temperatures. If liquid nitrogen is exposed to heat, it will expand to a very large volume of gas. This removes the oxygen from the space creating a lethal environment.

Operation and maintenance

There are common measures to ensure the smooth operation and protection of underground superconducting cables. Databases detail the location of any underground cables to help excavation planning. Above ground markers, warning tape and strip covers help locate the underground cables.

A superconducting cable is maintained in a similar way to a conventional underground cable system. The main difference is that the superconducting cable cooling system needs maintenance. Mechanical pumps and compressors must be serviced between every 12 and 18 months. Cryocoolers must be serviced every three to four years. If a cryocooler is damaged, this may damage the jacket.

Impacts

There are many environmental considerations and potential impacts during the construction, operation and maintenance of superconducting cables. This table provides a summary of potential high-level impacts – specific impacts in different locations may change based on detailed investigation and studies.

Impact	Potential construction and operation impacts
Aboriginal cultural heritage	In long underground superconducting cable routes, Aboriginal cultural heritage sites may be impacted by construction activities when the ground is disturbed. It may be possible to avoid some culturally significant areas by changing the route. Superconducting cables installed underground may not pose significant impact to intangible cultural heritage through their visual impact, but some above ground equipment will still be visible.
Aviation	Underground superconducting cables do not impact aviation activities.
Biodiversity	During construction of superconducting cables and easements, trees and vegetation may need to be cleared to build access tracks, laydown areas and foundations. The removal of habitat may have an impact on local fauna. The easement may also create a barrier, affecting some local fauna from moving between adjacent habitats. Only grasses or shallow rooted vegetation is permitted to grow in the easement. Underground superconducting cables pose no risk to birds.
Bushfire and other natural disasters	Underground superconducting cables are not affected by bushfires but should avoid flood plain areas as soil erosion may cause damage after flooding. Firefighting ground crews need to be aware of underground cables when creating fire breaks.
Electric and magnetic fields	Underground superconducting cables are fully shielded to prevent the generation of electromagnetic fields.
Historic heritage	In long underground superconducting cable routes, historic heritage sites may be impacted by construction activities when the ground is disturbed. It may be possible to avoid some historically significant areas by changing the route.
Landscape and visual amenity	Underground superconducting cables are not visible. Superconducting cables usually require above ground cooling systems every four to six kilometres.
Land use, including impacts on farming	During construction, partial or entire occupation of land by the project temporarily limits the land being used for other activities. During operation, there are some restrictions on what heavy machinery and equipment can be used over the easement. Grazing is permitted over the easement, but cropping is not. The cables can be buried deeper to allow cropping, but deeper cables means more ground disturbance. The cooling system needs an area of 20 metres by 20 metres every four to six kilometres.
Noise	During construction, there will be some noise and vibration from machinery. During operation, underground superconductor cables do not make any noise that we can hear. Pumping stations will produce a sound and mitigation measures can be considered.

Stations

All transmission infrastructure types need stations. Stations convert and connect power into different parts of the network.

High voltage alternating current terminal stations

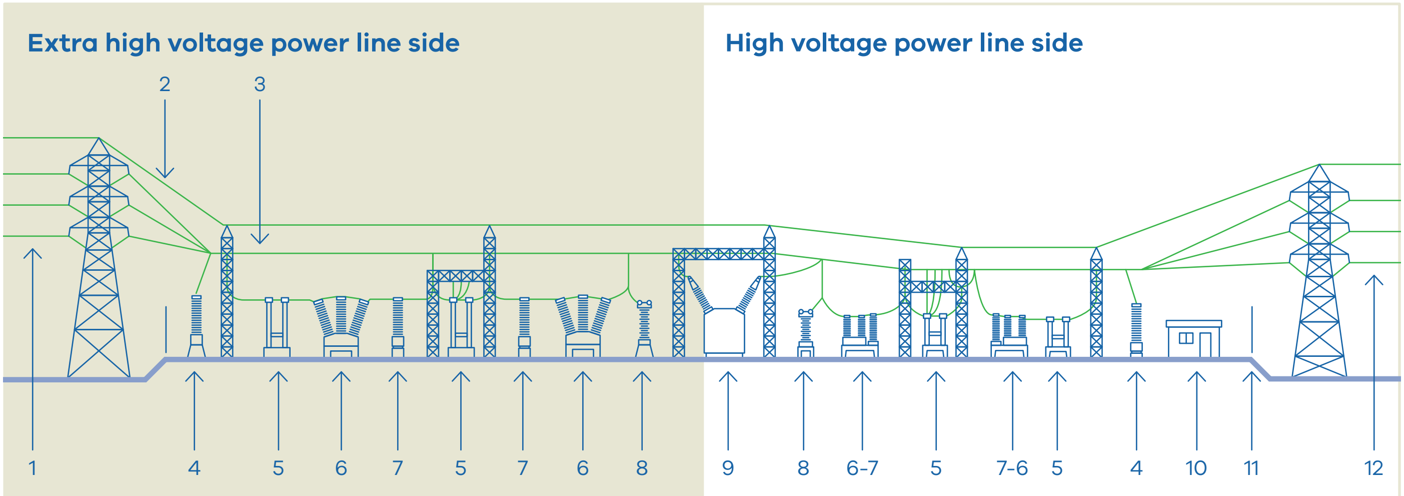
Across Victoria, terminal stations connect overhead lines or underground cables to move energy. You will likely have driven or walked past one of the 50 terminal stations located throughout Victoria's cities and regions.

A terminal station uses equipment called busbar and switchgear. The terminal station may include transformers to decrease or increase the voltage and allow for power to be transferred to different parts of the network. All parts of a terminal station operate as HVAC equipment.

Terminal station designs depend on the number of incoming overhead lines or underground cables. They also depend on the number of transformers needed. Maintaining reliability and security of the electricity network is important to the design of a terminal station.

The size of a terminal station depends on the voltage, the arrangement of the equipment and the transmission infrastructure type that is used. Higher voltages need more space between conductors.

FIGURE 9 **Key parts of a terminal station**



1 Extra high voltage line
2 Ground wire
3 Overhead lines
4 Transformer for measurement of electric voltage
5 Disconnect switch
6 Circuit breaker
7 Current transformer
8 Lightning arrester
9 Main transformer
10 Control building
11 Security fence
12 High voltage lines

Busbar

A busbar is a group of metallic tubes or bars that are a junction point where all incoming and outgoing electricity meet in one location.

Switchgear

Switchgear are electrical equipment used to control, protect and switch a circuit on or off. Switchgear includes circuit breakers and disconnect switches.

Transformers

Transformers increase and decrease the voltage so power is moved efficiently and safely.

Figure not to scale. For illustrative purposes only.

There are two types of terminal stations used in Victoria. Outdoor air insulated switchgear terminal stations and gas insulated switchgear terminal stations.

Outdoor air insulated switchgear terminal stations are common across most terminal stations in Victoria. In this type of terminal station the switchgear uses air insulation in a metal clad system.

Gas insulated switchgear terminal stations are also used in some locations. They are more expensive and harder to repair. Gas insulated switchgear terminal stations can be useful where space is limited and environmental impacts are high. Since the 1950s, gas insulated switchgear terminals use sulphur hexafluoride – a colourless, odourless, non-flammable and non-toxic gas. Sulphur hexafluoride provides electrical and current insulation. It can release into the atmosphere by accident and is a harmful greenhouse gas. For these reasons, the use of sulphur hexafluoride in terminal stations is being phased out in some countries.

High voltage direct current converter stations

In HVDC transmission, two or more converter stations are needed at each end of the overhead line or underground cables.

A converter at the start of the line converts the AC power to DC. A converter at the end of the line converts the DC power into AC. These converters connect to the AC networks through HVAC terminal stations. A converter station includes:

- converters
- a converter cooling system
- transformers to increase the voltage.

The two main types of HVDC converter stations are line commutated converters and voltage source converters. A line commutated converter uses thyristor valves as the main device to convert AC to DC and back again. The primary function of a thyristor is to control electric power and current by acting as a switch. In Australia, Basslink is a line commutated converter. Voltage source converters are self-commutating. This means they switch on and off insulated gate bipolar transistors to build or generate AC and DC waveforms. In Australia, Directlink and Murraylink are voltage source converters.

HVDC systems can be installed in various arrangements, each providing different voltage and power capabilities, levels of redundancy and availability under outage conditions.

The size of a converter station will depend on the voltage, the arrangement of equipment and the HVDC configuration.

Differences between converter station types

	Line commutated converter	**Voltage source converters**
Switching technology	Thyristors	Insulated gate bipolar transistors
Comparative converter losses	Lower	Higher
Harmonic filtering required	High	Low to zero
Need for reactive power compensation	Yes	No
Footprint size of converter station	Large	Small

FIGURE 10 **Stations for HVAC and HVDC**

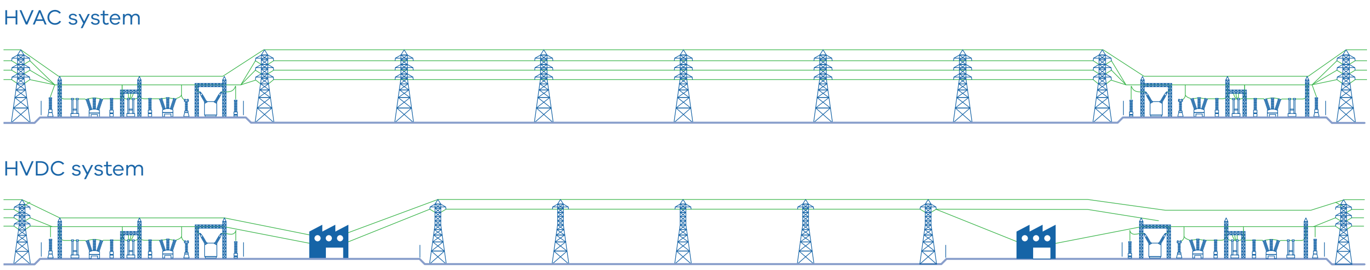
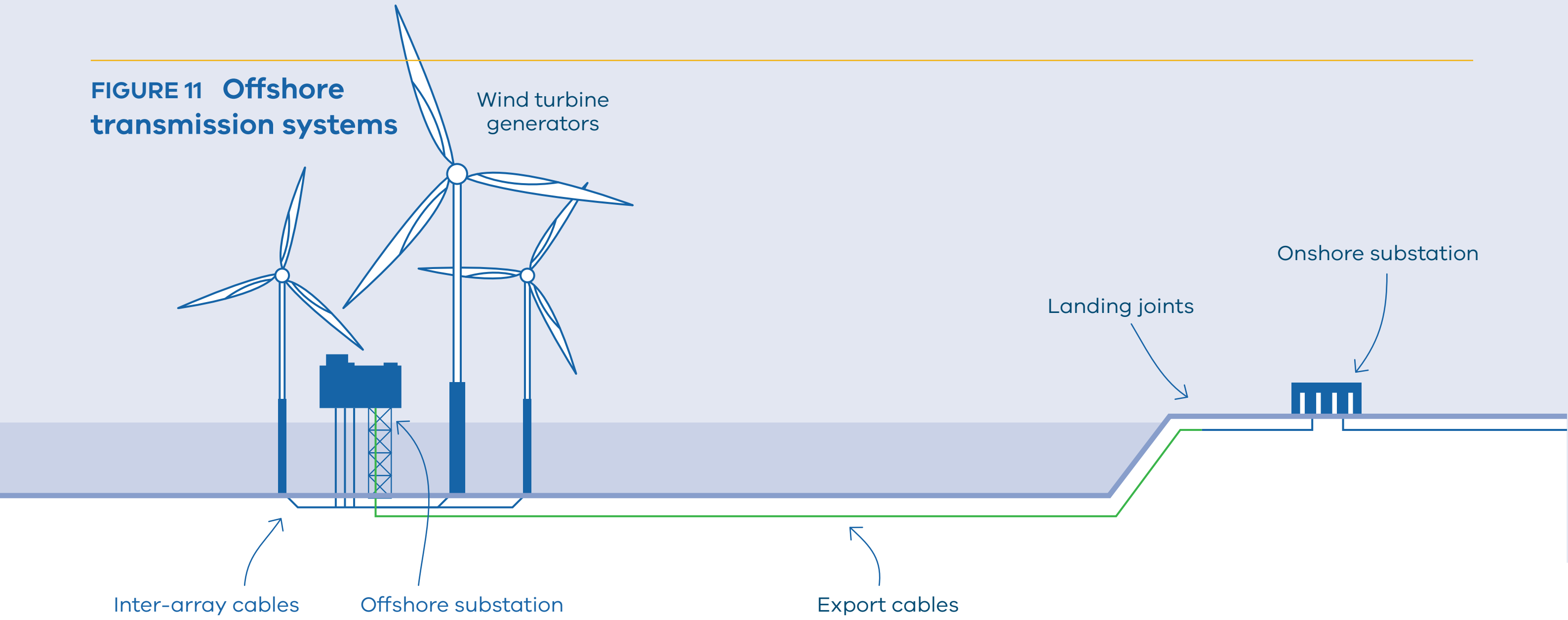


Figure not to scale. For illustrative purposes only.

Offshore transmission

Offshore transmission systems are a network of cables that connect offshore turbines to offshore and onshore substations. These substations then connect to the existing energy grid.

FIGURE 11 Offshore transmission systems



Offshore substations using AC or DC include a mix of:

- transformers
- switchgear
- converter stations
- additional reactive power and filtering infrastructure.

Substation platforms

Offshore substation platforms are where the substations sit in the ocean. They can either be fixed or floating platforms. They need to be carefully designed to avoid colliding with vessels and be protected from changing winds, waves and currents. The substations are made up of either AC, or AC and DC equipment. They include transformers to increase the voltage along subsea cables to an onshore substation.

Offshore substations commonly only connect to a single offshore wind farm. This is because the cost of an offshore substation increases as its size increases. It is usually easier to build one substation for a single offshore wind farm. In some cases where the size of the connection is smaller, multiple offshore wind farms can connect to a single offshore substation which can reduce the number of shore crossings.

Subsea cables

Subsea cables can be either AC or DC. For AC, the subsea cables connect an offshore AC substation which then connects to a corresponding onshore AC substation. For DC, the subsea cables connect to an offshore DC converter station. This then connects to a converter station onshore, or to another converter station offshore.

Construction

Offshore transmission systems are complex. They require careful planning, design, and construction to ensure they are safe, reliable, and efficient.

Thorough site investigations and assessing the environmental and geological conditions occurs prior to construction. This includes assessing the seabed, water depth, currents and weather patterns.

Installing subsea cables is an important part of constructing offshore transmission infrastructure. These cables must be insulated and protected against damage from saltwater, currents, and waves.

Offshore stations and substations need to withstand the harsh marine environment and the high voltages and currents. Onshore stations and substations are also designed and constructed to connect to the offshore system.

The construction process must minimise environmental impacts, including to marine life, habitats, and ecosystems. Installing cables and structures must minimise disturbance to the seabed.

Operation and maintenance

Regular maintenance of the offshore system ensures that the system is working safely and efficiently. Maintenance of offshore DC and AC systems typically involves inspections, testing different equipment, cleaning and any necessary repairs.

Impacts

There are many environmental considerations and impacts during the construction, operation and maintenance of offshore transmission. This table provides a summary of high-level impacts – specific impacts in different locations may change based on detailed investigation and studies.

Impact	Potential construction and operation impacts
Aboriginal cultural heritage	Aboriginal cultural heritage areas can extend from the coastline into the ocean. This means that Aboriginal cultural heritage sites may be impacted when the ground is disturbed offshore. It may be possible to avoid some culturally significant areas by changing where infrastructure is placed.
Biodiversity	Seabeds and ocean biodiversity can be disturbed when subsea cables are laid. Slow moving or growing species are the most likely to impacted. Subsea cable routes can be chosen to reduce disturbance. If subsea cables are not buried, they can provide a solid structure that non-local sea plants can attach to, leading to changes in the local ecology.
Electric and magnetic fields	During operation, subsea cables generate electric and magnetic fields. These electric fields are screened by the metallic sheath that is built into the cable. Interactions between the magnetic field around the subsea cable and the surrounding saltwater create an electric field. These magnetic fields may affect the orientation of fish and marine mammals and their migratory behaviour. Marine animals living on or near the ocean floor may also be exposed to higher EMF levels from subsea cables. Subsea cables can be buried deeper under the seabed to help limit magnetic field levels and ensure they are below the international levels for public exposure.
Landscape and visual amenity	Subsea cables are not visible but may also include above ground components that have the potential for visual impact. Cable connections on land can be buried to avoid visual impacts.
Maritime heritage and archaeology	Maritime archaeological sites like shipwrecks can be located near a subsea cable and may be impacted. Surveys help find these sites so that subsea cable routes can avoid them.
Marine protected areas	Subsea cables may impact marine protected areas. Routes can be chosen to avoid marine protected areas.

energy.vic.gov.au

VICTORIA State Government | Energy, Environment and Climate Action

ISBN 978-1-76136-354-2 (Print)
ISBN 978-1-76136-355-9 (pdf/online/MS word)

Accessibility

If you would like to receive this publication in an alternative format, please telephone the DEECA Customer Service Centre on 136 186, email customer.service@delwp.vic.gov.au, or via the National Relay Service on 133 677 www.relayservice.com.au. This document is also available on the internet at www.engage.vic.gov.au/offshore-wind-transmission-in-gippsland-and-portland.