UNDERGROUND CABLES IN THE TRANSMISSION GRID
AN INNOVATIVE TECHNOLOGY FOR GRID EXPANSION
Amprion’s transmission grid has a length of about 11,000 kilometres. This grid enables us to transmit electricity for more than 29 million people across an area from Lower Saxony down to the Alps.
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Man and the environment
Underground cables are a comparatively young technology in the world of transmission grids. They offer Amprion an additional option when it comes to expanding its grid. But not all cables are alike: Depending on whether they are to be laid on the seabed or run overland, or they are to carry a DC or an AC voltage, there are key technical differences that have a great impact on the applicability of a cable. We at Amprion are proactively working to fulfil our statutory duty and are utilising not only our own know-how but also the expertise of universities and component manufacturers to successfully implement underground cabling. This involves answering some still unanswered questions – such as how this technology can be integrated safely and reliably into the day-to-day operation of our grid. To this end, we will be trialling different types of cable and laying methods over the coming years, while collecting data and gaining experience in the operation of such cable routes.
Amprion’s responsibilities

Our power network has a similar structure to that of a road network: there are stretches for long-distance ‘traffic’ – the transmission grid – and stretches for local ‘traffic’ – the distribution grids. Since 1998, these have been separated from one another organisationally. While the distribution grids in Germany belong to around 800 different companies, such as municipal utilities, the ‘electricity highways’ are the responsibility of four transmission system operators (TSOs), one of which is Amprion GmbH.

With the aid of our 11,000 kilometre-long extra-high-voltage (EHV) grid, we transmit electricity for some 29 million people living in an area that stretches from Lower Saxony in the north right down to the Alps. Our number one priority is to ensure safe, reliable and cost-effective transmission of power to these people’s homes and workplaces. This means that our System Operation and Control Centre in Brauweiler, just outside Cologne, has the crucial task of balancing generation and consumption levels every second of every day. To be able to do this, our grid and operations require exceedingly reliable technologies.

Grid expansion for the energy world of tomorrow

The German government is following a clear objective with its energy transition policy: by 2040 wind turbines and photovoltaic panels are to supply 65 per cent of the country’s average annual electricity requirements. However, this power is for the most part not generated where it is actually needed, with wind farms predominantly located in the north and solar parks in the south of Germany. Furthermore, more conventional power stations are to be taken off line over the next ten years. The same applies to the country’s nuclear power stations, all of which will have been shut down by 2022. As a result, more and more electricity is being transmitted longer distances across the grid in order to reach the customer.

This development is fundamentally changing the structure and the nature of our energy system. And it’s this change that we are busily preparing our grid for. In order to be able to take up even more renewable energy into, and transport it via, our grid, we are working hard to fulfil our statutory duty by expanding our grid at the points necessary. During the next ten years alone, Amprion will be upgrading or building new lines covering a total of some 2,000 kilometres. To this end, we will be investing more than 5 billion euros between now and 2025. And we are going down some new paths and integrating some innovative technologies into our grid, such as high-voltage direct-current transmission (HVDC), grid-voltage stabilising systems and underground cables. We will be trialling and weighing up the pros and cons of each of these technologies with the greatest of care. Our objective: We want to maintain the high level of safety and availability of our grid at all times, expand it in a manner as acceptable to the general public as possible and operate it as eco-compatibly as possible.
Power line construction projects per Energy Grid Expansion Act (EnLAG No.)

- Ganderkesee › Wehrendorf
- Diele › Niederrhein
- Bergkamen › Gersteinwerk
- Krittel › Eschborn
- Wesel › Doetinchem
- Niederrhein › Osterath
- Osterath › Weißenthurm
- Wehrendorf › Gütersloh
- Gütersloh › Bechtudissen
- Lüstringen › Westerkappeln
- Kruckel › Dauersberg
- Dauersberg › Hünfelden
- Marxheim › Kelsterbach

Power line construction projects per German Federal Requirement Plan Act (BBPlG No.)

- Emden Ost › Osterath (A North)
- Osterath › Philippsburg (Ultranet)
- Conneforde › Merzen
- Hamm-Uentrop › Kruckel
- Metternich › Niederstedem
- Ürberach › Daxlanden
- Rammelsbach › Herbertingen
- Wullenstetten › Niederwangen
- Oberzier › German-Belgian border (ALEGrO)
- Neuravensburg › German border with Austria
The umbrella term 'cables' refers to a variety of technologies designed for a variety of tasks. Which technology is used depends on the voltage level, the transmission capacity and transmission distance, as well as the question of whether the power is to be transmitted cross-country or under the sea. In order to understand what the technology behind underground cables is capable of, it’s important to take a closer look at the technical details of the matter.
Submarine cable

All around the globe, high-voltage and extra-high-voltage transmission make almost exclusive use of overhead lines. However, wherever power is to be supplied to islands, offshore wind farms are to be connected with the mainland or the grids of two countries are to be connected to one another across the sea, the only way to transport this electricity is by means of cables laid on the seabed. This was the reason behind the development of the very first high-voltage power cables for use under the sea. Transmission system operators (TSOs) have been gaining more and more experience in this field ever since the 1950s. Depending on how long a power connection is, such subsea cables are planned either as AC or DC cables.

Subsea cables, also known as submarine cables, are laid with the aid of special cable-laying ships. These ships are loaded with very long lengths of cable, which they then transport to where they are to be laid at sea. The cables are then installed on the seabed. These ships can lay cables that are many nautical miles long. Consequently, very few cable joints are required.

JOINTS – THE ACHILLES HEEL OF UNDERGROUND CABLE ROUTES

The term ‘cable joint’ – or ‘joint’ for short – refers to the connectors used to connect the individual cable sections of a power line to one another. If a joint is damaged, the entire section of power line suffers from a fault and disruption. The section cannot be used to transmit electricity until the joint has been replaced. As repair work is complex and equally as laborious, it can take up a lot of time. This greatly affects the availability of underground cable systems compared with overhead lines.
Cross-country cables

Standard technology for low-voltage lines
When new buildings, housing estates or industrial/trading estates are connected up to the power grid or telephone network, the standard procedure in many places around the world has long since been to bury the cables underground. Such underground cabling is standard technology in the local distribution networks operating at the 230/400-V low-voltage level and the medium-voltage level between 10 and 30 kilovolts. In the urban environment in particular, the majority of power lines that supply small-scale industrial plants and households have for many years been laid underground. The power levels they transmit are relatively low, so they can be very compact.

The higher the power level to be transmitted and the higher the voltage applied, the more technically complex underground cables and their laying become. That’s why they account for a much smaller proportion of lines in the 110-kV distribution networks that distribute electricity generated by regional power producers to their local region. As a rule, underground cabling is reserved for inner-city sections. On land, overhead lines are standard at this voltage level owing to their greater cost-effectiveness.

A first in the field of extra-high voltage
Amprion’s transmission grid carries enormous amounts of energy across long distances at voltages of 220 and 380 kilovolts. It delivers power to entire cities and conurbations. To do this, the grid makes almost exclusive use of overhead lines. We have been using this technology for almost 100 years, and it’s both reliable and cost-effective. This, however, doesn’t apply to underground cable systems at this voltage level. They are high-tech products whose integration into the transmission grid has not yet been fully tested. What’s more, underground cables used for high transmission capacities – as opposed to distribution networks – require much more space and cannot be laid anywhere near as compactly as at low voltage levels.

Number of joints required for cross-country cabling
Laying underground cables on land is laborious and time-consuming. Trucks transport the cables on drums from the factory to the construction site. Since they have to use public roadways and cross over and under bridges, these cable drums are restricted with regard to their size and weight. One such drum is capable of carrying an underground cable of up to 1,300 metres in length. As a result, a cable joint has to be fitted roughly every kilometre, meaning many more of them have to be installed over a given distance compared with subsea cables.
Cross-country cables carrying DC or AC voltage

Amprion is currently implementing underground cabling projects designed to transmit electrical energy over land. We’re integrating this new technology into our transmission grid as part of a pilot application – a quite formidable challenge. That’s because our grid is a complex electrical system in which a very large number of components – such as overhead lines, transformers and switchgear – have to function in perfect harmony. One reason for the high level of complexity is the structure of our network. Our experts talk about it being ‘close-mesh’. Every network node, such as a substation, is connected to several more nodes by overhead lines. The high level of meshing and the use of tried, tested and dependable technologies form the foundation for the high degree of reliability offered by our transmission grid.

We will be expanding this system in future by adding further cable sections. Depending on the specific power transmission role a new link is to fulfil, we will be using either DC or AC voltage. These two technologies differ from the point of view of their physics, particularly in respect of their ‘capacitance’.

When electrical engineers talk about capacitance, they’re referring to a physical variable that describes how much electrical charge a capacitor, for example, is capable of storing. As a rule, a capacitor comprises two conductive surfaces that are electrically isolated from one another by a non-conductive material (dielectric) and on which electrical charges can be stored. When we connect a capacitor to a voltage, charge carriers flow until the capacitor has been charged to the level of the voltage applied to it. Underground cables also behave like capacitors in an electrical sense. In the case of such a cable, current can only be transmitted once this charging process has been completed.

And in the case of underground cables, the capacitance plays a very special role. Its effects differ greatly with DC and AC voltages, and this makes it the crucial factor in determining the feasible length of an underground cable link from the point of view of the system.
UNDERGROUND CABLES

DC VOLTAGE
The voltage is constant.

Complex converters are required to switch between the various voltage levels.

Is primarily suitable for transmitting higher power outputs over long distances from point to point.

Underground DC cable

No reactive power required during operation (one-off charging capacity at switch-on)

Longer cable routes are possible.

Statutory prioritisation of cables to be used in DC links

AC TRANSMISSION
The polarity of the voltage changes 50 times every second (50 hertz).

Is simple to convert to different voltage levels (transformer)

Is suitable for transmitting in meshed grids and for supplying customers/distribution networks with electrical energy.

Underground AC cable

Reactive power required continuously during operation – approx. 10 to 20 times more than an overhead line

The length of AC cables is physically restricted to just a few kilometres.

Partial underground cabling of sections legally possible along defined pilot links

CAPACITOR
As a rule, a capacitor comprises two conductive surfaces that are electrically isolated from one another by a dielectric and on which electrical charges can be stored. When we connect a capacitor to a voltage, charge carriers flow until the capacitor has been charged to the level of the voltage applied to it.
DC voltage

Physical properties

A DC voltage or direct current voltage is a voltage that is constant. DC transmission is very suitable for transmitting large amounts of energy over long distances with minimal losses. The disadvantage of this technology is that converters are needed if DC voltage is to be converted to a different voltage level or to AC voltage. These systems can be technically complex depending on the power level to be transmitted. This explains why DC technology has not established itself for lines that transmit and distribute electrical energy over land in a meshed grid.
AC transmission

Physical properties

AC voltage has established itself as the standard for power supply systems. Its key characteristic is that the polarity of the voltage – positive or negative – and therefore the direction of current flow, too, keep changing (reversing): in the power systems of Europe, this happens 50 times every second, which is equivalent to a frequency of 50 hertz. There’s another characteristic that is of great importance to us transmission system operators: with the aid of transformers, it’s relatively simple to change the voltage level of the power supply. This enables us to connect power generating installations and power consumers, such as distribution networks or electricity-intensive enterprises, to the various network levels without any problem.
Capacitance of DC cables

Before a DC cable is able to transmit power, its capacitance must be charged up. Engineers talk of ‘reactive power’. To achieve this, a DC voltage is applied to the cable.

This procedure can be illustrated by means of a water hose analogy. That said, the inner wall of this water hose is not smooth but is made up of little pockets. If we now pump water into the hose from one end, these pockets are filled up first.

Once all of the pockets are full, the water that is being pumped in at the one end starts to flow out from the other end – and we can use it. The situation is similar with DC cables: once the capacitance of the cable has been charged up, electricity can be transmitted along the cable.

The big advantage of DC voltage is that the voltage remains constant and the capacitance of the cable therefore only has to be charged up once. The ‘pockets’, then, are ‘filled with reactive power’ only when the current flow is switched on. As a result, an underground DC cable is able to transmit electricity over hundreds of kilometres.
Capacitance of AC cables

With AC cables, too, their capacitance first has to be charged before electricity can be transmitted. However, because the positive and negative poles change every 20 milliseconds, a charging and discharging current flows continuously in AC cables – what’s known as the ‘reactive power’. This is the crucial difference between AC and DC cables.

The issue of the reactive-power demand can once again be explained by means of a water hose analogy. That said, the inner wall of this water hose is not smooth but contains little pockets. If we now pump water into the hose from one end, these pockets are filled up first.

Mimicking the behaviour of an AC voltage, we now switch the pump feeding in the water from pump mode to suction mode and back again every 20 milliseconds. This also reverses the direction of flow of the water and the pockets are drained again. Owing to this rapid switching back and forth of the flow, only a certain length of the hose is filled with water. If the hose is too long or the filling time too short, no water flows out at the other end of the hose.

The situation is similar with AC cables: the capacitance of the cable must first be charged up before active or real power is transmitted along the cable. The constant changing of the direction of flow every 20 milliseconds means that the capacitance of a long cable cannot be fully charged. That’s why no power reaches the other end. Consequently, the length of an AC cable is limited for technical reasons.
Not possible without converters

DC cables require a converter station at both ends of the link – at the starting point and the end point. These transform direct current into alternating current and vice versa.

The converters themselves will be made up of transistors, diodes, capacitors and reactors. To protect these components and the associated control electronics against wind and weather, we will house everything in a station shed. Converters of the scale required by an EHV grid are high-tech installations and accordingly extremely expensive to build. That said, they also offer us some decisive advantages: Apart from being able to convert DC voltage to AC and vice versa, we can also use them to stabilise and control the grid voltage.
Reactive-power compensation

The reactive-power problem can be partially alleviated by means of reactive-power compensation, more commonly referred to as power factor correction. This function is performed by reactors, which resemble large transformers and provide reactive power.

This correction, however, also gives rise to another physical phenomenon. If we connect up reactors and cables electrically and then connect these to an AC source, compensating currents flow continuously between these elements. This results in resonance phenomena that in an extreme case can even endanger the stability of the grid. These resonances likewise limit the maximum possible length of the cables in an AC grid. This is comparable to the effect that can occur when a large number of pedestrians walk over a bridge in lockstep: the resonances triggered by this can even cause a bridge to collapse.
Experience gained so far with DC cables

Until now, DC cables have been used primarily for undersea applications. For example, this technology is being used in the North Sea to connect large offshore wind farms located far out to sea with the onshore grid. The industry currently has very little experience with laying DC cables underground on land. To date, they have been used to connect wind power installations out at sea to the transmission grid further inland via what are known as ‘point-to-point connections’. Thanks to the new legal framework regulating construction of the corridors using high-voltage direct-current transmission (HVDC), underground DC cables will increasingly be finding their way into the transmission grid in future. The industry currently has absolutely zero experience with long-distance, cross-country EHV DC cables.

Prioritisation of underground cables for DC lines

In Germany, legislators have set up the necessary legal framework to enable the use of underground DC cables in the nation’s transmission grid. With this measure, brought into effect at the start of 2016, the government has prioritised the use of underground cabling for four DC connections located across the country – two of which Amprion bears responsibility for: the ALEGrO project, which will transport electricity between Germany and Belgium, and the project named A North. The purpose of this second DC link is to transmit wind power from northern Lower Saxony to the Rhineland and from there to Baden-Württemberg by means of an overhead line.

According to the ‘Amendment to Energy Grid Expansion Act’, overhead DC lines are in future only to be used whenever

- existing or already approved transmission routes can be used without any need for additional notable impact on the environment,
- the topography or environmental protection necessitate it, or
- a responsible administrative body, such as an administrative district or a local council, expressly demands overhead lines.

Furthermore, the lawmakers have provided us with a methodology for planning underground DC cabling. The key principle of this methodology: the DC cable is to run in as straight a line as possible between the legally stipulated starting and end points. This is why we are, as far as possible, planning underground DC cable routes as direct links. We only deviate from the ideal of a straight line if we need to bypass a nature reserve or a housing settlement, for instance.
Experience gained so far with AC cables

Until now, very few underground EHV AC cable routes have been installed – especially for lines with high power levels. On the one hand, this has to do with the high reactive-power demand; on the other hand, we still need to find out how underground cables fit into a close-mesh transmission grid. They will definitely not be able to replace overhead lines one to one, among other things because the two technologies behave differently in operation. For that reason, we’ll be studying the operation of AC cables very closely and trialling them in pilot projects. Based on these experiences, we’ll then be in a position to decide to what extent underground cables can be deployed in the country’s transmission grid.

Pilot projects in the AC grid

In 2016, Germany’s legislators agreed to give greater scope for testing underground cabling in pilot projects. The Energy Grid Expansion Act (EnLAG) designated six and the German Federal Requirement Plan Act (BBPlG) five projects as such pilot projects. These pilot projects allow the country’s four TSOs to bury subsections of lines underground, under quite specific conditions, and to acquire much needed knowledge regarding the construction and operation of this technology. Basically speaking, we’re planning our AC projects with this partial underground cabling option along precisely the same lines as we do any overhead line: as space-saving as possible, in compliance with the principles of regional planning policy, and preferably bundled with existing infrastructure such as motorways and along existing routes. For the more we are able to make use of existing routes, the less we have to interfere with natural habitats.

AC voltage: important for linking different network levels

With the aid of transformers, it’s simple and cheap to change the voltage level of the power supply. In substations, these transformers are connected to one another by means of busbars and switchgear bays and also connected to the overhead-line and cable connections. The busbars are comparable to multiway connectors, the switchgear bays to switches.
Structure of an underground cable system

Overhead lines can frequently be seen traversing the landscape from a long way away. This is one area in which underground cables can really score. Despite this, this transmission technology still isn’t completely invisible: above and to either side of the underground cable trench, a protective strip must be kept free of deep-rooting trees and shrubs, and no buildings are allowed to be built. What’s more, an underground cable route comprises a large number of components: the underground cables themselves, cable joints, cable transfer stations and, in the case of AC lines, power factor correction equipment. The last of the above consists mainly of reactors, which are already installed in a number of Amprion’s substations. Reactors are similar to large transformers. We only ever switch them into the grid if the voltage on a line is too high. The reactors correct the power factor and lower the voltage on the line again. If the opposite is the case, that is, the voltage on the line is too low, correction equipment, such as capacitor banks, is put to use.

Underground cables as a transmission medium

Underground cables essentially consist of a conductor, an insulating system, a wire screen and a sheath. At the core is an electric conductor; in the case of extra-high-voltage (EHV) lines, this is usually made of copper. The conductor is enclosed by an insulating system (dielectric) whose main component is made of plastic, for example. An outer copper wire screen discharges leakage currents and keeps the electric field in the cable. The outer cable sheath protects the cable against moisture.

Cable joints as connectors

Owing to the obvious transportation limitations, cross-country EHV cables can only be supplied to the respective installation locations in sections currently around 1,000 to 1,300 metres in length. Bridges and other structures impose limits on the size of the cable drums that can be transported by truck. As a result, when laying these cables, the sections have to be connected using cable joints. In order to be able to conduct electrical measurements whenever necessary, some joints allow the connections inside to be accessed from outside.

Cable transfer stations for connecting to the grid

At those locations where the cables are introduced into the ground or emerge out of it again, we build what are known as ‘cable transfer stations’. These are required to connect the underground cables to the overhead lines. Such a station is very much like a small substation. Longer cable sections in the AC grid also require reactors to correct the power factor. What’s more, they require additional switchgear, which in turn takes up more space and means the transfer station as a whole requires more space.
Practically all underground cables used in today’s AC grid implement a plastic insulation medium (dielectric). Thanks to the new cable joint design, which enables the joints to be prefabricated and makes them faster to install on-site, as well as the better operating characteristics compared with all other types of insulation, underground cables with a plastic dielectric have succeeded in establishing themselves. The insulation material itself is usually made of polyethylene (PE) that is cross-linked in a thermochemical process to produce what’s known as XLPE. This enables the cable system to be operated at higher temperatures. However, we’re talking here about a single-layer insulation medium that has to be elaborately repaired whenever it is found to be faulty (using repair joints). Plastic-insulated cable systems are available on the market for applications ranging from medium voltage right up to 500 kilovolts.

DC cable systems have a similar structure to AC cable systems, but they make much greater demands on the insulation material and on the joint technology. Many cable systems used in the DC grid have a paper-insulated, mass-impregnated insulation (MI). With this form of insulation, a large number of layers of paper are wrapped around the copper conductor and then impregnated with an impregnating compound. This technology has been tried and tested and also offers yet another advantage: the insulating compound can rectify small faults in the insulation, rendering it to a certain degree ‘self-restoring’. The main disadvantage of this technology is that the cable joints are extremely complicated to install and they have to be wrapped on-site. Of late, cables with plastic insulation have started to be used. Initial experiences with these are currently being gained in the voltage level up to 320 kilovolts.
Planning and projects

Germany’s Energy Grid Expansion Act (EnLAG) and Federal Requirement Plan Act (BBPlG) have set out five projects with complete or partial underground cabling, which fall within the competence of Amprion. Like all grid expansion projects, these five projects must pass through a statutory approval process.

Step by step in constant dialogue

As part of the planning procedure for all of our projects, we deliberately inform the local population, public agencies and public interest groups of our intentions from a very early stage. This naturally applies to underground cable projects, too. By doing so, we make our planning process transparent to the public at large. It also allows us to incorporate additional information, ideas and suggestions into our deliberations. On this basis, we want to develop solutions that best meet the needs of the people and the environment, are economically viable, and at the same time ensure that the new power link operates safely and reliably for a very long time.

During the course of the planning work, we weigh up a multitude of considerations based on our experiences and the discussions held with the local stakeholders, ranging from the method of construction, through the cable route, to the location of the cable transfer stations. The final decision on the actual design and configuration of the underground cable link is made by the authority responsible for the zoning approval procedure.

DC projects

1. EMDEN OST–OSTERATH (Project A NORTH)
   - Prioritisation of underground cabling for the entire link (BBPlG No. 1)
   - Technology: High-voltage direct-current transmission (HVDC)
   - Amprion is planning the DC link known as ‘A North’ primarily as an underground cable connection. To this end, we’re searching for a route between the grid connection points in Emden Ost and the Osterath area that is as straight as possible – i.e. the shortest possible route. To enable us to later connect this link to the AC grid, we’ll be building a converter station in Emden. At the southern end of the link, a second converter station in the Osterath area will connect the link to the ‘Ultranet’ project.

20. OBERZIER–GERMAN-BELGIAN BORDER (Project ALEGrO)
   - Prioritisation of underground cabling for the entire link (BBPlG No. 30)
   - Technology: High-voltage direct-current transmission (HVDC)
   - The ALEGrO project is a joint venture between Amprion and our Belgian partner Elia. It’s to be the first EHV DC link to be built in the Amprion grid area and will run between the Düren/Aachen area in Germany and Liège in Belgium. At the same time, we’re investigating how successfully an HVDC link and the necessary converter stations can be integrated into our grid. The entire project is scheduled to employ underground cable from end to end.
CONNEFORDE–MERZEN
Partial underground cabling option for the entire link (BBPlG No. 6)
Technology: AC transmission
In cooperation with TenneT, Amprion is planning a new 380-kV line between the grid connection points Cloppenburg and Merzen. Which sections turn out to be both economically viable and technically feasible for installing underground cabling will be revealed during the course of the planning phase.

DIELE–NIEDERRHEIN
Underground cable sections at Raesfeld, Borken and Legden (EnLAG No. 5)
Technology: AC transmission
Mid-2016 saw us successfully launch trials on the pilot section in Raesfeld. Two more underground cable sections are planned for North Rhine-Westphalia: one in Borken and another in Legden.

WEHRENDORF–GÜTERSLOH
Partial underground cabling option for the entire link (EnLAG No. 16)
Technology: AC transmission
The line to be built using underground cable for some sections is to connect the regions of Osnabrück and Eastern Westphalia. Thanks to its central location within our grid, it’s of great importance and it will in future be used to transmit wind power from the north to the south of the country. Which sections turn out to be both economically viable and technically feasible for installing underground cabling will here too be revealed during the course of the planning phase.
Underground cable section in Raestfeld following completion of the construction work.
Construction process and recultivation

The task of building underground cable links as cost-effectively and in an ‘soil-friendly’ way as possible is a challenge Amprion – working hand in hand with research institutes, experts and professional associations – is very willing to take on. Underground cables can be laid using a number of different methods. Whether an open or a closed construction method is chosen depends, among other things, on the respective soil and groundwater conditions and the natural geographical and also man-made features of the landscape – such as rivers or motorways that may have to be crossed. Furthermore, we always take aspects relating to environmental law into account when choosing the construction method.

The open construction method: Raesfeld, for example

Particularly when laying underground cables in open trenches under agricultural land, it’s essential that we go easy on the ground, the soil and its water balance (hydrology). We’ve already gained extremely valuable experience and know-how in this regard from our first pilot section in Raesfeld, where we successfully installed the underground cables in an open trench while protecting the soil. We cooperated closely with the local farmers and actively sought and acted upon the advice of agricultural scientists.
Layer for layer

Underground cable projects demand a huge amount of detailed information on the composition of the soil. Whereas in the case of an overhead line Amprion surveys the ground only at the points where the pylons are to stand, that is, typically every 400 metres, test drillings have to be made every 50 to 250 metres when planning a cable route. The test samples are then analysed by pedologists (soil scientists), who determine how the various soil layers are to be handled. The more layers there are, the more complicated it is to excavate and later backfill the soil. Remember that the individual layers have to be carefully separated. The data from the soil analysis is incorporated into the plans for the cable system and the expert opinion itself lays down essential soil protection measures for each section of the route. Independent soil experts monitor the construction activities on-site throughout the entire project.

Bedding the cables

To begin with, excavators remove the soil layer by layer and deposit these layers separate from one another at the side of the cable trench. At a depth of around two metres, we then lay empty conduits for the cables that are later fed through in stages. The conduits lie in a stone-free bedding material that very effectively deflects and dissipates heat and allows the soil to drain in a controlled manner.

As the cables emit heat, they have to be laid a good half a metre apart depending on the power level to be transmitted. Given the number of cables necessary – in Raesfeld there are twelve parallel individual conductors – this means the amount of excavation work involved for cable systems for the transmission grid far exceeds that necessary for distribution networks.

**AC TRANSMISSION: LAYING CABLES ON OPEN/AGRICULTURAL LAND**

*AC cable system for transmitting up to 4,000 MW*

- **Excavated material (backfill)**
- **Topsiill**
- **System A**
- **System B**
- **Wire mesh with trench warning tape**
- **Cover plate**
- **Conduits for underground cables**

Width required for construction site approx. 45 m
Backfilling and recultivation

The cable trench is backfilled in reverse order to excavation – from the bottommost to the topmost layer. To minimise settlement and to prevent cavities from forming, we backfill the earth as finely grained as possible. It has to be dry to do this and wet, even damp, weather can slow down construction work accordingly. Afterwards, the various layers lie almost exactly as they did before we started work: the structure of the soil is maintained and it is able to regenerate very quickly. A soil scientist accompanies and monitors the construction and recultivation activities.

Closed construction

Open construction is not the method of choice for all situations. If we have to run the underground cables under water or roadways, the closed construction method offers genuine advantages – despite being far more expensive and time-consuming. The only points at which we require areas for setting up construction site equipment is at the start and destination points of such a route. There are a number of different processes available, such as pilot tube tunnelling, horizontal wash drilling and microtunnelling. Which method we choose depends on the local geology and the length of the route.
Underground cables in operation

Underground cables are still a comparatively young technology in the world of EHV grids. Up to now, the only underground cables in use in the EHV grid are ones that carry comparatively low power levels over relatively short stretches – such as for connecting individual customers or generating facilities. However, the energy transition necessitates that high power levels are transmitted over very long distances. And yet we still don’t have any substantial experience demonstrating how such cables behave in Germany’s meshed transmission grid. That said, one thing is certain: the fact that underground cable systems comprise a large number of operating elements makes the power grid more complex. Integrating all of them safely and reliably into the network demands innovative solutions. This is why we at Amprion are actively promoting research and development – together with our partners in scientific research. We use research projects to test different cable technologies and laying methods.

Warming of underground cables

Wherever current flows, heat arises. Overhead lines release this heat to the surrounding air. Underground cables warm up the soil around them. The temperatures reached as a result of this depend on technical parameters such as the degree of utilisation and the way the cables have been laid. The deeper the cables are in the ground and the closer the individual cables are laid next to one another, the higher the degree of localised warming and the greater the restrictions with respect to power transmission. For this reason, whenever we plan a new cable system, we calculate the installation depth of and the clearances between the cables very precisely. We bed the cables in materials that dissipate the heat emitted by the cables optimally to the earth surrounding and above the cables.

Reliable grid operation

In today’s meshed power network, the following rule applies: If a link fails owing to, say, a fault, the electricity must always be able to be transmitted via an alternative route – and without this causing another fault or indeed a power failure. This is known as the N-1 criterion, and it essentially guarantees the high level of system reliability and availability in Germany.

Right from the very design phase of an underground cable system, we ensure that we comply with this criterion. We do so by applying the experience gained with underground cable systems operating at low voltage levels. We know from this that the average availability of underground cables lies far below that of overhead lines. While statistics show that the failure rate of an underground cable system is lower, the length of time it takes to repair a fault is much longer. There are a number of reasons for this: if a fault arises with an overhead line, the line is easily accessible and quick to repair. With underground cables, however, you first have to localise the location of the fault and then excavate and undercover it. The actual repair work and concluding EHV test are also complex and take time.
Man and the environment

Underground cables also involve more than just technical challenges. They lead to new concerns and worries for landowners, in particular, and they are impossible to lay or operate without having a significant impact on nature. When it comes to their respective impact on the ground and soil, overhead lines and underground cables differ quite fundamentally. While the construction of a new overhead line necessitates underground construction activities only at those locations where the pylons are to be erected, the construction of underground cable systems involves much more extensive excavation work. That’s why independent experts draw up comprehensive environmental studies for each of our underground cable projects. These studies serve as the basis for the statutory environmental impact assessment. If permanent negative effects are unavoidable, the responsible authority stipulates, on the basis of the expert opinion, the compensatory measures that must be taken. Once construction of the underground cable system has been completed, the areas above the cables can in most cases be used for agricultural purposes, as they were before, with the exception of a few minor restrictions within the area of the protective strip.

Protective strip and land use

In order to ensure that the power link operates without any problems, no buildings, deep-rooting trees or shrubs are allowed to stand on a defined protective strip above and to either side of the underground cable trench. There are no restrictions on animals grazing and fields being tilled. Farmers can work their land as normal. The protective strip is marked by signposts along the route.

PROTECTIVE STRIP

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Warming of the soil and crop yields

Many farmers ask us what impact the heat dissipated by the cables could have on their crop yields. Scientific studies have revealed that the heat from the underground cables has no negative impact.

Before our pilot project in Raesfeld began, we, in collaboration with the University of Freiburg, conducted in-depth investigations into potential effects of underground cables on the thermal balance and water balance of the soil – also with a view to later agricultural output. To simulate a cable as realistically as possible and by simple means, an initial field test carried out in 2005 saw us bury pipes in a sand bed and fill them continuously with hot water. In 2011, we then studied an experimental cable route set up in a substation near Düsseldorf. This involved trialling various bedding materials, including fluidised soil, in Raesfeld after we had assessed the results of all the trials. Over a period of four years, we then grew a range of crops above and next to the cable system: potatoes, maize, winter wheat, spring barley and winter oilseed rape.

What we found was that the cables lie so deep in the ground that heat in the soil above them dissipates quickly as it rises and the temperatures in the top layers of the soil are similar to those measured in the reference field located next to the cable system. The seasonal and weather-related fluctuations in temperature have a big influence on the soil layers. Any influence exerted by the underground cable is scarcely detectable.
Monitoring in Raesfeld (since 2016)

In the meantime, we have implemented the first underground cable section of our Diele–Niederrhein (EnLAG Project No. 5) power line construction project in Raesfeld/Münsterland and launched trial operation. In this pilot project, and working hand in hand with soil and agricultural experts, we have also implemented an intensive monitoring programme designed to verify previously obtained results under real-world operating conditions. A total of 700 sensors continuously measure the level of warming and the water balance of the soil. Furthermore, the Chamber of Agriculture of North Rhine-Westphalia will be conducting and documenting trials to see how the soil develops during the course of recultivation.

Electric and magnetic fields

Wherever current flows, magnetic and electric fields arise: constant fields in the case of DC voltage (also known as static fields or DC fields) and pulsating, periodically changing fields in the case of AC voltage (alternating fields).

An electric field is caused by the voltage present between two points. The higher the voltage, the larger the electric field. Electric fields arise wherever electrical appliances are connected to the power supply. When an electrical appliance, such as a coffee machine, a TV or a PC, is connected to a power socket, an electric field is generated – even when the appliance is not switched on. In other words, all household appliances that are constantly plugged into the wall socket by means of their power cable are surrounded by an electric field – even when they’re not in use (coffee machine, microwave oven, electric bread cutter, radio, TV, PC, etc.). EHV cables do not ‘emit’ an electric field: their wire screen keeps it entirely in the cable.

A magnetic field is caused by the flow of a current. Whenever you switch on your hairdryer, electric iron, TV, PC or lamp, a magnetic field is generated in addition to the electrical field. This magnetic field surrounds the appliance and the conductor through which the current is flowing – for example, the power cable of the hairdryer, iron, TV, PC or lamp.

The 26th Ordinance on the Implementation of the German Federal Immission Control Act (26. BImSchV) stipulates ceilings for the strength of electric and magnetic fields generated by electrical installations. For the magnetic DC fields of DC voltage systems, 26. BImSchV stipulates compliance with a limit of 500 microteslas (μT) for places where people reside permanently. The ceiling for the magnetic field strength with 50-hertz AC systems is 100 μT. The fields generated by our underground cable systems will comply with these requirements.
CEILINGS IN GERMANY

The 26th Ordinance on the Implementation of the German Federal Immission Control Act (26. BlmSchV) stipulates ceilings for the strength of electric and magnetic fields generated by electrical installations. The fields generated by our underground cable systems will comply with these requirements.

Magnetic fields in AC lines

100 µT

Magnetic fields in DC lines

500 µT

CONTACTS AND FURTHER INFORMATION

Further information can be found on the Internet at www.amprion.net.

Free info hotline (from within Germany)
0800 5895 2474

E-mail
netzausbau@amprion.net

For further information, go to:
www.amprion.net
UNDERGROUND CABLES
AMPRION IN FIGURES

79,200 km²

the area covered by the Amprion grid, stretching from Lower Saxony down to the Alps

~29 M

the number of people supplied with electricity via the Amprion grid

11,000 km

the total length of power lines that make up the Amprion transmission grid

~63 GW

the total installed generation capacity in the Amprion grid area