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Factsheet

Swiss cable study: technical and operational limits of underground cables in the Swiss transmission grid

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1 Initial situation

1.1 A growing proportion of underground cables in the Swiss transmission grid

Laying new underground cables in the Swiss transmission grid only remains possible to a very limited extent. This is shown by Swissgrid's cable study. As an innovative company, Swissgrid is open to new technologies and examines both overhead line and underground cable options for grid projects. The Federal Council decides during the sectoral plan procedure whether a section of line should be implemented as an underground cable or an overhead line. 42 kilometres of underground cable have now been installed in the Swiss transmission grid. Official decisions have already been made to lay a further 250 kilometres, for example the new cable line in the second tube of the Gotthard Road Tunnel.

1.2 The cable study shows the effects during operation and in the event of disturbances

Swissgrid has been drawing attention to the technical and operational challenges entailed by an increase in the use of underground cables in the extra-high-voltage grid for some time. Swissgrid has prepared a detailed cable study based on scenarios in order to look objectively at the discussion on the choice of technology and to strengthen the reliability of the basis for decision-making. The study has been validated by the company RTEinternational and reviewed by the Swiss Federal Office of Energy (SFOE) and the Federal Electricity Commission (ElCom). In addition, the results of the study commissioned by the SFOE have been confirmed by the Swiss Federal Institute of Technology (ETH).

This cable study shows that laying too many underground cables in the transmission grid has a negative impact on grid stability and security of supply in Switzerland. This is due to the specific physical properties of underground cables, which make the operation of the transmission grid and the rectification of disturbances much more difficult. As these physical properties increase disproportionately as the voltage rises, the technical and operational challenges associated with an increase in underground cables are particularly great in the extra-high-voltage grid (380 and 220 kilovolts). At lower voltage levels (up to 145 kilovolts), however, they are much less significant.

2 Technical and operational limits at a glance

2.1 Reliable and stable grid operation: voltage maintenance

A constant voltage is fundamental to ensure the reliable operation of the Swiss transmission grid. Due to their physical properties, underground cables increase the voltage much more than overhead lines. In addition, long underground cables either reduce the effective power of a line (active power) or require systems to compensate for reactive power. This difficulty increases in proportion to the length of the underground cable.

The voltage is mainly maintained by generators in power plants, which feed electrical energy directly into the transmission grid. If there is more reactive power in the grid than the power plants can absorb, there is a risk of overvoltages. This increases the risk of disruptive oscillations and oscillation amplification, causing instability in power plants and grid operations. This can lead to grid failures and damage to systems or the triggering of protection devices, and therefore to the disconnection of grid components. Even now, situations occur in which the potential of power plants to absorb reactive power is not sufficient to keep the voltage within the permissible limits in all regions. Swissgrid is therefore already planning investments in additional systems for reactive power compensation.

Compared to overhead lines, underground cables generate more reactive power on account of their compact design: their conductors are much closer together than in overhead lines, and they are encased in a thick insulating sheath. This increases their capacity – in simple terms, their ability to absorb and return electrical charges – and hence also their reactive power. If the proportion of underground cables in the transmission grid increases, there would be another huge rise in the need for compensation systems. This would make grid operation more complex and make the transmission grid more susceptible to faults. In addition, compensation systems take up a lot of space, which is often lacking at substations – the most suitable locations – and they cause noise emissions. The cable study shows that building the additional compensation systems required for extensive underground cabling would incur costs of around CHF 1.4 billion. Generally speaking, underground cables are between two and ten times more expensive over their entire life cycle than overhead lines of the same length. These additional costs for underground cables have to be borne by all electricity consumers.

2.2 Reliable and stable grid operation: resonances

Every technical infrastructure has a natural frequency at which it «vibrates» by itself once it has been «activated» – like a swing that swings back and forth at its own natural frequency after being pushed. Electrical grids also have their own natural frequencies, which are referred to as resonant frequencies. To prevent disturbances in the transmission grid, its resonant frequencies must be as far away as possible from the frequencies of any vibrations that could interfere with the lines. This includes the harmonics present in the grid, which are caused by the interaction of many different electrical non-linear consumers or power electronics such as rectifiers, frequency converters or motor controllers.

As mentioned above, an underground cable in the extra-high-voltage grid has fundamentally different physical properties than an overhead line due to its compact, solid construction. The resonant frequency of grids with underground cables is also much lower than that of grids that consist exclusively of overhead lines – like a tuning fork that «hums lower» the greater its mass. However, the lower the resonant frequency of grids, the closer it is to the frequency of potentially disruptive external influences. This means that there is a risk of dangerous oscillation amplification with underground cables – comparable to the effect of soldiers walking in step across a bridge. If the frequency of their steps equals the natural frequency of the bridge, oscillation amplification can cause the bridge to collapse.

If the number of kilometres of underground cables in the transmission grid in a particular region rises, its overall resonant frequency decreases. This heightens the risk of potentially disruptive resonances and oscillation amplifications – and therefore the risk of grid failures or damage to grid components and electrical devices. In contrast to reactive power, the physical phenomena that lead to resonance problems cannot be dampened by compensation systems. This can only be done by filters. However, introducing filters into the grid is risky, as they can have a positive or negative effect on the grid, depending on its condition. For example, a filter may not provide any damping or may even amplify oscillations if certain lines are out of service.

2.3 Restoration of lines after disturbances or planned shutdowns

Regionally limited disturbances in the supply of electricity can be triggered by natural events (e.g. lightning strikes, ice, falling trees). In the transmission grid, line shutdowns planned by Swissgrid to carry out maintenance work or grid expansion projects are by far the most frequent. In all these cases, it is important for the lines to be switched on (again) as quickly and smoothly as possible. This generates electrical oscillations.

Since grids with underground cables in the extra-high-voltage grid have a lower resonant frequency, as described above, the potential of these oscillations to cause amplification and damage is much greater. There is therefore a risk of damage every time underground cables are restored after disturbances or planned shutdowns. An additional factor is that underground cables often remain out of service for weeks or months in the event of damage, as they are much more complex and expensive to repair than overhead lines due to the fact that they are laid in the ground.

2.4 Grid restoration after a power system failure

Power system failures are large-scale disturbances to the supply of electricity caused by the simultaneous outage of several grid elements in the transmission grid. In contrast to regionally limited disturbances or planned shutdowns, power system failures are very rare. However, their effects can be dramatic. This is why restoring the grid as quickly and smoothly as possible after a large-scale power system failure is vital for Switzerland's security of supply. Swissgrid has divided the Swiss transmission grid into four grid restoration cells to cope with this scenario. Each of these cells comprises an area with «black start-capable» power plants. After a power system failure, they can use their own electricity generation to build up the necessary frequency, voltage and power to gradually restore the surrounding grids and supply them with electrical energy.

The Swiss cable study shows that depending on the length of the cables and their proximity to power plants with black-start capability, the resonance effects can make it completely impossible for a cell to restore the grid after a large-scale power system failure.

3 Looking to the future

The electricity system is undergoing the greatest transformation in its history. In this context, Swissgrid must also address general developments in extra-high-voltage transmission technology. As an innovative company, Swissgrid is open to new technologies. When planning current projects, Swissgrid relies on tested and proven technologies, but also monitors the technology market and participates in innovation processes and pilot projects. Swissgrid is in close contact with European grid operators and engages in technical dialogue with the authorities, research institutions and industry. As far as the challenges of underground cables in the Swiss transmission grid are concerned, however, it is quite clear that the problems identified in the cable study urgently – and rapidly – require appropriate framework conditions for underground cabling in the interests of sustainable and secure grid development.

The cable study shows that the proportion of underground cables in the transmission grid must be kept low from a technical and operational point of view. Uncontrolled cabling on a «first come, first served» basis has a negative impact on grid stability and security of supply in Switzerland. For future grid projects, it should therefore be carefully weighed up from a general perspective at which points in the transmission grid underground cabling is a necessary and acceptable option.

Swissgrid is endeavouring to create a system that defines the technical and operational framework conditions for underground cabling. A sound decision-making basis for determining the acceptable cable length for future grid construction projects – in relation to the overall grid as well as to other planned grid projects – should be available at the latest at the preliminary project stage and during the sectoral plan procedure. This should be combined with other framework conditions, such as regional planning aspects or existing infrastructure links, to form a comprehensive catalogue of criteria geared to the requirements of the overall system.

As underground cables can have an impact not only on the local grid, but also on distant grid regions, it is not possible to quantify the maximum possible cable lengths per region. The system needs to show which lines should not be considered for underground cabling for technical and operational reasons. Swissgrid will coordinate the system with the authorities and present it to the various stakeholder groups and the general public.

4 Conclusion

Laying new underground cables in the Swiss transmission grid only remains possible to a very limited extent. The Swiss cable study confirms the major technical and operational challenges associated with an increase in underground cables in the extra-high-voltage grid, which Swissgrid has been emphasising for some time. These challenges are based on the specific physical properties of underground cables. The study comes to the following conclusions:

1. **More systems, greater complexity and costs:** underground cables generate much more reactive power than overhead lines. To avoid risky overvoltages and grid failures, this reactive power must be absorbed by additional compensation systems. Compensation systems increase the complexity of grid operations, cause high costs, take up a lot of space and generate noise.
2. **Difficult grid restoration after a power system failure:** underground cables reduce the resonant frequencies in the transmission system. This increases the risk that the restoration of the grid may become impossible in entire regions after a power system failure due to resonance effects. These resonance effects also increase the risk of damage to grid components and electrical devices.
3. **The lower the proportion of cables, the more stable the grid operations:** due to the phenomena demonstrated in the cable study, the proportion of underground cables in the transmission grid must be kept low.
4. **Planning with foresight:** uncontrolled cabling on a «first come, first served» basis has a negative impact on security of supply in Switzerland. In consultation with the authorities, Swissgrid is endeavouring to develop a system that will make it possible to weigh up from a general perspective where underground cabling is a necessary and acceptable option for future grid projects.
5. **Longer outages to repair damage:** while overhead lines are available again within a few minutes or hours in the event of a disturbance, it can take weeks or months to repair underground cables. This is because a disturbance on an underground cable is usually associated with damage.

The results of the study support the principle put forward in the consultation draft for the revision of the Federal Electricity Act (Acceleration of the Conversion and Expansion of the Electricity Grid) («Grid express»), which suggests applying an overhead line principle in the transmission grid in the future and only examining the option to use underground cables if the relevant criteria are met.