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Detailed information on energy research

The hotline in the grid

Higher temperatures with overhead lines can help to transport additional electricity

BINE
Information Service

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The electricity grid that has been used for decades reaches its limits when transporting increasing amounts of electricity over long distances. There are already limiting bottlenecks. One way to integrate more wind and solar power into the grid is provided by overhead lines with a higher maximum temperature. These can transport more electricity, enabling grid congestion to be avoided. One problem, though, is that metals expand more at high temperatures. As a result the line lengthens and sags more. However, special high-temperature conductors can provide a remedy here.

With a comparable conductor cross-section, the transport capacity of existing lines could almost double. Existing lines are designed for temperatures up to 80 °C. With greater electricity, the temperature rises but more power is also transported. This offers the potential to reduce the grid expansion. The problem with the conventional design is that the higher temperatures cause the lines to sag more. This can lead to critical situations. HTLS conductors (High-Temperature Low-Sag conductors) can permanently withstand temperatures of up to 210 °C and lengthen less than conductors with a conventional design.
Project member Dr Ralf Puffer from the Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen) explains: „The conductors are generally operated below their maximum temperature. As the higher capacities are rarely used, the additional losses are kept within reasonable limits.“ In other words: the higher electricity-carrying capacity is primarily a flexibility option. No overhead line in Germany is permanently operated at full capacity. This is due to the so-called n^{-1} criterion. This stipulates that the grid still has to remain stable when a transmission line fails. The remaining components would then have to take over the power. Therefore each piece of equipment requires a certain safety margin.

Fig. 1 *The laboratory rig enabled the researchers to simulate various weather conditions. The daylight bulbs above simulated the solar radiation, while the wind tunnel blew air at the conductor at an angle of 90°.*

Higher temperatures with new materials

Routes for overhead lines were mostly designed in the past for standard conductors. Greater sagging could have fatal consequences: the distance to the ground or to other equipment would be reduced and safety would not be ensured at all times. With a mast spacing of 400 metres, the sagging can vary by several metres depending on the weather and electricity flow.

To prevent greater expansion owing to the higher temperature differences, HTLS conductors have an adapted structure: in contrast to the standard stabilising steel core and aluminium casing used for the power transmission, these have a core consisting of carbon fibre composite material, aluminium-ceramic fibre composite material or special steel alloys. These materials expand less at high temperatures and can therefore provide the supporting core for the conductive aluminium layer. The aluminium also has a slightly different composition that is also durable at high temperatures.

A special feature of HTLS conductors is the way the conductor expands after the so-called inflection point. From this point, the aluminium is more stretched than the core. This means that it no longer contributes to the stability. Instead the core supports the entire load. Since the aluminium can no longer expand lengthwise, the outer layers loosen up a little. This is similar to a shoelace that is compressed at both ends so that the diameter increases. „This feature has a positive cooling effect on the transmission line," adds project manager Tobias Frehn. „The bunching up causes the surface of the conductor to increase. This enables the heat to be dissipated more easily.

Gathering experience in the field trial

To determine the sag of HTLS conductors, the researchers undertook extensive laboratory and field tests. The field trial was conducted on a roughly 10-kilometre section belonging to a 220-kV transmission line. This section was partly chosen because the existing transmission capacity was not entirely sufficient, which meant that the line needed to be expanded or upgraded. In addition, the re-installation work matched the previously drawn up project plan timewise. The engineers installed three different conductor cable types (Fig. 5). Two parallel standard conductors were installed for each phase up to the test section; the high-temperature conductors, however, only had one cable per phase. The electricity flow was therefore twice as high here. During the test, the researchers determined the conductor sag and, in addition to the electricity values, they also recorded the weather data, conductor and terminal temperatures at one-minute intervals. They also determined the tensile forces on the terminals.

Fig. 2 *Both the wires in the core and the aluminium zirconium wires in the jacket contribute to the tensile strength and conductivity of the ACCR cable.*

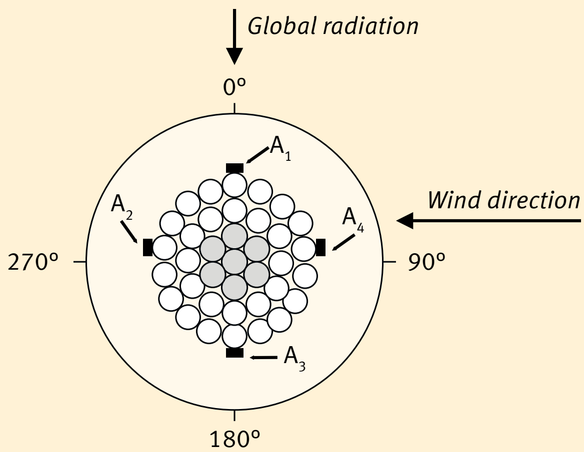

Fig. 3 *Precisely determining the conductor surface temperature was an important step in verifying the calculation models and identifying their inaccuracies. To achieve this, the researchers installed groups of four measuring sensors at specific intervals on the conductor with an angular displacement of 90°.*

Three conductor types in the test

The core of the first conductor, the Aluminium Conductor Composite Core (ACCC), consists of a carbon fibre composite material. The expansion of

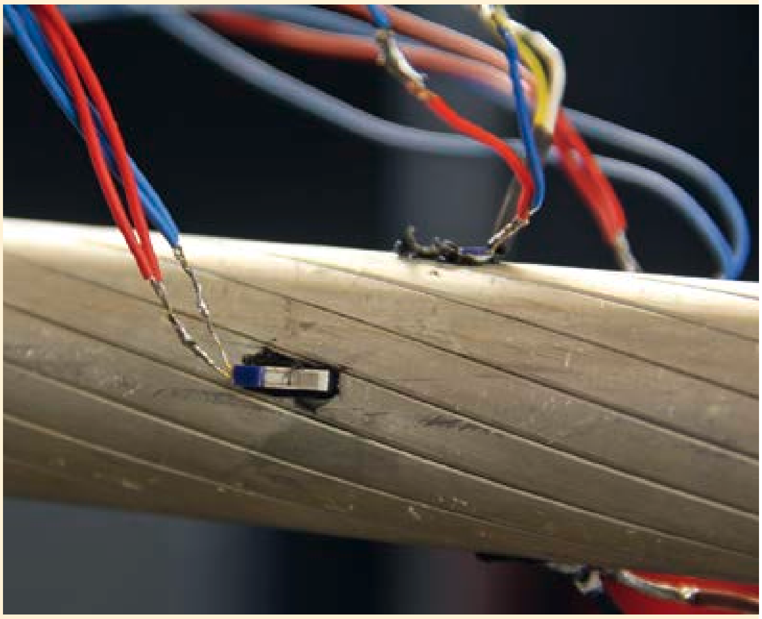

Fig. 4 *The temperature sensors are fixed to the conductor with thermally conductive, high-temperature silicone adhesive.*

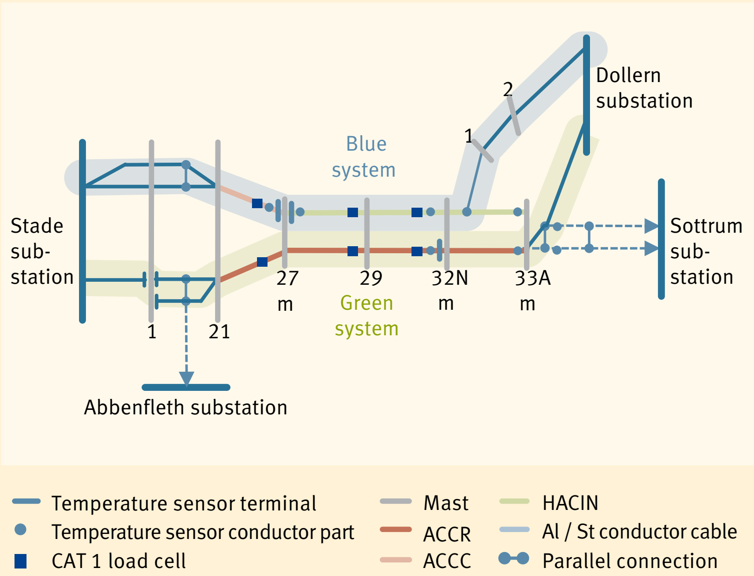

Fig. 5 *Schematic showing the various types of conductors deployed during the field trial: HTLS conductors were used between masts 21 and 33A. The locations for the temperature measurements on the conductors are marked with a circle. The locations for the terminal temperatures are marked with a dash.*

the core material is only one seventh of steel for any given temperature rise. After increasing in length by around two per cent of the original length there is abrupt failure. When there is thermal overloading, conductors with steel cores deform plastically before breaking. In practice, this makes it easier to identify an overloaded line and to replace it before it completely fails.

Cables with an aluminium oxide fibre metal matrix composite core were also investigated. Of the variants tested, these Aluminium Conductor Composite Reinforced (ACCR) conductors expand the most for any given rise in temperature. However, they are only around halve the size of conventional conductors and can permanently withstand temperatures of 210 °C. Although visually similar to standard conductors, they are stiffer, weigh significantly less and achieve greater conductivity. As a third variant, steel wires combined with a nickel-iron alloy were used in the inner part of the conductor. This Invar alloy reduces the thermal expansion to around one third.

Reproducible conditions in the laboratory

In parallel, the scientists tested the thermal behaviour under reproducible conditions in the laboratory. „We were able to influence the underlying weather conditions here such as the wind, temperature and global radiation. A laboratory for this purpose is unique worldwide," explains Dr Ralf Puffer. In addition to the electricity intensity, the underlying weather conditions also have a significant impact on the temperature and cooling of the conductor. The laboratory rig was 7.5-metres in length (Fig. 1). This made it possible to investigate the conductor and core temperature irrespective of marginal effects such as the cooling of valves. The electricity flows amounted to no more than 3,000 amperes in the test.

As a worst-case scenario, the project team set the temperature at 35 °C with a wind speed of 0.6 m/s and a solar radiation of 900 W/m². This corresponds to a windless, midsummer day with a cloudless sky. Using the wind tunnel, the wind speed was increased to 15 m/s in order to check its cooling effect.

To measure the temperature, the researchers equipped the conductor with groups of four measuring sensors placed at different locations (Fig. 3). These detected the temperature influence of the global radiation and the wind on the conductor surface. One result of the measurements: at temperatures up to 100 °C, existing calculation models are very accurate even with HTLS overhead lines. They reach their limits, however, above this temperature. Although no critical conditions occurred in the conductor during the measurements and calculations in accordance with existing standards, the calculations are, however, somewhat conservative, so that not all line reserves would be used optimally.

Guideline recommendation for new standards

To enable widespread use, grid operators need to be able to rely on valid standards. After all, the conductors hang on the masts for decades. In addition to their high technical availability, they should also not pose a risk. The results of the research project were therefore incorporated in recommendations for upgrading the overhead line standards in regards to high-temperature conductors. Among other things, the researchers recommend supplementing the Technical Note provided by the Forum network technology / network operation (FNN) in the German VDE association and to expand other existing standards. With standards that are directly applicable for HT and HTLS conductors, and with the resulting increased safety for people and materials, HTLS cables can help the existing grid achieve more flexibility on a larger scale. Operators need this flexibility in order to be able to feed into the grid and transport the continually increasing proportion of renewable energies.

Flexible low- and medium-voltage grids

High-temperature overhead line conductors mainly provide flexibility in the transmission grid. However, considerable flexibility is also required in the distribution grid for the low- and medium-voltage levels. This requires effective voltage stability. This can be achieved, for example, with intelligent substations. These can help to integrate decentrally generated power into the grid.

Achieving static voltage stability – the bottleneck in grid integration

Traditionally, voltage stability is achieved as a side effect of the grid construction with passive instruments, whereby the design of the grids and their components are the decisive factors. If active instruments control the voltage, this can improve the management of local grids and improve the integration of decentrally generated energy. These active instruments can include, for example, controllable local grid transformers or photovoltaic systems. Active instruments also include supplementary components such as longitudinal voltage regulators and distributed measurement technology.

Controllable local substation as a research component

Together with research partners, SMA AG has developed a controllable local substation with intelligent control and operating procedures for the low-voltage grid. In the three-year research project, the project partners have developed, among others, a controllable local power transformer that is switchable under load conditions. This has been utilised in further research work, such as in the Green Access project that is running as part of the Future-proof Power Grids initiative until the end of 2018. A high level of integration in the distribution grids makes it possible to use energy in the regions where it is produced. This is the basic requirement for supplying the distribution grids with the subordinate medium-voltage grids and for transporting the energy to load centres further away, for example with high-temperature overhead conductor cables.

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  imp GmbH, Arnsberg, Michael van Fondern, http://www.imp-gmbh.de

Links and literature (in German)

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  Website for the „Future-proof Power Grids“ research initiative
- Frehn, T.; Puffer, R.; Fondern, M. von u. a.: Hochtemperaturleiter für Freileitungen. Feldversuch, Richtlinienempfehlung und Modellbildung. Abschlussbericht zum Verbundvorhaben „HTL“. FKZ 03ET7508A. RWTH Aachen. Institut für Hochspannungstechnik (Hrsg.); TenneT TSO GmbH, Bayreuth (Hrsg.). April 2016
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