Superconducting fault current limiters

The use of superconducting technology in power grids marks an important technological advance. The new procedure is necessary since power grids must now be radically changed in order to handle energy loads generated by a large number of different energy sources.

Today, large centralized power plants feed power into a hierarchically structured grid in which current flows from the highest-voltage level to the medium-voltage level, then to the low-voltage level and finally into households and businesses. To reliably transmit and distribute electricity from producers to consumers, these voltage levels are separated from one another by grid elements like transformers. In the course of Germany’s current energy transition, distribution grids will have to increasingly handle small, decentralized and also volatile renewable power plants without significant changes to the established hierarchical grid structure.

However, the instability that can be produced by energy feeds into distribution grids with these established structures may result in large-scale power cuts. In the final analysis, there are too many energy sources in the network – sources that feed too much power into the grid and thus overload it. One solution is to change the distribution grids’ network structure.

For example, in the future, (new) high-voltage lines will feed wind-generated power from the north of Germany to the south, while a dense distribution grid will ensure that this power is reliably distributed to consumers. However, the new power generation structure may lead to an increase in the amount of short-circuit current in distribution grids. The grids will lack suitable mechanisms to protect them from this increased current since the measures that have successfully secured and protected grid operation to date – such as the use of transformers or similar measures to separate grid structures – will no longer be effective. As a result, new technologies will be required to ensure that short circuits do not permanently damage grids in practice.

The use of superconducting technology in short-circuit limiting reactors will support the existing grid structure. The short-circuit currents occurring in power transmission and distribution grids will be limited very quickly, effectively, automatically and, thus, with a high degree of intrinsic safety. After a short cooling period, superconducting fault current limiters can return to operation without additional measures.

The special properties of high-temperature superconducting materials are utilized for this purpose. A number of manufacturers are now marketing second-generation superconducting bands on a commercial basis. These bands, which are cooled by liquid nitrogen, completely lose their direct-current resistance in the superconducting state. In alternating current applications, an extremely small residual resistance remains. This resistance normally has virtually no impact on current flows. If a certain “current value” is exceeded, the superconductor reacts immediately and generates resistance in milliseconds. This resistance limits the increase in current generated by short-circuits extremely quickly and very effectively, thereby protecting the power grid. The superconductor is heated in the process. After a short regeneration phase, the current limiter can return to normal operation. Regeneration – like current limitation – is fully automatic and takes place without external intervention.

In the particular case of the superconducting fault current limiter being developed for Stadtwerke Augsburg, a short-circuit limiting reactor is bypassed by a superconducting fault current limiter and a downstream circuit breaker. In normal operation, current flows through the no-loss superconductor. When a short-circuit current occurs, the superconductor limits it very quickly and shunts it into the limiting reactor. Current flow through the superconductor is then interrupted to allow the superconductor to regenerate. As a result, the losses to the power grid from the limiting reactor occur only during breakdowns. During normal grid operation, the limiting reactor is “invisible” and current flows through the superconducting fault current limiter.

Interesting facts and figures about the superconducting fault current limiter and the field test:

- Unlike conventional limiting reactors, resistive superconducting fault current limiters (SFCLs) have no resistance and no negative impact on a power grid’s stability. As a result, SFCLs protect grids when short-circuits occur but are “invisible” for the grid during normal operation.
- Short-circuit limiting reactors are a conventional alternative to superconducting fault current limiters. They are used, if at all, in distribution grids (up to 30 kV) primarily in the industry sector. Only in exceptional cases are short-circuit limiting reactors used in distribution grids (110 kV and higher).
- As designed by Siemens, superconducting fault current limiters consist of an SFCL element that bypasses a parallel-connected short-circuit limiting reactor in normal grid operation. As a result, the limiting reactor is currentless and causes no losses during normal operation. However, the SFCL itself needs energy for cooling purposes. On a rough estimate, the power loss of an SFCL can be assumed to total about 50% of the energy consumed by a comparable short-circuit limiting reactor.
- A large number of short-circuit limiting reactors are currently installed in power grids. According to some estimates, there are as many as 44,000 installed worldwide. In normal operation, a short-circuit limiting reactor always has resistance, which typically causes a power loss of 25 kilowatts. As a result, up to 1,100 megawatts of electricity – or the total output of a large-scale power plant – are lost worldwide due to the use of short-circuit limiting reactors.
- Siemens researchers are attempting to reduce these losses by 50% or more through the use of superconducting fault current limiters – SFCLs themselves require energy for cooling purposes.
- A superconducting fault current limiter with a rated current of 817 amperes will secure the connection between Stadtwerke Augsburg’s grid and an industrial company. In operation, an energy load with a maximum feed-in power of 15 megawatts will be fed from the company’s grid into the Stadwerke’s grid. Without appropriate measures, this load would exceed the permissible short-circuit level. During the field test, a short-circuit limiting reactor, which will be used as a backup solution, will be bypassed by a superconducting fault current limiter. As a result, the negative impact and the losses due to the limiting reactor in normal operation will be avoided. The SFCL will only limit the current and the limiting reactor will only be used if there is a short circuit. This special arrangement will also make it possible to directly compare the operation of a conventional solution (short-circuit limiting reactor) with that of a superconducting fault current limiter (SFCL).

- Siemens has developed an extensive patent portfolio for superconducting fault current limiters. For example, for an invention that the company reported to the U.S. Patent Office already in 2000, it was granted a patent in 2003.
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