# SUPERCONDUCTING FAULT CURRENT LIMITERS – A NEW TOOL FOR THE "GRID OF THE FUTURE"

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## ABSTRACT

*Nexans SuperConductors has designed, built, tested and installed a number of such SFCL systems in different areas and cases of operation with various requirements and specifications from DNOs or power generation industry. The designs as well as the test and operation results are presented. Prospective short-circuit currents in the order of 50 kA have been limited to below 10 kA according to the design of the limiter. The limiters have shown reliable operation during field tests with durations of about one year each.*

## INTRODUCTION

In the future the mix of conventional and renewable power generation will lead to high technical requirements for the power networks. Also the present changes in electricity networks like the ramp-up of distributed generation and the stronger need for interconnection result in an increasing demand for protection against high short-circuit currents. Superconducting fault-current limiters (SFCL) provide a new efficient approach to the reliable handling of such faults. The technology has already been tested in applications like busbar couplings and in-line protection of local networks as they e.g. exist in the house load of power plants. SFCLs handle fault currents completely autonomous and after the fault is cleared, the SFCL returns automatically to its original state without any electronic or external action. The SFCL doesn't interrupt the current completely but limits it to a well defined value. This so called follow-current can be designed according to customer specifications. The installation of an SFCL also leads to additional benefits like savings in switchgear equipment and reduction in hazard potential.

## FAULT CURRENT MANAGEMENT

Distribution network operators are today challenged to take a huge effort in laying-out their grids against steadily increasing short circuit currents.
Due to the installation of distributed generation the "conventional" power flow in the grid is no longer in one direction only. Today distribution grids are often only built for uni-directional load flow, i.e. the power is going from higher to lower voltage levels. Distributed generation can invert and change this situation. However, this change of load flow can also create larger fault currents.

With conventional technology there is often no or at least no sufficient solution for an effective short circuit detection and limitation.
The integration of current limiting reactors adds unwanted inductance and impedance to the grid, leading to real and reactive power losses as well as to potential voltage instabilities. Fuses or limiters based on pyrotechnical means require external triggering, direct access to the device and expensive exchange of parts after each limiting event.

## OPERATING MODE OF SFCL DEVICES

SFCLs have the unique characteristics of almost zero impedance under normal operating conditions and high impedance at fault conditions.

### Working principle

Superconductors show a nonlinear voltage-current-characteristic of the form $U \sim (I/I_c)^n$ , where $I_c$ is the critical current of the superconductor, defined as the current, at which 1 µV voltage drop per cm superconductor length is reached. The exponent $n$ is usually between 5 and 30 for typical high temperature superconductors (HTS). With the short circuit event the current increases and the voltage follows this power law. Within a few ms the associated heat brings the superconductor above its critical temperature, the material completely loses the superconducting properties and behaves like a normal resistor with a proportional law (fig. 1). A further heating of the material during the short circuit leads to further increasing resistance and decreasing limited current (fig. 2). This transition from the superconducting to the normal conducting regime is called a "quench". SFCLs make use of this transition, when the normal operating current is below the critical current $I_c$ and the quench is triggered by the high current occurring during a short circuit event.

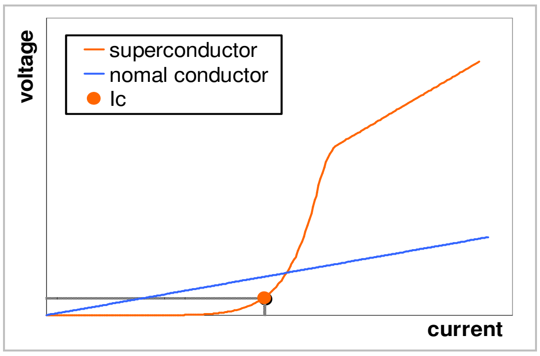

**Figure 1:** Voltage – current characteristics of a superconductor compared to a normal conductor.

## Behaviour in the grid

The SFCL technology provides the unique possibility to design new innovative grid structures: the grid can have very low impedance, e.g. by grid coupling or low impedance equipment, but without the risk associated to high short circuit power.

With a resistive SFCL in the line, the limiter minimises the phase shift between current and voltage during a short circuit. This effect strongly reduces the stress and thus the requirements on the circuit breakers in line, because the current and voltage are almost in phase, which also means zero crossing is occurring simultaneously. In any case, all circuit breakers, busses and cables downstream of a limiter can have much lower ratings and significant equipment cost can be saved.

Especially high savings are expected for power plant installations in the case of building new blocks or expanding existing ones.

An interesting aspect of using SFCLs is also that equipment can be operated close to its limits, such that investment can be avoided or shifted by temporarily installing a SFCL.

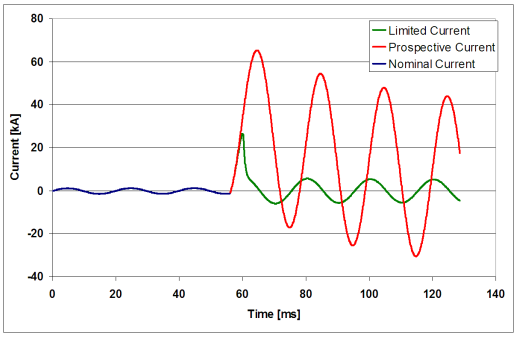

**Figure 2: Prospective and limited current during a short-circuit event.**

## Capabilities

SFCL as versatile devices for fault current management can be applied at different positions within a typical grid, as shown in fig. 3

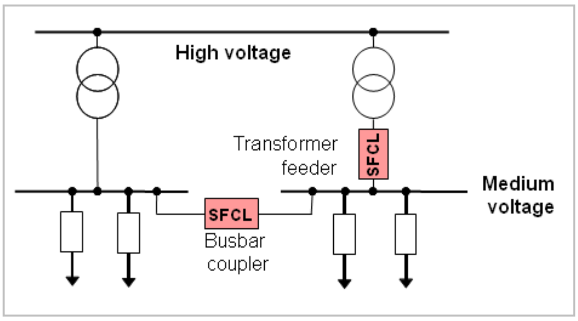

**Figure 3:** grid installations of SFCLs

### Feeder application

Depending on the protective function, the SFCL can be used either in incoming feeders, e.g. as transformer feeder, or in the outgoing feeders. This in-line application protects all elements downstream of the point of installation.

### Busbar coupling

The SFCL is especially advantageous for busbar couplings, since under normal operating conditions perfect load levelling is reached. In case of a fault, the limiter ensures that the short-circuit contribution from the un-faulted bus is strongly reduced. Even more, the un-faulted side can maintain almost stable voltage and operation.

## BENEFITS BY USING SFCL

The SFCLs have a number of advantages which in this combination are unique and not available with other limiting devices:

- The systems are intrinsically safe, no detection electronics are needed, the system limits under all circumstances, even in the case of a defective limiter.
- The current flow is not interrupted so that the detection of the short circuit location is not hampered.
- The limited current can be adjusted according to the specifications.
- After a short circuit the system automatically recovers if cooling is provided, dependent on the system, in less than 30 s.
- The reactive load under normal operation conditions is negligible.
- Due to a mainly ohmic resistance current and voltage are in phase and the interruption of the current path by a circuit breaker is simplified.
- The SFCL offers special advantages in combination with the installation of a HTS cable, which does not need to be short-circuit-proof, allowing easier cable design and higher availability of the cable system.

## REALIEZED PROJECTS

Nexans SuperConductors has designed, built and successfully tested four SFCL systems for different installations sites. The specification range covered with these systems is listed in Table 1. At present two more systems are under design and construction. All these devices are full 3-phase systems for the medium voltage grid.

**Table 1:** Specifications of SFCL systems

| parameter | from | to |
|---|---|---|
| rated voltage | 12 kV | 24 kV |
| nominal current | 100 A | 1 kA |
| inrush current | 460 $A_{rms}$ | 4.1 $kA_{peak}$ (50 ms) |
| prospective current | 25 kA | 63 kA |
| Limitation in the 1st half-wave | 7.7 kA | 21 kA |
| follow current*) | 0.9 kA | 7.0 kA |
| limitation time | 80 ms | 120 ms |
| operating temperature | 65 K | 77 K |

*) limited current after first limited half wave

In the following classifications the first number gives the voltage in $kV_{rms}$, the second the nominal current of the systems in $A_{rms}$.

## SFCL 10-100 and 10-400

Two systems have been installed as busbar couplers in medium voltage power stations in the UK. The field test of the first system has been completed as planned after 9 months with full customer satisfaction.

## SFCL 12-800

This system – also based on BSCCO-2212 superconducting elements – has been the first SFCL system installed in the house load of a thermal power plant world-wide. It has proven stable operation for more than one year before the infrastructure was re-used for the qualification of another superconductor material in the frame of the project ENSYSTROB.

## ENSYSTROB (SFCL 12-800)

Project funded by the German government where the superconducting bulk material of a foregoing project (see above) was substituted by 2G REBCO tape. This new conductor recently became available in the required quantities and with the required characteristics. As a main advantage of this new material, the AC losses – and thus the necessary cooling effort – have been reduced. In addition this material offers a stronger limitation which could be - if needed - an additional argument.

**Figure 4:** SFCL 12-800

# PROJECTS IN 2012

Within the year 2012 Nexans SuperConductors is going to build and test two more medium voltage systems.

## ECCOFLOW (SFCL 24-1000)

This European funded project is also based on YBCO coated conductors. It is designed for two completely different applications, a busbar coupler and a transformer feeder. According to these applications it will be tested and thus demonstrate the versatility of this new technology.

## AmpaCity (SFCL 12-2300)

Within this project, funded by the German government, a concentric 3-phase superconducting cable will be installed in the distribution grid of Essen, Germany. This cable will be combined with a SFCL, which protects the superconducting cable against high fault currents. With this protection the cable design can be less complex, lighter and remains operational immediately after a short circuit. For the first time such different superconducting devices (a cable and a fault current limiter) are integrated in the same system.

# FUTURE PROSPECTS

Where the integration of distributed generation meets existing grids and leads to excess short circuit overloading, SFCLs can be a very promising solution.
Due to the performance of SFCLs, they will also be highly interesting for high voltage applications.

## Economical aspects

Today's SFCL technology is not yet well-known among grid experts and only a few pilot- and trial-installations worldwide have been realized. The cost of HTS wires still dominates the SFCL price level. However, for the next future significant price reductions can be expected as the superconducting wire manufactures are ramping-up their production capacities. In addition, standardization of SFCL elements will contribute to significant cost reduction for the complete systems.
For studies of economical feasibility, not only the

capital costs need to be taken into account. Important aspects are also operating costs, space requirements, effects of load levelling and reduced equipment ageing, as well as any effects coming from a possible deferral of investment.

Next to the technical advantages of SFCL systems, also the price level could be acceptable for standard applications in future grids.

## Voltage level

So far three-phase resistive SFCL applications in real grid have been realized for medium voltage. For these cases, all required technologies have been developed and can be applied. The development steps to higher voltage will especially involve new or adapted insulation concepts. SFCLs for rated voltages of 110 kV would already contribute positively to the power system stability.

## Integration of renewables

The present movement in the power generation towards renewable energies leads to a fundamental downsizing of average power generation units.

Most generation units are able to supply directly into the medium voltage grid, but that would need a higher short-circuit capacity than in many cases available. The usual solution is the connection to the high voltage grid with a separate and expensive transformer with heavy requirements for breakers and cables. An alternative solution could be the integration via SFCL, as shown in Figure 5.

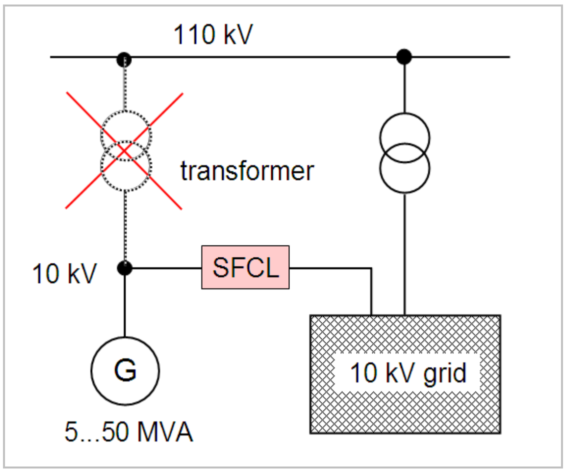

**Figure 5:** grid connection of DG with a SFCL

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