COMMERCIAL APPLICATION OF SUPERCONDUCTING FAULT CURRENT LIMITERS IN THE WESTERN POWER DISTRIBUTION GRID IN THE UK

Beate WEST
Nexans Deutschland GmbH – Germany
beate.west@nexans.com

Mark STEMMLE
Nexans Deutschland GmbH – Germany
mark.stemmle@nexans.com

Jonathan BERRY
Western Power Distribution – UK
jberry@westernpower.co.uk

Achim HOBL
Nexans SuperConductors GmbH – Germany
achim.hobl@nexans.com

ABSTRACT

This paper gives an overview of two superconducting fault current limiters that will be installed in the grid of Western Power Distribution in Birmingham, UK. The installation of the two superconducting fault current limiters is part of the FlexDGrid project. The grid application of these innovative devices will be described in detail. The superconducting fault current limiters will be the first of their kind to be integrated into the grid of Western Power Distribution. Two 132/11 kV substations, with slightly different requirements with respect to the operating current, were chosen for the installation of the fault current limiters. In both substations the devices will be introduced in the 11 kV bus ties in order to improve the network short circuit strength and enable an increased level of distributed power generation with low CO_2 *emissions to connect. The operating current of the two devices is 1600 A and 1050 A, respectively. In both applications the prospective peak short circuit current will be limited from about 20 kA to below 10 kA. The superconducting fault current limiters will be commissioned in the grid in mid 2015.*

INTRODUCTION

Whilst the demand for electricity and system reliability continues to increase, distribution system operators around the world are adding significant levels of additional distributed generation and are building new grid connections. All these measures result in higher fault current levels, challenging the ability of substation equipment to withstand mechanical and thermal stresses and strain associated with these high fault levels. Therefore, distribution system operators are required to react by adapting their equipment to meet the challenges of the higher level of fault currents. Existing fault current mitigation techniques, such as fault current limiting air core reactors and selective tripping schemes, all exhibit distinct drawbacks. An ideal solution would be a re-usable, automatic device that does not affect the operation of the power system during normal operation, but yet would limit fault currents before reaching the peak current value.

Resistive type superconducting fault current limiters [1] are versatile devices that are able to overcome the existing problems resulting from high fault currents. Due to the strong increase in resistance of a superconducting fault current limiter, initiated by a fault, the technology is well suited to protect today's electricity grids. The very low reactance in all operating conditions is a further advantage of these superconducting devices. Utilities in Europe have recently started to employ resistive type stand-alone superconducting fault current limiters based on high-temperature superconductors (HTS) in their grids. Several of these devices have been successfully tested in grids during the last decade [2,3,4].

FUNCTIONALITY

A key feature of all resistive type superconducting fault current limiters is that the superconducting material goes from the superconducting state, under normal operation conditions, into the resistive state, for the instance of a fault on the system.

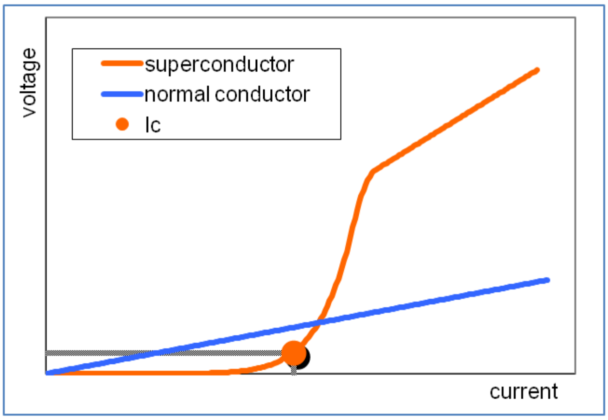

Figure 1: Current-voltage characteristics of a superconductor compared to a normal conductor

For superconducting materials, the relation between voltage and current has the form $U \sim \left({}^{I}/_{I_c}\right)^n$, with I_c the critical current of the superconductor, see Figure 1. It is defined as the current at which a voltage drop of 1 μV per cm superconductor length is reached. The exponent n is usually between 5 and 30 and differs with superconducting material type and performance.

In the instance of a fault, the current increases and the voltage follows the power law given above. The resistance of the superconducting material increases from almost zero to a few Ohms; the superconducting material then leaves the superconducting state and behaves like a normal conductor. This transition is called “quench”.

The superconducting fault current limiter makes use of this transition. The normal amplitude of the rated current is below the critical current I_c and the quench is triggered by the high current that occurs during a fault.

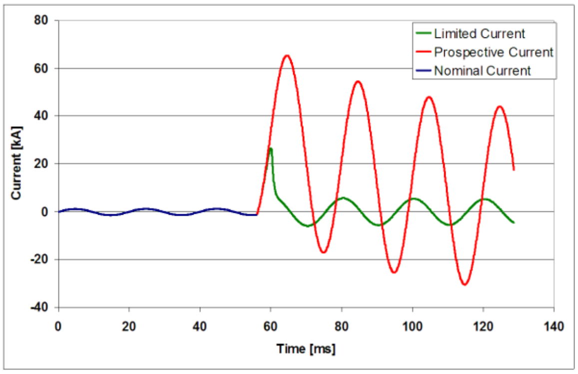

Figure 2: Prospective and limited current during a short-circuit event (schematic drawing)

The increasing resistance leads to a limitation of the current, illustrated in Figure 2. The red line marks the prospective current without a fault current limiter. The green line denotes the limited current and shows that effective and reliable limitation occurs within the first half cycle. The symmetrical waveform in the following half cycles, denominated as follow current, shows the almost purely resistive behaviour of the fault current limiter. The amplitude of the follow current can be adapted by the selection of appropriate materials.

During fault current limitation the superconductor heats up in the resistive state and takes energy away from the grid. Due to the high power density, the temperature rise of the superconducting tape is almost adiabatic during this period. To avoid deterioration of the superconductor properties, there is an upper limit to the permissible temperature, like the melting point of solder, or the oxygen diffusion onset temperature; typically the superconductor temperature should not exceed 350 K. The device, upon detection of a fault current, as well as initiating limitation instructs a circuit breaker to trip, in order to limit the device’s exposure to large current flows. As the device is limiting the fault current this circuit breaker, as with all others connected, needs only to be rated for the limited current. At zero current the superconductor cools back to its operating temperature by transferring heat to the surrounding liquid nitrogen usually within about 30 s. The heat deposited to the liquid nitrogen is either compensated by a small, temporary, higher liquid nitrogen temperature and pressure, or converted to evaporated nitrogen gas, respectively, dependent of the cooling or re-liquefaction concept.

INTEGRATION IN THE GRID

The Distribution Network Operator, Western Power Distribution, aims to develop and trial advanced fault level management solutions in the framework of the FlexDGrid project to improve the utilisation of Distribution Network Operators’ 11 kV (HV) electricity networks, while facilitating the cost-effective and early integration of customers' generation and demand connections. The FlexDGrid project is funded through Ofgem’s Low Carbon Networks Second Tier funding mechanism. In total, five primary substations will be equipped with advanced fault level management solutions:

- Two power electronic active fault de-couplers supplied by Alstom
- One pre-saturated core fault current limiter by GridON
- Two resistive superconducting fault current limiters by Nexans

The technological solutions have been selected as the result of a thorough analysis of the existing and most promising technologies and the decision process has been based on the detailed specifications of the five most relevant substations in the WPD Birmingham grid. Both superconducting fault current limiters will be installed between two bus bars as a coupling element. The first installation will be done in Chester Street substation, Figure 3, and the second installation will be done in Bournville substation, Figure 4.

SYSTEM DESIGN

Table 1 lists the main design parameters for the superconducting fault current limiters installed in the substations, Chester Street and Bournville.

Table 1: Design parameters for Chester Street and Bournville

Parameter	Chester Street	Bournville
Rated voltage U_r (kV)	12	12
Rated current I_r (kA)	1600	1050
Prospective peak current I_{peak} (kA)	20	22
First peak limiting I_p (kA)	9.9	7.7
Limitation duration (ms)	100	100
Recovery time (s)	30	30

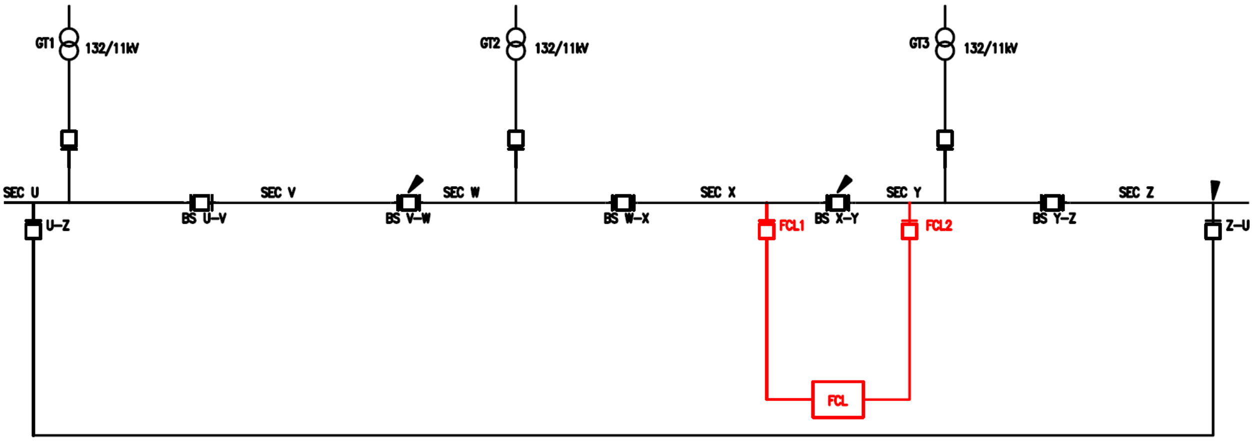

Figure 3: Grid installation of the fault current limiter for Chester Street

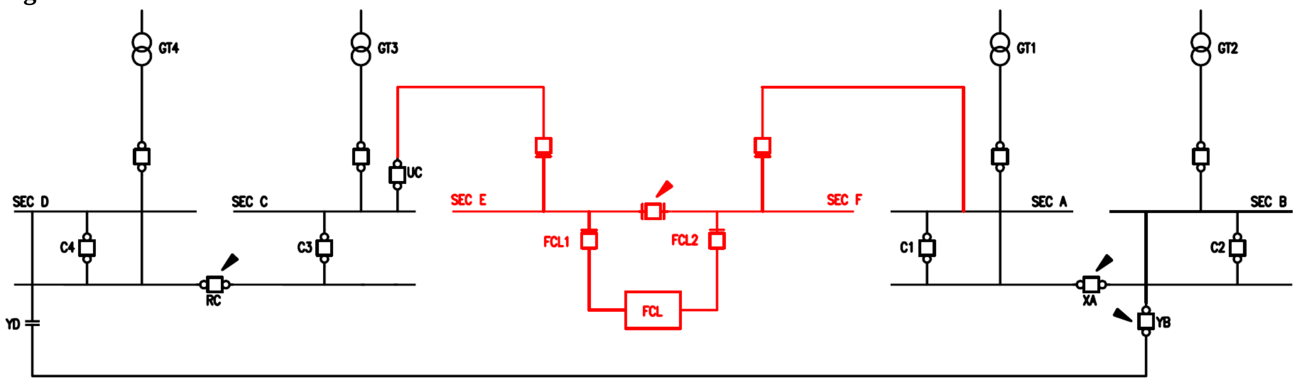

Figure 4: Grid installation of the fault current limiter for Bournville

For both superconducting fault current limiters 12 mm wide yttrium barium copper oxide (YBCO) tapes are used as the superconducting material. The superconducting tapes are wound in a parallel manner to form a component. The number of superconducting tapes needed depends on the I_c of each tape. A certain number of components are stacked to form a module. Depending on the required rated current and voltage, the number of superconducting tapes and their length in each component, as well as the number of components, will differ.

Figure 5 shows a picture of a CAD-model of a superconducting module. Each module, one for each phase, together with current leads is placed inside a nitrogen vessel surrounded by a vacuum tank (cryostat). The cryostats are filled with liquid nitrogen to cool down and keep the components at their operating temperature of about 77 K. The cryostat is connected to a cooling system that ensures the correct temperature and pressure of the liquid nitrogen. Small, commercial cryocoolers are installed to recondense the evaporating liquid nitrogen gas on cold heads in a closed circuit inside the cryostat. Therefore, after initial cool-down and filling no handling of liquid nitrogen is required. The cooling power is dependent on the load current present through the limiter and is controlled by the number of cryocoolers running or being in stand-by.

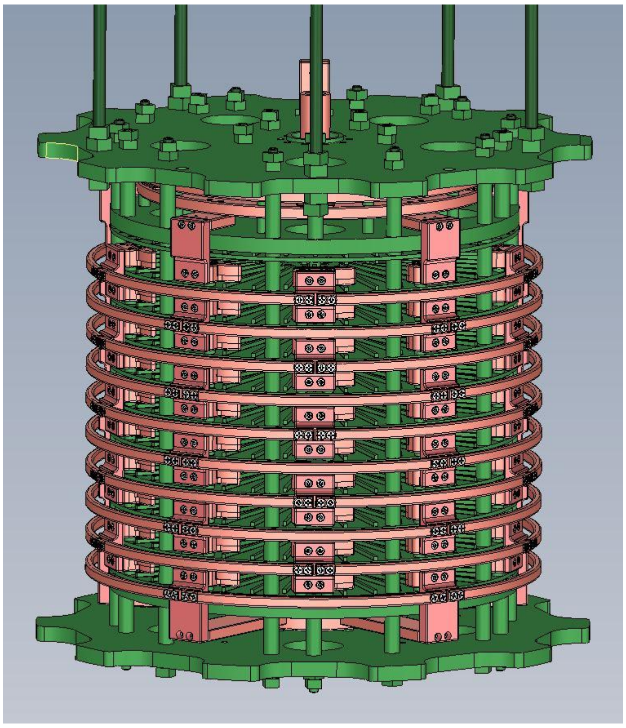

Figure 5: CAD-model of a superconducting limiter module. The components inside the module are connected in series.

The main cryogenic losses of the limiter, apart from the heat losses of the cryostat, are current dependent and result in heat input to the liquid nitrogen:

- AC losses of the superconductor
- Joule heating in the contacts of the superconductor
- Joule heating in the normal conducting materials of the superconducting components
- Conductive heat leak and Joule heating of the current leads

The cooling system compensating these losses has an electrical power between 18 kW and 50 kW for Chester Street substation, and between 18 kW and 30 kW for Bournville substation, respectively, dependent on the particular load through the limiter. The maintenance on the cryocoolers is expected at an interval of two years. Due to the operation of the components, the maintenance interval is dependent on the average load through the limiter. Thanks to the system monitoring, the cryocooler service can be thoroughly planned as scheduled maintenance and is only a few hours of work on the system.

A control system is implemented to monitor all relevant data and to control the temperature and pressure inside the cryostat. Furthermore, it provides the control interface to WPD. A protection device is used for voltage differential protection of the superconducting fault current limiter, providing an additional trip signal for the circuit breakers.

For Chester Street substation the superconducting fault current limiter system will be installed in a concrete enclosure to allow an outdoor installation. For Bournville substation the superconducting fault current limiter system will be integrated in an existing building already containing MV switchgear equipment.

CONCLUSION

The technology of superconducting fault current limiters provides the exceptional possibility to design new innovative grid structures. The grid can have very low impedance equipment, but without the risks associated with high short circuit power.

Two superconducting fault current limiters for Western Power Distribution's grid in Birmingham, UK, are now being manufactured and will be installed in the grid in mid 2015.

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