Superconducting FCLs go on trial in the UK

The first of three pilot installations in a project to develop an innovative superconducting device, a commercial scale fault current limiter, is now undergoing field trials in the UK. This kind of FCL could play a key role in future distribution networks.

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Figure 2. The FCL device ready for shipment

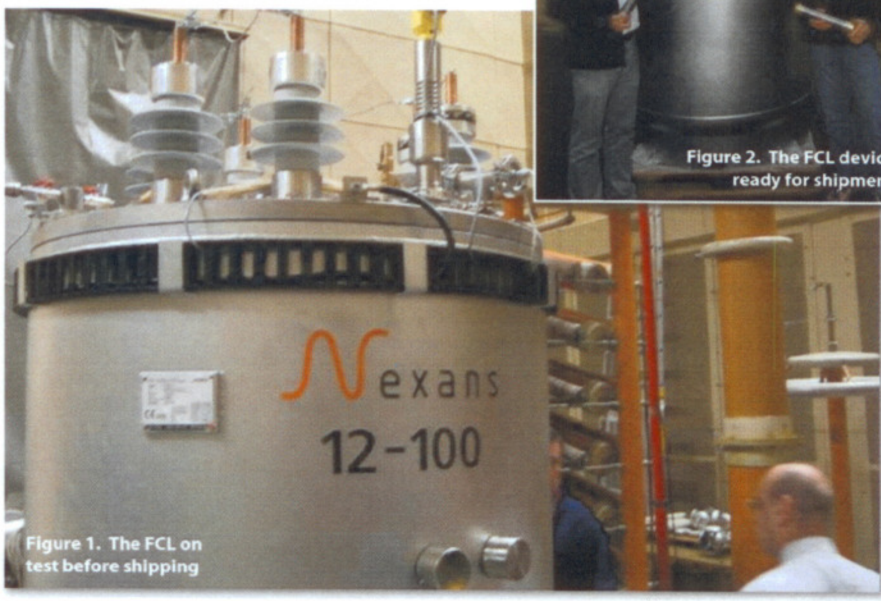

Figure 1. The FCL on test before shipping

Fault current limiters are currently one of the most attractive applications for high temperature superconductors in electric power systems. Resistive concepts in particular seem to have excellent chances of achieving economic and technical viability. This has been demonstrated up to the 10 kV/10 MVA level in the successful German project CURL 10 which utilised melt cast processed (MCP) BSCCO 2212 superconductor from Nexans SuperConductors. The publicly funded project was the world's first live demonstration of a resistive HTS fault current limiter.

The next stage is to develop a commercial version of the superconducting fault current limiter (SFCL). The trials, initially for the UK market, are being undertaken by Applied Superconductor Ltd (ASL) in collaboration with NSC, the New and Renewable Energy Centre in Blyth and distributed network operator partners CE Electric UK, Electricity North West and ScottishPower EnergyNetworks.

The first of three SFCL pilot installations (Figure 1) has just been carried out in a substation in the Electricity North West network. The limiting module comprising superconducting components, cryostat, current leads and sensors for temperature, coolant level and vessel pressure monitoring was designed, engineered and assembled at NSC according to the specifications defined by ASL together with the DNOs.

Funding incentive

This project is being undertaken under the UK's Innovation Funding Incentive (IFI) in which network operators are encouraged to investigate and be involved in the development of new techniques and technologies which have the potential to bring improvements to their networks. The IFI, introduced by the UK gas and electricity regulator Ofgem in 2004, allows all electricity distribution network owners to spend a percentage of their revenue on innovative projects.

How SCFCLs work

Leading manufacturers and research establishments have been investigating fault current limiting devices for several years in order to offer an alternative to network reconfiguration/ asset replacement in tackling rising fault levels.

The superconducting FCL is designed to be a low risk fail-safe device, utilising a non linear 'high-temperature' superconducting ceramic rather than electronic, electromechanical, mechanical or pyrotechnic components.

When the superconducting material is cooled below its critical temperature it loses all electrical resistance, thereby allowing normal load current to flow with negligible losses. Either the increased current density caused by the passage of fault current, or the loss of the liquid nitrogen cooling medium, causes the temperature of the superconducting material to rise with the result that the material reverts to a normal resistive state.

This added resistance has the effect of reducing the fault current to a lower, more acceptable level. This process is referred to as 'clamping' because it effectively sets a limit above which the fault current will not rise.

The SFCL operates in a few milliseconds, after which its resistance remains high until the fault current is cleared by a circuit breaker. The SFCL's operation is sufficiently fast, bearing in mind that at 50 Hz a quarter wave represents 5 mS, to ensure that the first peak of the fault current is limited; this is vitally important when considering the closing of a circuit breaker onto a section of faulty network. The degree to which the subsequent current is limited can be set at the design stage to suit a specific application. It will, in many cases, be convenient to choose this level such that existing protection arrangements do not need to be adjusted.

The three pilot installations will result in the development of commercially available devices that are capable of clamping fault levels to within network design limits. This can bring a number of benefits.

- SFCLs could be strategically deployed on the network in areas either with existing high fault level issues, or experiencing a high degree of distributed generation connection activity (eg urban combined heat and power generation systems). In this application SFCLs could provide a method of deferring the replacement of switchboards or reconfiguration of networks whilst ensuring fault levels are maintained within safe limits.
- Where fault levels are generally high, there may be operational benefits associated with minimising the often complicated switching required to ensure that equipment operates within its fault rating during network reconfiguration and outages. This could reduce the risk of incurring customer interruptions arising from either network switching or from operating parts of the network temporarily on single circuit security. An improvement in staff safety may also be delivered.
- If network fault current magnitudes are restricted equipment will be subjected to reduced electrodynamic and thermal stress (these are both proportional to the square of the current, so a modest reduction in fault level results in a considerable reduction in these stresses), potentially reducing the probability of consequential faults and prolonging the asset life.

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- SFCLs may, subject to resolution of protection issues, allow existing radial circuits to be operated interconnected, with associated improvements to customer supply continuity and power quality (flicker and harmonics). This could facilitate a radical change in the way networks are designed and operated.

Benefits specific to this project

In addition to the above, there are specific benefits associated with the type of design used in this project, which is based on the superconducting to normal transition.

- In its normal operating state, the SFCL does not add significant reactance to the network and therefore does not affect the upper threshold of the network impedance envelope so that DNOs can ensure that they do not exceed voltage levels in the event of sudden loss of load etc. It will also not increase network losses.
- A significant issue for DNOs today is the increase in the network X/R ratio (reactance-resistance ratio) which increases the DC component and therefore the asymmetrical current when a circuit breaker opens. This also (to a lesser effect) impacts the peak making current under fault conditions. Introducing a series reactor into the network will reduce the AC component of short-circuit current, but it may make the X/R ratio rise and although it reduces the overall asymmetrical current, the DC component can be made greater. Circuit breakers are not tested for this increased DC component and associated longer arcing times.
- During the transition from the superconducting to normal state, the SFCL adds resistance to the fault path. This reduces the AC and DC components of current and the level of asymmetry dramatically. This provides much easier making and breaking duties for a circuit breaker and additionally, greatly reduces the peak voltage generated (transient recovery voltage) at the point of current interruption.
- The level of fault contribution from connected inductive load is now calculated according to IEC60909 and DNOs are finding sites where the peak making currents of circuit breakers are being exceeded. The fast clamping of the SFCL reduces these peaks to within circuit-breaker ratings. This eliminates the need to reconfigure networks before closing operations.

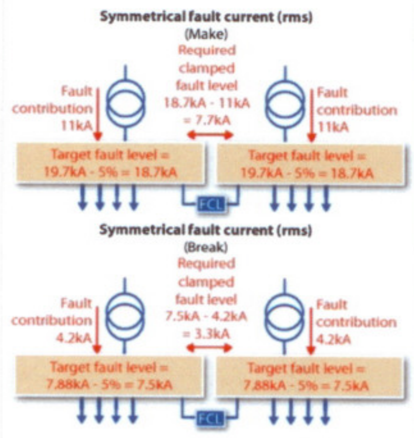
Choice of HTS material

The SFCL is based on high temperature superconductor (HTS) ceramic material that becomes a superconductor when cooled to around -196°C – a temperature that can be obtained using relatively inexpensive and readily available liquid nitrogen.

SFCL prototypes have been designed using two types of HTS – known as BSCCO and YBCO - in various guises. A tubular BSCCO component manufactured by NSC was used for the first major live network trial, 'CURL 10', hosted by RWE at Siegen in Germany in 2004. It was therefore decided to use a BSCCO material (Bi-2212) for the development of a commercial SFCL.

The basic SFCL component is made from a tube of melt-cast Bi-2212 soldered to the interior of a copper-nickel-manganese tube, which provides a metallic shunt to prevent the formation of hot spots in the HTS. This arrangement is then cut into a helix giving an effective length of 3 metres for each component. The component is supported from the inside by a tube of fibre-reinforced plastic. Pairs of tubes are joined end to end and 24 of these connected in series provide the current limiting function for each of the three phases.

Figure 3. Simplified schematic circuit diagram of the SFCL unit



Deployment of the first UK SFCL

The site for the first UK pilot was selected in 2006. It is in a semi-urban location in Lancashire and was chosen for two reasons – there is plenty of space for the installation and the site provides an example of where an SFCL might be installed in response to a real need.

The two 33/11kV transformers feeding the substation had been recently upgraded, with the result that the fault level increased to above the making and breaking capacities of the circuit breakers. It was therefore necessary to build a new substation and install a new 11kV switchboard of primary distribution circuit breakers comprising ten feeders, two incomers and one bus-section. So, while the fault-level problem was addressed in a conventional manner, the situation has allowed the design of the SFCL to be determined according to realistic criteria, as it was actually being used to provide a solution to the fault level issue.

The old switchgear was rated at 11 kV with a short-circuit capability of 150 MVA. This equates to a breaking capacity of 7.87 kA and a making capacity of 19.7kA. The fault contribution of each of the two transformers is calculated to be 11 kA peak, 4.2 kA_{rms}. It was decided that the SFCL should limit the fault current seen by any circuit-breaker to 95 % of the old breaker rating, that is, 7.48 kA break and 18.72 kA make.

The SFCL, which is deployed in a bus-section configuration, effectively in parallel with the existing bus section circuit breaker (which is being left open during the trial), must limit the fault contribution from the healthy to the faulted busbar when a fault occurs on an outgoing circuit. This contribution, together with the contribution from the transformer directly feeding the faulted bar, must be no more than 95 % of the rating of the old switchgear. The limiting, or clamping performance of the SFCL is therefore defined by the network characteristics and the rating of the available plant.

SFCL module

The active part of the SFCL consists of 48 superconducting elements per phase connected in series, immersed in liquid nitrogen in a cryogenic vessel (Figures 4, 5). The element assemblies are connected to the outside of the vessel through high voltage bushings and current leads designed to cope with the temperature gradient between the liquid nitrogen and the exterior of the vessel. The liquid nitrogen is cooled by an external cryocooler. A circuit breaker in series with the limiter is tripped when the fault current has been reduced.

The first SFCL to be deployed successfully completed a series of tests at IPH in Berlin, for short-circuit performance, lightning impulse and AC voltage withstand and partial discharge. In early 2009 it was installed into the network and the field trial programme is now underway.

Further steps

Worldwide interest in FCL devices is growing steadily, especially in relation to their suitability for smart grids. Concurently with this project, NSC has developed a 12 kV system for 800 A operating current which will be installed in a German power plant later in 2009. A follow-up system for the UK (pilot 2) based on the specifications of ASL and another DNO is also in the design phase. MPS

Figure 4. The fault current limiter under construction

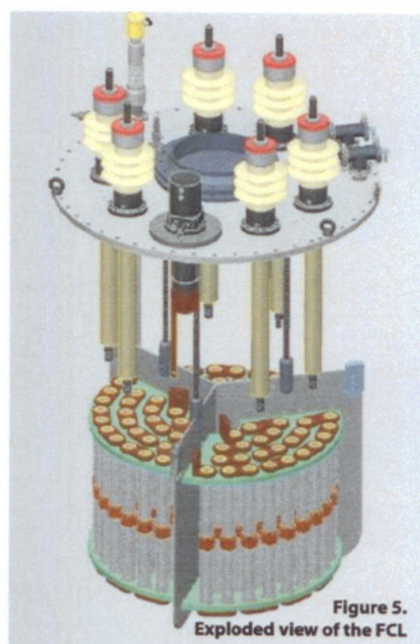


Figure 5. Exploded view of the FCL