SUPERCONDUCTING FAULT CURRENT LIMITERS – UK NETWORK TRIALS LIVE AND LIMITING

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ABSTRACT

A consortium comprising three UK Distribution Network Operators (DNOs) has deployed three superconducting fault current limiters (SFCLs) in the UK distribution system. Funding through the UK energy regulator's Innovation Funding Incentive (IFI) scheme is contributing to the DNOs' financial commitment to this project. The limiters have been supplied by Applied Superconductor Limited (ASL) which is now engaged in several additional projects including a 33kV pre-saturated core project for Northern Powergrid and a magnesium diboride based resistive limiter for Western Power Distribution.

INTRODUCTION

Applied Superconductor has since the last CIRED acquired the fault current limiter activities of Zenergy Power based in the USA and Australia.

For the first two projects, hosted by ENW and ScottishPower, the fault limiting circuits comprising bulk BSCCO components, installed in vacuum insulated

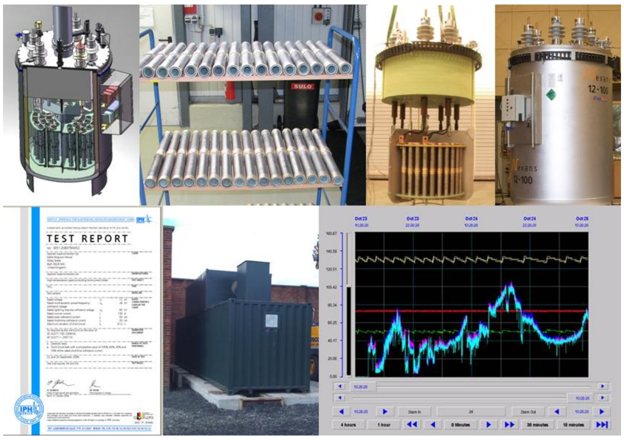

Figure1 Pilot 1 SFCL

cryostats and fitted with pressure relief devices, high-voltage bushings and temperature, pressure and level sensors were provided by Nexans SuperConductors. The balance of plant including cryocoolers, helium compressors, water chillers, series circuit-breaker, voltage transformers and supervisory systems was designed and assembled by ASL.

The first trial has been completed, the limiter having been installed in the substation at Bamber Bridge in ENW's network for a year, carrying load current for around four months.

Figure 2 Pilot 2 SFCL during installation

The (resistive) SFCL, rated 11kV; 400A, for the second site (ScottishPower) was installed in a substation in the Liverpool area in February 2012 and commissioned and made live in the following August.

The third trial is of a pre-saturated core SFCL provided to ASL by Zenergy Power. The SFCL, rated 11kV; 1250A, was connected into the Northern Powergrid network in July 2012. The unit is installed in a primary distribution substation where there were previously operational restrictions in place because the fault level locally exceeded the making capacity of the installed switchgear. The limiter was designed to address this problem so that the restriction could be lifted.

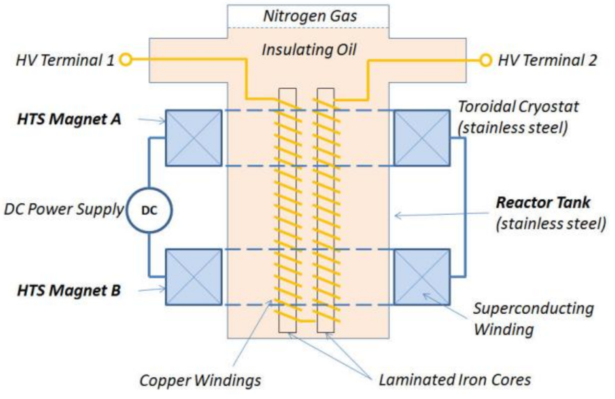

Figure 3 Pre-saturated core SFCL schematic diagram

The limiter's oil-filled reactor tank (see figure 3) contains three pairs of iron cores, each pair carrying the primary circuit windings of each phase. A single pair of superconducting solenoids, arranged in a Helmholtz configuration, produces the magnetic flux to drive the laminated iron cores into saturation. A first half cycle of fault current drives one of the two cores out of saturation, raising the inductive reactance of the ac coil around that core. A subsequent half cycle of the opposite polarity de-saturates the other core of the pair raising its inductive reactance. The increased reactance of the limiter provides the current limiting effect. The limiter's components are dimensioned in order that the reactance remains at a low level during normal load conditions, and that during a fault, the required limiting characteristics are achieved.

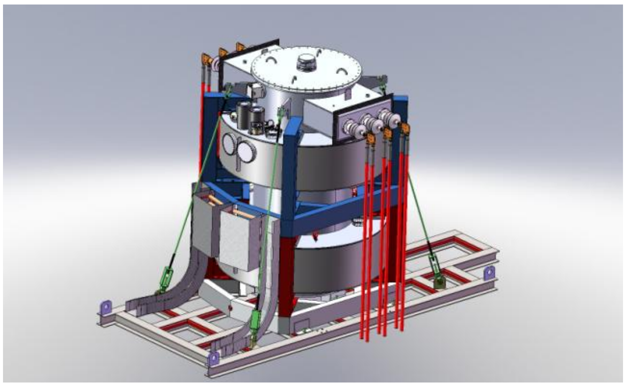

Figure 4 Pre-saturated core SFCL showing reactor tank, bias solenoids and HV cable connections

The limiter was tested in September 2011 at KEMA Powertest in Chalfont, Pennsylvania, USA. Its ability to limit a 6.2kA rms symmetrical fault to 5kA was confirmed, along with pro-rata limiting of the first peak. Five tests were performed with a fault current duration of 250ms and the final test was extended to 3 seconds. Lightning impulse and other high-voltage tests were also performed successfully.

Figure 5 SFCL at KEMA Powertest

The SFCL was installed in the 11kV primary substation in March 2011 and connected into an incoming circuit as shown in Figure 6 the following July.

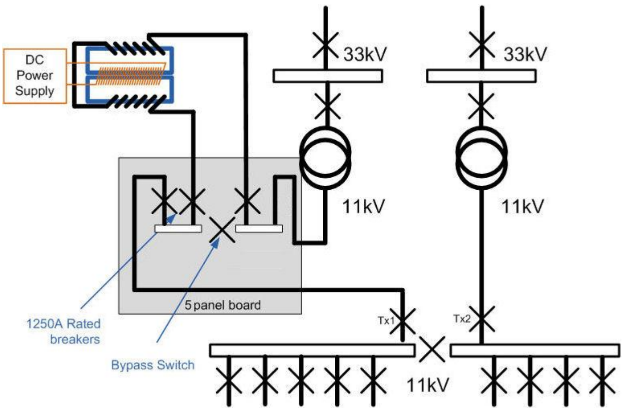

Figure 6 ASL Pilot 3 connection

A few weeks following installation a cable fault, which began as a phase to phase fault and evolved into a full 3 phase fault occurred shown in figure 7. The upper 6 traces are the voltages on each terminal of the limiter and the lower 3 are the phase currents.

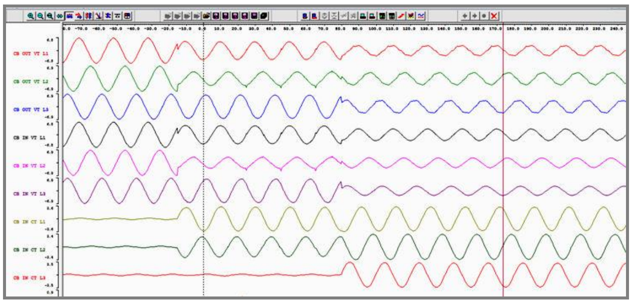

Figure 7 2/3 phase fault, 3.4kA for 0.6 seconds

The fault caused a severe voltage sag which affected the substation LV supplies. The limiter's battery back-up supplies switched in automatically and the control system re-stated the helium compressors and chillers, which comprise the cooling systems, following the fault. The limiter picked up load current immediately. Two further single-phase faults have since occurred on feeders supplied by the substation. The limiter is installed in a custom-made GRP housing with soundproofing, shown in figure 8.

Figure 8 ASL Pilot 3 in service

FURTHER PROJECTS

Two further SFCL projects are currently being carried out in the UK by ASL. The first of these is a 33kV pre-saturated core limiter which will be installed in a Northern Powergrid 275/33kV substation fed by two 100MVA transformers. This project is financed by the UK Low Carbon Network Fund, under Tier 1. The fault level is below the switchgear rating currently but to provide headroom for the connection of distributed generation, a fault level reduction will be required.

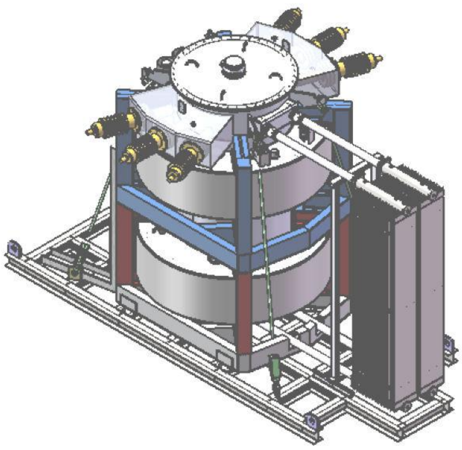

Figure 9 General Arrangement of 33kV SFCL

A comprehensive study of available solutions for this has shown that the FCL competes very favourably with other approaches including switchgear replacement, transformer replacement (with high impedance transformers) or fitting reactors. The use of a suitably rated FCL can facilitate the connection of distributed generation, even when the fault level is approaching the switchgear ratings. The limiter will be connected to the 33kV side of one of the two supergrid transformers by means of overhead busbars in the high-voltage compound, reducing the cost of installation and allowing outdoor isolators to be used to connect the FCL. Figure 10 shows the fault limiting performance required.

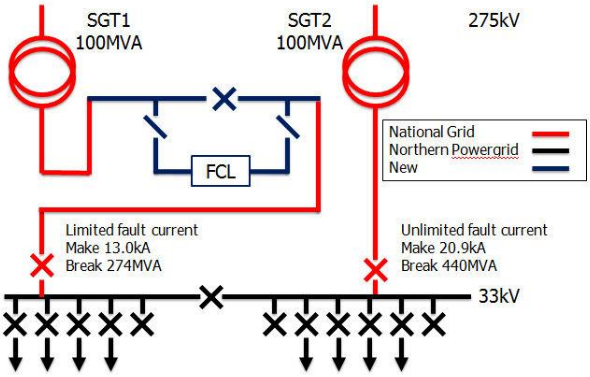

Figure 10 Installation of 33kV SFCL

The second of ASL's further projects is to develop and demonstrate a resistive FCL using magnesium diboride wire for the superconducting circuits. This development builds on work undertaken previously by Rolls-Royce, mostly carried out in its Technology Centre at the University of Manchester. ASL is Lead Partner in a consortium also comprising E.ON New Build & Technology, Rolls-Royce plc and Western Power Distribution. The project is being funded by the Energy Technologies Institute (ETI), a public-private partnership between global energy and engineering companies including EdF and E.ON and the UK Government. The ETI's role is to bring together engineering projects which accelerate the development of affordable, secure and sustainable technologies which help the UK to address its long term emissions reduction targets as well as delivering nearer term benefits. The ETI is supporting projects to develop technologies in the heat, power and transport sectors and in the infrastructure which links them.

MgB_2 is already competing favourably with low-temperature superconductors in the manufacture of MRI magnets, driven partly by the diminishing availability and rising cost of liquid helium and partly by the low cost of MgB_2 compared with other materials. It also has excellent current limiting behaviour due to its rapid transition from the superconducting to the normal state, which reduces the maximum current which the limiter allows through during the initial rise of the fault current. The low cost of the wire makes possible the implementation of a resistive SFCL which can withstand a fault duration of 3 seconds and which can also, if the fault duration is limited to below some 150ms using ASL's differential voltage protection, recover in a 3 minute period. MgB_2 has a critical temperature of

39K so it is not possible to use liquid nitrogen as a coolant. ASL has developed a dry cooling system using copper and alumina components to remove heat from the superconducting assemblies.

ASL is preparing a single phase prototype for initial testing prior to commencing manufacture of the full-scale 3-phase unit, which will be rated 12kV; 1250A. The unit will be connected into Western Power Distribution's network in a 132/11kV primary substation in a bus-section deployment.

FUTURE PROSPECTS

ASL is also developing a new family of fault current limiters based on technology which was in development by Zenergy Power at the time of the acquisition by ASL. The new approach takes the pre-saturated core SFCL architecture shown in figure 3 as its basis.

The solenoids producing the saturating magnetic flux are taken inside the oil tank as shown in figure 11 and the superconducting tape used to wind the solenoids is replaced with copper wire. With a modest increase in footprint and weight, current limiting capabilities similar to those achieved with the superconducting solenoids can be achieved. ASL is currently in discussions relating to opportunities to demonstrate this approach in networks in the UK and elsewhere.

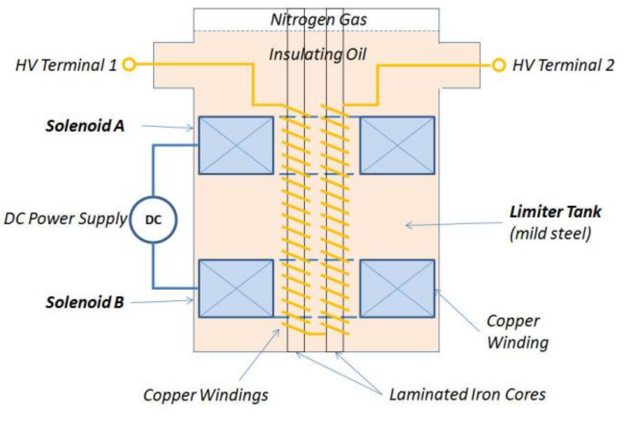

Figure 11 Non-superconducting PSC FCL

Applied Superconductor is currently in conversation with a number of companies involved in the electricity supply industry where interest in fault limiting techniques has risen steadily over the last few years. The main topics are the control of fault level where new generation is to be connected, where supplies are to be enhanced by the installation of new or larger transformers, where the transmission network is being upgraded or where it is desired to mesh-connect existing networks to improve load flexibility and capacity. Several potential projects in these areas are emerging and it is clear that interest in fault limiting technologies is increasing sharply.