FAULT LIMITING TECHNOLOGIES IN DISTRIBUTION NETWORKS

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ABSTRACT

A consortium comprising three UK Distribution Network Operators (DNOs) is deploying three superconducting fault current limiters (SFCLs) in the UK distribution system. This paper reports progress to date with the work which is being undertaken by Applied Superconductor together with DNO partners CE Electric UK, Electricity North West and ScottishPower EnergyNetworks. Funding through the UK energy regulator's Innovation Funding Incentive (IFI) scheme is contributing to the DNOs' financial commitment to the project.

INTRODUCTION

Three pilot installations are being undertaken as part of this project. The first and second pilots deploy resistive superconducting fault current limiting technology; the third deploys pre-saturated core technology. The first trial has been completed, the limiter having been installed in a primary substation near Preston in Electricity North West's network for a year, carrying load current for around four months. Key observations and lessons from this exercise will be outlined. Sites for the second and third trials have been confirmed and specifications for the SFCLs have been prepared. These installations will be described in detail.

The sub-systems for the resistive SFCL units forming the first and second trials are based on BSCCO superconducting components [1], designed and produced by Nexans SuperConductors (NSC) in Hürth, Germany. The 11kV 400A SFCL to be installed at the second trial site (Scottish Power) passed high-voltage withstand and short-circuit tests in December 2010 and is ready to be installed on site.

The third trial SFCL will use pre-saturated core technology provided by Zenergy Power. The 11kV 1250A SFCL will be connected into the CE-Electric network at a primary distribution substation where there are currently operational restrictions in place to manage the fault level which exceeds the making capacity of the installed switchgear when the bus section is in its (normal) closed position. The specification, construction and principle of operation of the pre-saturated core technology will be described in detail. By June 2011 we will be in a position to report on the test results, covering full-scale voltage withstand and short-circuit limiting tests and also thermal tests under normal rated load current.

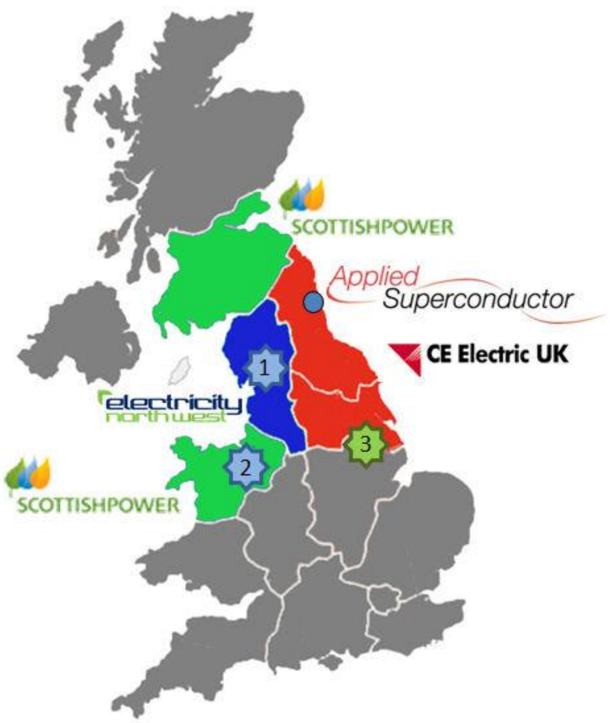

Figure 1: The three 11kV UK trial sites

TRIAL 1 – ENW

The first trial installation of a SFCL connected to the ENW distribution network has been completed successfully. The SFCL design was based on helical elements made from bulk Bi2212 manufactured by Nexans SuperConductors.

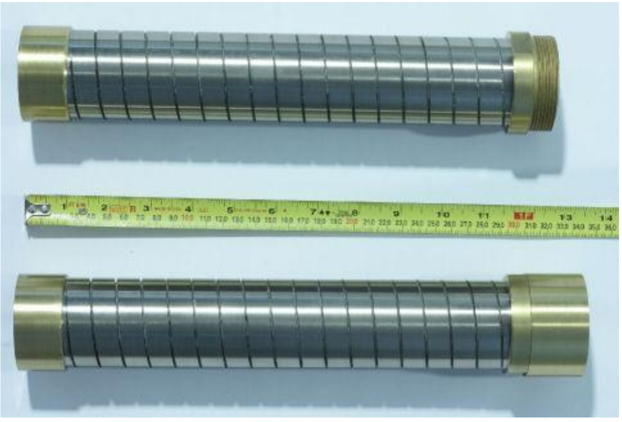

Figure 2 : Helical HTS Elements

Among the significant lessons learned from the implementation of the first trial are:

- It is possible to design, connect and operate a SFCL successfully on a 11kV UK distribution network
- Noise primarily from the cooling system required mitigation
- The cryocooler compressor requires cooling water and ambient air temperatures to be maintained within a narrow range
- Liquid nitrogen handling is straightforward and safe with appropriate training
- The SFCL impedance has a negligible effect on the current sharing on the 11kV switchboard
- Remote resetting of communication modems and PCs is required

TRIAL 2 – SCOTTISH POWER

The SFCL to be installed at the second trial site has been designed, manufactured, assembled, filled with liquid nitrogen and successfully tested at IPH, Berlin, for high voltage withstand (95kV lightning impulse and 28kV power-frequency) and current limiting performance under full-scale short circuit conditions with a prospective fault current of 20kA symmetrical; 50kA peak, at 12kV. The SFCL is based on a bi-filar limiting element made from Bi2212 material also manufactured by Nexans SuperConductors.

The elements are encapsulated in epoxy resin and mounted to a fibre-reinforced plastic support plate. Two of these plates, mounted one above the other, hold the 62 elements required for each of the three phase assemblies which constitute the complete current limiting module (Fig 4). These assemblies are housed in a vacuum-insulated cryoststat equipped with six 11kV bushings on the lid and two cryocooler coldheads each able to remove 500W from the liquid nitrogen, which is held at 70K, with a head gas pressure at about 0.5 bar.

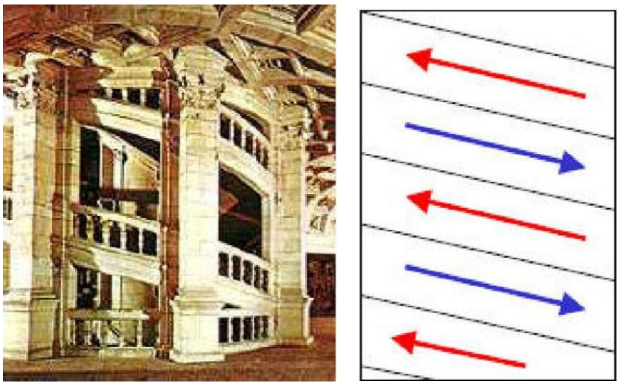

Figure 3: Principle of bi-filar element design

Figure 4: Internal construction of the SFCL for trial 2

The SFCL will be installed in the bus-section location in a primary substation in the Liverpool area in a region of the UK where the 33kV and 11kV networks are mesh connected as opposed to radially connected, as is the case in the rest of the country. The fault level at the substation will rise to 270MVA when a planned new transformer is installed, exceeding the UK DNO 250MVA design fault level. The SFCL has been designed to reduce the current passing through it to from a prospective value of ~7.5kA to less than 3.2kA, limiting the busbar fault level at the substation to around 200MVA, which is 80% of the switchgear capability.

The SFCL cryostat is fitted with sensors for monitoring the internal temperature and pressure and has level detectors to ensure that the liquid nitrogen level remains within safe limits. The cryocoolers and the water cooling equipment fitted to the cryocooler helium compressors are also thoroughly instrumented. Signals from the instrumentation are collected and digitised in a PLC. Samples are taken at 250ms intervals for the control system and stored at 5 second intervals in the PLC's internal RAM for 7 days on a rolling basis. This data is retrieved daily using file transfer protocol to a server in ASL's premises, via the internet using a 3G modem. Two modems provide redundancy in order to maintain communication in the event of the failure of one unit. This allows the SFCL to be monitored both locally and remotely in real time and allows performance to be analysed retrospectively. The PLC is also configured to maintain the temperature of the liquid nitrogen within one degree Kelvin and to provide alarms in the event of any abnormal measurement of any of the monitored quantities.

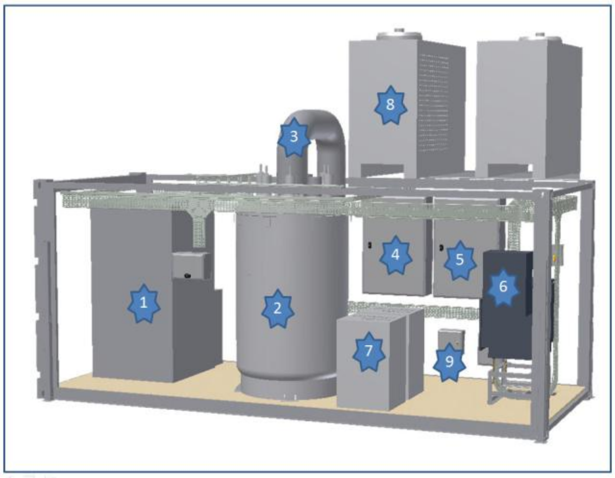

Figure 5: General arrangement for the SFCL used in trial 2

Key to Figure 5:

1) Vacuum circuit-breaker
2) SFCL Cryostat
3) Pressure relief channel
4) Power distribution panel
5) PLC and control relay panel
6) Voltage transformer
7) Helium compressors
8) Water chillers
9) DNO control and communications interface box

Power network current and voltage are also monitored by the PLC under normal load conditions and records of fault events are captured by the protection relays which are fitted to the circuit-breaker which is connected in series with the limiter. The PLC is coupled to a control panel accessible from outside the SFCL enclosure allowing full monitoring and control locally without the need to enter the enclosure.

TRIAL 3 – CE-ELECTRIC UK

The SFCL for the third trial site will be a pre-saturated core device manufactured by Zenergy Power and will be installed in a 33/11kV primary substation in North Lincolnshire. The SFCL is rated to carry 1250A continuously. The SFCL will be installed in the circuit between one of the 33/11kV transformers and the incoming circuit-breaker on the existing 11kV switchboard. It will limit the 17kA peak fault current from one of the 33/11kV transformers to below 13.25kA peak, in order to keep the peak fault level within the making capacity of the switchgear. Additional switchgear, allowing the limiter to be isolated or bypassed, will be provided by CE-Electric as part of the project, however it is anticipated that in future applications the SFCL would be installed without the additional bypass switchgear.

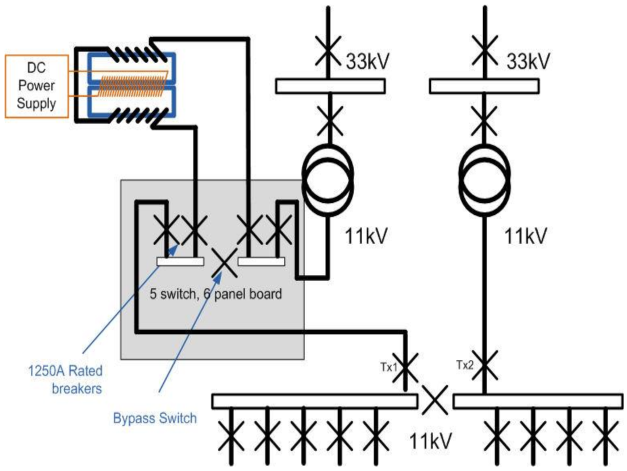

Figure 6: Trial 3 deployment showing additional switchgear

The pre-saturated core current limiting module comprises a cylindrical stainless steel tank (1) filled with oil, fitted with cable boxes (2) on opposite sides for connection to the network. The tank contains the three assemblies, one per phase, of saturable magnetic cores and main circuit windings. Surrounding the tank are two toroidal cryostats (3 and 4) containing the superconducting coils which, carrying a DC current of around 100A, provide the magnetic field to drive the cores into saturation.

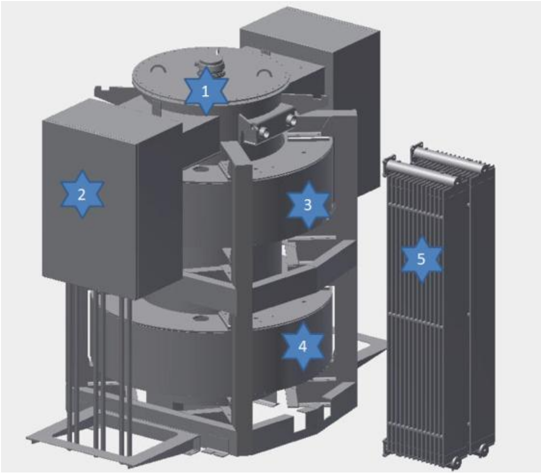

Figure 7: Pre-saturated core current limiting module

The tank is cooled by means of a radiator assembly (5) through which the insulating oil is allowed to circulate. The superconducting coils are cooled by means of a cryogen-free, "dry" system, developed by Zenergy Power for the cooling of the magnetising coils used in the company's "billet heater", a new type of induction furnace in which the metal to be heated is rotated in a fixed magnetic field.

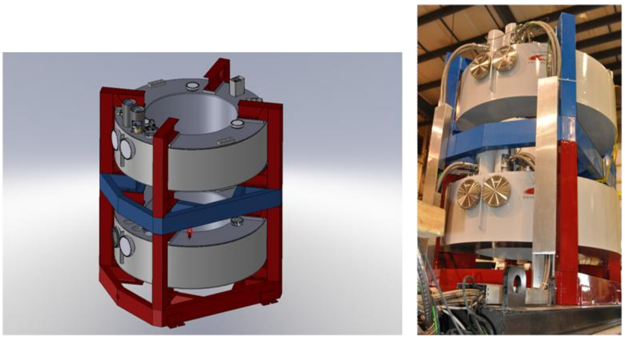

Figure 8: Cryostat assembly

Cooling is provided by two pairs of cryogenic compressors, housed separately from the FCL module, along with two

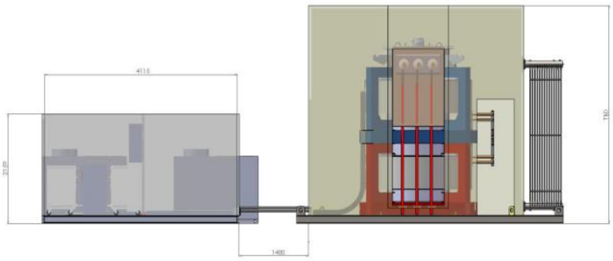

Figure 9: Cooling equipment (left); FCL module (right)

water chillers. The cryocompressors feed the coldheads, two of which are mounted on each cryostat assembly. The SFCL is currently being manufactured and will be tested at KEMA in Pensylvania in February 2011 with installation planned during the second quarter of 2011.

NEXT STEPS

ASL is undertaking a further major project which will see a fault current limiter, supplied by Zenergy Power, installed into the CE-Electric UK 33kV network in Yorkshire. This work is currently at the stage of selecting a suitable site; feasibility studies have been undertaken for a number of candidate sites and carbon cases prepared for each. The application of SFCLs in the 33kV network will increase the fault-level headroom required to facilitate the connection of distributed generation. This will allow larger generators to be connected at a specific point in a network and may in certain cases allow generators to be connected at points where currently there is insufficient fault-level headroom without the need for other network reinforcement. The connection of distributed generation is seen as a means of helping to meet the UK Government's renewable energy targets.

REFERENCES

[1]]J. Bock, S. Elschner, P.F. Herrmann, 1995, "Melt-cast processed MCP-BSCCO 2212 tubes for power applications up to 10 kA", *IEEE Trans. Appl. Supercond.*, vol. 5, No. 2, pp.1409-1413.