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Superconducting Fault Current Limiters for HVDC Systems

Background

High-voltage direct current (HVDC) transmission systems using Voltage-Source Converters (VSC) are widely regarded as offering significant potential for long distance high power delivery, particularly for offshore wind farm connections. One of the barriers for the development of multi-terminal HVDC systems is the lack of technologies which enable direct fault isolation. This study investigates DC fault current limiting technology to reduce fault currents to acceptable levels allowing DC circuit breakers to operate quickly and reliably. Superconducting fault current limiters (SFCL) are a promising candidate, satisfying most of the ideal fault current limitation requirements.

Ideal fault current limiter (FCL) requirements for HVDC systems:
- Minimum impedance during normal operation.
- Fast fault current limitation.
- Quick and automatic recovery.
- Fail safe.
- Compact structure, small footprint and light weight.
- Applicable at high DC voltages.
- Cost effective.

A resistive SFCL is the simplest and most compact SFCL design which directly uses the natural characteristics of the superconductor material. The schematic circuit of a resistive SFCL is shown in Fig. 1.

A inductive saturated iron-core SFCL is shown in Fig. 2 . It consists of two iron cores, which are driven into saturation by a DC bias supply. Two iron cores are used so that the unit can limit the current in both directions.

Resistive SFCL

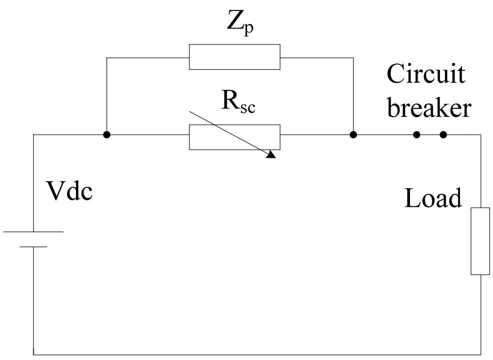

Fig. 1. Resistive SFCL

Inductive SFCL

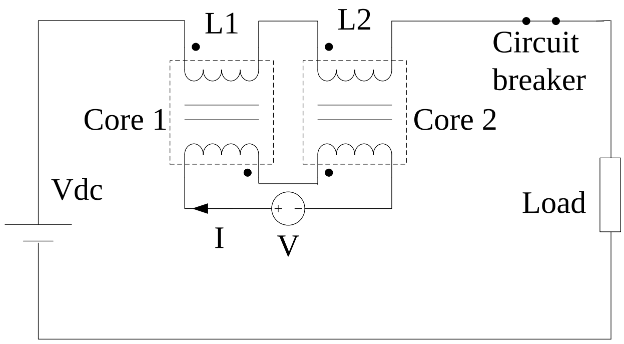

Fig. 2. Inductive SFCL

Table 1. Comparison of SFCLs for HVDC systems

Type	Advantages	Disadvantages
Resistive SFCL	• Compact structure, simple design and light weight. • Automatic triggering. • Fast and effective fault current limitation. • Intrinsically fail safe. • Variable coil inductance.	• Long lengths of superconducting wire required. • Hot spot problems. • High energy dissipated in the SFCL coil. • Long recovery time. • Room temperature/cryogenic interface is required for the current connections from the device to the external power system.
Inductive SFCL	• Inherently fail safe. • Fast recovery. • Does not require a room temperature/cryogenic interface in the power line. This is useful for high voltage design.	• Bulky and very heavy due to the need for iron cores. • Significant losses in the primary windings and iron cores during normal operation. • Complex current supply for the superconducting winding.

Key issues

Cryogenic cooling system

- Superconductor has hysteretic losses in the presence of time varying field or currents.
- The DC system is normally connected to the AC grid using voltage source converters which can introduce a ripple current into the direct current system.
- The cooling efficiency of superconductors operating at cryogenic temperatures is limited, i.e., the efficiency of the AL600 cryocooler at 30K is only 0.87%.
- The capital cost to build the offshore platform to house the cryocooler would also be expensive.

Superconductor cost

Table 2. Approximate HTS superconductor cost

Material	Nominal operating temperature (K)	Approximate material cost ($/kAm)
BSCCO	77	180
YBCO	77	400
MgB_2	25	13

Conclusions

Multi-terminal VSC-HVDC systems have been identified as one of the key technologies to develop offshore wind farm connections. Fault current levels are one of the barriers for this technology. This study demonstrates the potential for reducing fault currents to more acceptable levels using SFCLs in VSC-HVDC systems. Resistive and inductive SFCLs are compared. Resistive SFCLs are thought to be more suitable for HVDC systems. The key issues such as the cryogenic cooling system and superconductor material cost are highlighted. Practical SFCL systems are predicted to become realisable by the 2020s.

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