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Flux-lock type of superconducting fault current limiters: A comprehensive review

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A B S T R A C T

Power systems must be developed and extended to supply the continuous enhancement of demands for electrical energy. This development of systems in addition to the integration of distributed generation (DG) units to the power systems results higher capacity of system. Hence, short circuit current of network is confronted with persistent increasing. Since exploration of high temperature superconducting (HTS) materials, superconducting fault current limiters (SFCLs) have attracted a lot of attention all over the world. There are different types of SFCLs. Flux-lock type of SFCL because of its characteristics in fault current limitation is an important category of SFCLs. This paper aims to present a comprehensive review of research activities and applications of Flux-lock type of SFCLs in power systems.

Contents

1. Introduction

DUE to daily increasing in electrical power demand, the interconnections of networks becomes more complicated. Also, new power generation units are added to the network to provide this exponentially increasing demand. This results power networks with higher capacity and therefore, higher fault currents. Short-circuit fault has the most destructive effects on power systems [1]. In some cases, fault currents may exceed to more than 20 times the maximum nominal current. Since this current is much higher than the interrupting capacity of circuit breakers, the protection systems will fail to act properly. This high current will cause severe damages to the expensive equipment of power systems such as transformers, circuit breakers, cables, etc. If this fault current is not limited in a proper time, the network may confront with severe stability issues [2].

Today, the most promising approach for reducing the damages of fault currents in highly interconnected power networks is limitation of fault current based on superconducting fault current limiter (SFCL) devices. These devices become more practicable since exploration of high temperature superconducting (HTS) materials due to their low refrigeration costs and high insulation capacity. These devices have less effects on normal operation of circuit. After occurrence of fault, their impedance increase immediately with a nonlinear equation. Hence, the fault current flowing through the circuit is limited [3–5]. Different models of SFCL have been developed and their performances with each other have been compared in power systems [6,7].

The flux-lock type SFCL is capable to limit different fault current levels and also can operate in different modes. Its adjustable current limiting operation is calculated based on magnetic coupling between two windings on the same iron core. Hence, this appliance is suitable for network which confronts with expansion [8–10].

Up to now, different studies have been made on this branch of superconducting fault current limiters. This paper presents a com-

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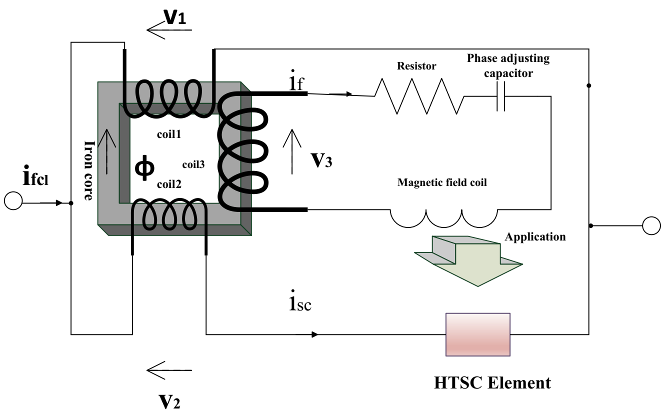

Fig. 1. Proposed configuration for flux-lock type SFCL.

prehensive review on flux-lock type SFCLs researches and investigate their different configurations in power systems.

2. Evolution of flux-lock type SFCL configurations

Performance of flux-lock type SFCL for the first time has been introduced and investigated in [8]. The proposed configuration as shown in Fig. 1 consists of three coils which have been wounded on the same iron core, a magnetic field coil act as backup for HTS element and a series resistor. Two coils with turns number N_1 and N_2 are in parallel and the HTS element is inserted in series with secondary coil. In the normal operation, since the linkage flux is constant, the voltage across three windings is zero (for more details referred to [8]). Hence, this SFCL has less effects on the normal operation of circuit. To achieve more limitation for higher fault currents, an AC magnetic field coil connected to the third winding increases the resistance of HTS element. This SFCL has the ability to control initial limiting current level by adjusting the inductance between two coils.

Because of the resonance between phase adjusting capacitor and magnetic field coil, the magnetic coil cannot produce enough magnetic field after fault occurrence. By adjusting either the inserting resistance or phase adjusting capacitor can change the amplitude of magnetic field coil. A control circuit has been designed for magnetic field coil of flux-lock type SFCL and its current limiting characteristics have been analyzed in [11]. The proposed control circuit consists of solid state switches driven by sinusoidal pulse width modulation (SPWM) operation. By switching operation of the control circuit the amplitude of fault current is under control.

The performance of magnetic field coil is related to the current flowing through it. Hence, fault current limiting characteristics of flux-lock type SFCL is depended on flowing current through the third winding. By using a tap changer which has the ability to adjust turns number of the third winding, the operational characteristics of flux-lock type SFCL can be influenced [12]. The considered configuration is the same as before, but a tap changer is added to coil 3 and the phase adjusting capacitor is eliminated. It has confirmed that by adjusting the current in coil 3 with a tap changer, the line fault current can be controlled.

Fault current limiting operation of flux-lock type SFCL is depended on fault angel and core saturation [13]. With consideration of saturation of iron core, the actual limited fault current flowing through the circuit can be higher than expected. Hence, this higher fault current can damage the equipment of power system. To overcome this drawback, utilization of E-I core instead of iron core has proposed [14].

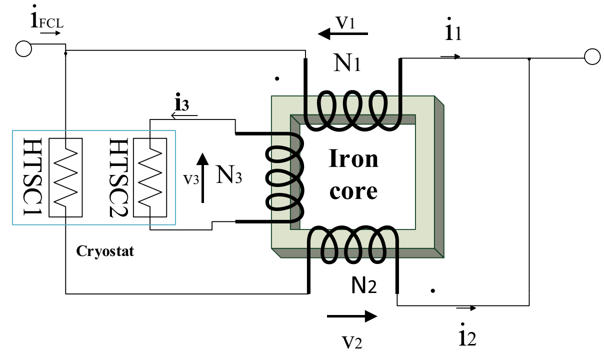

Fig. 2. Proposed configuration for flux-lock type SFCL in [15].

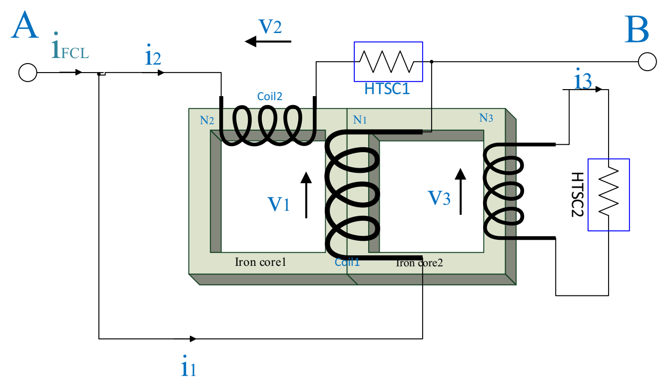

Fig. 3. The proposed topology for flux-lock type SFCL in [18].

Furthermore, authors have focused on current limiting characteristics of flux lock type SFCL by considering another HTS element added instead of magnetic field coil [15–17]. If the fault current is low, only the first HTS element by quenching limits fault current. But, for higher fault currents, also the second HTS element is quenched and makes the total limitation impedance much bigger. Therefore, the limiting impedance of this configuration as shown in Fig. 2 is in proportion to peak amplitude of fault current. Hence, effective fault current limiting performance can be achievable.

As shown in Fig. 3, another topology with two magnetically coupled circuit has been introduced for flux-lock type SFCL [18]. The experimental results have indicated that the fault current limiting characteristics of the proposed configuration are similar to the flux-lock type SFCL using its third winding.

If the fault current flowing through the HTS element is too high, then the flux lock type SFCL can be destructed. Hence, researchers have focused to reduce the power burden of HTS element. Fault current limitation of a flux-lock type SFCL and its recovery characteristics with an isolated transformer have been analyzed in [19]. The current limiting and recovery characteristics of proposed configuration as shown in Fig. 4, is more effective in compared with usual flux lock type SFCL.

The current limiting operation of flux-lock type SFCL with consideration of resistance of two different coated conductors has been investigated in [20]. Quench characteristics of flux-lock type SFCL has been analyzed in [21]. Authors have considered several HTS element in series with secondary coil of flux-lock type SFCL. By simultaneous quenching between series HTS element, the power burden of each HTS element is reduced. This scheme has the ability to increase the applied voltage to a flux-lock type SFCL. Hence, the capacity of power system can be increased.