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Bridge-type superconducting fault current limiter effect on distance relay characteristics

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ABSTRACT

The growth of the electrical energy generation and the increased interconnection of networks lead to higher fault current levels. The superconducting fault current limiter (SFCL) offers a solution to these problems with many significant advantages. The bridge-type SFCL can limit the fault current without any delay and smooth the surge current waveform. The application of SFCLs in networks can affect the protection system. In this paper, the impact of the bridge-type SFCL on the apparent impedance of the distance relay is studied. The analytical and simulation studies are presented for phase to ground and phase to phase faults, to show the impact of the bridge-type SFCL on the performance of the distance relay and its characteristics.

Introduction

Fault current limiters (FCLs) are expected to play an important role in the protection of the future power network. The addition of new generation capacity and the increased transmission interconnection of networks lead to higher fault current levels. Traditionally, handling these increasing fault currents often requires the high capital costly replacement of substation equipments or the reinforcement through switchgear that may lead to decreased operational flexibility and system security. A promising alternative approach to reduce the fault current is the application of FCLs in network. The application of FCL in power network allows existing equipments to remain in service, even if the fault current exceeds its rated peak and short-time withstand current [1–3]. An ideal FCL should have low impedance at normal operation, large impedance during fault and quick response characteristics [2–5]. Depending on transient and steady state FCL behaviors, they might influence the system characteristics and protection systems during fault. Therefore, the operation of existing protection schemes may be compromised due to the presence of the FCL impedance in the network during a fault [3,4]. In recent years, various types of FCL such as, current limiting reactors (CLRs), high impedance transformers, current limiting fuses, solid state FCL, resonant circuit and SFCL have been proposed and developed [5–10]. SFCL offers a solution to limit the fault current with many notable advantages such as, lossless operation during normal operation and limiting first peak of fault current within sub cycle. Additionally, the application of the SFCL would not only decrease the stress on devices but can also improve the reliability [6], and power quality [7], limit the inrush current of transformers [8], reduce the TRV across CBs [9] and improve transient stability of power systems [10] by reducing the fault current. Various types of SFCLs are developed based on different superconducting materials and designs such as, flux-lock, transformer, resistive, and bridge-types SFCL such as [8–12]. The bridge-type SFCL has zero impedance under normal conditions and large impedance under fault conditions (the same as other FCLs) [11]. But, it has specific characteristics such as follows:

- The fault current limitation is without any delay.
- The fault current waveform is smoothed.
- The fault current is distorted (i.e., non-sinusoidal).
- The DC component of the fault current is very low and has no exponentially decaying dc offsets.
- The fault current gradually increases during the fault.

The verification test (or development), using superconducting coil in a 6.6 kV single-phase bridge-type SFCL as a limiting coil has been reported in [12]. This development was a preliminary step to investigate the feasibility of the FCL application for high-voltage transmission lines. Thus, in an important step toward realization of the bridge-type SFCL application for high-voltage transmission lines, a 66 kV model coil has been designed and

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fabricated [13,14]. Also, in [15], a practical study of the 66-kV class, testing items and future subjects of the bridge-type SFCL system has been presented.

The main principle of the distance relay is to calculate the impedance between the relay and fault points from the voltages and currents at the relay location [16,17].

Because of the presence of FCL in a fault loop, the voltage and current signals seen from the relay point will be affected in both steady state and during fault states. Therefore the apparent impedance seen by the distance relay will be affected. In this paper, the impact of the bridge-type SFCL on the impedance calculated by distance relay is investigated. The PSCAD/EMTDC software is used to study this effect for single phase to ground and phase to phase faults.

Bridge-type SFCL

Structure of bridge-type SFCL

The bridge-type SFCL is shown in Fig. 1. The superconducting coil (SC) of FCL is connected to the secondary winding of the series coupling transformer (T_A, T_B and T_C). The SC has been modeled by L_d. The diode bridge-converts three-phase AC current to DC current, which flows through the SC.

During fault characteristic of bridge-type SFCL

The circuit shown in Fig. 2 is used for analytical studies. The source impedance is modeled by $Z_s = r_s + j\omega L_l$. The impedance, $Z_L = r_L + j\omega L_l$ presents the line and load impedances. The transformer is assumed to be ideal and its turn ratio is equal to 1. Fig. 3 shows the V–I curves of bridge-type SFCL during the fault. The slope of the V–I curve is equal to the impedance of the FCL. The impedance is divided into two parts, steep and gentle slopes. As shown in Fig. 3, the steep slope part appears when the line current is equal to the reactor current, i.e., the fault current is limited. So, the slope of the V–I curve means the tendency of the impedance including inductive component. The gentle slope appears when the line current is smaller than the reactor current, i.e., FCL does not limit the line current.

Fig. 4 shows the line current and DC reactor current. In normal operation mode, after charging the SC and in the steady state condition, the current of SC is approximately constant as shown in Fig. 4 and, we have:

$$V_d = L_d \frac{di_d}{dt} = 0 \tag{1}$$

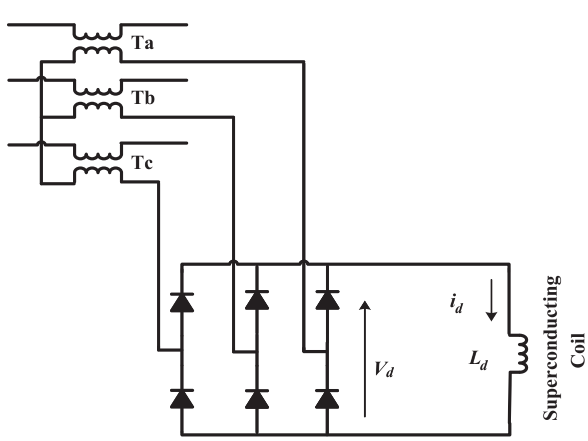

Fig. 1. Bridge-type SFCL.

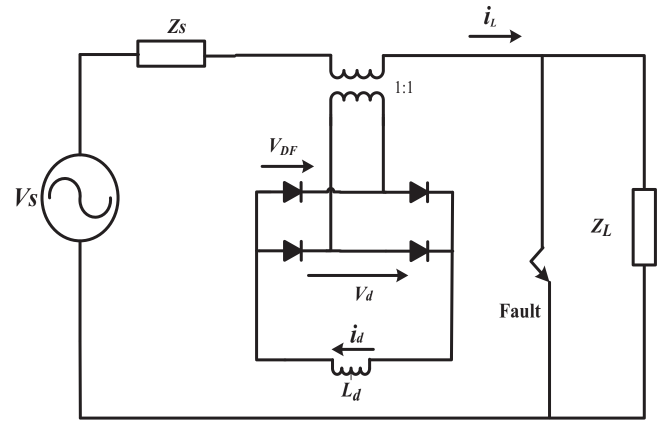

Fig. 2. Circuit topology for analytical analysis.

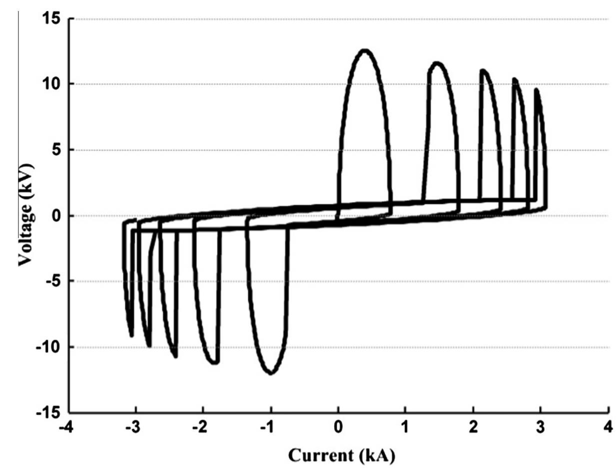

Fig. 3. V–I curve of bridge-type SFCL (during fault).

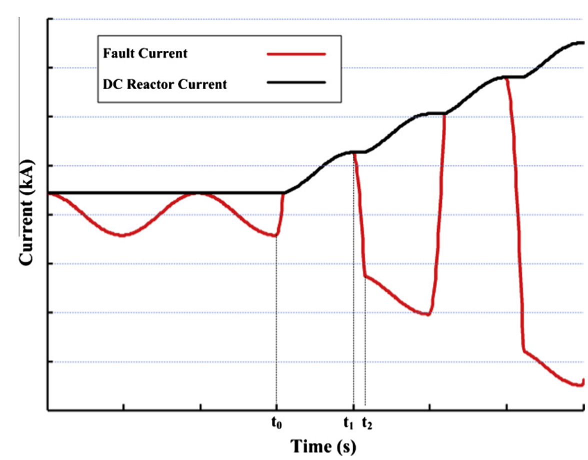

Fig. 4. Effect of bridge-type SFCL on SC and fault current during fault and normal operation mode.

Therefore, the impedance seen by the primary side of the coupling transformer is very low.

When, the fault occurs at $t = t_0$, it can be seen that the fault current does not have the surge waveform, but the fault current increases during the fault period gradually. In the period $t_0 < t < t_1$, the DC reactor current is equal to the line current and the circuit KVL is written, as follows: