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Operating characteristics according to the application position of a superconducting fault current element integrated into a transformer

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We analyzed operating characteristics to limit the peak value of initial fault current by inserting superconducting element into a neutral line. In order to detect the fault current, a current transformer (CT) was installed at the secondary winding and a SCR that changed current-flow by switching operation was installed. The fault current was reduced by inserting the superconducting element into a neutral line and was limited by connecting the normal conductivity element to the third winding. We confirmed that the peak value of initial fault current was reduced at lower level due to quench of the superconducting element connected to a neutral line, and the burden given to the superconducting element was significantly reduced as the normal conductivity element limited the fault current remarkably after switching operation.

1. Introduction

Recent increased demand on power brings a huge extension of more electric power systems. Such situation lowers impedance of electric power system that is structured as a network type and the size of the fault current are growing bigger and bigger when a fault occurs. The gradual increase of the fault current has reduced the reliability on the power supply, because the preventive measures such as installing serial reactors and replacing circuit breakers changed the operating and the transient characteristics of the electric power system [1–8]. Therefore, more effective measures are necessary to decrease the fault currents. Recently, the superconducting fault current limiter (SFCL) using the superconducting element has been spotlighted as the measures for the reduction of the fault current. While the SFCL operated without any impedance under normal condition and did not affect the transmission line, it generated impedance to reduce fault current less than cut-off rating of a circuit breaker under fault condition. Then, the SFCL returned to the zero impedance state automatically after limiting the fault current to perform the normal operation [1–8]. Thus, the problems of conventional power fuse were solved but the burden given to a superconducting element still remained. Our research team proposed a superconducting fault current limiter (SFCL) applied to a transformer for power system. The superconducting element of the SFCL was connected to the secondary winding of the transformer. As a result, the system performed the effective current-limiting behavior and the fault current was limited stably. However, from the research results, we found that the peak value of initial fault current was not reduced while a half-cycle after fault instant [2–5]. When the fault current is applied to the power system without the reduction of the peak value of initial fault current, very high current flows into the superconducting element transiently and it can give huge shock to the element. The superconducting element can be damaged when the fault is occurred frequently. In addition, if the fault is extended to other power apparatus, power system can be destroyed in the worst case. Also, the cost for the replacement of superconducting elements and power apparatus cannot be ignored. As a result, reduction in peak value of the initial fault current is very important. So, we connected a superconducting element with a neutral line of the secondary winding in a transformer to solve these problems.

2. Circuit diagram of a SFCL applying the superconducting element to third winding of the transformer and its operating characteristic

Fig. 1(a) shows a single phase circuit diagram for a simulated fault of the SFCL integrated into the third winding of a transformer suggested by our previous research [2–5]. The power source and the load was Y–Y connected through the three phase transformer. The SW-1 supplied the power and the SW-2 generated the

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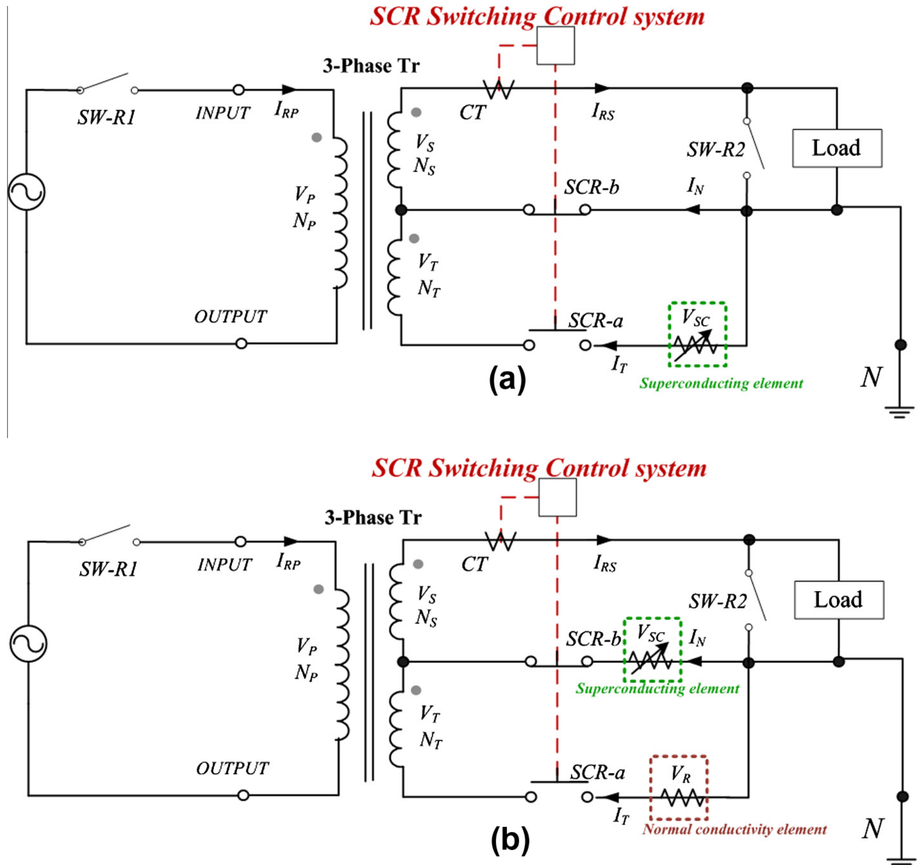

Fig. 1. The single phase circuit diagram of the superconducting fault current limiter integrated into the three-phase transformer: (a) when the superconducting element was applied to the third-winding and (b) when superconducting element was applied to a neutral-line.

simulated fault. A CT was installed at the secondary winding to detect the fault current. Also, a SCR that changed current flow by switching operation and a SCR control system that supplied the power were installed in series with the CT. The superconducting element used in this experiment was 2 inch diameter YBCO/Al_2O_3 thin film of a meander-line shape. The critical temperature of the superconductor was measured at 88 K, and the critical current density at 2 MA/cm^2. The gold layer of 0.1 μm was mounted on the YBCO thin film to prevent the heat deterioration by moisture in the air at room temperature [2–5]. The superconducting element operates without any impedance in normal state and it does not make any ohmic loss. But, when the current higher than the critical value flows into power system during the fault occurrence, the fault current is limited by any impedance generated from the superconducting element. The turn ratio was set at N_P:N_S:N_T = 3:2:1 so that the three-phase transformer integrated with the SFCL operated like a step-up transformer. Then, each phase was applied with 200 Vrms and a line-to-ground fault was produced at the line 1. Fig. 2 shows the voltage and the current curves of each phase of the SFCL integrated into the three phase transformer. When the SW-2 generated a fault, the CT connected to the secondary winding detected the fault and the SCR control system supplied the power to the SCR. Then, the SCR-a contact conducted turn-on operation straightly. However, the turn-off operation by the SCR-b contact was conducted after a half cycle due to switching surge [2–5]. Thus, the fault current of 108.26 A flowed dividedly into the neutral line and the third winding. When the SCR conducted turn-off operation after a half cycle, the fault current flowed into the third winding to which the superconducting element was connected and the fault current was limited at 37.39 A after 9.76 ms from the fault occurrence. There was slight increase of the currents on the sound phases, S, T-phases, because of using the integrated three-phase transformer but the operation returned to normal within a half cycle.

3. The circuit diagram of a SFCL applying the superconducting element to a neutral line of the transformer and its operating characteristic

Transformer type SFCL proposed by our research team performed the fault current limiting operation stably as shown in Fig. 1(a). However, Fault current was limited after a half-cycle because of time delay caused by switching surge [2–5]. Thus, the peak value of initial fault current flowed into the circuit during a half-cycle without being limited. As we mentioned before, Damage or destruction of other power equipment can be induced if the peak value of initial fault current is not reduced. In order to solve this problem, we proposed the structure of Fig. 1(b). Fig. 1(b) shows that superconducting element is connected in series with a neutral line in the structure of the existing transformer type SFCL to reduce the peak value of initial fault current. Also, resistance used in normal conductivity element was connected to the third-winding of the transformer for its limiting operation. When an accident occurred in the Fig. 1(b) circuit, immediately SCR-a contact performed the operation of the turn-on as shown in Fig. 1(a) circuit. However, SCR-b contact performed turn-off operation after a half-cycle due to switching surge. When an fault occurred in Fig. 1(b) circuit, superconducting element applied to a neutral line