1선지락사고에 대한 초전도한류기의 동작특성

Operating properties of resistive type superconducting fault current limiters with a single line-to-ground fault

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Abstract

We analysed the operating properties of resistive type superconducting fault current limiters (SFCLs) based on YBCO thin films with a single line-to-ground fault. When a single line-to-ground fault occurred, the short circuit current of a fault phase increased up to about 6 times of transport currents immediately after the fault instant and was effectively limited to the designed current level within 2 ms by the resistance development of the SFCL. The fault currents of the sound phases almost did not change because of their direct grounding system. The unsymmetrical rates of a fault phase were distributed from 6.4 to 1.4. It was found that the unsymmetrical rates of currents were noticeably improved within one cycle after the fault instant. We calculated the zero phase currents for a single line-to-ground fault using the symmetrical component analysis. The positive sequence resistance was reduced remarkably right after the fault but eventually approached the balanced positive resistance component prior to the system fault. This means that the system reaches almost the three-phase symmetrical state in about 60 ms after the fault. The ground currents were almost 3 times of the zero phase currents since most of the fault currents flowed through the grounding line.

1. Introduction

A superconducting fault current limiter (SFCL) is a device that limits the short-circuit current fast and effectively without having a high impedance during normal operation of the power system. The SFCLs are currently being developed in many countries [1, 9]. There are various concepts of SFCLs: resistive, inductive, hybrid types, and so on. Resistive SFCLs are very simple in principle and structure. Especially resistive SFCLs using thin films are easy to be made small-sized and compact. We have developed the resistive type using thin films so far [6, 12]. In order to apply these SFCLs to the real power system, the fault analyses for three-phase system are essential. The faults for three-phase system are classified into symmetrical and unsymmetrical one. Unsymmetrical faults are more common. The most common type is a line-to-ground fault. Approximately 70 % of the faults in power systems are single line-to-ground faults. In this study, we, therefore, analyzed the current limiting effects through unsymmetrical fault calculations based on the experimental results of resistive SFCLs using thin films.

2. Experimental details

Three SFCL units were used for fault tests in a three-phase system. Individual critical current values are shown in table 1. The critical currents of the three samples were uniform within 0.5 % and these samples showed comparatively homogeneous properties for the three-phase test. It is important to select the samples with almost same properties because the operation-starting currents of the SFCL are the same for the protective cooperation of the system.

Table 1. The critical current values (Ic) of three SFCL units.

Parameter	SFCL A	SFCL B	SFCL C
Critical current values (Ic, A)	15.55	15.58	15.60

3. Results and discussion

Fig. 1 shows current limiting characteristics of a single line-to-ground fault with zero ground impedance in a three-phase system. Phase a of a three-phase system goes to ground through zero impedance. The fault angle is zero degree. It is confirmed that the fault current of phase-a increased up to 32 Arms and then was limited effectively within 1-2 msec after the fault instant. If the SFCL is not operated, the fault current will instantly increase to an infinite value. This is certified by the voltage curves measured between the terminals of SFCL units. The fault phase-a was only quenched due to a single line-to-ground fault. The unsymmetrical rate of fault phases was 6.4 at the fault instant but decreased by 1.4 after 3 cycles. It was found that the unsymmetrical rates of currents were noticeably improved within one cycle after the fault instant as shown in Fig. 1.

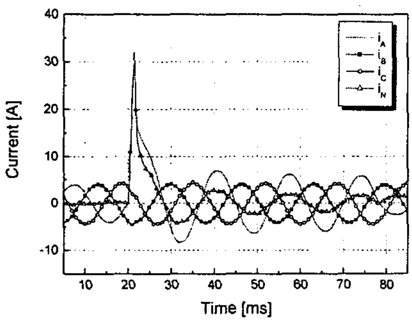

Figure 1. A single line-to-ground fault in a three-phase system.

These sequence components calculated from the measured line currents are given in Fig. 2. The positive sequence current are shown in Fig. 3. The values at fault instant are distant from 19.8 A, but the distance of peak currents reduced to 1 A and became stable in three cycles from the fault. The systems were very unstable at the early stage of the fault and shortly became close to symmetrical state. It is considered that this is because of the rapid increase of the resistance of an SFCL unit after fault.and should be equal at that systems. The distance between peak values of and the current of phase-a exists at balanced three-phase systems. So, the positive sequence current are relatively low because of the rapid interruption of fault currents by the SFCL. However, the zero sequence current still causes an electromagnetic induction to a communications line and the negative sequence current leads to reduction of motor power due to its braking operation, if we consider that these values are almost zero at the symmetrical state prior to fault conditions. Only the positive sequence current is the highest, which gives torque to the machines such as an electrical motor. On the other hand, the zero and negative sequence currents

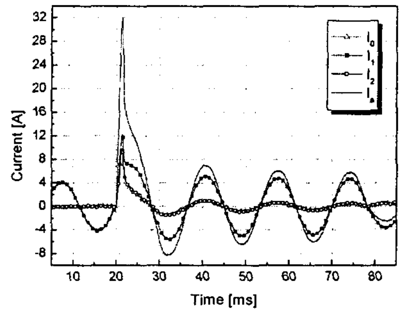

Figure 2. The symmetrical currents calculated from measured fault

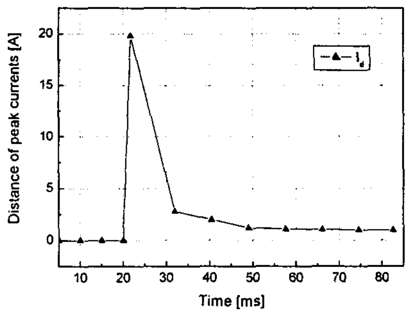

Figure 3. The distance between peak currents of fault phase a and positive sequence phase.

Fig. 4 shows the resistance developments calculated from sequence current and voltage components. As we expected from Figs. 2 and 3, the positive sequence resistance was reduced remarkably right after the fault but eventually approached the balanced positive resistance component prior to the system fault. If the system does not apply the SFCLs to the single line-to-ground fault, the positive sequence resistance will continuously sustain the lower value. From the Fig. 4, we could deduce that the system reaches almost the three-phase symmetrical state in about 60 ms after the fault.

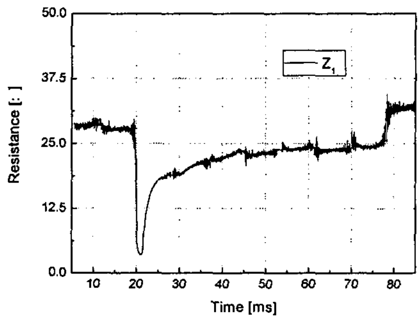

Figure 4. The symmetrical resistance calculated from symmetrical voltages and currents.

4. Conclusions

In summary, we performed the unsymmetrical fault analyses of resistive type superconducting fault current limiters based on YBCO thin films with a single line-to-ground fault in a three-phase system. The fault current of phase a increased up to 32 A_{rms} and then was limited effectively within 1-2 msec after the fault instant because the resistive type superconducting fault current limiters were applied to the three-phase power system. In addition, the unsymmetrical rate of fault phases was 6.4 at the fault instant but decreased by 1.4 after 3 cycles. It was found that the unsymmetrical rates of currents were noticeably improved within one cycle after the fault instant. When applying symmetrical component method to fault analysis, the positive sequence resistance was reduced remarkably right after the fault but eventually approached the balanced positive resistance component prior to the system fault. This means that the system reaches almost the three-phase symmetrical state in about 60 ms after the fault.

Almost of all unbalanced currents in a single line-to-ground fault flow into a grounding line but the zero sequence current, $3I_0$ reduced noticeably within 2 ms after the fault and gradually decreased afterwards by the interruption operation of the SFCLs in the three-phase system. In order to apply the SFCL to the three-phase power system, It is necessary to find the optimal conditions of the SFCL within the range of minimizing the interference to the balanced three-phase power system. The symmetrical component analysis for the SFCL will be applied usefully to determine these optimal conditions of the SFCL.

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