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A Study on Characteristics of Flux-offset-type Fault Current limiter according to Initial fault current

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Abstract

Our research team proposed a flux-offset type fault current limiter as a new limiter. The flux-offset type fault current limiter uses a fault current limit technology based on the flux offset principle of the primary and secondary windings of a transformer. Stable fault current limit characteristics were achieved through a preliminary study. However, it was discovered that the initial fault current was not limited. Therefore, in this paper, a high-speed interrupter and a superconducting element were separately applied to the secondary winding of the flux-offset type fault current limiter and the operating characteristics were comparatively analyzed. In the experiment, when the superconducting element was applied to the secondary winding of the transformer, the initial fault current was limited while the limitation in the operation time was further shortened.

Keywords: *Flux-offset type FCL, Superconducting element, Initial fault current, transformer, High-speed interrupter.*

1. Introduction

The flux-offset type fault current limiter is a fault current limit technology that uses the flux offset principle of a transformer. It combines a transformer for the electric power system and a high-speed interrupter into one module. Our research team verified the stable fault current limit characteristics of the flux-offset type fault current limiter through a preliminary study. However, a fault occurred during the study, and it was found that the initial fault current was not limited. If the initial fault current is not limited, a large fault current will be applied to the actual system within a short time, which will impose a significant burden on the power equipment. Moreover, the power system could even break down in the worst case if faults occur continuously and spread to the surrounding power equipment. In addition, the replacement and repair costs of the power equipment cannot be ignored. Thus, it is critical to limit the initial fault current [1-4]. Therefore, in this paper, a new structure that uses a superconducting element to limit the initial fault current is proposed.

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2. Maintain

2.1. Flux offset principle of transformer

A transformer is a device that receives alternating current power from one circuit through electromagnetic induction and supplies power to another circuit. After setting the same turn ratios for the primary and secondary coils of a transformer (N_P = N_S), power is supplied to the primary winding of the transformer.

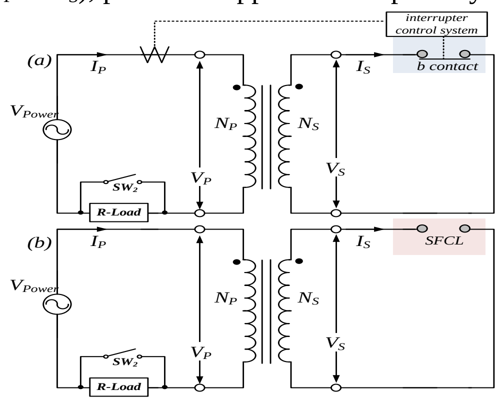


Figure 1. Circuit of a flux-offset type fault current limiter (a) Applied on high-speed interrupter, (b) Applied on superconducting element

When the current flows through the primary winding of the transformer, a magnetic field is formed and a flux (Φ_1) is generated. Then a counter electromotive force (e_1) is generated in a direction that inhibits the increase or decrease in the flux.

If a short circuit occurs in the secondary winding of the transformer, a current is induced in the secondary winding of the transformer through electromagnetic induction. At the same time, a counter electromotive force (e_2) is generated in the secondary winding of the transformer, Φ_2 is generated in a direction that offsets Φ_1, and Φ_1 and Φ_2 are mutually offset. As a result, the inductive reactance generated in the primary and secondary coils of the transformer becomes zero, and the impedance becomes zero, as shown in Equations (1) to (3).

$$L_1 = N_1\Phi_1 / I_1 \text{ [H]},\ L_2 = N_2\Phi_2 / I_2 \text{ [H]} \quad (1)$$

$$\Phi_1 = -\Phi_2 \text{ [wb]},\ L_1 = 0 \text{ [H]},\ L_2 = 0 \text{ [H]} \quad (2)$$

$$Z \approx X_L = 2\pi f L = 2\pi f * 0 \quad (3)$$

However, if the secondary winding of the transformer is open, the secondary current does not flow even though a counter electromotive force is generated by the primary winding of the transformer. As a result, the Φ_1 generated in the primary coil of the transformer is not offset. Therefore, there will be an inductive reactance due to Φ_1 in the circuit, as well as a random impedance value, as per Equations (4) to (5).

$$L_1 = N_1\Phi_1 / I_1 \text{ [H]} \quad (4)$$

$$Z \approx X_L = 2\pi f L = 2\pi f * L_1 \quad (5)$$

2.2. Experiment Design

In this experiment, a mock system was set up similar to an actual power transmission and distribution system. Figure 1 (a) shows the circuit diagram of the flux-offset-type fault current limiter to which a high-speed interrupter was applied, which was researched before. To generate a simulated fault, a fault generation switch, SW_2, was installed in the primary winding of a transformer. Furthermore, a CT and an interrupter control system were installed to detect the fault current and to apply power to the high-speed interrupter. Our research team produced the high-speed interrupter by combining a solenoid with a vacuum interrupter [3]. Figure 1 (b) shows the circuit diagram of the flux-offset-type fault current limiter to which a superconducting element was applied to limit the initial fault current. A fault generation switch was installed in the same way as that shown in Figure 1 (a). Figure 2 and Table 1 show the superconducting element used in this experiment and its specifications [2 and 4]. For the transformer, a three-phase transformer was used only in the single phase. The turn ratio (N_P:N_S) of the transformer was set equally for the primary and secondary windings to 4:4. The applied voltage (V_{Power}) was set to 120 V. Figure 3 and Table 2 show the transformer used in this experiment and its settings.

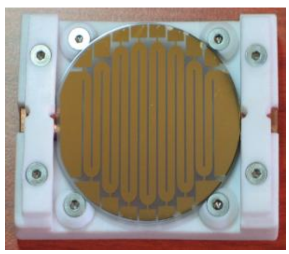


Figure 2. Superconducting element

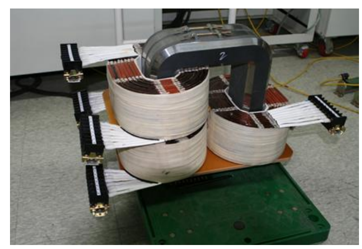


Figure 3. Transformer for the power system used in this experiment

Table 1. Specification of superconducting element

Parameter	Value	Unit
Diameter	2	inch
Strip width	2	mm
Length	540	mm
YBCO thickness	0.3	m
Au thickness	0.1~0.2	m
Critical current	18	a

2.3. A structure of a high interrupter applied to the secondary winding of the transformer

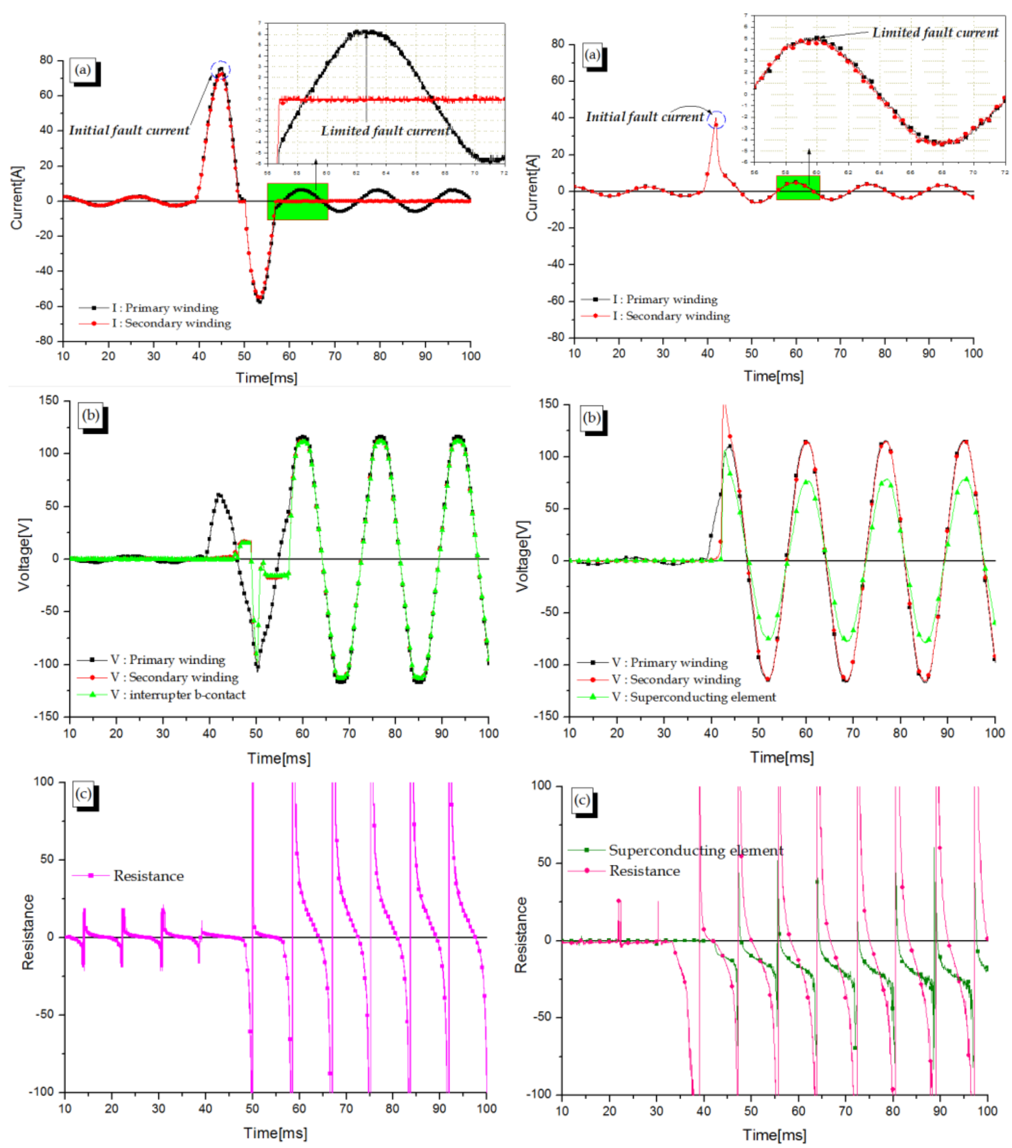
Fig. 4(1) shows curves that represent the characteristics of the current, voltage, and resistance of the flux-offset-type fault current limiter with a high-speed interrupter applied to the secondary winding of the transformer. This structure is the flux-offset type fault current limiter that was researched before. A voltage of 120V was applied to the primary winding of the transformer. As mentioned, in a normal case, the flux Φ_1 in the primary winding of the transformer is offset with the flux Φ_2 in the secondary winding of the transformer, which results in zero inductance. As a result, a normal current of 2.5 A was conducted in the line with no impedance. Of course, there was a core loss and a leakage flux, which are the losses of the transformer itself, in the line. However, this loss was assumed to have been zero because it was insignificant compared to the total power system.

When a simulated fault was generated with the fault generation switch (SW_2) after two cycles, an initial fault current of 75 A was generated. This was detected by the CT and the interrupter control system, and power was inputted to the high-speed interrupter.

At 17.7 ms after the fault, the b-contact of the high-speed interrupter was opened, which in turn opened the secondary winding of the transformer. As a result, the flux balance of the primary and secondary windings of the transformer was broken, an impedance was generated by the flux in the primary winding of the transformer, as per Equations (4) to (5), and the fault current was limited to 6.3 A. As shown in the resistance curve in Figure 4(1)-(c), while an insignificant resistance was generated in the normal state, the resistance increased as soon as the fault occurred and the secondary winding of the transformer was opened. Therefore, the fault current limit ratio of the flux-offset type fault current limiter of this structure was 91.6%. This was calculated using Equation (6).

$$I_L = (I_F - I_N / I_F) * 100 \ [\%] \qquad (6)$$

(I_L : Limiting rate of fault current, I_F : Fault current, I_N=Normal current)



(1) High-speed interrupter (2) Superconducting element

Figure 4. Operating characteristics of the flux-offset-type FCL with a high-speed (1) Interrupter and a superconducting element (2): (a) current, (b) voltage, and (c) resistance

2.4. A structure of a superconducting element applied to the secondary winding of the transformer

Figure 4(2) shows curves that represent the characteristics of the current, voltage, and resistance of the flux-offset type fault current limiter with a superconducting element applied to the secondary winding of the transformer. Likewise, a voltage of 120 V was applied to the primary winding of the transformer. A steady current of 2.5 A flowed into the primary and secondary windings of the transformer through electromagnetic induction. As shown in the resistance curve in Figure 4(2)-(c), the primary and secondary fluxes of the transformer were mutually offset in the normal state, and only an insignificant loss of the transformer existed in the line with no impedance. However, as soon as the fault occurred, the superconducting element applied to the secondary winding of the transformer was quenched, and the initial fault current was limited to 40 A.

Furthermore, the primary and secondary fluxes of the transformer became unbalanced due to the quenched superconducting element. Therefore, the fault current was finally limited to 4.8 A by Φ_1, as per Equations (4) to (6). The flux-offset type fault current limiter with a superconducting element showed a fault current limit ratio of 88%, as per Equation (6).

3. Discussion

In this experiment, a superconducting element was applied instead of a high-speed interrupter to limit the initial fault current of the flux-offset type fault current limiter that had been researched before, and the dynamic characteristics were analyzed. Figure 6 and Table 3 compare the dynamic characteristics of the application of a high-speed interrupter with that of a superconducting element. In the experiment, when a superconducting element was applied to the flux-offset-type fault current limiter instead of a high-speed interrupter, the fault current was limited to a half lower value. The structure with a superconducting element limited the fault current much faster than the structure with a high-speed interrupter. However, in general, the flux-offset type fault current limiter of the structure with a high-speed interrupter more stably limited the fault current.

4. Conclusion

Our research team proposed a flux-offset type fault current limiter as a new fault current limit technology. Stable fault current limit characteristics were achieved through a preliminary study. However, a problem of the limiter was discovered: its unlimited initial fault current. To address this problem, a superconducting element was applied instead of a high-speed interrupter. As a result, the structure with a superconducting element limited the initial fault current by quenching the superconducting element. Furthermore, the fault current limit operation time became faster than in the case of the high-speed interrupter.

The flux-offset-type fault current limiter technology is still in its initial stage. More in-depth research and development based on the results of the experiment in this study should improve the stability and reliability of power supply.

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References

[1] H. S. Choi, O. B. Hyun, and H. R. Kim, “Quench characteristics of resistive superconducting fault current limiters based on YBCO films,” *Physica C*, Vol. 351, pp. 415-420, 2001. doi:10.1016/S0921-4534(00)01632-4

[2] H. S. Choi, O. B. Hyun, H. R. Kim, K. B. Park, “Switching properties of hybrid type superconducting fault current limiter using YBCO stripes,” *IEEE Trans, Appl. Supercond*, Vol. 12, pp. 1833 - 1838, 2002. DOI: 10.1109/TASC.2002.801816

[3] B. I. Jung, H. S. Choi, “Combined Effect of the SFCL and Solenoid Coils,” *IEEE Trans, Appl. Supercond*, Vol. 24, pp. 5600404, 2014. DOI: 10.1109/TASC.2013.2283526

[4] H. W. Choi, H. S. Choi, B. I. Jung, “Operating characteristics according to the application position of a superconducting fault current element integrated into a transformer,” *Physica C*, Vol. 494. pp. 344-348, 2013. doi:10.1016/j.physc.2013.06.001