Current Limiting Characteristics of Flux-lock Type SFCL according to Inductance Variation

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We investigated the current limiting characteristics of flux-lock type superconducting fault current limiter(SFCL) according to inductance variation of coil 2. The flux-lock type SFCL consists of two coils. The primary coil is wound in parallel to the secondary coil through an iron core, and the secondary coil is connected to the superconducting element in series. The operation of the flux-lock type SFCL can be divided into the subtractive and the additive polarity winding operations according to the winding directions between the coil 1 and coil 2. The current limiting characteristics in two winding directions were dependent of on the ratio of the number of turns of coil 1 and coil 2. The fault current increased when the number of turns of coil 2 increased in the subtractive polarity winding. On the contrary, the fault current decreased under the same conditions in case of the additive polarity winding.

Keywords : Flux-lock type SFCL, Superconducting element, Ratio of the number of turns

1. INTRODUCTION

Electric power systems have been grown gradually by continuous economic growth and the increasing electric power demand. It caused impedance decrease of power system apparatuses and the fault current of power grid increased. So, the fault current exceeds interception capability of the breaker and the impedance is lower in all congestion areas.

As a simple method for solving these problems, the replacement of the breaker with high-capacity causes huge expense and technical limit. Insertion of serial reactor into power grids produces a voltage drop at a normal operation[1-3].

The superconducting fault current limiter(SFCL) is one of the most promising applications for solving these problems[4-7].

In this paper, we investigated the current limiting characteristics of the flux-lock type SFCL according to the subtractive and additive windings.

2. EXPERIMENTAL

A experimental circuit diagram of flux-lock type SFCL is shown in Fig. 1. V_s represents the applied voltage and S_{W1} is a switch for a normal operation. R_{in} is a standard resistance to measure electric current change and RL is load resistance and S_{W2} is a switch for short-circuit operation. The iron core was connected in parallel to coil 1, coil 2 and high-temperature superconducting (HTS) current limiting element also connected by series to coil 2. Figure 2 shows the pattern shape of a YBCO thin film which is a superconducting element used in this experiment. The superconducting element was fabricated using 300 nm thick $YBa_2Cu_3O_7$ (YBCO) thin films grown on 2 inch diameter Al_2O_3 substrates. The surface of the YBCO was coated with 200 nm thick gold-layer which scatters the joule heat generated after quenching and protects the YBCO thin film from moisture. The critical current of the HTSC thin film is 18 A_{rms}.

The thin film was immerged into liquid of nitrogen bath to maintain its superconducting state.

Current and voltage waveforms in case of the subtractive polarity winding are shown in Fig. 3 and Fig. 4. In order to investigate the dependence of inductance, the number of turns in the secondary coil was varied in 21 and 42 with fixing the primary winding in 63 turns. The resistance was generated at the superconducting element after the fault onset.

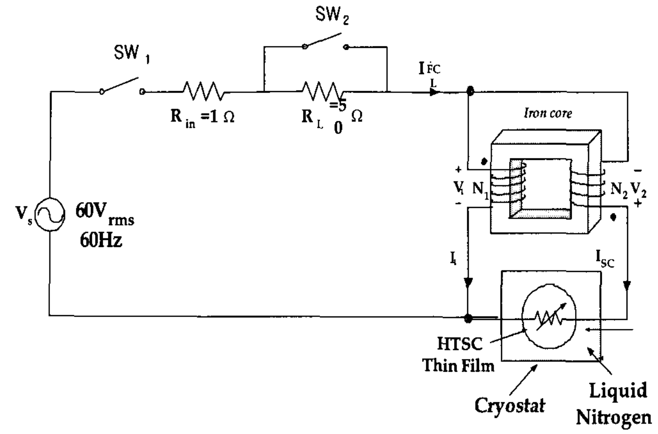

Fig. 1. Experimental circuit diagram with flux-lock type SFCL.

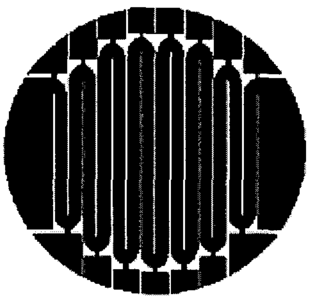

Fig. 2. The pattern shape of a superconducting current limiting element.

Line current, I_{FCL} increased to 41 A_{rms} immediately after fault onset, but the current was limited and stabilized within a half cycle due to the quench of the superconducting element as shown in Figs. 3 and 4. When the number of turns was increased from 21 to 42 turns the line current, I_{FCL} and HTS element voltage, V_{SC} increased in proportion to the number of turns. This could be explained by following equations.

$$I_{FCL} = I_1 + I_{SC}$$
$$V_{SC} = V_1 + V_2 \quad (1)$$

Meanwhile, the quench starting time in the HTS element from the fault onset was 0.77 ms in 21 turns and 0.94 ms in 42 turns, respectively. The quench starting time was made longer because the inductance in the secondary winding increased according to the increase of number of the turns and current flowing into the HTS element, I_{SC} decreased due to the increase of the inductance.

Current and voltage waveforms in case of the additive polarity winding are shown in Figs. 5 and 6. In order to

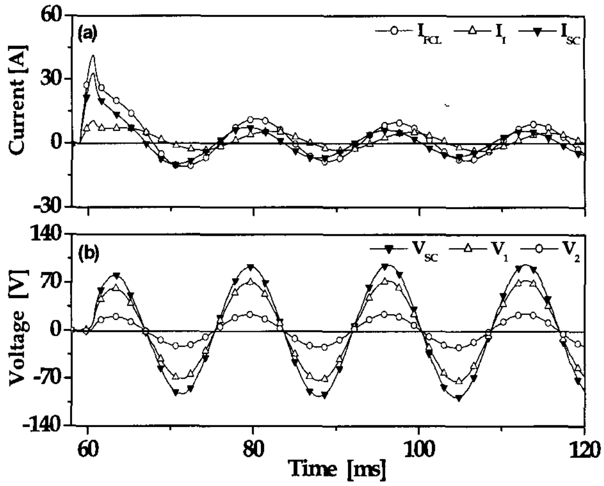

Fig. 3. Current and voltage waveforms in case of subtractive polarity winding(N1=63, N2=21). (a) Current, (b) Voltage.

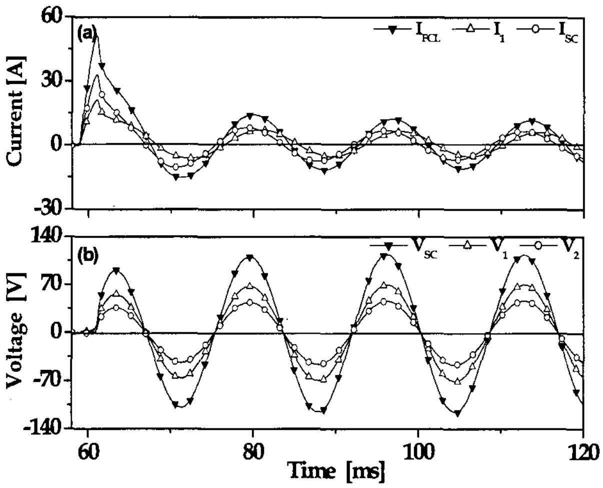

Fig. 4. Current and voltage waveforms in case of subtractive polarity winding(N1=63, N2=42). (a) Current, (b) Voltage.

investigate the dependence of inductance, the numbers of turns in the secondary coil were varied in 21 and 42 with fixing the primary winding in 63 turns.

The phase difference of 180° existed between the current flowing in the primary winding, I_1 and the line current, I_{FCL} due to the additive polarity winding. When the number of the turns in the secondary winding increased, the line current I_{FCL} decreased as show in Figs 5 and 6. This could be also explained by the following equations which are for the additive polarity winding.

$$I_{FCL} = -I_1 + I_{SC}$$
$$V_{SC} = V_1 - V_2 \quad (2)$$

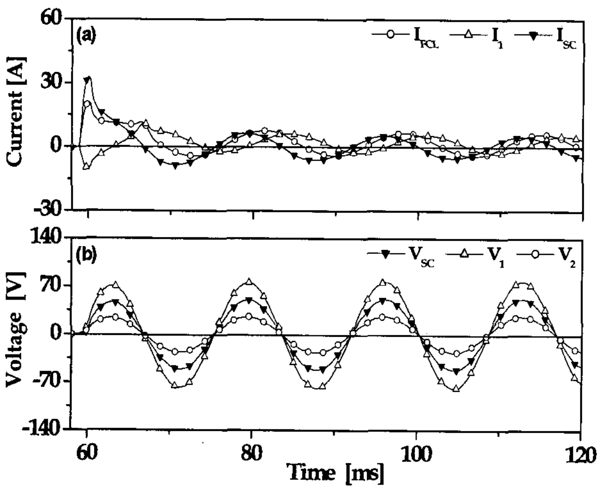

Fig. 5. Current and voltage waveforms in case of additive polarity winding (N1=63, N2=21). (a) Current, (b) Voltage.

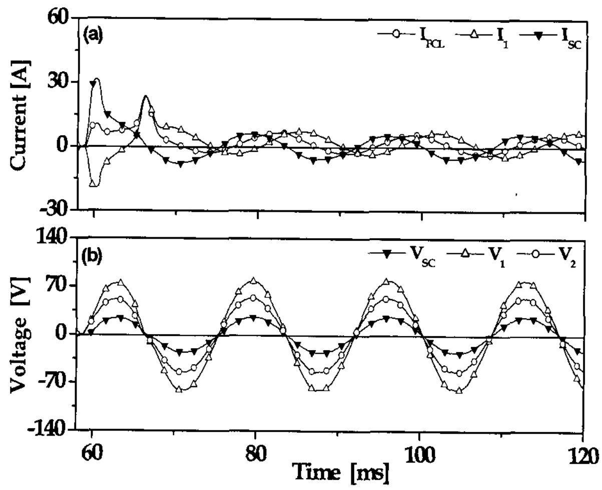

Fig. 6. Current and voltage waveforms in case of additive polarity winding (N1=63, N2=42). (a) Current, (b) Voltage.

When the inductance in the secondary winding increased, the current limiting characteristics are similar to those of the subtractive polarity winding. However, the line current, I_{FCL} in the additive polarity winding was lower than that of the subtractive polarity winding under the same conditions.

The quench starting time in the HTS element after fault onset was 0.6 ms in the 21 turns and 0.92 ms in the 42 turns, respectively. When we compared the quench starting time between the subtractive and additive polarity winding, it was shorter in the additive polarity winding under the same conditions. It was because the current flowing into the HTS element, I_{SC} was increased due to the flux linkage behavior in the additive polarity winding.

3. CONCLUSION

We have analyzed the current limiting characteristics that flux- lock type SFCL according to inductance variations between the primary and the secondary windings. We confirmed that the line current of the subtractive polarity winding increased according to increase a number of turns of the secondary winding. Meanwhile, the line current of the additive polarity winding decreased under the same conditions because of the difference of the flux linkage behavior between the subtractive and the additive polarity windings.

When the fault in the power grid occurred, the line current in the additive polarity winding was lower than that in the subtractive polarity winding under the same conditions.

Consequently, we could find that the flux-lock type SFCL with the additive polarity winding had more advantages than that of the subtractive polarity winding in the viewpoint of the current limiting characteristics.

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