Operating characteristics of superconducting fault current limiter using 24kV vacuum interrupter driven by electromagnetic repulsion switch.

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Abstract. Using a high temperature superconductor, we constructed and tested a model Superconducting Fault Current Limiter (SFCL). SFCL which has a vacuum interrupter with electromagnetic repulsion mechanism. We set out to construct high voltage class SFCL. We produced the electromagnetic repulsion switch equipped with a 24kV vacuum interrupter(VI). There are problems that opening speed becomes late. Because the larger vacuum interrupter the heavier weight of its contact. For this reason, the current which flows in a superconductor may be unable to be interrupted within a half cycles of current. In order to solve this problem, it is necessary to change the design of the coil connected in parallel and to strengthen the electromagnetic repulsion force at the time of opening the vacuum interrupter. Then, the design of the coil was changed, and in order to examine whether the problem is solvable, the current limiting test was conducted. We examined current limiting test using 4 series and 2 parallel-connected YBCO thin films. We used 12-centimeter-long YBCO thin film. The parallel resistance (0.1 Ω) is connected with each YBCO thin film. As a result, we succeed in interrupting the current of superconductor within a half cycle of it. Furthermore, series and parallel-connected YBCO thin film could limit without failure.

1. Introduction

Fault current have been increasing because of the continuous growth of power systems and the increasing of distributed generators. To resolving this problem, it is available that Superconducting Fault Current Limiting (SFCL) is installed in power system. Various SFCL have been developed, we have studied Resistive SFCL using the electromagnetic repulsion plate(ERP) and Vacuum Interrupter(VI) to limit the heat of YBCO by interrupting the current which flow element within a first half cycle. We have so far examined by connecting an electromagnetic repulsion switch using Bi2223 silver sheath wire and YBCO bulk. Since Bi2223 silver sheath wire and YBCO bulk have low resistance, long length is necessary to obtain the specified resistance. For this reason, we are inquiring using the YBCO thin film with high resistance after a quench[1]. Because of YBCO thin film is weak against heat. There is a possibility of meltdown by heat generation at the time of a quench.

We set out to construct high voltage class SFCL. We produced an electromagnetic repulsion switch equipped with a 24kV VI and experimented. Furthermore, the current limiting test was done using the commercial high-speed circuit breaker as substitute for the electromagnetic repulsion switch.
2. Interrupting test of electromagnetic repulsion switch equipped with 24kV VI

![Sample oscillogram of current limiting test.](image)

**Figure 1.** Sample of the experimental waveform.

We have ever constructed trial SFCL and experimented on operation test. [2] Figure 1 is shown as sample oscillogram of current limiting test. We used a power source of 50 Hz and applied a fault current connecting only the prototype model SFCL. In the figure 1, most of the current flows to a parallel coil at the same time as quench, the ERP is driven, and current of the superconductor is interrupted about 5ms.

There are problems that opening speed becomes late. Because the larger VI needs the heavier weight of its contact. For this reason, the current which flows in a superconductor may be unable to be interrupted within a half cycles of current. In order to solve this problem, it is necessary to change the design of the coil connected in parallel and to strengthen the electromagnetic repulsion force at the time of opening the VI. Then, the design of the coil was changed, and in order to examine whether the problem is solvable, the current limiting test was conducted.

![Specifications of YBCO thin film.](image)

**Figure 2.** Specifications of YBCO thin film.

YBCO thin film has limitations of current and voltage. It is difficult to make SFCL using only a thin film. Therefore, it is necessary to connect some thin film with the series and parallel. In parallel connection, there is problem that the current in the superconductors is not equal. In series connection, there is problem that the superconductors don’t quench at once for the critical current (Ic) variations of the several superconductors. If some superconductors with low Ic quench, the other superconductors could not quench as the circuit current is limited. Then it is expected that the voltage of the superconductor with low Ic is quite high and these superconductors break. To verify these problems, we executed a current limiting test using 4 series and 2 parallel –connected YBCO thin film. The elements which we used are shown in figure 2. The YBCO thin film with a thickness of 0.25 μm was prepared on 120 × 10 × 0.5mm³CeO2 buffered sapphire substrates by Metal Organic Deposition (MOD process). Silver electrodes with a thickness of 0.3–0.4mm were vacuum-deposited at ends of element and every 1cm. The parallel resistance (0.1Ω) is connected to each YBCO thin film. Form of the resistance using this test is non-inductively wound Manganin wire resistor. These parallel resistances are put in liquid nitrogen.
Experimental circuit is shown in figure 3. Simulating a short circuit current, the current was applied using L-C resonance circuit. In this experiment we experimented by adjusting charging voltage of capacitor (18800 μF). Figure 4 shows the case in which the charging voltage is 90V. The stroke of ERP, whole current of the circuit, the current of current limiting part and current of parallel coil are shown. ERP begins to move when the current of parallel coil exceeds 500A from conducting a current after about 3ms, and the current flow in the current limiting part is interrupted by driving a VI within the 0.5 cycle from conducting a current after about 20ms. The current in the current limiting part is equivalent to circuit current just after conducting a current, and limited by a quench of the superconductor. Then, the current of the current limiting part is commutated to the parallel coil and the value of the circuit current is limited from 8kApeak to 1kApeak. ERP begins to move at around 3ms after quench. The current in the current limiting part is suddenly decreased after a quench. The reason of the kink in current limiting part is the voltage of arc in the VI. The maximum value of VI stroke is 4mm and the stopper of the VI mechanism maintains its stroke at 3.7mm.

In this experiment, L-C resonant circuit is used for the power supply. Large capacitor is connected to the circuit. After YBCO thin film is quenched, this circuit becomes serial resonance circuit composed of capacitor (C), coil (L) and parallel coil. For this reason the frequency of the conducting current mutated into about 25 [Hz]. Consequently, the current flow in the current limiting part was interrupted at 20 ms. On the other hand, if our SFCL connect with a real power system, the current which flows into a superconductor will meet a current zero within 10 ms. In this experiment, After the occurrence of a quench, ERP started to move within 10 ms. That is to say, even if this SFCL applies to the actual power system, our SFCL has enough ability to interrupt the current which flows in the superconductor within 10ms as shown in figure 1.
We also investigate the current limiting tests using this current limiting module. The experimental result is shown in figure 5. Figure 5 is a voltage waveform of each element. For applying to high voltage, it is problem that the superconductors in series connection don’t quench at once for the Ic variations of the several superconductors. In this case, the superconductors could be broken. Connecting parallel resistance (0.1 Ω) with series and parallel-connected YBCO thin film, all elements is quenched and the value of voltage of each superconducting element is same value.

3. Current limiting test using conventional high speed vacuum circuit breaker (HSVCB)

We substituted conventional High Speed Circuit Breaker (HSVCB, Figure 6) for electromagnetic repulsion switch, examining the possibility of separating the superconductor within a half cycle. HSVCB is operated by voltage at the time of a quench. Experimental result is shown as figure 7. Figure 7 shows that HSVCB began to open at 6 ms. After that, the current of superconductor is completely cut off at 20 ms. This result indicated that the current in the superconductor is interrupted within 0.5 cycle using not only electromagnetic repulsion switch but also HSVCB. Our proposed SFCL is realized. In addition, as in the case of electromagnetic repulsion switch, series and parallel-connected YBCO thin film could limit without failure.

![Figure 6. Overview of high speed circuit breaker.](image)

| Rated voltage | 7.2kV |
|---------------|-------|
| Rated current | 600A  |
| Rated interrupting current | 12.5kA |

![Figure 7. Experimental result.](image)
4. Conclusion

The text of your paper should be formatted as follows:

1) Using electromagnetic repulsion switch equipped with 24kV class VI, we succeed in interrupting the current of superconductor within the 0.5 cycle after the occurrence of a fault by changing the design of the parallel coil and being strengthen the electromagnetic repulsion force at the time of opening the VI.

2) We substituted conventional high speed circuit breaker for electromagnetic repulsion switch and experiment in current limiting we done. According to the results, the current of a superconductor is completely interrupted within half cycle of current. This successes result in one of the new method which actualize our concept of SFCL.

3) We make the current limiting module using four series and two parallel-connected YBCO thin films. The parallel resistance (0.1Ω) is connected with each YBCO thin film. As a result all YBCO thin films are quenched without destruction. Success of series and parallel operation enable us to create any voltage range.

We proposed a new concept SFCL to shunt the current of the superconductor to a parallel coil immediately. Our proposed model has a simple architecture and can keep the load of the superconductor to a minimum. Therefore, the size of the superconductor can be reduced.

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References

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