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Simultaneous Quench Characteristic of Resistive Superconducting Fault Current Limiting Modules by using BSCCO Tape

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Abstract-- **Recently, the resistive Fault Current Limiter (SFCL) made with Coated Conductor (CC) has been researched with an advanced capability in CC. Current limiting elements must be connected in series in order to fabricate the resistive SFCL having large capacity. By the way, unless the applied voltage in the SFCL is distributed to the elements when the fault occurred, those elements will be critically damaged. Thus simultaneous quench of the elements is an important factor to design the resistive SFCL. In this paper, simultaneous quench characteristics of current limiting module by using BSCCO 2223 were researched before manufacturing the resistive SFCL by using CC. At the first fault stage, the elements generated the resistance at the same time. However, the unequal voltage is applied to the each element in process of time. The method is suggested to solve the problem of the unequal distribution. These experimental results will play an important part in developing for the resistive SFCL by using CC.**

1. INTRODUCTION

The Superconducting Fault Current Limiter (SFCL) recently has been researched all over the world and it is estimated that its commercialization will be possible in a few years. The SFCL has many advantages in comparison with the existing facilities like that circuit breaker and will settle the problems of the existing facilities such as instability and slow reaction time of circuit breaker, cost increase pursuant to circuit breaker replacement.[1][2]

Although the SFCL has many advantages such as fast current limitation, application to power system using fast recovery and unnecessity of replacement regardless of increasing power demand, the commercialization of the SFCL is delayed by its stability problem. One of the ways to guarantee the stability of SFCL is to increase the number of the current limiting elements that were connected in series when we design the resistive SFCL with large capacity. However, it causes penalties of cost and size to increase the number of elements that are unnecessary. So the number of the element must be properly selected according to the maximum voltage that the element can withstand. In this case, the important factor is that applied voltage to the SFCL must be distributed to all elements. Namely it requires the simultaneous quench.[3]

In this paper, the short circuit tests are performed in order to observe the simultaneous quench of the elements. The resistive SFCL was composed of three elements. The elements were bifilar solenoid coils wound with BSCCO 2223 tape. To induce the simultaneous quench the shunt resistor was used.

2. MANUFACTURE OF THE RESISTIVE SFCL

2.1. Manufacture of the elements for short circuit tests

In this experiment, the BSCCO 2223 tape was used for manufacturing the resistive SFCL. As shown in Fig. 1, the elements were bifilar solenoid coil to reduce the AC loss in normal state.[4] Total number of manufactured elements is six and each specification is showed in Table I. As shown in Table I, we manufactured the elements that had different critical current and resistance at 300K in order to investigate how the critical current and characteristics of BSCCO 2223 tape effect the simultaneous quench. The critical current of all tapes in group A was 128A except the one with 123A. Group B showed what will happen if all elements have same condition.

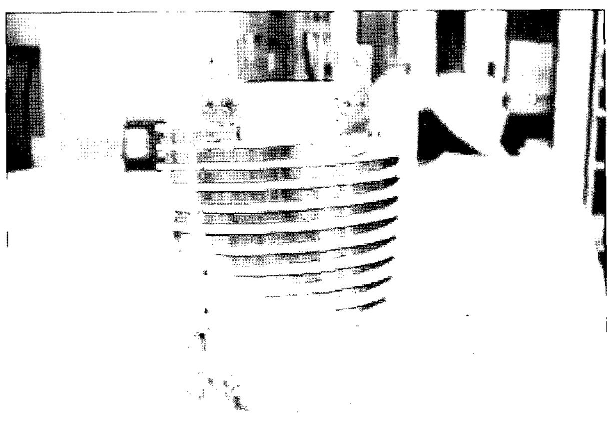

Fig. 1. BSCCO Bifilar SFCL.

2.2. Experimental method

Current limiting characteristics of the bifilar coil were investigated by short-circuit test. Fig. 2 shows the circuit diagram for the test. A transformer was used for generating large current. The fault switch made the circuit fault condition. Fault duration was 0.1 sec. Fig. 3 shows the series connected BSCCO bifilar coils. Because the length of tape is short, the position of coils will possibly affect the quench characteristics. So the tests are performed by changing the position of the module such as 1-2-3, 1-3-2 and 2-1-3 etc.

TABLE I
SPECIFICATION OF BSCCO BIFILAR COIL

Group		Tap length	Ic	Inductance	Resistance (300K)
A	1	3m	123A	5 μH	95 mΩ
	2	3m	129A	4 μH	110 mΩ
	3	3m	130A	4 μH	110 mΩ
B	4	3m	118A	5 μH	107 mΩ
	5	3m	119A	5 μH	107 mΩ
	6	3m	119A	5 μH	107 mΩ

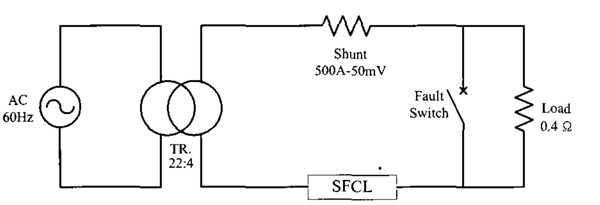

Fig. 2. Circuit diagram for short circuit test.

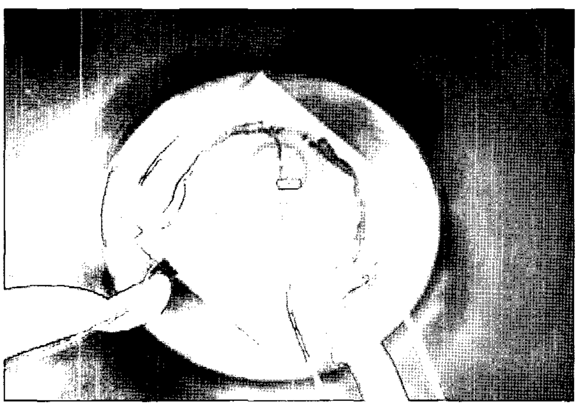

Fig. 3. Series connected BSCCO bifilar SFCLs.

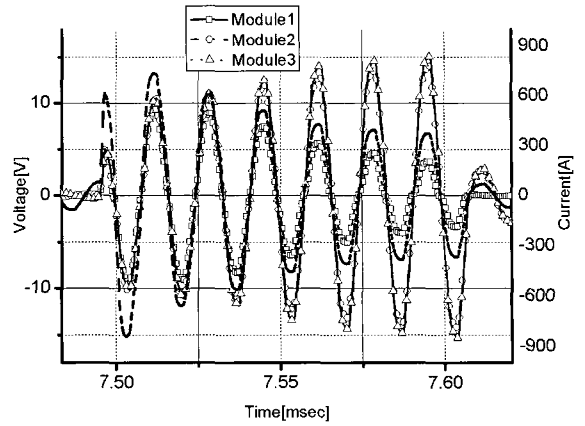

Fig. 4. Voltage graph of BSCCO Bifilar SFCLs. (from module 1 to module 3)

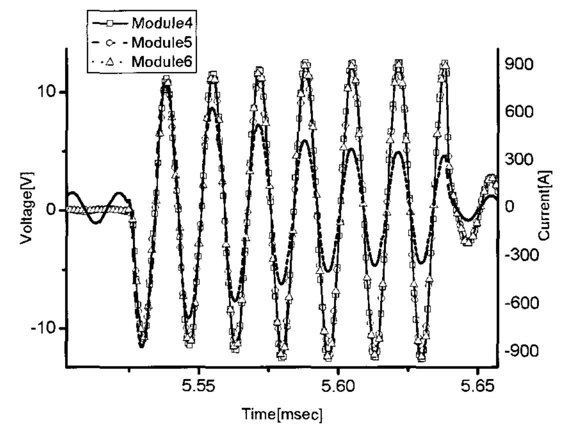

Fig. 5. Voltage graph of BSCCO Bifilar SFCLs. (from module 4 to module 6)

3. RESULTS OF THE TEST

3.1. Results of simultaneous quench

Fig. 4 is the result of the group A's short circuit test. Applied voltage is 27V. As shown in Fig. 4, the quench occurred at the same time. At the first fault stage, the elements generated resistance at the same time. However, as shown in Fig. 4, the unequal voltage is applied to each module in process of time. BSCCO 2223 is made by PIT (Powder-In-Tube) process, so a matrix material acts as a shunt resistor.[5] Thus quench occurred at the same time. The important point is that unequal voltage is applied to each module in process of time.

Although the voltage of module 2 and module 3 is increased, the voltage of module 1 is decreased. That reason is not the different critical current but the characteristic of BSCCO tape. As shown in Table. I, the resistance of module at 300 K causes that the unequal voltage is distributed. Since resistance initially generated in each module is proportional to that in room temperature, the voltage is distributed with the ratio of the resistance in room temperature under constant total voltage. Thus the difference in applied voltage per unit length increases that of generated resistance.

As shown Fig. 5, the equal voltage is distributed in same condition.

3.2. Method to solve the unequal voltage problem

Because BSCCO 2223 tape is made by PIT (Powder-In-Tube) process, characteristic of tape is not uniform. So when the fault occurs, the generated resistance is different each other. To be equal the resistance, the shunt resistor is connected in parallel to the module. The ratio of the module's resistance at 300K is maintained in a low temperature. The difference between the modules causes that the unequal voltage is distributed.

The shunt resistor of module 2 is given by

$$R_1 = \frac{95}{110} R_2 \tag{1}$$

where, R_1 is resistance of module 1, R_2 is resistance of module 2 and 3.

To equal the applied power, following condition should be satisfied,

$$i^2 \times R_1 = i_2^{\ 2} \times R_2 \tag{2}$$

where i is the line current, i_2 is current that flows through R_2

The current i1, i2 that flow through shunt resistor and R_2 respectively are given by

$$R_{Sh} = \frac{i_2}{i_1} \times R_2 \tag{3}$$

From equation (1), (2) and (3)

$$R_{Sh} = 13.15 R_2 \tag{4}$$

As shown in Fig. 6, the shunt resistor is connected in parallel to the module. The resistance is 1 Ω at 300K and 850 mΩ at 77K. Since resistance of module 2 when power applied to each module becomes different is 20 mΩ , by equation (4), the resistance is decided as 280 mΩ with three resistors connected in parallel. The short circuit tests are performed by connecting the shunt resistor to module 2,3. Fig. 7 shows the result of test. As shown in Fig. 7, the equal voltage is distributed.

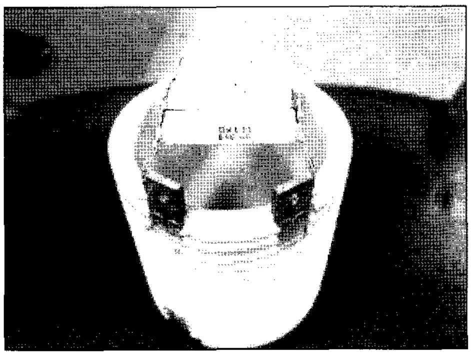

Fig. 6. BSCCO Bifilar SFCLs with parallel resistance.

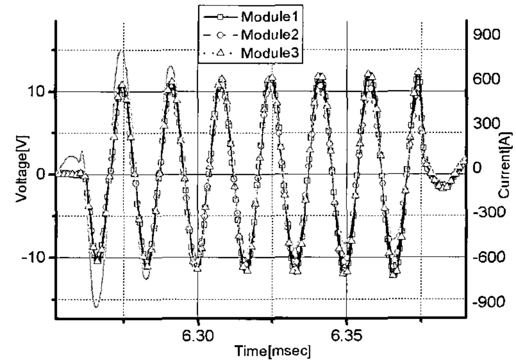

Fig. 7 Voltage graph of BSCCO Bifilar SFCLs with parallel resistance.

4. SUMMARY AND CONCLUSION

In this paper, simultaneous quench characteristics of current limiting module by using BSCCO 2223 were researched. In this case, quench occurs at the same time. However, the unequal voltage is applied to each element in process of time. This unequal voltage distribution is a major problem. If the problem cannot be solved, the module of the resistive SFCL will be damaged.

To solve the problem of unequal voltage distribution, the shunt resistor is connected in parallel to the module. In addition, we controlled the current that flows through the module so that energy generated in module yields the same result.

The present status of R&D of YBCO Coated Conductor shows significant progress. If commercialization of CC is possible, the problem of simultaneous quench and voltage distribution will be solve due to uniformity of CC.

ACKNOWLEDGMENT

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