Fault Current Limiter Using Coated Conductor

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Abstract— ***As one of the programs in the Ministry of Economy and Trade and Industry (METI) project carried out in FY2006 and 2007, a coated conductor utilized for resistive-type superconducting fault current limiter (SFCL) was developed and evaluated. The conductors used in this work were ReBCO tapes, such as YBCO and GdBCO, formed on ion-beam-assisted deposition (IBAD) substrates by using a pulse laser deposition (PLD) process. In order to obtain high resistance of the conductor, which is preferable to an SFCL, the thickness of the protecting layer made of silver was decreased as possible. Then high-resistive metal stabilizing layer was attached on the silver layer to improve stability. The critical current of the conductor with this configuration was increased up to over 300A/cm. When excess current was applied to the developed conductor, uniform voltage distribution was obtained in the longitudinal direction. In the program, three-phase 6.6kV superconducting fault current limiter (SFCL) was finally fabricated and some evaluation tests were implemented.***

I. Introduction

A super-to-normal transition type superconducting fault current limiter is a recent promising approach in the power applications using superconducting coated conductors, and its practical realization is strongly expected.

One of the programs carried out by the Japanese Ministry of Economy, Trade and Industry (METI) in FY2006–07 investigated fundamentals of SFCLs. One subject was the development of ReBCO (YBCO and GdBCO) conductor for SFCL, which possesses sufficiently high resistivity in addition to good superconducting performance. The other subject was the evaluation of SFCL coils using the developed conductor. The target rated voltage was 6.6 kV, which was a preliminary step toward higher voltages in future.

This paper summarizes the configuration of the developed ReBCO tapes with high resistivity and the current limiting performance of the coil would with the conductor.

II. COATED CONDUCTOR FOR SFCL[1]

The conductors used in this work were YBCO (GdBCO) tapes formed on ion-beam-assisted deposition (IBAD) substrates by using a pulse laser deposition (PLD) process.

Fig. 1 shows the configuration of the conductor schematically. In a first process, a silver-layer thickness of 10 μm was used instead of the normal thickness of 20 μm. Although it is possible to reduce the thickness more, this thickness was determined for maintaining uniformity over the long length required for coils. In a second process, a high-resistance stabilizing metal layer was laminated to the silver layer as a stabilizer. Nickel-chromium alloy was selected as the stabilizer. It has a high resistivity of about 9×10^{-6} Ω-m at 300 K, is nonmagnetic, and can be easily processed. If an ideal conductor that is homogenous along the longitudinal direction is obtained, the additional layer of nichrome alloy is not necessary. However, the configuration we used, because of its thermal capacity, avoids local voltage increasing which might occur in the conductors which are non-uniform. Moreover, this configuration was easy to handle, preventing chemical or mechanical damage to the coil due to carelessness.

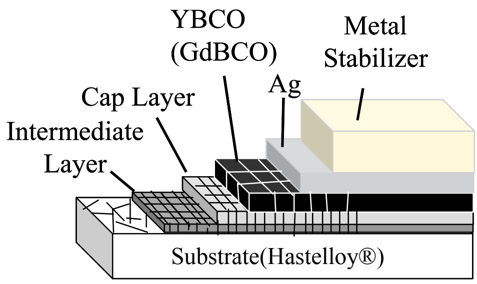

Fig. 1. Conductor configuration for FCL (Hastelloy® is a registered trademark of Haynes International Inc.)

Voltage distributions in the longitudinal direction for two types of conductors were compared, one without the nichrome layer, and the other with. YBCO samples with lengths of 600 mm were electrically connected to an induction voltage regulator (IVR), which applied an excess current to the samples to simulate a short-circuit failure mode. The excess current was three cycles at a frequency of 50 Hz. Six voltage taps were attached at equal intervals along both samples. The ratio of local voltages for the six locations for the conductors without and with the nichrome layer are shown in Fig. 2 (a) and (b), respectively. The effect of the nichrome layer is quite obvious. The homogenous voltage distribution was obtained in the conductor with the nichrome layer, which was not the case for the conductor without the nichrome layer.

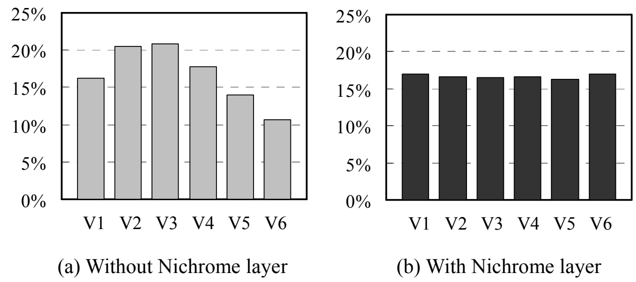

Fig. 2. The ratio of local voltages for the six locations for the conductors

III. Design and Test of SFCL Coil [2]

A. Current Limiting Coil and Three-phase SFCL

The three-phase current-limiting coils were wound with the developed conductors. The specifications of the coils are shown in Table I. Two tapes were wound in parallel on four-layer bobbins made of fiber-reinforced plastic. The four layers, measuring different diameters, were located concentrically and were electrically connected in series. The self-inductance of the coils was reduced by arranging the windings with an appropriate number of turns and directions in the four layers. The photo of the coil is shown in Fig.3.

Although the developed conductor has critical current up to over 300A/cm, the current capacity of the coil was specified based on the power system conditions at the user site where the SFCL was planned to be installed. The critical current of the conductor was around 60 A / 5 mm at 77 K. This value met the requirement that the coil wound with two tapes possess a critical current two times higher than the rated current when it was cooled down to 70 K.

The three-phase coils were installed into one sub-cooled nitrogen cryostat. The cryostat were connected with other switchgear, such as circuit breakers, and mounted in a cubicle. The cubicle included relay-based sequence control. When the fault detector detected a fault based on the voltage measured in the main circuit, it triggered the circuit breakers to open. Simultaneously, the current-limiting coils passively suppressed the fault current.

B. Short Circuit Experiment

The SFCL performance was evaluated by a short circuit test using a short circuit generator. The prospected short-circuit current value was set by a reactor coil to 550 A rms., according to the short circuit current value of the actual setting in the field where the SFCL was installed later. A typical experimental result is shown in Fig. 4. The applied voltage was 6.6 kV rms, the three-line ground fault (3LG) condition was used, and the fault occurred at an angle of zero degrees in the R-phase voltage. The prospected short-circuit current without the SFCL, obtained in advance, is superimposed in the figure. Comparing with the waveforms without the SFCL, the fault current of 1560 A for the R-phase was successfully suppressed to 840 A, which demonstrates a good current limiting effect. The other two phases also showed current limiting effects. The R-phase coil limited the fault current before the first wave peak. The experimental result was in good agreement with the numerical result.

TABLE I
Specifications of current-limiting coil

Conductor	Hastelloy/YBCO/Ag 10 mm/NiCr
Voltage	6.6 kV
Critical Current	200 A at 70 K
Impedance	120 μH
Number of layers	4
Number of parallel tapes	2
Length of winding	120 m
Inner radius	0.15 m
Outer radius	0.24 m
Height	0.50 m

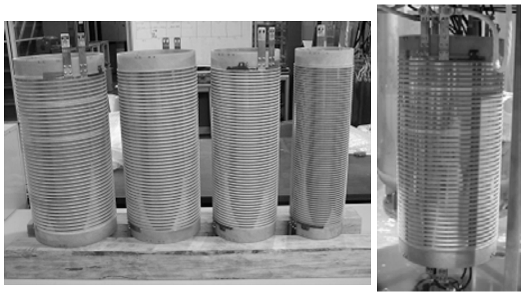

Fig. 3. Photo of the current limiting coil; each four layer(left) and assembled figure (right)

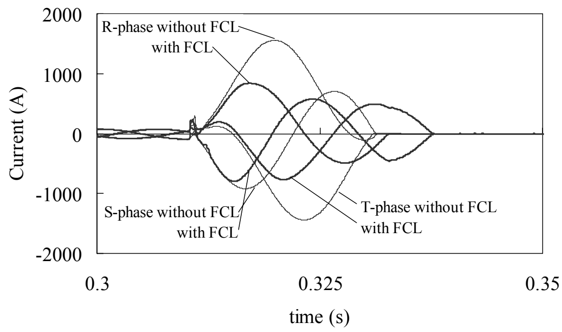

Fig. 4. Short Circuit Experiment

IV. Conclusion

This paper focused on evaluation of the fault current limiting performance of a resistive SFCL using ReBCO tapes with an IBAD substrate. The high-resistive metal stabilizing layer was attached on the silver layer to obtain homogenous voltage distribution in the longitudinal direction, the increase of thermal capacity and the ease of handling. The current-limiting coil was wound with the developed conductors. And three-phase 6.6kV superconducting fault current limiter (SFCL) was finally fabricated. The SFCL showed a good current limiting effect in a short-circuit experiment.

Acknowledgement

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References

[1] T. Yazawa, et. al., *Physica C*, Vol. 468 (2008), pp. 2046.-2049

[2] T. Yazawa, et. al., presented at ASC2007., Chicago, Aug. 18-22, 2008.