Peak current limiting properties of SFCL with parallel connected coils using two magnetic paths

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Background

a superconducting fault current limiter (SFCL) has been considered as a very effective way to reduce the fault current with its nature of zero electric resistance in the normal condition, which neither incur loss nor influence the system. Most of the existing relative researches have been on either the load to handle the fault current during the period of limiting operation or the operating characteristics and its effectiveness after improving the adjustment of impendence, because sensing the fault current and limiting operating of fault current occur simultaneously .

Objectives

❖ We made it freely control the high peak fault current, and, by increasing the inner magnetic flux of the iron core, prevent the iron core saturation.

❖ The structure of the proposed SFCL has the two magnetic paths with the first coil, the second coil, and the third coil around one single E-I iron core.
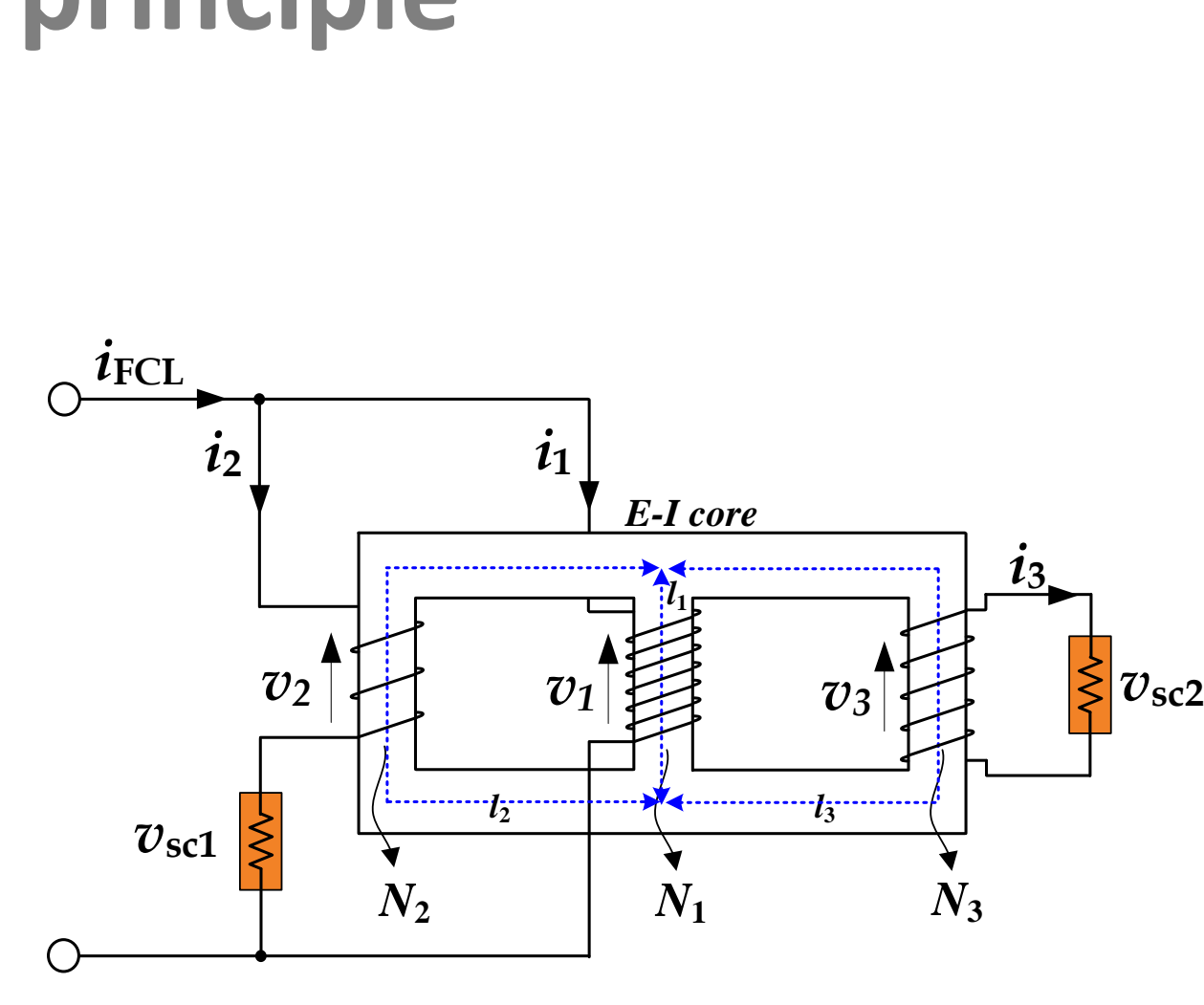
Conclusion

❖ Through a short circuit simulation, we analyzed the operation of two superconducting elements and the fault current limiting characteristics according to the peak amplitude of the fault current and the coil directions before and after failure occurrence.

❖ The peak current limiting operations were confirmed to be occurred contemporaneously with the moment that the current induced in the third coil exceeded the critical current of the second superconducting element.

❖ On the other hand, in the case of the additive polarity winding connection, right after failure, only the first superconducting element caused quench. Furthermore, the current induced into the third coil did not exceed the critical current of the second superconducting element, which did not perform the peak current limiting operation of this SFCL.

❖ We articulated that the additive polarity winding connection, from the viewpoint of the peak fault current limiting operation, was less effective than the subtractive polarity winding connection.

Methods

Structure and principle

In the case of a great fault current, it can decrease the load of the fault current by enabling two times of current limit resections occur from two superconducting elements. Its structure consists of three coils and two superconducting elements around the three-leg E-I iron core.

E-I iron core is the combined form of E and I. It enhances the inductance value and prevents the sudden magnetic flux saturation. It also prevents the magnetic field from escaping to another place when the iron core forms a magnetic circuit.

Equivalent circuit

L1, L2, and L3 show the inductance of each coil. Rsc1 and Rsc2 show the resistance of each superconducting element. In order to simplify the description of the equivalent circuit, the mutual inductance between coils is omitted. The size of the fault current, which initiates the current limit action of SFCL having two magnetic paths in parallel, can be induced from the electric equivalent model. Like Formula (1), the equation of the first operating current, the value of SFCL about the first fault current limit action, can be set up with controlling L1, and L2, and IC. The Eq.(2) of the second operating current for the second fault current limit action can be set up with controlling the critical current value of the second superconducting element connected to the third coil in series.

$$I_{OP1} = \left(1 \mp \sqrt{\frac{L_2}{L_1}}\right) \cdot I_c$$

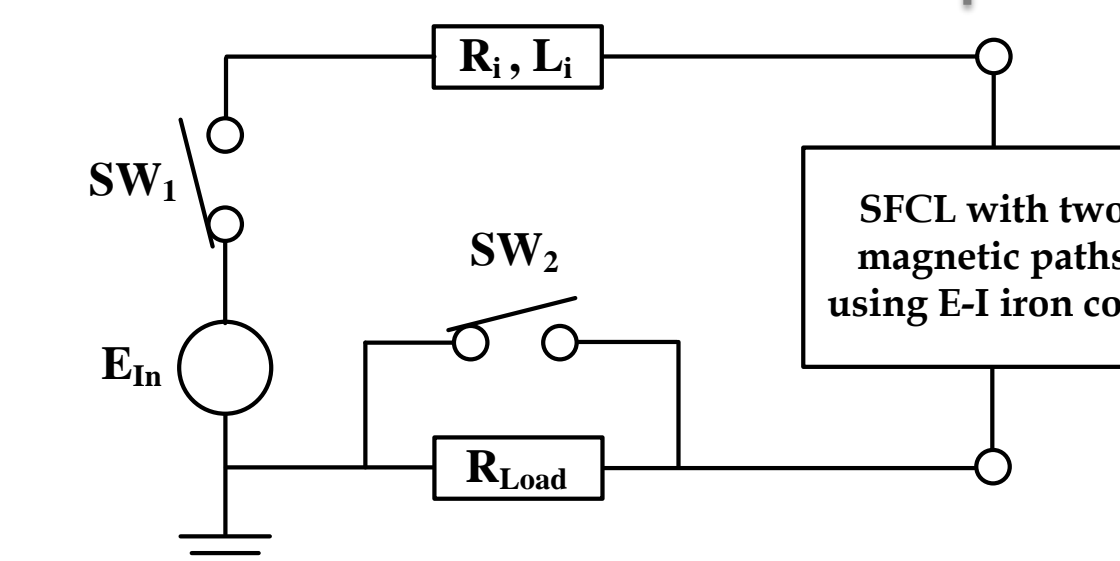$$I_{OP2} = \left(\pm\sqrt{\frac{L_3}{L_1}}\right) \cdot I_c$$

Samples

Dimensions

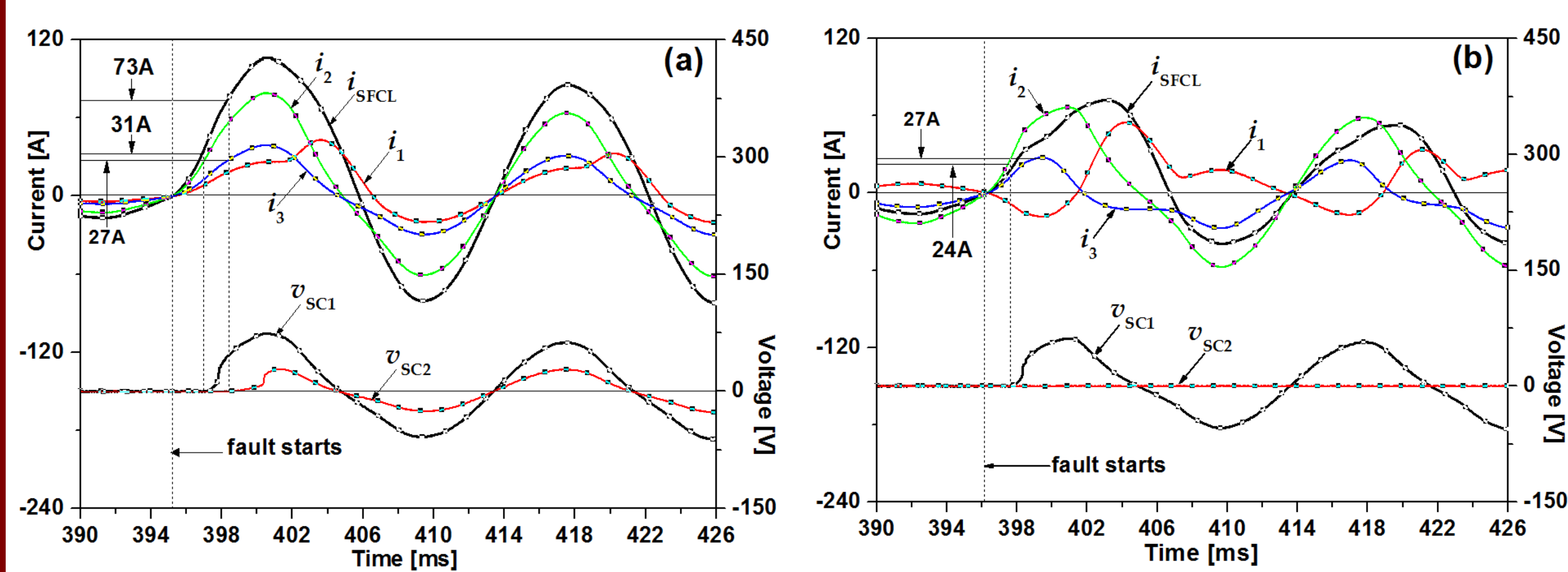| Iron core & coils	Value	Unit
Total Mean Length (l_2+l_3)	1,160	mm
Second Leg Length (l_1)	310	mm
Cross Sectional Area (S_{core})	2,500	mm^2
Turn Number of Coil 1 (N_1)	45	Turns
Turn Number of Coil 2 (N_2)	15	Turns
Turn Number of Coil 3 (N_3)	30	Turns
Material	YBCO	-
Critical Temperature	87	K
Critical Current	27	A

Experimental Preparation

In SFCL, the first and the second coils have two magnetic paths and they are connected in parallel. Including the third coil, the two coils are twined in the same direction with E-I iron core.

The YBCO thin film, whose critical temperature is 87 K, is used as the superconducting element. It is connected to the second and the third coils as well. In order to protect it from the heat released in the case of quench, the Au layer is additionally coated to a thickness of 200 nm. The critical current value is measured with 27 A. In order to plot a failure occurrence, Figure 3 shows the block diagram of the experimental circuit. It consists of 60 Hz AC voltage (Ein=160 V), line impedance (Li=1.82 mH, Ri=0.097 Ω), load resistance (RLoad=41.2 Ω), and SFCL. We put SW1 first, and during the period of failure, we operated SW2 to cause the circuit fault for 5 cycles. In so doing, we measured the induced voltage from the current flowing in three coils including lines, and the superconducting elements 1, and 2 through CT and PT, and analyzed them.
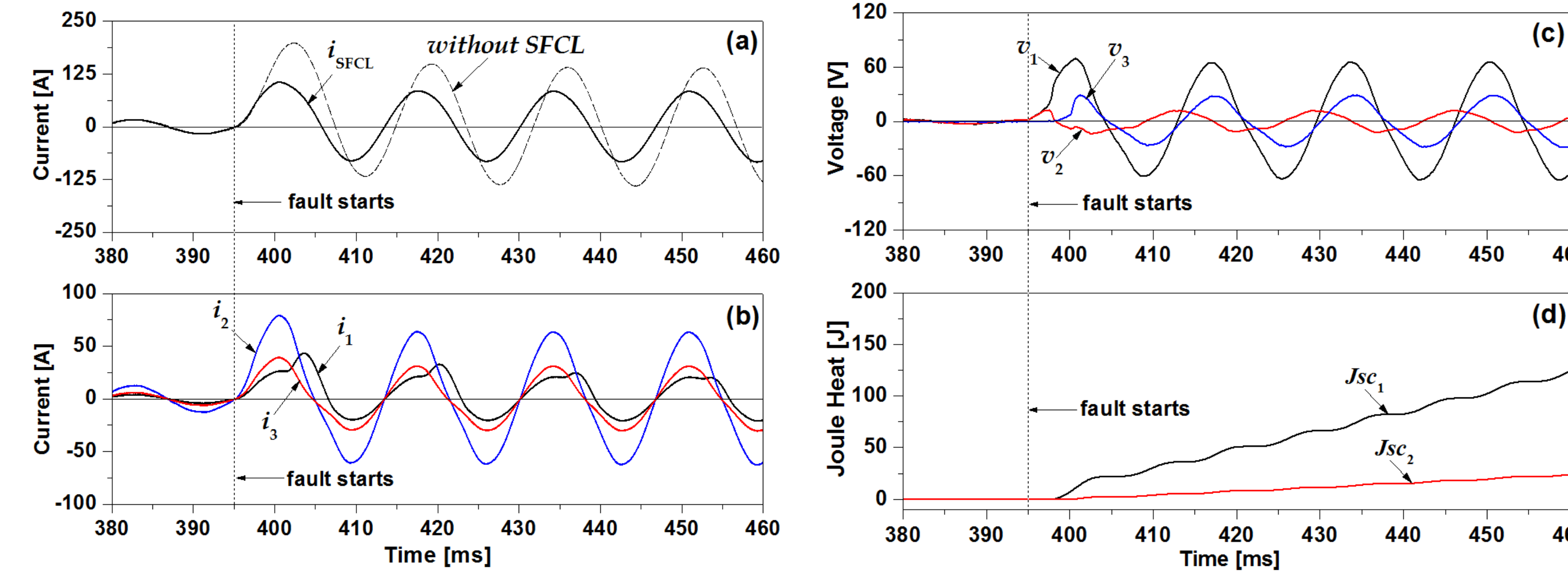
Results

Fault Current Limiting Characteristics

Fault current limiting characteristics of SFCL with two magnetic paths due to the winding direction in the case that the fault occurred at 0°. (a) Subtractive polarity winding. (b) Additive polarity winding.
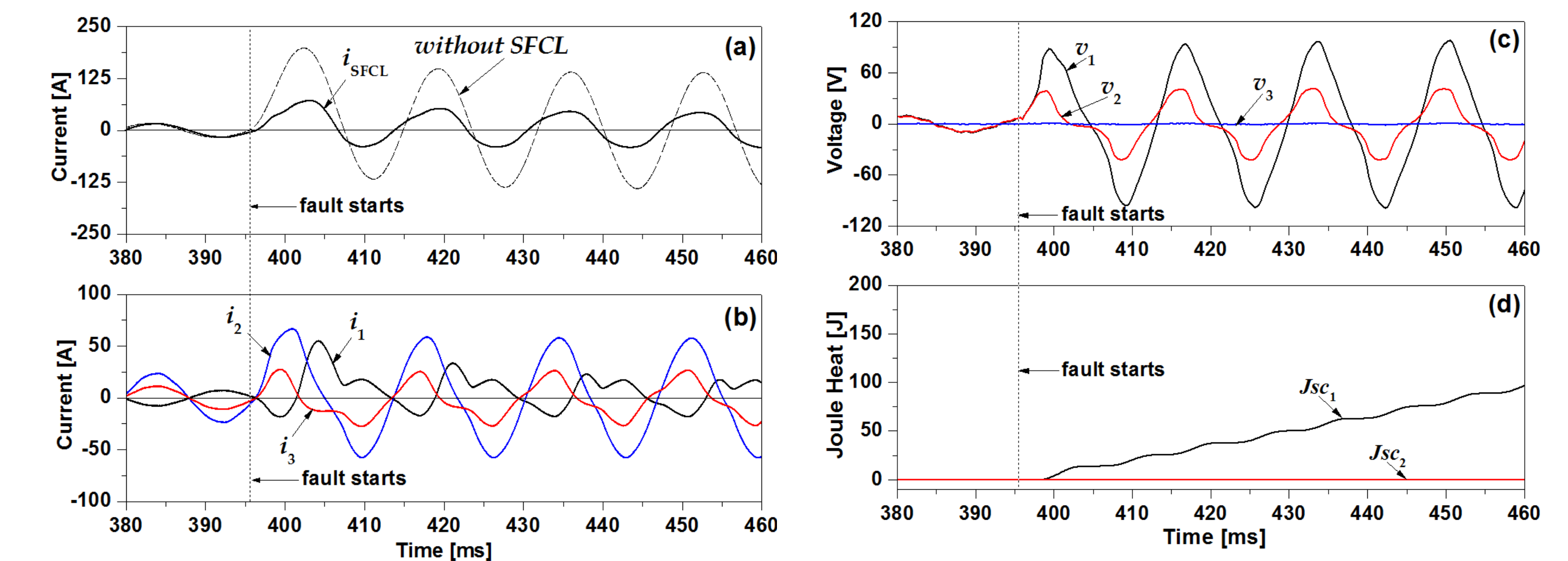
Figure 4 shows the fault current limit characteristics of SFCL after the circuit fault occurs from the fault angle 0°. As seen in Figure 4(a), we could ascertain that when the first and second coils are tied in the subtractive polarity winding connection a resistance occurrence due to the quench of the first superconducting element immediately after a failure happens. This makes the induced voltage to the third coil not exceed the critical current value of the second superconducting element, and thus the operation of the peak current limit does not occur as depicted in Figure 4(b).

Current limiting characteristics and voltage waveforms of parallel connected SFCL with two magnetic paths; its two coils are designed to have subtractive polarity winding (N1, N2). (a) Current waveforms of line (iSFCL and without iSFCL), and (b) each coil (i1, i2, i3). (c) Voltage waveforms of each coil (v1, v2, v3), and (d) Joule heat curve of each HTSC element.

Figure 5 shows the current limit characteristic of SFCL and the voltage shape of each coil. After the failure, a resistance occurs due to the creation of the quench from the first superconducting element. Then we found the operation of the peak current limit in the case that the induced voltage in the third coil exceeds the critical current of the second superconducting element after the resistance occurs. Like this, when the operation of the peak current limit is made, we found, the fault current limit is also in operation although it is less than that from the additive polarity winding connection. In considering Joule's heats of the superconducting elements, the first element shows higher than the second, and it is gradually increasing.

Current limiting characteristics and voltage waveforms of parallel connected SFCL with two magnetic paths; its two coils are designed to have additive polarity winding (N1, N2). (a) Current waveforms of line (iSFCL and without iSFCL), and (b) each coil (i1, i2, i3). (c) Voltage waveforms of each coil (v1, v2, v3), and (d) Joule heat curve of each HTSC element

Figure 6 shows the peak current limiting characteristics of SFCL having two magnetic paths with E-I iron core and the voltage shape induced in each coil, in case that the turns ratio between the first coil and the second coil is 0.33 and they are tied with the additive polarity winding connection. When a failure occurs at the fault angle, 0° the peak current limiting operation in the additive polarity winding connection was taken less effectively than that in the subtractive polarity winding connection. However the fault current limiting operation was improved.