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기계적 접점을 이용한 FCL의 동작 특성

Operational Characteristics of the FCL Using the Mechanical Contact in the Power System

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(Byung -Ik Jung · Hyo-Sang Choi)

Abstract - These days, SFCLs are being developed in order to limit fault current. However, the superconducting elements that limit the fault current have such problems as capacity increase and require auxiliary devices including cooling device. If devices that comprise the current power network can withstand fault current for at least one cycle, it is possible to limit the fault current with current limiting elements by bypassing it on the fault line. In this study, the fault current limiter was configured with current transformer, vacuum interrupter, and current limiting element. Through the experience, it was confirmed that the fault current was limited within one cycle. The superconducting element, as a current limiting element, limited the fault current by 80 % within one cycle from fault occurrence, and the passive element limited it more than 95 %. Also, through the comparison between resistance curve and power consumption curve, it was confirmed that the current limiting element using a passive element was more stable than the superconducting element that required capacity increase and other auxiliary devices. It was considered that the FCL proposed in this study could limit fault current stably within one cycle from fault occurrence by using the existing power technologies such as fault current detection and solenoid valve operating circuit.

Key Words : Superconducting fault current limiter (SFCL), Passive element, Solenoid valve, Vacuum interrupter, Fault current dection

1. Introduction

The fault current generating at the power network not only destroys insulation of various power devices but may also lead to a large-scale power outage. In order to remove such fault current, power breakers with a large breaking capacity are developed and applied. However, the fault current is increasing beyond the breaker's capacity due to low impedance phenomenon of the power network. Upon this, many researches are being made to develop fault current limiters (FCLs) that can limit such fault current. Currently, it is expected that the line-switching type fault current limiter using a vacuum interrupter will be commercialized fast [1-6]. This fault current limiter assumes that the power network can withstand fault current for one cycle after the fault.

This introduces a system that can bypass the faulty line by using a vacuum interrupter. It also examines the characteristics of the current limiting elements through the comparison between the superconducting element, which is expensive and requires a cooling device, and the passive element (R).

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2. Principle and Experimental Procedure of a FCL

2.1 Operational Principle of a FCL

The power transformer and the breaker that comprise the power network are used to interrupt the fault current within 3 to 7 cycles. This signifies that the existing power devices are insulated to withstand the fault current at least for 3 cycles. Many superconducting fault current limiters (SFCLs) protect the insulation of power devices by limiting the fault current within a half cycle of fault occurrence. Considering that it has been delayed to develop a more efficient fault current limiter due to various problems of the superconducting fault current limiter, the condition of limiting the fault current after a half cycle from fault occurrence could be a driving force to accelerate its development.

A conceptual diagram of a current limiter that can bypass the fault current using a vacuum interrupter under such circumstance is shown in Fig. 1. To ensure early commercialization of the current limiter, the principles of power devices that are used stably are applied. Generated fault current is detected by CT and fault is determined by SCR control system (SCR C/S). In order to bypass the fault current, a vacuum interrupter (V/I) is used, for which driving force a solenoid valve (S/V) is used. The fault current limiter operates in the following sequence:

1. CT detects fault current.
2. SCR C/S determines fault status, and operates SCR.
3. SCR operates, to supply 220V power to S/V.
4. V/I operate, to bypass the fault current.
5. The fault current is limited by the current limiting element.

In this sequence, the factor that may delay FCL operation is the time between when a fault is detected and when the V/I start operating. If this delay time is shorter than one cycle, fault current can be limited successfully.

In a normal condition, current flows to "b" contact of the V/I. When a fault occurs, the fault current is detected and V/I operates in a sequence described above, causing "a" contact to operate as "b" contact and thus bypassing the fault current. The current limiting unit limits the fault current in this way.

2.2 Experimental Procedure of a FCL

The experimental setup for fault current limiter consists of the circuit shown in Fig. 1. SW_1 is a fault generation switch and SW_2 is another fault generation switch. For the load resistance, 50 Ω resistance is used. As for the current limiting units, 2 inch thin-film superconducting element and 20 Ω passive element (R) are used respectively.

Fig. 2 is a photo showing the configuration of V/I and S/V. Operation of S/V triggers V/I to operate, and the operation of “a” and “b” contacts operate to bypass the fault current.

Table 1 shows the specification of V/I. The superconducting element used as current limiting element is 2 inch thin-film element etched into minder-line type [7-9]. 20 Ω passive element (R) is also used for comparison to examine the characteristics of fault current limiting.

3. Results and discussion

In this study, the operation for bypassing the fault current using V/I was analyzed. In addition, the experiments using the superconducting element and the passive element (R) as fault current limiting elements were performed, of which results were compared and analyzed.

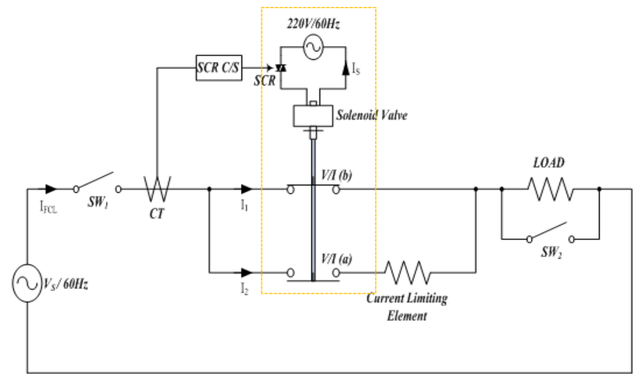


Fig. 1 Experimental circuit diagram of FCL using the mechanical switching device

Fig. 2 V/I and S/V configuration.

Table 1 Specification of V/I

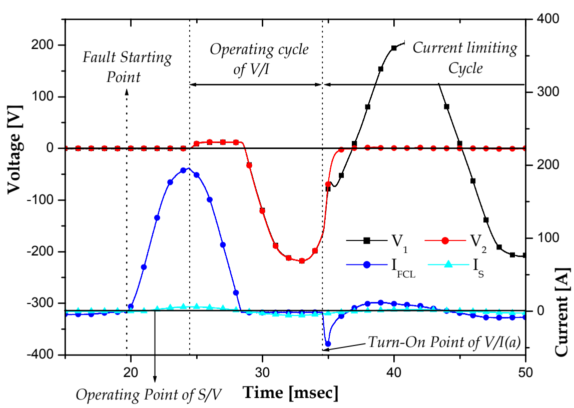
Parameter	Value
Rated Voltage	3.6kV
Rated Current	400A
Rated Breaking Current	4.5kV

3.1 Operational Characteristics of V/I

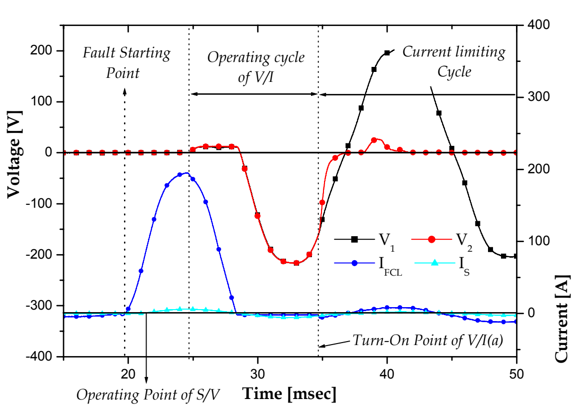
Fig. 3 shows a curve for the operation characteristics of the current limiter using V/I.

After the occurrence of a fault, it took 1.8 msec of time for CT to detect the fault current and activate S/V that would operate V/I. In 3.2 msec at which the current (IS) applied to S/V reached its maximum value, V/I started to operate. However, due to the overvoltage generated between contacts because of the fault current flowing to V/I (b-contact), V/I did not open immediately but fully opened later when the fault current became 0 A. At this time, V/I (a-contact) and V/I (b contact) had the same voltage through parallel connection. Because of the void between V/I (a-contact) and V/I (b-contact) after a half cycle from the fault occurrence, all were opened to “a” contact. V/I (a-contact) was activated by S/V completely travelled the void between the contacts, to bypass the fault current in 15 msec after the fault occurrence. From this moment, the fault current was limited the superconducting element and the passive element (R). In other words, it was confirmed that the fault current was started to be limited by the current limiting element after being bypassed within one cycle after the fault occurrence.

When a superconducting element was used as a current limiting element, the current limiting operation was started

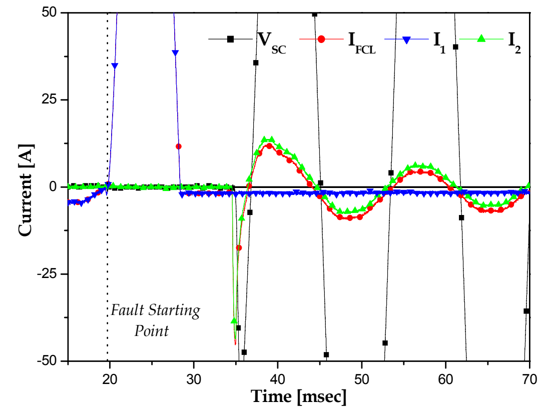


(a)

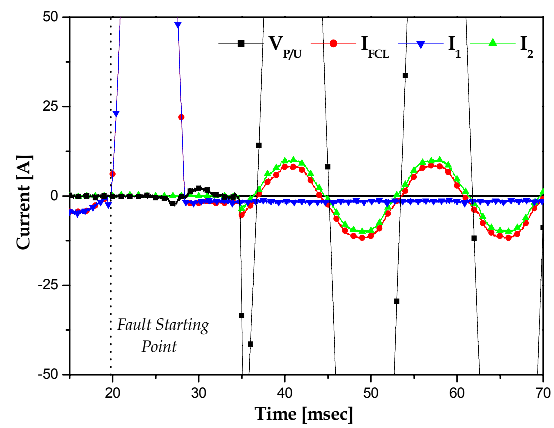


(b)

Fig. 3 Operational characteristics curves of vacuum interrupter. (a) When the superconducting element is used, (b) When the passive element is used



(a)



(b)

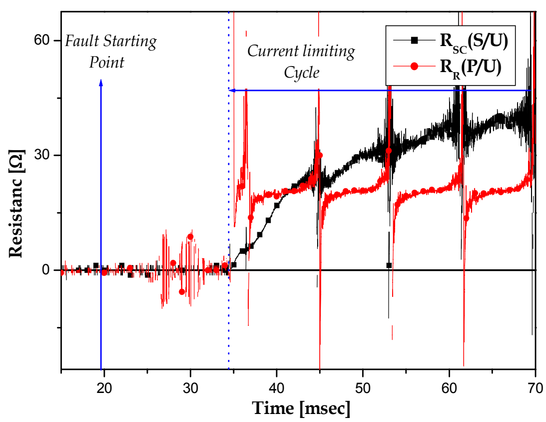
Fig. 4 Fault current limiter characteristics Curve of a FCL. (a) When the superconducting element is used, (b) When the passive element is used

by the resistance of the superconducting element once the current increased to the threshold current where it was quenched (Fig. 3(a)). On the other hand, when a passive element (R) was used, the fault current was limited immediately (Fig. 3(b)).

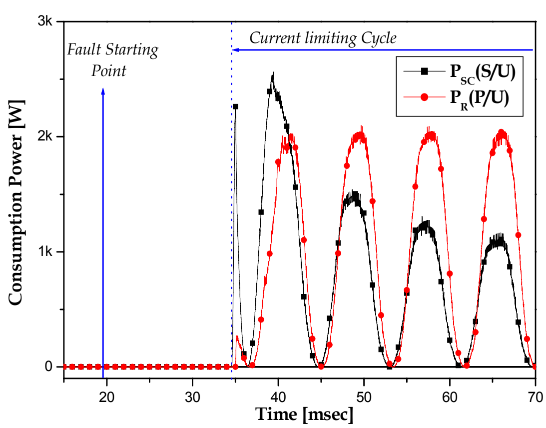
3.2 Current Limiting Characteristics of a FCL

Limiting element by V/I activated by S/V, to perform the fault current limiting operation within one cycle from the fault occurrence.

For the superconducting element (Fig. 4(a)), fault current was bypassed, causing the superconducting element to be quenched in 0.23 msec and 197 A fault current to be limited by 80 % to 45 A. It was confirmed that the fault current was reduced to 6 A in two cycles due to the resistance generation characteristics of the superconducting element. For the passive element (R) (Fig. 4(b)) on the other hand, 195 A fault current was limited by 95 % to 6 A immediately after bypass and then to 8 A in two cycles after the fault occurrence. This implies that the passive element limits the fault current consistently because of constant impedance. The voltages generated from superconducting element and from the passive element (R) were the same as 204 V after one cycle.



(a)



(b)

Fig. 5 Resistance and consumption power curves of the current limiting element. (a) Resistance curves, (b) Consumption power curves

Fig. 5 shows curves of resistance and power consumption generated by the superconducting element and the passive element. For the superconducting element, when the fault current was quenched when it exceeds the threshold current, and resistance was generated nonlinearly. Therefore, the fault current was limited nonlinearly. This was the same as the result obtained from the superconducting fault current limiter. On the other hand, the passive element (R) had constant impedance (20 Ω) and thus the fault current was limited consistently. This could also be confirmed by the curves (Fig. 5(b)) for power consumed by the two types of current limiting elements. For the superconducting element, large fault current flowed because of small impedance at the moment of quench, causing large power consumption. After that, the power consumption was decreased by the nonlinearly increasing resistance. On the contrary, the passive element generated constant impedance, resulting constant power consumption.

4. Conclusion

The superconducting fault current limiters that had been studied previously had problems like increase in the capacity of superconducting element and simultaneously quenching, and also required auxiliary devices including a cooling device. In this study, a vacuum interrupter was used for bypassing the fault current and to operate the interrupter, a circuit was designed using a solenoid valve. Also, the superconducting element and the passive element (R) as current limiting elements were used for the experiments, for comparison and analysis. CT was used for detecting the fault, and it was confirmed that it took less than one cycle for the vacuum interrupter to operate to bypass the fault current and limit the fault current. For the superconducting element, 80 % of the current was limited within one cycle by the resistance generated nonlinearly from quench and more than 95 % was limited after 2 cycles later. However, for the passive element (R), it was confirmed that more than 95 % of the fault current was limited in less than one cycle. This result signifies that the passive element is more effective in limiting the fault current than the superconducting element which requires capacity increase and other auxiliary devices. In addition, for the passive element, it is possible to control the fault current limiting rate depending on the impedance size. If it is possible to limit the current within one cycle after the fault occurrence, using the existing power technologies such as fault current detection and solenoid valve operating circuit, it is deemed possible to limit the fault current stably even without using the superconducting element that requires additional devices including unstable cooling devices.

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