

Analysis on the Protective Coordination with the Superconducting Fault Current Limiter for the Application into the KEPCO Grid

Jin-Seok Kim* · Jae-Chul Kim · Sung-Hun Lim**

Abstract

In this paper, the protection coordination of the protection devices such as the over-current relay (OCR) and recloser (R/C) with superconducting fault current limiter (SFCL) was investigated in a KEPCO grid. The operation time and protection coordination of the protection devices were changed by the SFCL. Through the analysis for protection coordination between the SFCL and the protection devices in the KEPCO grid, the operation time was observed to depend on the impedance of the SFCL.

Key Words : Superconducting Fault Current Limiter (SFCL), KEPCO Grid, Protection Coordination

1. Introduction

1.1 Background

Due to the continued increase of demand for high-quality power, it has been necessary to expand electrical facilities. Because of limited installation space for the facilities, recent climate change and environmental problems, the structure of power systems has changed. As a result, fault current has

increased in power systems. The increase in fault current may cause power facilities and protective devices to exceed their interrupting capacity [1-3].

A Superconducting Fault Current Limiter (SFCL) has emerged as an effective means to control fault current. There have been a lot of studies on the SFCL. In Korea, the development of the SFCL has been promoted with the launching of the Development of Advanced Power System by Applied Superconductivity Technologies (DAPAS) program. To apply it to the real system, a simulation and protective coordination test have been conducted at the Gochang Power Testing Center. If the SFCL is applied to the distribution system, the mechanism of protective devices changes due to change in the conventional distribution system if failure occurs. Therefore, it is required to investigate the application of the SFCL [3-7].

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This paper has attempted to determine the mechanism of protective devices after application of the SFCL with PSCAD/EMTDC after analyzing the cases at the Gochang Power Testing Center.

2. Body

2.1 Hybrid SFCL

The hybrid SFCL is developed under the DAPAS project. Superconducting element has a mechanism to detect and control fault current after transferring a circuit to the current-limiting device. This mechanism has the advantage of minimizing the use of superconducting elements and making them reclosing after quenching. Fig. 1 reveals the real model of the hybrid SFCL, which consists of superconducting element, a cryogenic system, fault current-limiting reactor and a high-speed switch for quick circuit change [8-11].



Fig. 1. Hybrid superconducting fault current limiter (KEPRI&LSIS)

Fig. 2 shows the operation of a hybrid SFCL in waveforms. In the beginning, current flowed into the

superconducting element. Since fault occurred, resistance took place at the superconducting element due to fault current. Then, the flow of fault current to the current-limiting device (CLR) was observed due to the operation of a high-speed switch. In addition, the resistance and impedance which occur in superconducting element and SFCL are covered by the resistance of superconducting element in the beginning of the fault. Due to the operation of a high-speed switch, superconducting element are recovered. In terms of fault current-limiting time, impedance was observed in current-limiting devices.

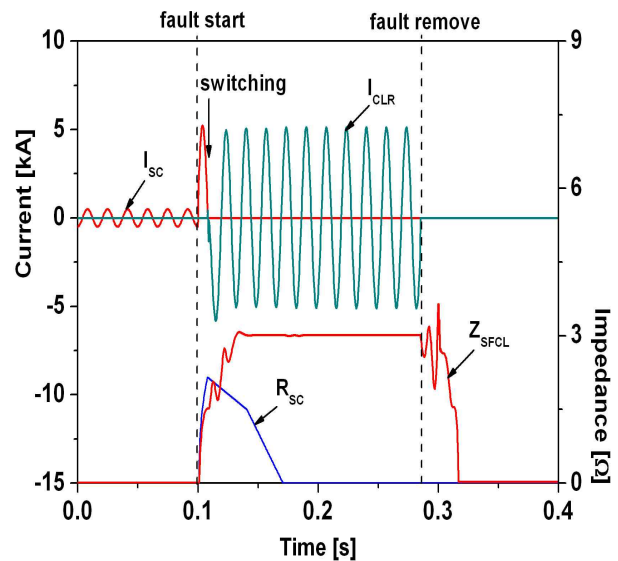


Fig. 2. Waveforms of hybrid superconducting fault current limiter based on simulations

2.2 Configuration and combination of the Gochang Field Test Center

For a test operation of the hybrid SFCL, it has been applied at the Gochang Power Testing Center. To select line combination in the test in order to test if the hybrid SFCL and protective devices are properly operated, the grid has been reconfigured as shown in the figure below. The hybrid SFCL has

been installed between nodes, 91 and 92, and the Over Current Relay (OCR) has been installed at both sides tips which were connected to the line. In addition, three reclosers (R1, R2 and R3) have been installed in the Gochang Power Testing Center.

In terms of power supply to the Gochang Power Testing Center, there is the Hongnong Substation (S/S) outside, and a smart substation (Gochang S/S) inside the center. Using the two power sources, the cases and line combination have been chosen to analyze the protection coordination among the hybrid SFCL, OCR and recloser.

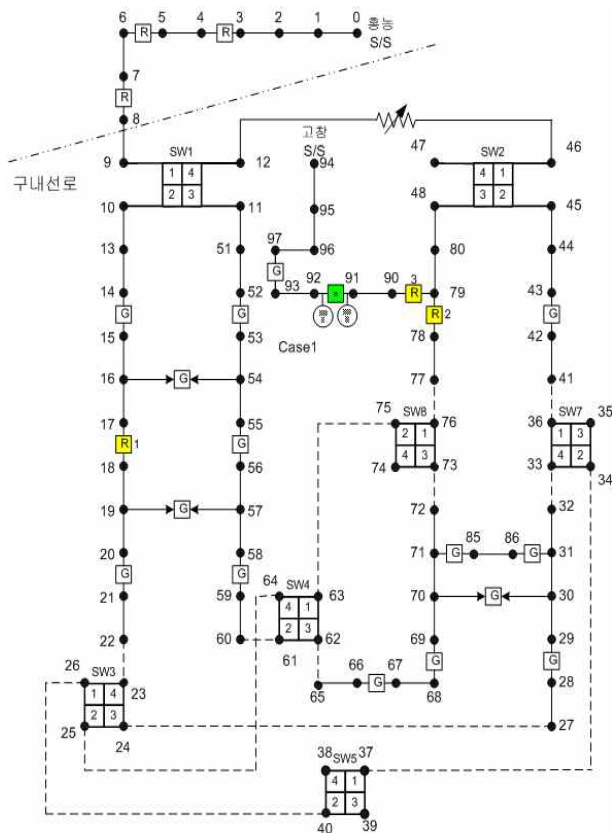


Fig. 3. Schematic diagram of KEPCO's Gochang Power Testing Center

Table 1 describes the line configuration of the Gochang Power Testing Center in which protection coordination can be analyzed. Except for the

redundant cases among test cases, the line configurations, which make the protection coordination of the OCR and recloser, have been selected. In addition, operational change by hybrid SFCL has been analyzed. According to the line configuration, the Artificial Fault Generator (AFG) is a piece of test equipment to generate fault current.

The Gochang Field Test Center is a test site for power facilities. No certain level of load is connected to the test line. Therefore, the setting guidelines for the OCR or recloser have been randomly set. In terms of OCR, 8MVA of load has been assumed for setting guidelines. In terms of the setting of the recloser (R1), which is close to the SFCL, 100A has been assumed. In the case of R2, on the contrary, 1/2 of a load has been assumed and set under 50A of load current.

Table 1. Configuration of Gochang Power Testing Center in which protective coordination can be analyzed

		Line Configuration	Operation of Protective Coordination
Gochang S/S	CASE 1 OCR Instantaneous / Delay Test	94~97-93~90 -AFG	SFCL OCR
	CASE 2 OCR R/C R/C Coordination Test	94~97-93~90 -79-80-48-45 ~36-33~27~24 -23~17-AFG	SFCL OCR R1
Hongnong S/S	CASE 3 SFCL-R/C Coordination Test	0~9-12-46 -45-48-80-79 -90~93-AFG	SFCL R3
	CASE 4 R/C-R/C Coordination Test	0~9-10~23-24 ~27~33-36~45 -48~79~93~AFG	SFCL R1 R3

The main current of each OCR has been set by redundancy for overload (load current x 1.5) and

setting guidelines (max. load current x 1.5). Tables 2 and 3 below summarize the estimation process of the main current for the OCR and recloser:

Table 2. OCR settings

Instantaneous Current	Load Current (Iload)	Max. Load Current (Iload_Max)	Delay Current (Ipickup)	TD
6.3 [kA]	201 [A]	302 [A]	544 [A]	3

Table 3. R/C settings

Recloser	Current	Load Current (Iload)	Max. Load Current (Iload_Max)	Delay Current (Ipickup)
R1		100 [A]	150 [A]	420 [A]
R3		50 [A]	75 [A]	210 [A]

3. Results and analysis of switch combination

3.1 Analysis of fault current

The characteristics of the fault current have been analyzed by cases. Figs. 4 and 5 show changes in fault current when AFG impedance had 0[Ω] at a 3-phase short-circuit fault before and after installation of the SFCL was applied. In terms of the characteristics of the fault current, the fault current was lower as the fault distance was farther away depending on the line configuration of the Gochang Field Test Center. In addition, as the impedance of the SFCL increased, the fault current was further limited. In addition, the reactor-type SFCL was more effective than the resistive-type SFCL.

3.2 Simulation analysis

If the fault current changes due to the SFCL, as shown in Fig. 4 and Fig. 5, while protective devices

which are operated depending on fault current are set as shown in Tables 2 and 3, protective devices are also influenced. This kind of mechanism has been confirmed through PSCAD simulation.

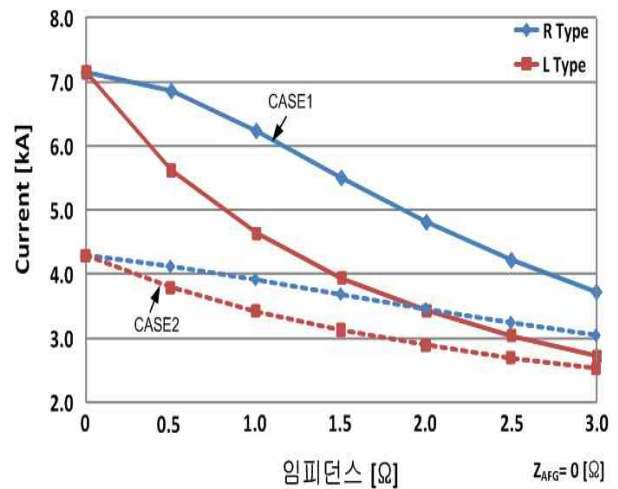


Fig. 4. Change in 3-phase short-circuit fault current by impedance (CASES 1 & 2)

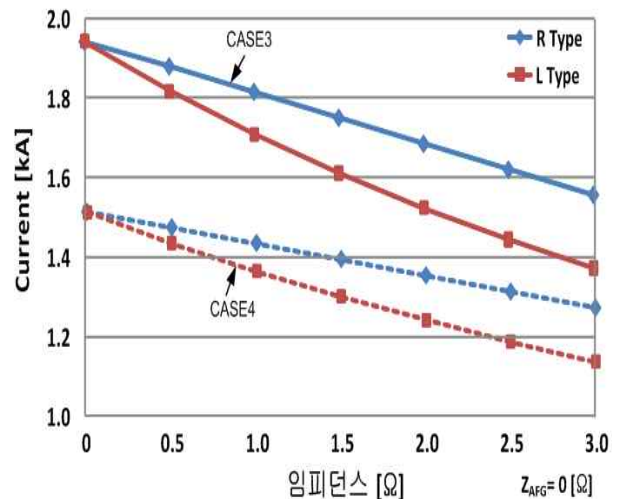


Fig. 5. Change in 3-phase short-circuit fault current by impedance (CASES 3 & 4)

Fig. 6 reveals protective coordination on the instantaneous operations of the SFCL and OCR. Before the delay signal of the OCR (TOCR_travel) occurs by fault current (If) before the SFCL is applied, instantaneous operation (TOCR_trip) is

performed. However, after the SFCL is applied, fault current is limited to the instantaneous set value (6.3[kA]) or less by the resistance (RSFCL) generated after quenching. Therefore, instantaneous operation is not performed. Instead, delay signal occurs.

The impedance of SFCL, which is the instantaneous set value of OCR or less, was 1[Ω] in the resistive type. According to the PSCAD simulation, the result was obtained as shown in Fig. 6. In general, the resistive-type SFCL with approximately 1[Ω] is instantaneously operated. However, delay operation was observed when the resistance value was exceeded.

Fig. 7 reveals the result of the analysis of changes in the delay operation of OCR (Case 1) when the SFCL was applied. As the impedance of the SFCL increases, fault current-limiting effect increases as well. Then, the time for the delay operation of inverse type OCR, which is operated depending on the magnitude of the fault current, is further delayed. The impedance of the SFCL should be limited depending on the setting guidelines of protective devices.

The resistance value of the resistive-type SFCL should be limited to 1[Ω] in accordance with the mechanism and set value of OCR. The operational changes have been confirmed through the PSCAD simulation. The operating time of OCR would be further delayed due to the application of SFCL. However, 0.5 sec. of operating time in accordance with the operating rules of protective device at 1[Ω] would be satisfying. However, the result that exceeds the setting guidelines has been observed at the larger resistance. In consideration of the characteristics of time-delay operation of OCR, therefore, the resistance of the SFCL could be applicable up to 1[Ω].

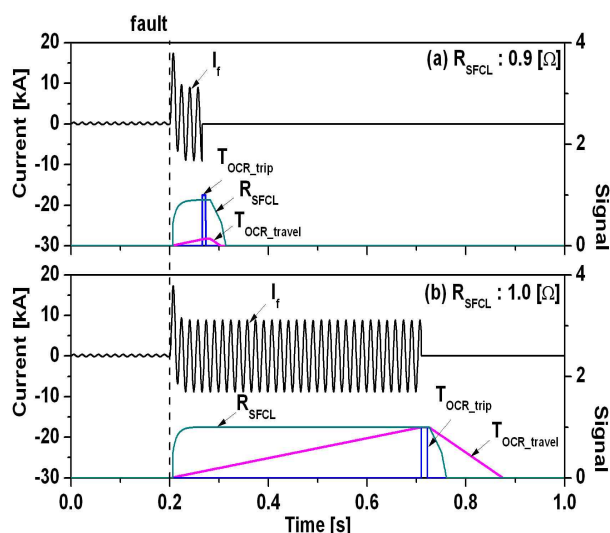


Fig. 6. Operation of OCR after application of hybrid SFCL(instantaneous characteristics)

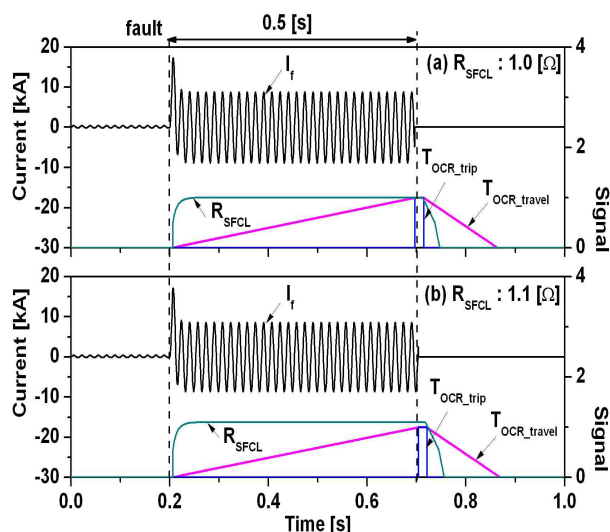


Fig. 7. Operation of OCR after application of hybrid SFCL (delay characteristics)

Fig. 8 reveals changes in recloser and OCR operations when the SFCL was applied (Case 2). Due to system failure before the SFCL was applied, delay operation was performed twice after carrying out instantaneous operations twice. As a result, lock-out results were obtained. However, fault current has been limited due to the application of the SFCL. As a result, the operating time for protective

devices was delayed. During the system failure, a recloser failed to complete its operations. In addition, it failed to protect the system from fault. Furthermore, OCR operations were delayed as well due to the SFCL.

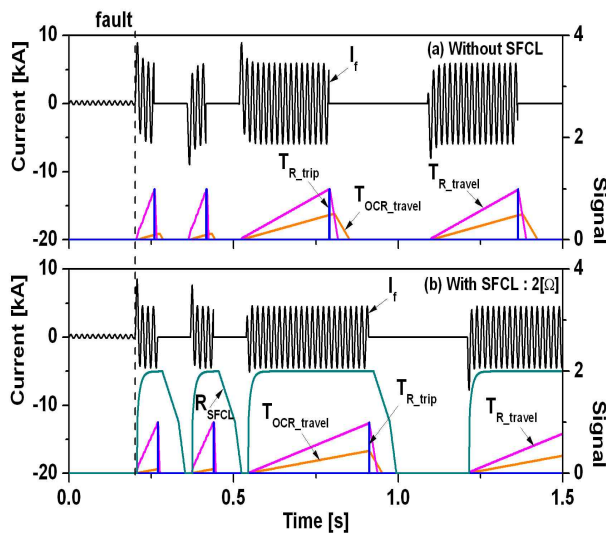


Fig. 8. Protective coordination between recloser and OCR after application of hybrid SFCL

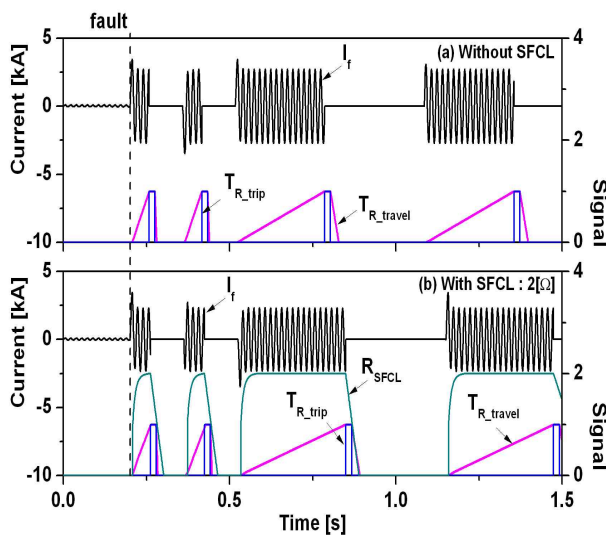


Fig. 9. Operation of recloser after application of hybrid SFCL

Fig. 9 shows changes in recloser operations (Case 3) after application of the SFCL. Because recloser

operations are a part of redundancy for overload, they have shown the mechanism of the OCR caused by the SFCL. As a result, decline in fault current and delay in operating time have been observed due to the SFCL. In addition, due to a delay in recloser operations, the overall operating time greatly increased, compared to the situation before the SFCL was applied. In multiple recloser operations (Case 4) as well, a delay of operating time by fault current has been confirmed. In addition, the protective coordination mechanism among multiple reclosers was similar to the mechanism between OCR and recloser.

4. Conclusion

This paper has chosen switch combinations which make protective coordination possible in the line configuration at the Gochang Power Testing Center. It has been confirmed that OCR and recloser mechanisms change due to the SFCL. In addition, the protective coordination between protective devices has been performed based on the protective coordination before the SFCL was applied. In conclusion, it is necessary to examine if protective devices are properly operated in order to apply the SFCL to the distribution system.

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References

- [1] Lee Kang-wan, 'Fault Current in the Power System and Superconducting Fault Current Limiter,' Journal of the Korea Institute of Applied Superconductivity and Cryogenics, Vol. 3, No. 1, pp. 8-12, 2001
- [2] T. Hara, T. Okuma, T. Yamamoto, D. Ito K. Tasaki, and K. Tsurunaga, "Development of a new 6.6kV/1500A class superconducting fault current limiter for electric power system," IEEE Trans. Power Delivery, vol. 8, no. 1, pp. 182-192, Jan. 1993
- [3] Kim Jin-seok, Lim Sung-Hun, Kim Jae-chul, 'Research Trend and Protective Coordination for Application of Superconducting Fault Current Limiter to Power System,' Journal of the Korea Institute of Applied Superconductivity and Cryogenics, Vol. 24, No. 1, pp. 36-42, 2010
- [4] Ahn Jae-min, Kim Jin-seok, Moon Jong-Fil, Lim Sung-Hun, Kim Jae-Cul, Hyun Ok-bae, 'Analysis of Protective Coordination at Application of Superconducting Fault Current Limiter to Distribution System,' Journal of Electrical Engineering & Technology, vol. 57, No. 5, pp. 755-760, 2008
- [5] Kim Jin-Seok, Kim Myoung-Hoo, Yoo Il-Kyoung, Moon Jong-Fil, Kim Jae-Chul, Lim Sung-Hun, Ahn Jae-min, 'Impedance Analysis of Superconducting Fault Current Limiter for Protective Coordination at Replacement into Large-capacity Transformer at Distribution Substation,' Journal of Electrical Engineering & Technology, vol. 58, No. 8, pp. 1479-1484, 2009
- [6] Kim Myoung-Hoo, Kim Jin-Seok, Yoo Il-Kyoung, Moon Jong-Fil, Kim Jae-Chul, Lim Sung-Hun, 'Study of Recloser-fuse Coordination Method at Application of Superconducting Fault Current Limiter to Distribution System,' Journal of Electrical Engineering & Technology, vol. 58, No. 10, pp. 1835-1841, 2009
- [7] Yoo Il-Kyoung, Kim Jin-Seok, Kim Myoung-Hoo, Kim Jae-Chul, Lim Sung-Hun, 'Current-limiting Characteristics by Induction Location of Superconducting Fault Current Limiter to Distribution System,' Journal of the Korea Institute of Applied Superconductivity and Cryogenics, Vol. 23, No. 12, pp. 90-95, 2009
- [8] Gyeong-Ho Lee, Kwon-Bae Park, Jungwook Sim, Young-Geun Kim, Il-Sung Oh, Ok-Bae Hyun and Bang-Wook Lee, "Hybrid Superconducting Fault Current Limiter of the First Half Cycle Non-Limiting Type", IEEE Transactions On Applied Superconductivity, vol. 19, no. 3, pp. 1888-1891, June 2009.
- [9] O. B. Hyun, J. W. Sim, h. R. Kim, K. B. Park, S. W. Yim, and I. S. Oh, "Reliability Enhancement of the Fast Switch in a Hybrid Superconducting Fault Current Limiter by Using Power Electronic Switches", IEEE Trans. Appl. Supercond., Vol. 19, No. 3, pp. 1843-1846, June 2009.
- [10] I. K. You, S. H. Lim, J. C. Kim, O. B. Hyun, "Operational Characteristics of Hybrid SFCL With First Half Cycle Non-Limiting Operation Considering Its Design Parameter," IEEE Trans. Appl. Supercond., vol. 20, no. 3, pp. 1168-1171, June 2010.
- [11] Ok-Bae Hyun, Kwon-Bae Park, Jungwook Sim, Hye-Rim Kim, Seong-Woo Yim, and Il-Sung Oh, "Introduction of a Hybrid SFCL in KEPCO Grid and Local Points at Issues", IEEE Transactions On Applied Superconductivity, vol. 19, no. 3, pp. 1946-1949, June 2009.

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