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Analysis on protection coordination of protective devices with a fault current limiter in the application location of a dispersed generation

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Abstract: As one of the solution of the increase problem of the fault current in a power system, the superconducting fault current limiter (SFCL) has been noticed as the attractive device because it has no power loss in a normal time and can limit the fault current rapidly without additional device to detect the fault current. However, the introduction of the SFCL in a power distribution system affects the protection coordination between the existing protective devices such as the over-current relay (OCR) and the recloser, which causes the operation of the protective devices to get out of their original setting values. Therefore, the analysis on the effect of the SFCL introduction on the existing protective devices is required and the method to keep the protection coordination between the protective devices in a power system with the SFCL should be first considered. In this paper, the protection with a SFCL due to application location of a DG in power distribution system was analyzed. The lower resistance generation of the SFCL due to the decrease of the feeder current in case that the DG was applied into the middle point of the fault feeder was analyzed.

Index Terms: Dispersed generation (DG), protection coordination, short-circuit current, superconducting fault current limiter (SFCL).

I. INTRODUCTION

The continuous increase of the power demand and the persistent enlargement of the power generation system including the renewable energy resources have exceeded the rated capacities of the main power transformer in a substation of the power distribution system together with the increase of the short-circuit current, which caused to review the replacement of the main transformer with the larger one [1]–[3].With the increased awareness for the energy problem such as the environmental pollution and the global of SFCL during the fault period was described through the analysis on the experimental results. The operation time of there closer (R/C), in case of the DG applied into the middle point ofthe fault feeder, was confirmed to be less affected by the SFCL Compared to other application locations of the DG in a power Distribution system introduction of the dispersed generation (DG) using renewable energy into a power distribution system [1]–[4]. However, introduction of numerous DGs with larger capacity has been reported to cause the increase of the short-circuit current as well as the mal operation of the protective devices and the deterioration of the power quality [3]–[5].As one of the countermeasures to solve the problem of the fault current due to the introduction of the DG in a power distribution system, the superconducting fault current limiter (SFCL) has recently been taken into consideration [5]–[9]. Nevertheless, the studies for the effective SFCL's application for the protection coordination of the protective devices considering the application location of the DG in a power distribution system

have been rarely progressed. In this paper, the protection coordination of the protective de- vices with a SFCL due to the DG's application location such as the primary bus line, the middle point of the fault feeder and the middle point of the sound feeder of the power distribution system was analyzed through the short-circuit tests for the simulated power distribution system, which was comprised of the protective devices, the SFCL and the DG. In addition, the effect of the application location of the DG on the resistance generation of SFCL during the fault period was described through the analysis on the experimental results. The operation time of the recloser (R/C), in case of the DG applied into the middle point of the fault feeder, was confirmed to be less affected by the SFCL compared to other application locations of the DG in a power distribution system. Warming the efforts to utilize the renewable energy such as wind power and solar cell effectively have been made.

Nevertheless, the studies for the effective SFCL's application for the protection coordination of the protective devices considering the application location of the DG in a power distribution system have been rarely progressed. In this paper, the protection coordination of the protective devices with a SFCL due to the DG's application location such as the primary bus line, the middle point of the fault feeder and the middle point of the sound feeder of the power distribution system was analyzed through the short-circuit tests for the simulated power distribution system, which was comprised of the protective devices, the SFCL and the DG. In addition, the effect of the application location of the DG on the resistance generation.

II. CONFIGURATION OF POWER DISTRIBUTION SYSTEM LINKED BY DG

Fig. 1 shows the configuration of the power distribution system with a SFCL, which is installed in the entrance of each feeder, and a DG linked to the bus line, the middle point of fault feeder and the middle point of the sound feeder, respectively. Instead of the several feeders, two feeders are represented for the simplicity, which are protected by the circuit breakers (CBs) through the operation of the over current relays (OCRs). The branch lines from each feeder are protected by the R/Cs as indicated in Fig. 1. To investigate the effect of the SFCL application on the operation of the protective devices and the protection coordination between the protective devices due to the application location.

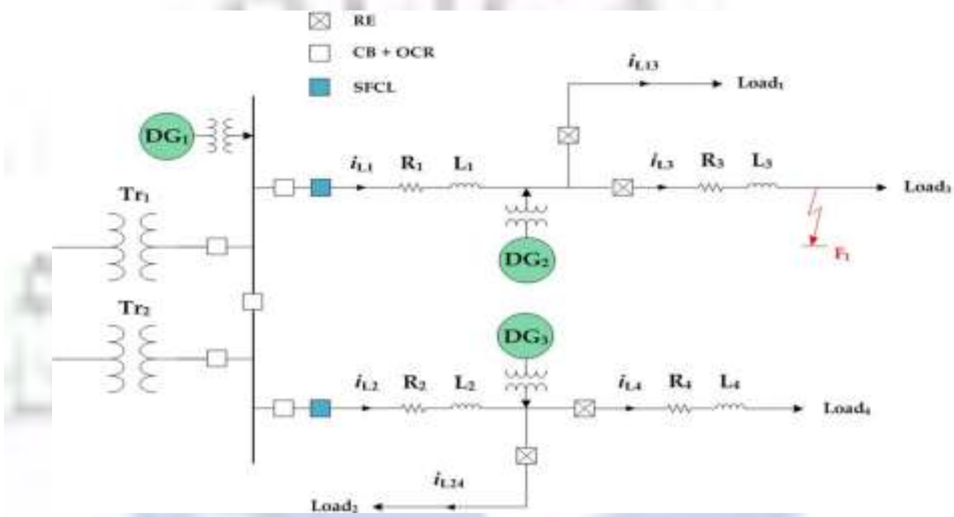


Fig. 1: Schematic configuration of experimental circuit for the protective coordination analysis in a power distribution system with a SFCL, which is appliedinto the entrance of each feeder, and a dispersed generation linked to the busline (DG1), the middle point of the fault feeder (DG2)and the middle pointof the sound feeder , respectively.

TABLE 1: SPECIFICATIONS OF COMPONENTS COMPRISING POWER DISTRIBUTION SYSTEM

Transformer 1, 2 (Tr_1, Tr_2)	Value	Unit
Capacity	5	kVA
Voltage of primary side	200	V
Voltage of secondary side	60	V
Distribution line	**Value**	**Unit**
$R_1 + X_1$, $R_2 + X_2$	0.097 + j0.686	Ω
$R_3 + X_3$, $R_4 + X_4$	0.140 + j1.033	Ω
Load	**Value**	**Unit**
$Load_1$	8 + j1.885	Ω
$Load_2$	10 + j1.885	Ω
$Load_3$	40 + j1.885	Ω
$Load_4$	5 + j1.885	Ω

of a DG in a power distribution system, the short-circuit test at load side location of the feeder 1, which is designated with in Fig. 1, was performed. In the short-circuit tests, for they easy adjustment of the resistance generation of the thin film type SFCL after the fault occurrence, the connection of the shunt resistance was considered and the shunt resistance of 1.15 was connected in parallel to the SFCL. The detailed specifications of the components comprising the tested power distribution system where the DG was applied into the bus line, the middle point of the fault feeder and the middle point of the sound feeder as indicated in Fig. 1 are shown in Table I. The reclosing event of the R/C was set to occur one time for scale-down of its operation time and other setting parameters of the protective devices including the SFCL are listed in Table II. Fig. 2 shows the bus voltages and the feeder currents before and after the fault occurs for two cases. One is the power distribution system linked by the DG in its bus line, one of the DS's application locations, and the other is not linked by the DG. In Fig. 2, the superscript "w/o" within the voltage and the current variable names represents the variable ones in the system without the DG. As seen in Fig. 2, the rise of both the bus voltage and the feeder current after the DG is linked to the system can be observed. The feeder current

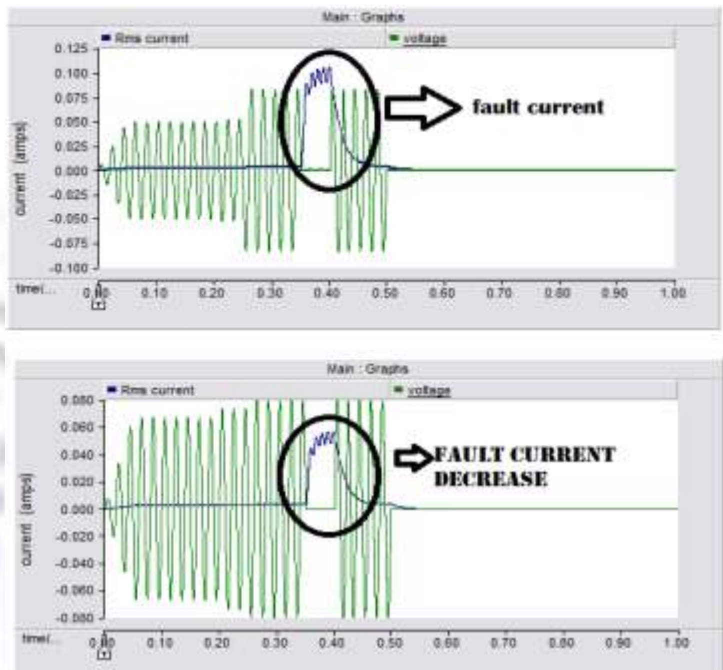


Fig. 2: Voltage and current waveforms before and after the fault occurs in a power distribution system either linked by the dispersed generation or not. (a) Input voltage of dispersed generation and bus voltage .
(b) Feeder currents and output current of a dispersed generation.

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

Through the short-circuit tests in the load side point of the feeder 1, which was displayed with in Fig. 1, the dependence of the protective devices on the SFCL's application in a power distribution system where the DG was introduced in its different locations was investigated. Fig. 3 shows the current waveforms flowing into the CB and the R/C in the fault feeder and their integral values considering the SFCL's application in case that a short-circuit occurs in the power distribution system where the DG is linked to its bus line. In case that the SFCL was not applied, after its fast and slow operations, the lock-out operation of the R/C, which means the permanent separation of the fault section, was observed to occur at 829 milliseconds. In case that the SFCL was applied, on the other hand, the lock-out operation of the R/C was seen to be completed at 904 milliseconds, which took more time than the Limiting operation by the SFCL's application. As the second application location, in case that the DG was linked to the middle point of the fault feeder, which was designated with in Fig. 1, the current waveforms of the CB and the R/C in the fault feeder and their integral values were displayed in Fig. 4. Compared with the DG linked to the bus line, the lock-out time of the R/C in case that the DG was linked to the middle point of the fault feeder in the power distribution system with the SFCL was shortened as 895 milliseconds, which was confirmed to be resulted from the reduction of the fault current limiting effect by the SFCL. In other words, the application of the DG into the middle point of the fault feeder was thought to cause the current flowing into the drawing point of the fault feeder to decrease, which lead to lower resistance generation of the SFCL and thus the lock-out time of the R/C in the system with the DG applied into the middle point of the fault feeder was not much delayed. In case that the DG is linked to a middle point of the soundfeeder, as the DG's another application location, the currentwaveforms and the integral values of the protective devices dueto the SFCL's application were shown in Fig. 5.

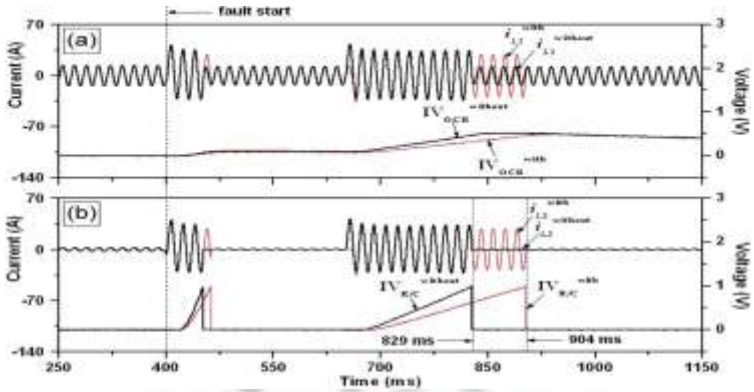
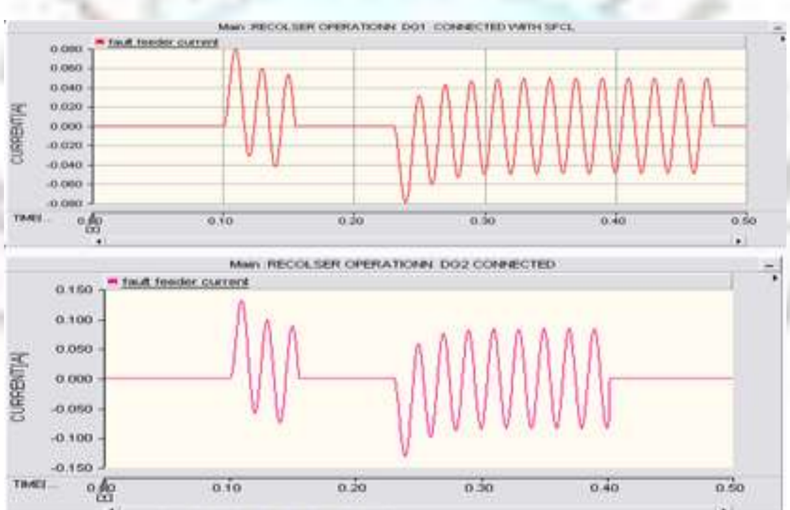


Fig. 3. Current waveforms and integral values of protective devices considering the application of the SFCL in case of the occurrence of the short-circuitin a power distribution system with a dispersed generation linked to a bus line. (a) Current waveform and integral value of OCR. (b) Current waveform and integral value of recloser.



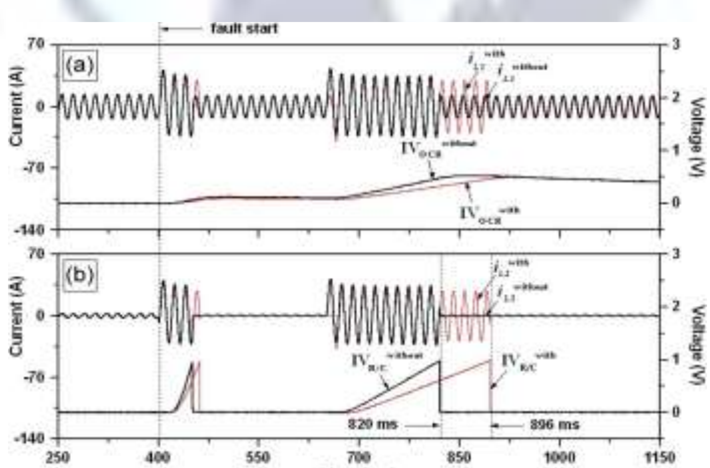


Fig. 4.Current waveforms and integral values of protective device considering the application of the SFCL in case of the occurrence of the short-circuitin a power distribution system with a dispersed generation linked to a middle point of the sound feeder. (a) Current waveform and integral value of OCR. (b) Current waveform and integral value of recloser.

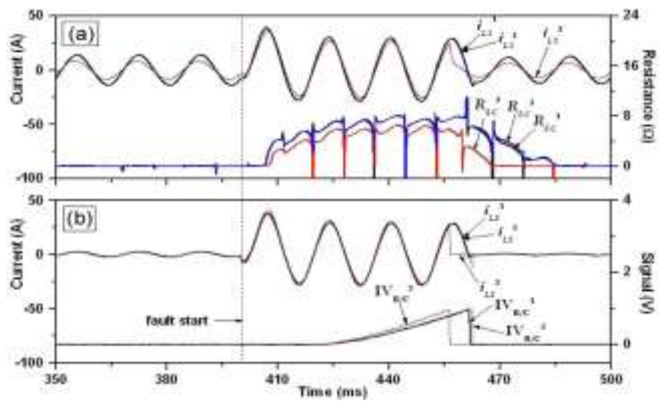


Fig. 5: Variation of current waveforms and integral values of protective devices including the resistance of SFCL due to the application location of the dispersed generation in a power distribution system immediately after the short-circuit happens. (a) Current waveforms of OCR and resistance curves of SFCL. (b) Current waveforms and integral values of recloser.

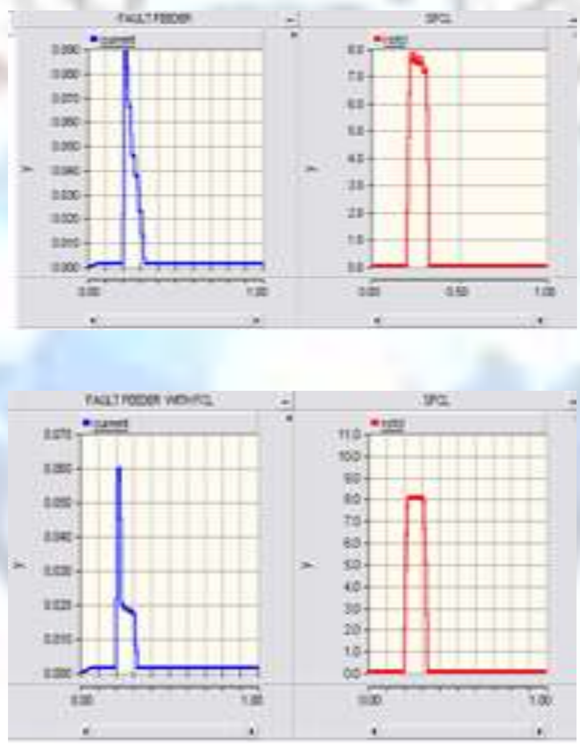


Fig. 6 : Variation of current waveforms and integral values of protective devices including the resistance curves of SFCL due to the application location of the dispersed generation in a power distribution system before and after the recloserlocks out after the short-circuit happens. (a) Current waveforms of OCR and resistance curves of (b) Current waveforms

The lock-out time of the R/C in case of the SFCL's application was seen to be similar to the case that the DG was linked to the middle point of the fault feeder, which was also thought to cause the current in the drawing point of the fault feeder to increase more compared to previous two application locations of the DG .SFCL dependent on the application location of the DG in a power distribution system before and after the R/C locks out after the short-circuit happens. As expected in Fig. 5, the amplitude of the resistance curve of the SFCL in case that the DG was applied into the middle point of the sound feeder could be confirmed to be similar to the case that the DG was applied into the bus line. Especially, the larger current flowing into drawing point of the fault feeder in case that the DG was applied into the middle point of the sound feeder could be confirmed to contribute to the fast lock-out operation of the R/C, which can be observed to be almost the same as the case of the DG's application into the bus line. From the above analysis, the operation of the protective devices was analyzed to be affected by the application location of the DG in the power distribution system due to the different fault current limiting effects of the SFCL and thus, the study for the effective protection coordination of the protective device with the SFCL considering the DG's application location in the power distribution system is expected to be progressed in the future.

CONCLUSION

In this paper, the protection coordination of the protective de- vices with a SFCL due to the DG's application location in a power distribution system was analyzed. Impact due to the Location of a Dispersed generation on the distribution system protection with SFCL was analyzed. As typical application location, the source bus line, the middle point of fault feeder and the middle point of healthy feeder were considered. From the above analysis, it is evident that the co ordination between the protective devices is improved substantially at one typical location for DG as compared to other typical location, while SFCLs are used along with DG. On the other hand, the lock-out operation of the R/C in case that the DG was applied into the middle point of the sound feeder could be analyzed to be relatively quickly completed due to the larger feeder current in spite of the larger resistance generation of the SFCL.

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