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Comparison of Fault Current Reduction Effects by the SFCL Introduction Locations

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Abstract-- **As power systems grow more complex and power demands increase, the fault current tends to gradually increase. In the near future, the fault current will exceed a circuit breaker rating for some substations, which is an especially important issue in the Seoul metropolitan area because of its highly meshed configuration. Currently, the Korean power system is regulated by changing the 154kV system configuration from a loop connection to a radial system, by splitting the bus where load balance can be achieved, and by upgrading the circuit breaker rating. A development project applying 154kV Superconducting Fault Current Limiter (SFCL) to 154kV transmission systems is proceeding with implementation slated for after 2010. In this paper, SFCL is applied to reduce the fault current in power systems according to two different application schemes and their technical impacts are evaluated. The results indicate that both application schemes can regulate the fault current under the rating of circuit breaker, however, applying SFCL to the bus-tie location is much more appropriate from an economic view point.**

1. INTRODUCTION

The transmission network in Korean power system is protected by 40kA rate of a circuit breaker for 345kV systems and 31.5kA and 50kA rate of a circuit breaker for 154kV systems. As power system s grow more complex and electrical demands increase, the fault current has the tendency of increasing gradually. Unless an appropriate countermeasure is applied, the fault current will soon exceed the circuit breaker rating for some substations. To solve this problem, several methods are implemented on the power system; changing the system configuration from a loop to a radial system; splitting the bus; and upgrading lower rated equipment to higher rated equipment. Superconductors are utilized for fault current limiter applications because they can transform into a normal state in a few milliseconds, have high resistivity in the normal state and return to the superconducting state once fault conditions are removed. Superconducting fault current limiter (SFCL) reduces the fault current and allows the use of lower rated circuit breakers. Therefore, we can obtain cost savings by avoiding the need to upgrade lower rated equipment in existing installations. In these days, companies world-wide have conducted research on SFCL: ABB (Switzerland), GEC-Alsthom (France), Tokyo Electric (Japan), General Atomics (USA), and Siemens (Germany) [1-4]. They planned to develop 154kV voltage class SFCL at the research centre and university in Korea. In this paper, resistive type SFCL are applied to reduce the fault current in Korean power systems and technical impact of SFCL is evaluated.

2. SHORT CIRCUIT CURRENT PROBLEM IN KOREAN ELECTRIC POWER SYSTEM

2.1. The System Growth and Configuration

The power system size has been grown about 8.5 times within 20 years from 4,800 MW in 1976 when 345 kV transmission system was at the initial stage of operation to 41,000 MW in 1997. Although load growth was a little set back during 1997-1998 because of financial crisis, the increase of demand for electricity during 1999 to 2002 shows that Korean economy is rapidly recovering from the crisis and the system size is forecasted to ultimately reach 90,000 MW within 30 years. The sizes of unit generators are becoming a standard such as 1,000 MW for nuclear plant, and 500 MW for coal fired steam plants. According to generation expansion planning, 800 MW coal fired steam generators and 1,300 MW nuclear generators will be added to the system in the years 2003 and 2008 respectively. With the increase of the size of unit generator and the number of generators installed at a station, the installed capacity becomes larger than 6,000 MW at some stations and 10,000 MW size of generation stations will appear in the future. Also many combined cycle gas turbine generators are being installed near load centers like Seoul and Busan metropolitan areas in order to support load variation as well as the system voltage profile. The transmission system has also been reinforced to supply electricity to the growing load demand. The transmission system consists of 154 kV, 345 kV and 765 kV systems. 765 kV system was energized in 2002 and additionally are under construction to efficiently transfer the electric power of more than 6,000 MW from large generation complex to the load center of Seoul metropolitan area.

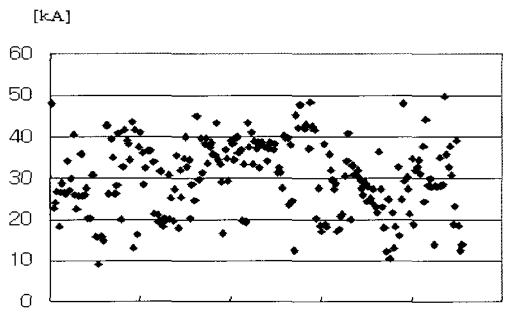
2.2. Short Circuit Current

The transmission system is designed to be protected by 42 kA rating of circuit breaker for 345 kV system and 31.5

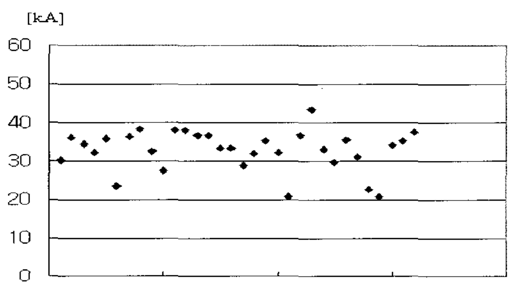
kA or 50 kA rating of circuit breaker for 154 kV system.

The short circuit current shows the tendency to exceed circuit breaker capacity at some substations and the tendency will continue if an appropriate countermeasure is not developed. Especially, short circuit current problem of Seoul metropolitan area is an important issue for the stable operation of power system. The network of 154 kV in the Seoul metropolitan area is very complex. In this paper, the distribution of short circuit currents in 2005,2006 and 2010 are analyzed by using the peak data of KEPCO and the PSS/E program. Fig. 1 to 3 shows the results of the analysis. In the figures, the horizontal axis represents the bus in the Seoul metropolitan area and the vertical axis represents the fault current of the bus. As shown in Fig. 1 and 2, the trend of short circuit currents between 2005 and 2006 is comparatively similar. This means that the distribution of short circuit currents is affected more by network topology than load and generation amounts of each year. However the distribution of short circuit currents in 2010, when the load expands rapidly, shows a different trend from distribution of short circuit currents in 2005 and 2006 as can be seen in the Fig. 3, and many buses exceeding the circuit breaker rating appear. The short circuit currents at 154 kV buses in 2005 and 2006 are distributed between 10 to 50 kA, while the short circuit currents at 345 kV are most heavily distributed between 20 to 40 kA. The short circuit currents at 154 kV buses in 2010 are widely distributed between 10 to 70 kA while the short circuit currents at 345 kV buses are widely distributed between 20 to 50 kA.

These show relation between load increment and distribution pattern of short circuit current that exceeds circuit breaker capacity.

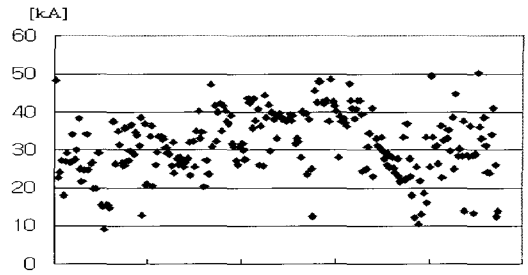


(a) 154 kV buses

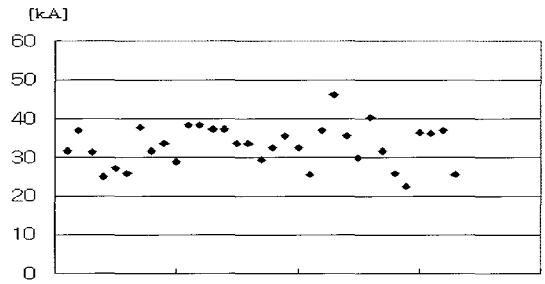


(b) 345 kV buses

Fig. 1. Short circuit currents in Seoul metropolitan area in 2005.

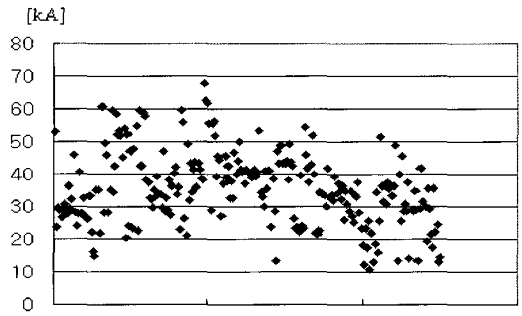


(a) 154 kV buses

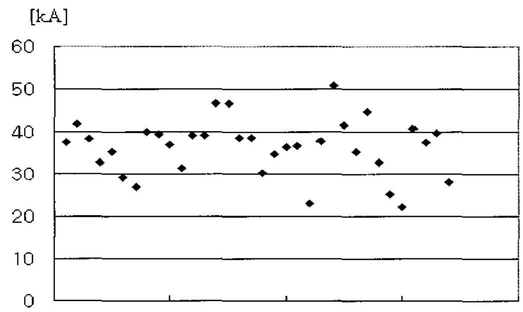


(b) 345 kV buses

Fig. 2. Short circuit currents in Seoul metropolitan area in 2006.



(a) 154 kV buses



(b) 345 kV buses

Fig. 3. Short circuit currents in Seoul metropolitan area in 2010.

3. APPLICATION SCHEME OF SFCL IN POWER SYSTEMS

There are two major ways to apply the SFCL in power systems, one is to install the SFCL to the transmission line and the other is for bus-tie location. In the first application scheme the SFCL is installed in the transmission line or secondary side of the transformer in series as shown in Fig. 4. In this way, the SFCL can be expected to limit the fault current effectively. However, many SFCLs are needed to reduce the fault current, because if a certain transmission line consists of 4 circuits, the four SFCLs are required to be installed in each circuit. In this regard, it has some demerit from an economic vantage point. In the second application scheme the SFCL is applied in the bus-tie location. This method uses only one SFCL as shown in Fig. 5, which gives greater economic benefit than applying the SFCL in the transmission line. The SFCL installed at the bus-tie location has almost zero impedance in a superconducting state, which provides the same power system configuration before splitting the bus. Once the fault is occurred, the state of SFCL is transformed from a superconducting state into a quenching state, which can provide the same effect as splitting the bus. That is, the SFCL can supply many technical advantages such as reliability of the power supply and power system stability. Otherwise, in the conventional fault current reduction method of splitting the bus, these technical aspects are lowered.

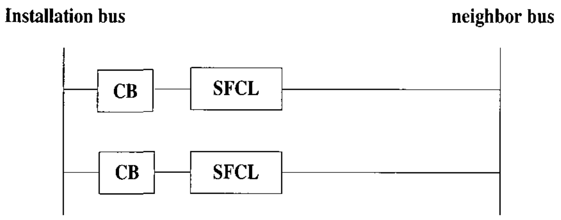


Fig. 4. SFCL in transmission line

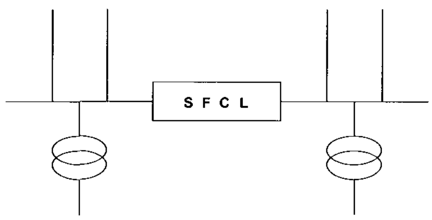


Fig. 5. SFCL in Bus-Tie.

4. TECHICHA EFFECT OF THE SFCL

4.1. Test Case

We have studied many cases, but in this paper, we introduce the southern Seoul metropolitan area case. Because the southern Seoul metropolitan area has very high load density, the possibility of the fault current to exceed the circuit breaker rating is higher than any other region in Korea. We used peak data of KEPCO in 2010 and the three-phase fault was considered. Assuming that the rating of the 154kV circuit breaker is 50kA, the fault currents of 8 buses exceed the rating of a circuit breaker. In these 8 buses, bus 2510 is selected as a test power system because this bus had the greatest large fault current exceeding 60kA in 2000 among the 8 buses and each case study showed similar results. Fig. 6 indicates the

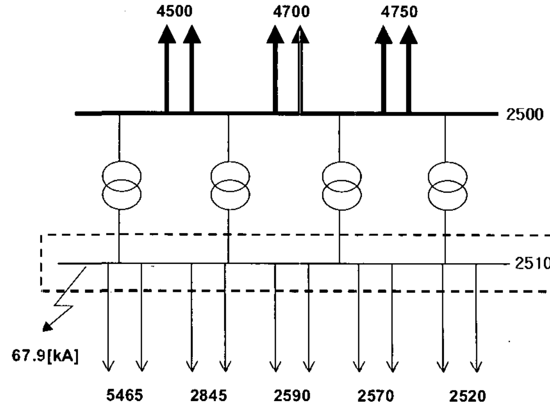


Fig. 6. Diagram of the test area.

configuration of bus 2510 and neighboring buses. The bold lines in Fig. 6 indicate 345kV lines and buses, the thin lines indicate 154kV lines and buses. The fault current of bus 2510, enclosed by dotted lines exceeds their circuit breaker rating of 50kA.

4.2. Application of the SFCL

(a) Installation of SFCL in Transmission Lines

In order to solve the fault current problem by using the SFCL, its most effective installing location must be predetermined. Though SFCL is installed at the same bus, the fault current reduction effect is different according to the location's relation to the neighboring bus. Usually the maximum fault current reduction effect could be obtained by installing the SFCL at a location connected to the neighboring bus with the biggest fault current contribution [5]. We proposed a procedure for applying SFCL to power systems to resolve the fault current problem as shown in Fig. 7.

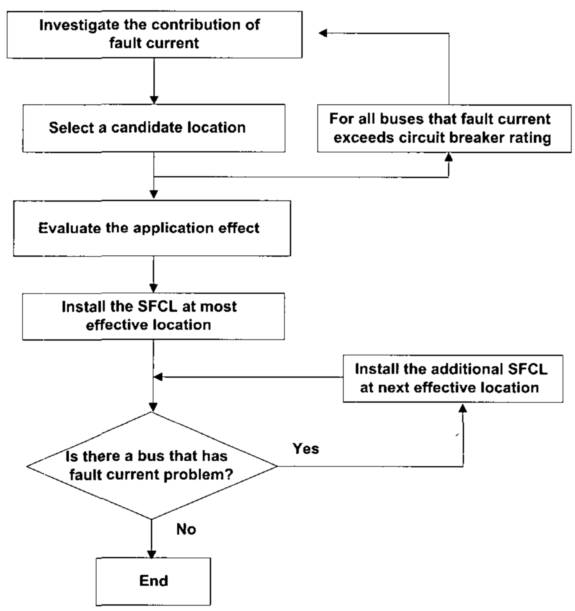


Fig. 7. Procedure of Applying SFCL in Power System.

First, investigate the contribution of the fault current and select a candidate location at each bus where the fault current exceeds the circuit breaker rating. The selected candidate locations are evaluated for the application effect. Finally, according to the application effect, determine the most effective location to limit the fault current [6]. Until the fault current problem is resolved, install the additional SFCL at next effective location. In this case study, there are six candidate locations for installing the SFCL as shown in Fig. 8. To select the most effective installing location, at first, the fault current contribution flowing into bus 2510 through each connected transmission line and transformer is evaluated by fault analysis.

As shown in Table I, fault current from bus 2500 is the most significant, having the magnitude of 32.9kA, which means location ① is the most effective installing location to solve the fault current problem at bus 2510. According to this result, the four resistive SFCLs with the impedance of 0.1p.u (about 23.7 Ω based on 100[MVA]) after quenching are installed at location ①.

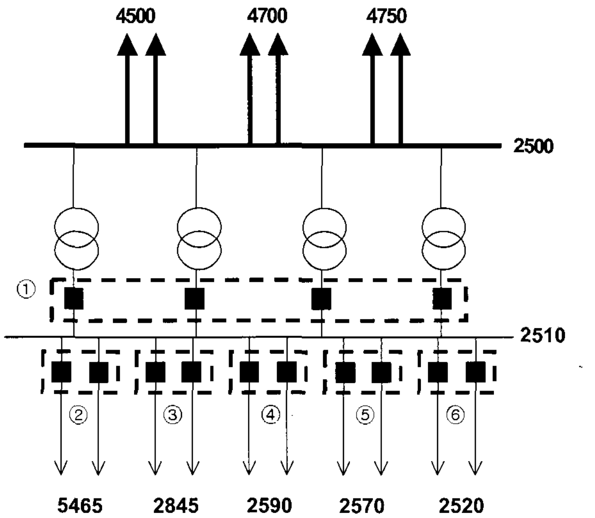


Fig. 8. Candidate locations of installing the SFCL at bus 2510.

TABLE I
FAULT CURRENT CONTRIBUTION.

Faulted Bus	Connected Bus	Fault Current [kA]
2510	2500	32.9
	2520	14.9
	2570	6.2
	2590	0.0
	2845	9.1
	5465	4.8

(b) Installation of SFCL in Bus-Tie

Bus 2510 is split into two buses, bus 2510 and 2511, and then a resistive SFCL is applied at bus-tie location between bus 2510 and 2511 to reduce the fault current as shown in Fig. 9. The impedance of SFCL after quenching is also 0.1pu (about 23.7Ω based on 100[MVA]).

The SFCL installed at bus-tie location has almost zero impedance in normal state, which gives the same power system configuration prior to splitting bus 2510. If the fault is occurred at bus 2510 and 2511, the SFCL gets to have immense impedance due to quenching of the superconductor, which can provide the same effect as splitting of bus 2510. In case that the three phase fault is occurred at bus 2510, the fault current I_{SFCL} flowing into bus 2510 from bus 2511 is reduced by the SFCL with the impedance of 0.1pu and the fault current of bus 2510 is also limited.

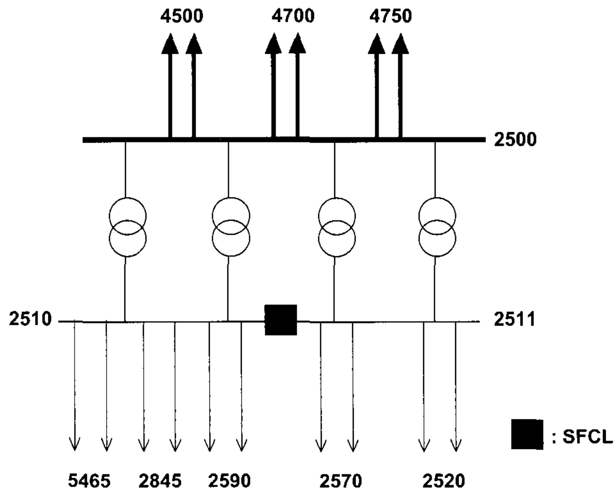


Fig. 9. Application of SFCL in Bus-Tie Location.

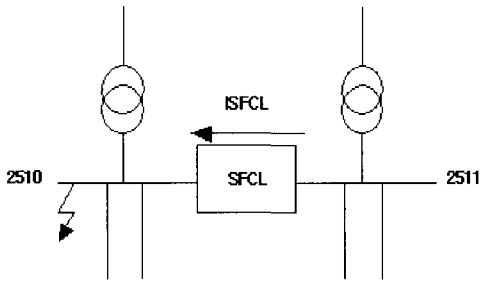


Fig. 10. Fault current reduction effect of SFCL.

4.3. Results of applying SFCL

To evaluate the application effects of the SFCL by different applying locations, the SFCL is installed at both the transmission line and bus-tie of bus 2510. Table II shows the application effects of the SFCL by applying location, respectively. As can be seen in Table III, both

SFCLs installed at transmission line and bus-tie can reduce the fault current of bus 2510 (bus 2511 in case of bus-tie) under their circuit breaker rating of 50kA. The four SFCLs are installed in case of transmission line application; otherwise, only one SFCL is used in bus-tie application with almost the identical fault current reduction effect.

TABLE II
APPLICATION EFFECTS OF SFCL.

Bus	Without SFCL	SFCL in Transmission line	SFCL in Bus-Tie
	Fault Current[kA]	Fault Current[kA]	Fault Current[kA]
2510	67.9	44.2	40.7
2511	-	-	47.5

5. CONCLUSION

A development project applying 154kV Superconducting Fault Current Limiters (SFCLs) to 154 kV transmission systems is proceeding with implementation slated for after 2010. In this paper, the technical impact of applying the SFCL in the Korean power system is carried out in relation to this project. In particular, the fault current reduction effect of the SFCL by application schemes is evaluated respectively.

In the case study, two application schemes can show positive technical effect. However, in an economic aspect, applying the SFCL to the bus-tie location is more feasible than to the transmission line. Therefore, we can say that the bus-tie location is the more appropriate location to reduce the fault current, taking into account the technical and economic aspects.

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