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Feasibility Study of Superconducting Fault Current Limiter Application to Korean Power System

Hak-Man Kim and Jong-Yul Kim
Korea Electrotechnology Research Institute
hmkim@keri.re.kr

***Abstract*-- The short circuit current problem is one of the operational problems that need to be solved by power system engineers in Korea. It is an important issue in the Seoul metropolitan area especially because of highly meshed configuration. Currently, it is regulated by changing 154 kV system configuration from loop connection to radial system, by splitting of the bus where load balance can be achieved, and by upgrading circuit breaker rating. A development project for 154 kV/2 KA SFCL application to 154 kV transmission system after 2010 is proceeding. In this paper, a feasibility study of superconducting fault current limiter (SFCL) is carried out in Seoul metropolitan area to find out the effects of its application and feasibility. This study shows that it can reduce fault current considerably, and as it can minimize the upgrading of circuit breaker rating, the economic potential of SFCL is evaluated positively.**

1. Introduction

As demands for electric energy have been increasing at high rate since 1980s, electric power system is growing into a large complex system which has the characteristics of high short circuit capacity and line loading constraints over the certain trunk transmission lines due to meshed system configuration in Korea. Load growth has been led by the electricity consumption in the areas of large cities and industrial complexes. In the course of power system growth, large capacity generation stations have been constructed in order to utilize the existing sites because of the difficulty of acquiring new generation sites. These sites are in general located at remote sites from load centers. With demand for electricity being concentrated in a few areas, this gives rise to an increase in the electric power transfer between areas. The transmission system has been developed into highly meshed configuration to enhance the supplying capability and to meet with a desirable level of reliability. Furthermore, 765 kV transmission systems 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 even though the transmission distances are shorter than 200 km.

These power system characteristics cast various operational problems to system engineers. Especially, the short circuit current problem is an important issue for load centers such as the Seoul metropolitan area. Currently, it is regulated by changing 154 kV system configuration from loop connection to radial system, by splitting of the bus where load balance can be achieved, and by upgrading of circuit breaker rating.

Recently, application studies of superconducting fault current limiter (SFCL) to power systems [1-4] and the development of SFCL [5-7] have been carried out in the U.S., Europe, and Japan. Currently, a prototype of 10MVA SFCL is being developed by ABB in Switzerland, 1MVA SFCL by Siemens in Germany, and 6.6 kV/1 kA SFCL by a consortium of Toshiba, Mitsubishi, and Sumitomo in Japan. In Korea, 600 V/30 kA SFCL and 20 kVA SFCL have been carried out at research centers and universities. A development project for 154 kV/2 KA SFCL application to 154 kV transmission system after 2010 is proceeding.

In this paper, a feasibility study of SFCL is carried out in Seoul metropolitan area to find out the effects of its application and feasibility. The results of this study show that SFCL application can reduce fault current considerably and can minimize the upgrading of circuit breaker rating in Korean power system.

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 2004,2005,2006 and 2010 are analyzed by using the peak data of KEPCO and the PSS/E program. Figs. 1 to 4 show 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 can be seen in Figs. 1 to 3, short circuit currents in 2004, 2005 and 2006 show a similar trend. 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 2004, 2005 and 2006 as can be seen in the Fig. 4, and many buses exceeding the circuit breaker rating appear.

The short circuit currents at 154 kV buses in 2004, 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.

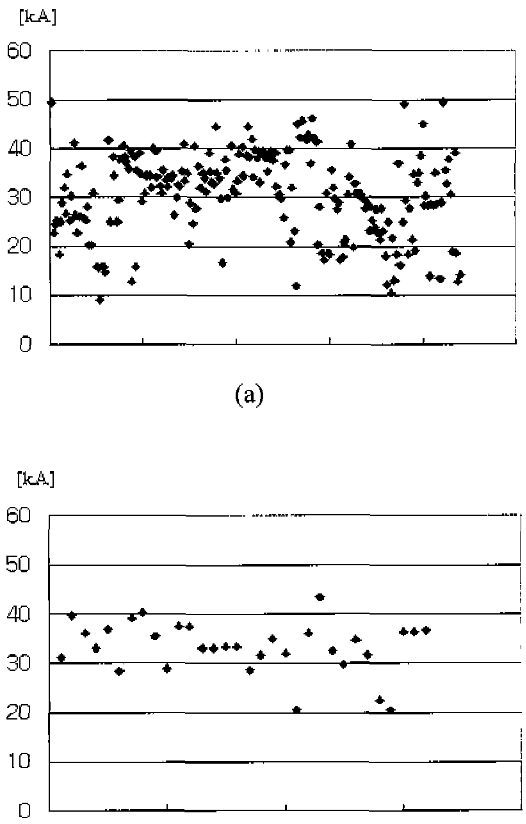
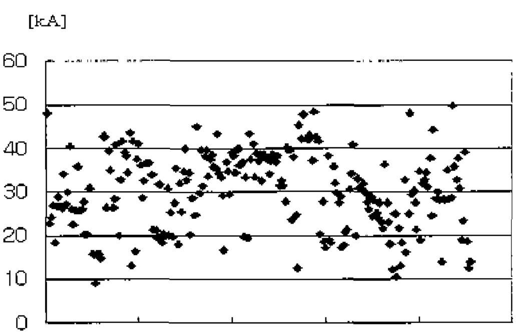
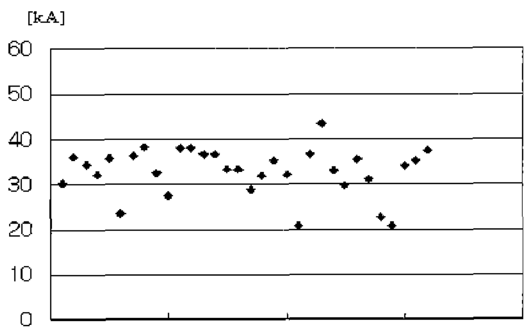


Fig. 1. Short circuit currents in Seoul metropolitan area in 2004. (a) 154 kV buses. (b) 345 kV buses.

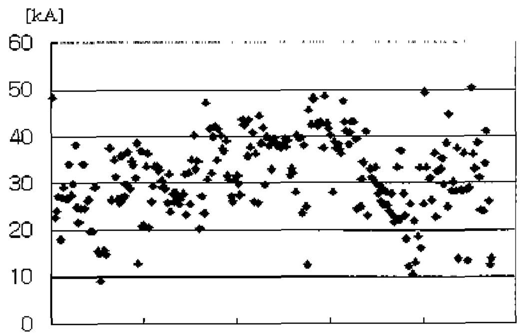


(a)

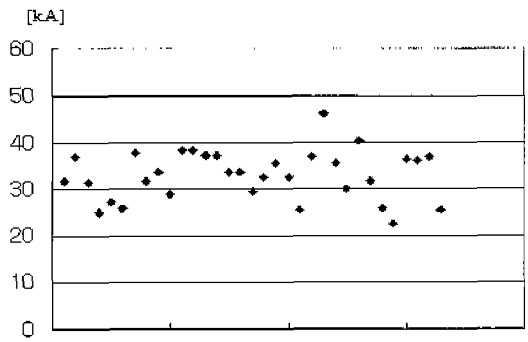


(b)

Fig. 2. Short circuit currents in Seoul metropolitan area in 2005. (a) 154 kV buses. (b) 345 kV buses.

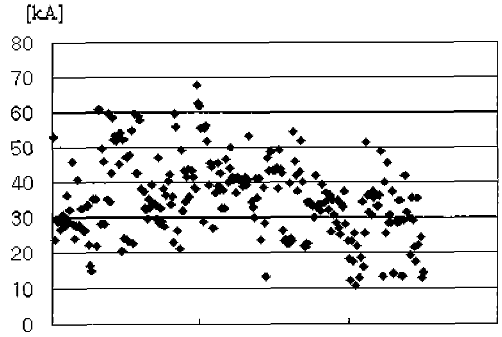


(a)

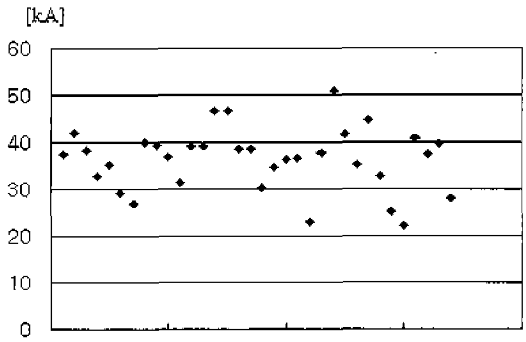


(b)

Fig. 3. Short circuit currents in Seoul metropolitan area in 2006. (a) 154 kV buses. (b) 345 kV buses.



(a)



(b)

Fig. 4. Short circuit currents in Seoul metropolitan area in 2010. (a) 154 kV buses. (b) 345 kV buses.

2.3. Reduction of Short Circuit Current

Currently, the following methods are being implemented to the system for the purpose of stable system operation:

(a) changing 154 kV system configuration from loop connection to radial system;
(b) splitting of 154 kV and 345 kV buses where load balance can be achieved;
(c) changing 345 kV bus configuration;
(d) substituting 31.5 kA rating of circuit breaker for 154 kV system to 50 kA rating;
(e) substituting 42 kA rating of circuit breaker for 345 kV system to 63 kA rating.

With these methods being applied to the system, short circuit current can be reduced to meet with the capacity of circuit breaker. However, (a), (b) and (C) may cause transient stability problem for certain contingencies especially near large capacity generation stations. Also, (d) and (e) are very expensive to substitute circuit breakers because there are 5 to 24 circuit breakers in a substation. Now, we are searching new methods and are studying SFCL as a potential countermeasure.

3. Effects of SFCL Application

3.1. Test Power System

We studied many cases but in this paper introduced one case study because each case study showed similar results. KEPCO's mid-term power system was used for this case study and also the PSS/E was used for simulation. 3-phase fault was considered and the resistive and inductive fault current limiters are modeled as they have 0.05PU resistance or inductance after quenching. Fault currents of 9 buses in Seoul metropolitan area exceeded the circuit breaker ratings. Fig. 5 shows the configuration of 2 buses of those 9 buses and neighbor buses. The bold lines in Fig.

5 indicate 345kV lines and buses, the thin lines indicate 154kV lines and buses. Fault currents of 2 buses, bus 4730 and bus 4675, enclosed by dashed line exceeded their circuit breaker ratings. Their circuit breaker ratings and the fault currents are shown in Table I.

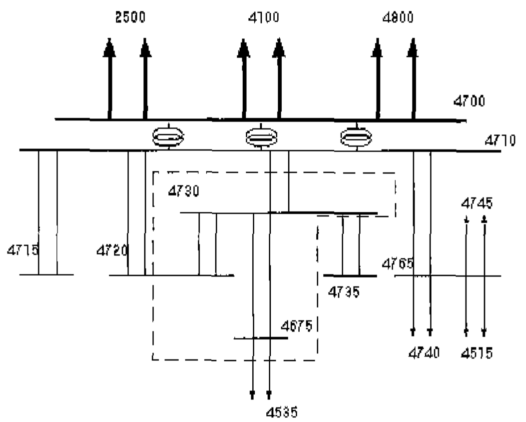


Fig. 5. Diagram of the test area.

TABLE I
CIRCUIT BREAKER RATING AND FAULT CURRENT

Bus	Circuit breaker rating (kA)	Fault current (kA)
4675	31.5	34.9
4730	31.5	37.6

3.2 Results of Case Study

To evaluate the effects of SFCL application, SFCL was installed at bus 4710, bus 4730 and bus 4675, respectively, by engineering judgement. The impedance of SFCL after quenching was assumed to be 0.05PU. Resistive-type SFCL and inductive-type SFCL were considered. Table II and III show the application effects of resistive-type SFCL and inductive-type SFCL, respectively.

TABLE II
EFFECT OF THE APPLICATION OF RESISTIVE-TYPE SFCL

Installation bus	Neighbor bus	Fault current (kA)	
		Bus 4675	Bus 4730
4710	4720	33.4	36.8
4730	4720	33.4	35.4
4730	4710	30.5	30.7
4675	4730	24.4	32.3
4675	4535	27.5	32.5

TABLE III
EFFECT OF THE APPLICATION OF INDUCTIVE-TYPE SFCL

Installation bus	Neighbor bus	Fault current (kA)	
		Bus 4675	Bus 4730
4710	4720	33.6	35.6
4730	4720	33.6	35.6
4730	4710	31.1	31.4
4675	4730	25.0	32.2
4675	4535	27.5	32.3

As can be seen in Tables II and III, both the resistive-type SFCL and inductive type SFCL installed at bus 4730 could reduce fault currents of bus 4730 and bus 4675 under their circuit breaker ratings. Though SFCL is installed at the same bus, the results according to position related to neighbor buses were different. This was explained by fault current contribution of bus 4730 as can be seen in Table IV. That is, the maximum effect could be obtained by installing SFCL at position connected to neighbor bus with the biggest fault current contribution.

TABLE IV
FAULT CURRENT CONTRIBUTION

Installation bus	Neighbor bus	Fault current (kA)
4730	4675	12.8
	4710	16.2
	4720	8.6
	4735	0.0

3.3 Feasibility of SFCL Application

By applying SFCL at bus 4730, the fault currents at bus 4675 and bus 4730, where fault currents exceeded their circuit breaker ratings, were reduced to below their circuit breaker ratings. This means that fault currents at neighbor buses can be reduced by SFCL application at one bus. In Korea, 5 to 24 circuit breakers are installed at a 154 kV or 345 kV bus. There are 14 circuit breakers of 31.5 kA rating in bus 4730 and bus 4675, respectively. This shows that SFCL application will bring considerable economic benefits though the economic feasibility was not considered in detail in this paper

4. CONCLUSION

A development project for 154 kV/2 KA SFCL application to 154 kV transmission system after 2010 is proceeding in Korea. In this paper, a feasibility study for SFCL application to the Korean power system was carried out in relation to this project. Especially, the application effects of SFCL as a potential countermeasure to reduce fault currents in Seoul metropolitan area were evaluated positively. The results found through this study are as follows.

(a) The fault current reduction effect obtained by SFCL application was excellent.
(b) The maximum effect of fault current reduction could be obtained by installing SFCL at position connected to neighbor bus with the biggest fault current contribution.
(c) The economic potential of SFCL was evaluated positively because fault currents at neighbor buses could be reduced by SFCL application at one bus

When selecting SFCL locations and types, consideration of various field factors such as site acquisition and environment are needed in addition to system analysis.

ACKNOWLEDGMENT

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