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A study on SFCL application for the interconnection operation of 154kV power systems under 345kV S/S in Korean power system

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Abstract-- **This paper is for studying the feasibility of SFCL application for the interconnection operation of 154kV power systems under 345kV S/S in Korean power system. All Korean 154kV power systems are constructed as loop systems in downtown. However, the present 154kV systems are operated with separated systems around 345kV S/S because of fault current and overload problems. In this study, we investigate the structure and operation of 154kV power system in Seoul and study the feasibility of interconnection operation of 154kV systems under 345kV systmes by applying SFCLs to 154kV bus-tie.**

1. INTRODUCTION

Fault current problem is becoming more serious recently in Korean power system as power demand increases. This problem is especially more serious in the downtown of a big city with large power demand. In the present Korean power system, various ways are being considered as solutions for the problem, which are opening operation of 154kV transmission lines interconnecting 345kV substations, bus split operation, and so on [1][2]. However, these ways have disadvantage to decrease reliability and stability of power systems. On the other hand SFCL is recently noticed as a solution for fault current reduction[3-5]. It is estimated that SFCL has smaller problem than other ways because it dose not affect the power system in a normal state[6]. Therefore many studies on SFCL are being conducted in Korea, which is related to the development and the power application of SFCL.

In Korean downtown area 154kV power systems are locally operated with opened transmission lines and splitted buses because of some problems such as a fault current and a overload. The structure of power system is changed by an operating point in real power system. We have to study considering the operating pattern of a real power system to apply SFCL to the system. In this study we investigate opened 154kV transmission lines and splitted buses in Seoul of the year of 2010 and then conduct the feasibility study for SFCL power application considering the structure of power system. This study proposes an operation method of power system having a higher reliability for power supply through the new construction of power system by the introduction of SFCL in Korean power system.

2. LINE OPEN AND BUS SPLIT OPERATION

We expect that 154kV SFCL being developed in Korea will be applied to real power system after 2010. So, we carried out a basic study about Korean power system in the year of 2010. Opened transmission lines are listed in Table I and splitted buses are as follows:

○ Bus split operating S/S
  - Samgakji/Samgakji-s (AREA 4 - AREA 5)
  - Danginli/Danginli-s (AREA 5 - AREA 7)
  - Bongcheon/Bongcheon-s (AREA 8 - AREA 9)

○ Line open operation : Interconnecting transmission lines between AREAs

TABLE I
OPENED TRANSMISSION LINES IN SEOUL (2010).

Interconnected AREAs	Opened lines (Interconnected lines)
AREA 1 - AREA 2	Wondang - Yangju (2 circuits)
	Moonsan - Keumchon (2 circuits)
	Moonbal - Keumchon (2 circuits)
	Soosac - Eunpyung (2 circuits)
AREA 1 - AREA 5	Soosac - Joongboo (1 circuit)
AREA 2 - AREA 3	Yangju - Ssangmoon (2 circuits)
	Geumo - Eujungboo (2 circuits)
	Unni - Wonnam (2 circuits)
AREA 2 - AREA 4	Hyunjeo - Heungin (1 circuit)
	Seosomoon - Uelji (1 circuit)
AREA 2 - AREA 5	Hyunjeo - Soonhwa (1 circuit)
	Seosomoon - Soonhwa (1 circuit)
AREA 3 - AREA 4	Anam - Yongdoo (2 circuits)
	Jongam - Heukyung (2 circuits)
AREA 4 - AREA 5	Joongang - Soonhwa (1 circuit)
AREA 1 - AREA 6	Sangam - Deungchon (2 circuits)
AREA 4 - AREA 9	Bokwang - Banpo (2 circuits)
AREA 4 - AREA 10	Kwangjang - Gueui (2 circuits)
	Dukso - Shinjang (2 circuits)
AREA 4 - AREA 11	Dukso - Icheon (2 circuits)
AREA 6 - AREA 7	Shinjung - Mokdong (1 circuit)
AREA 7 - AREA 8	Mokdong - Oryu (1 circuit)
	Youngdeungpo - Guro (2 circuits)
AREA 9 - AREA 10	Sunneung - Nonhyun (2 circuits)
	Daechi - Samsung (2 circuits)
AREA 10 - AREA 11	Sooseo - Sungnam (2 circuits)

Fig. 1 describes 154kV power system of Seoul in 2010. The 154kV power system is constructed as a loop system. However, the system is separated around 345kV S/S and interconnection operation between each area through 154kV transmission lines is not done in the system. AREA is divided according to the interconnection of 154kV power system under 345kV S/S for the convenience' sake.

Table 2 describes split operating buses in Seoul from 2004 to 2015. Bus split operation is one of the ways to separate 154kV systems under 345kV power system like a line open operation. Power system operators study the system from the various viewpoint of the structure and the demand of the power system every year. Operators choice a different operating plan every year based on the results of the study, and split operating buses are changed as table 2 shows.

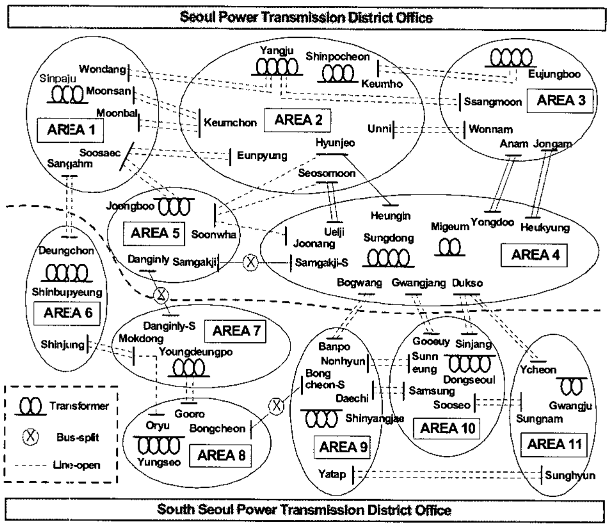

Fig 1. Power system in Seoul (2010).

TABLE II
BUS SPLIT IN SEOUL BY YEAR.

Splitted bus \ Year	2004	2005	2006	2007	2008	2009	2010	2015
Yangju1(1410) - Yangju1-s(1411)	O	O	X	O	X	X	X	X
Guemchon(1495) - Guemchon-s(1496)	X	X	X	X	X	X	X	O
Anam(1630) - Anam-s(1631)	O	O	O	O	O	O	X	O
Goonja(1655) - Goonja-s(1666)	X	X	X	X	X	X	X	O
Samgakji(1665) - Samgakji-s(1666)	-	O	O	O	O	O	O	O
Miguem1(1710) - Miguel-s(1711)	O	X	X	X	X	X	X	X
Gwangjang(1770) - Gwangjang-s(1771)	X	O	O	X	X	X	X	X
Dukso(1775) - Dukso-s(1776)	O	O	O	O	O	X	X	X
Hwayang(1785) - Hwayang-s(1786)	O	X	X	X	X	X	X	X
Danginli(1811) - Danginli-s(1812)	O	O	O	O	O	O	O	O
Soonhwa(1865) - SoonhwaS(1866)	O	O	O	O	O	X	X	X
Seosomoon(1870) - Seosomoon-s(1871)	O	O	O	O	O	X	X	X
Wondang(1925) - Wondang-s(1926)	X	X	X	X	X	X	X	O
Samsung(2740) - Samsung-s(2741)	O	O	O	O	X	X	X	X
Sadang(2735) - Sadang-s(2736)	X	X	X	X	X	X	X	O
Bongcheon(2745) - Bongcheon-s(2746)	X	X	X	X	X	X	O	X
Banpo(2780) - Banpo-s(2781)	O	X	X	X	X	X	X	X
Shinsa(2825) - ShinsaS(2826)	X	O	O	O	O	O	O	X
Hwagok(3870) - Hwagok-s(3871)	X	X	X	X	X	X	X	O
Icheon(4775) - Icheon-s(4776)	O	O	O	O	O	O	O	O

※ O : Bus split operation, X : Single bus operation

3. A BASIC STUDY FOR OVERLOADS AND FAULT CURRENTS

According to above works, it is expected that 2010 power system is operated with some opened lines and splitted buses. These operations are generally due to fault current and overload problems. In this chapter, to investigate thoroughly the reason for above operations in 2010 power system, we conducted a power flow analysis and a fault analysis, after closing all opened lines and merging all splitted buses in Seoul.

3.1. A basic investigation for overloaded lines

Firstly, to verify the effect of overload, we investigated overloaded transmission lines by a power flow analysis after closing all opened lines and merging all splitted buses in Seoul. In this study, overload means that the loading of transmission line is over 100% of it's rating.

Table 3 presents the results of overload after closing all opened lines and merging all splitted buses in Seoul. According to table 3, there is no overloaded line in seoul power transmission district office area and a new overloaded line come into existence in south seoul power transmission district office area. From the results, we can know the fact that interconnecting operation between AREAs affect overload.

TABLE III
OVERLOAD RESULTS AFTER CLOSING ALL OPENED LINES.

Overloaded lines	Circuit	Flow (MVA)	Capacity (MVA)	Overload (%)	Remark
Youngseo1 - Oryu	1	117.4	108.0	108.7	AREA 8
Youngseo1 - Oryu	2	117.4	108.0	108.7	
Youngdeungpo1 - Youe	1	148.8	127.0	117.2	AREA 7

3.2. Detailed studies on overload

This chapter presents detailed studies to investigate more thoroughly the opened lines and the splitted buses affecting overload. According to the results of chapter 3.1, there are overloaded lines in AREA 7 and 8. So, we conduct a power flow analysis to verify overloaded lines in AREA 7 and AREA 8, after closing all interconnecting lines and merging splitted buses related to the AREAs.

From the results in table 4, we can conclude that overload is one reason for the operation with bus split of Danginli/Danginli-s and the open of the line, Shinjung-Mokdong. It seems that overload is caused by power flows from AREA 7 to AREA 5 and 6. Danginli/Danginli-s is an interconnecting point between AREA 5 and AREA 7, and Shinjung-Mokdong is an interconnecting point between AREA 6 and AREA 7. Finally, Danginli/Danginli-s bus has to be splitted and Shinjung-Mokdong line has to be opened, becase of overload problem, even though solving a fault current problem in these AREAs. Therefore, we carried out this study under following basic conditions for the line and the bus.

○ Study conditions
- Danginli/Danginli-s : Bus split operation
- Shinjung-Mokdong : Line open operation

TABLE IV
OVERLOAD RESULTS BY THE STUDY CONDITION.

Condition	Interconnected AREAs	Overloaded lines
(Danginli/Danginli-s) Single bus	AREA 5 - AREA 7	Occurrence
(Bongcheon/Bongcheon-s) Single bus	AREA 8 - AREA 9	No occurrence
(Mokdong - Oryu) line closing	AREA 7 - AREA 8	No occurrence
(Youngdeungpo - Guro) line closing	AREA 7 - AREA 8	No occurrence
(Shinjung - Mokdong) line closing	AREA 6 - AREA 7	Occurrence

3.3. Fault analysis

Table 5 describes the results of a basic study on the verification of a fault current effect. In case of closing the interconnecting lines between AREAs, the structure of power system is more complicated and the number of buses over 50kA of fault current increases. In here, 50kA is the capacity of a present circuit breaker. Therefore, we can conclude that fault current problem has an great effect on the separating operation between AREAs.

From the above results, we can provisionally conclude that overload and fault current problems are complex reason for the line open and bus split operations in Seoul. It is likely that fault current problem has especially the greatest effect on the operation of power system. This study was conducted under the provisional conclusion that fault current problem is the largest reason of the separating operation between AREAs.

TABLE V
COMPARISON OF THE NUMBER OF BUSES OVER 50KA OF FAULT CURRENT IN SEOUL.

System structure	The number of buses over 50kA of fault current in Seoul
Existing structure (Some buses split and interconnecting lines open between AREAs)	7 Buses
Single bus operation of the splitted buses and closing operation of interconnecting lines between AREAs	158 Buses

4. POWER APPLICATION SCHEME OF 154KV SFCL

4.1. A solution for fault current problem in the present structure of power system

We have already carried out a study for solving the fault current problem under the present structure by applying 154kV SFCL[6, 11]. According to the results of the study, the most effective scheme for SFCL application is the bus-tie application to Sungdong bus. The result of this chapter is a solution for the fault current problem of AREA 4 among the above AREAs. If a fault current problem occurs in the separated 154kV systems, we can solve the problem by the bus-tie application of 154kV SFCL like above way.

TABLE VI
THE EFFECT OF SFCL APPLICATION TO SUNGDONG1 BUS-TIE.

Fault location			Fault current [kA]	
AREA	Bus number	Bus name	Before applying SFCL	After applying SFCL
AREA 4	1610	Sungdong1	53.4	37.1
	1619	sungdong1-s	-	37.7
	1611	Wangshipni	52.7	37.3
	1670	Majang	52.4	36.6
	1710	Miguem1	50.8	40.8
	41710	DMiguem1	50.8	40.8
	1745	Heuikyung	50.7	38.8

4.2. Feasibility test for SFCL application and interconnecting operation between AREAs

According to the above statements, 154kV transmission system in the metropolitan area is constructed as a loop system around 345kV S/S. However, we operate with opening 154kV interconnecting lines between 345kV substations and with splitting some 154kV buses. The fault current problem is the biggest reason why we construct system structure and operate transmission line like this. The most reasonable operating plan in the metropolitan area is to make all 154 kV systems into the loop structure which has high reliability for power supply.

But it is impossible to operate the interconnected 154kV systems because of fault current problem. This study proposes an alternative plan to operate interconnected systems between 154kV systems under 345kV S/S through SFCL application. Firstly, we studied the possibility of interconnecting operation between AREA 4 and AREA 5 in seoul power transmission district office area and between AREA 9 and AREA 10 in south seoul power transmission district office area. The selected AREAs are downtown of Seoul. This study is conducted, supposing that SFCL is applied to Sungdong1 and fault current problem is solved in AREA 4.

4.2.1. Possibility of interconnecting operation between AREA 4 and AREA 5

To evaluate the possibility of interconnecting operation between AREA 4 and AREA 5, we did a power flow and fault analysis after applying bus-tie SFCL to Samgakji/Samgakji-s bus like Fig. 2.

According to the result of power flow analysis, there is no overloaded line. Table 7 describes the results of fault analysis. From the results of table 7, we can find that the effect of fault current reduction is smaller than bus split operation, in case of applying SFCL to Samgakji/Samgakji-s, but it is enough to operate normally the system.

Therefore, it is likely that we can improve the reliability of power system and solve the fault current problem through applying SFCL to Samgakji/Samgakji-s bus between AREA 4 and AREA 5 in above case.

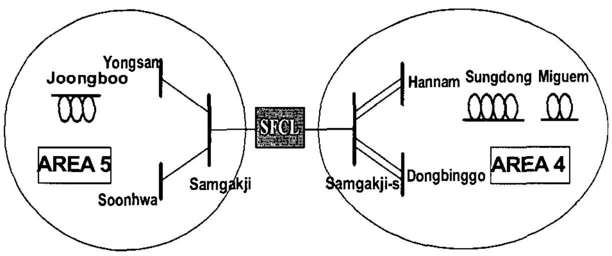

Fig. 2. SFCL application to Samgakji/Samgakji-s.

TABLE VII

COMPARISON OF FAULT CURRENT RESULTS BEFORE AND AFTER APPLYING SFCL TO SAMGAKJI/SAMGAKJI-S BUS.

Fault location			Fault current [kA]		
AREA	Bus number	Bus name	Single bus operation	After applying SFCL	Bus split (Without SFCL)
AREA 4	1619	Sungdong1-s	51.7	40.5	37.7
	1611	Wangshipni	51.0	40.1	37.3
	1710	Miguem1	50.9	43.1	40.8
	41710	DMiguem1	50.9	43.1	40.8
	1635	Hannam	50.3	37.7	34.8
	1745	Heuikyung	50.2	41.3	38.8

4.2.2. Possibility of interconnecting operation between AREA 9 and AREA 10

In this chapter, we studied the possibility of interconnecting operation between AREA 9 and AREA 10.

The AREAs have the highest density for power demand in Seoul. We conducted a power flow and fault analysis after applying SFCL to Samsung like Fig. 3. From the result of the power flow analysis, there is no overloaded line. Table 8 and table 9 show the results of the fault analysis.

In case of operating the interconnected systems between AREA 9 and AREA 10 by closing the opened lines, the number of the buses over 50kA of fault current is 31. In this case, the number of fault current problem buses decreased to one bus(Shinyangjae) by SFCL application, but we cannot completely solve the problem. In this AREAs, fault current is very high even though applying SFCL, because fault current is over 48kA in the existing structure of power system. If we apply SFCLs to a 154kV bus under 345kV S/S and a interconnecting point

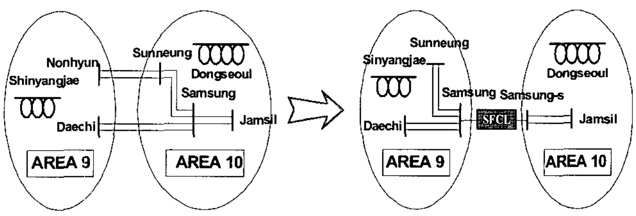

Fig. 3. SFCL application to Samsung/Samsung-s.

TABLE VIII

BUSES HAVING A FAULT CURRENT PROBLEM BEFORE AND AFTER APPLYING SFCL TO SAMSUNG/SAMSUNG-S.

Conditions	The number of buses over 50kA of fault current
Closing the lines, Sunneung - Nonhyun and Daechi - Samsung	31 Buses (AREA 9, 10)
Applying SFCL to Samusung/Samsung-s	1 Bus (Sinyangjae1 : AREA 9)

TABLE IX

FAULT CURRENT RESULTS BEFORE AND AFTER APPLYING SFCL TO SAMSUNG/SAMSUNG-S.

Fault location			Fault current [kA]		
AREA	Bus number	Bus name	Closing the opened lines	Applying SFCL	Line open operation
AREA 9	2710	Singyangjae1	67.6	50.2	48.5
	2720	Yuksam	65.6	47.7	45.7
	2765	Kyodae	62.6	47.3	45.8
AREA 10	2510	Dongseoul1	67.2	49.1	48.0
	42510	DDongseoul1	67.2	49.1	48.0

between two AREAs in this case, it is possible to solve the fault current problem. Table 10 shows the results. The cases for the study are as follows.

○ CASE 1 : Applying one SFCL - one in (Samsung/Samsung-s) bus-tie
○ CASE 2 : Applying two SFCLs - each one in (Shinyangjae1) and (Samsung/Samsung-s) buses
○ CASE 3 : Applying three SFCLs - each one in (Shinyangjae1), (Dongseoul1) and (Samsung/Samsung-s) buses

From the results of table 10, we can conclude that it is possible to operate interconnected system between AREA 9 and AREA 10 by applying two SFCLs or more.

TABLE X
FAULT CURRENT RESULTS BY APPLYING SFCL TO SAMSUNG/SAMSUNG-S.

Fault location			Fault current [kA]		
AREA	Bus number	Bus name	CASE 1	CASE 2	CASE 3
AREA 9	2710	Singyangjae1	50.2	33.9	34.0
	2720	Yuksam	47.7	34.6	34.7
	2765	Kyodae	47.3	34.3	34.4
AREA 10	2510	Dongseoul1	49.1	49.3	38.6
	42510	DDongseoul1	49.1	49.3	27.0

5. CONCLUSION

This paper is a study on the SFCL application to 154kV real power system. This study proved that the reduction effect of a fault current by applying SFCL to present power system. In other words, we can completely solve the fault current problem of separated 154kV systems under 345kV systems, by applying bus-tie SFCL to 154kV bus linked to 345kV S/S. We can do interconnecting operation between several 154kV systems under 345kV systems through applying SFCL to splitted buses and opened lines. In case of interconnecting operation using SFCL, we can do reliable operation of power system through new structure of the system. In the future, to apply SFCL to real power system, we select a proper site in the system and then have to conduct a more detailed study.

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