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A study on 154kV protective relaying systems for HTS power devices application in Korea

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***Abstract*-- This paper describes the consideration of 154kV protective relaying systems for applying HTS(High Temperature Superconducting) power devices to Korean power system. We investigates firstly 154kV relay systems of Korean power system and then do a basic study on the relay systems in the power system with superconducting devices. For the more detailed result, the study using EMTDC relay system modeling will be done from the viewpoint of superconducting devices application in the future.**

1. INTRODUCTION

Many studies on HTS power devices development and power system application have been done since high temperature superconductivity discovered [1-5].

It is, especially, very important to study problems and considerations in case of applying HTS power devices to conventional power system. And the related researches have been done in Korea [6-11].

In results of the studies, considerations for the technical analysis are on the rise, which are power distribution, voltage drop, protective relaying system, and so on. The protection system is very important because the failure of protective relays can have a ripple effect on the whole power system. If the proper action is not done for a power fault, the accident can lead to instability of the whole power system. In the worst case, the big blackout such as North American and Italian blackout can be occurred. Impedance of superconducting power devices change in quenching by a power fault. This characteristic may clash with protection system of the conventional power system [12-13].

Therefore we have to study the influence of protective relaying system by impedance change of superconducting devices such as HTS-FCL(Fault Current Limiter). And it is necessary to do a proper action for the system. This study focuses on the protection system for 154kV Korean power system application of HTS power devices.

2. PROTECTION SYSTEM IN KOREA

To study the influence of superconducting power devices to protective relaying system, firstly, we have to check the protection system in Korean power system [14-16].

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TABLE I
PROTECTIVE RELAYING SYSTEM OF 154KV KOREAN POWER SYSTEM.

Equipment		Protective Relaying
154kV Transmission Line	Primary	PCM current differential relay
		Directional-comparison tripping and blocking relay
	Back-up	Three step distance relay
154kV Bus	Primary	Phase-comparison current differential relay
	Back-up	Voltage differential relay
154/22.9kV Transformer	Primary	Proportional differential relay
	Back-up	Over-current relay

This chapter describes the 154kV power system protection in Korea. Table 1 summarizes the protection system.

3. BASIC STUDY

3.1. 154kV transmission line protection

3.1.1. Primary relaying

Primary relaying systems of 154kV transmission line are PCM current differential relaying and directional-comparison tripping and blocking relaying in Korean power system. The former operates when the vector difference of current signals received from both ends of a transmission line exceeds a predetermined amount. The latter apply distance relays to determine whether a fault location is inside of the line or not. It seems that these relays may not fail by applying HTS power devices to real power system. However, directional-comparison tripping and blocking relays may not determine the exact fault location. It is necessary to set the distance relays considering quenching impedance of HTS power devices for the determination of the exact fault location.

3.1.2. Back-up relaying

A three step distance relay protects power systems with time delay after it determines a fault location (Zone-1, 2, 3) using a distance relay. The distance relay measures the impedance from any measuring point to a fault location and then compares the value with the setting value of the relay for the determination. If we apply HTS power devices such as HTS-FCL, the relay can fail in operation because of the quenching impedance of the HTS devices. This is a very big problem and can be in all zones (zone-1, 2, 3). Therefore, we have to do an action to solve this problem such as setting of the relay considering the quenching impedance. In this paper, we do more detailed study about this problem.

3.2. 154kV bus protection

Primary protection of 154kV buses is phase-comparison current differential relaying and back-up protection is voltage differential relaying. Phase-comparison current differential relays determine whether power faults are internal or external faults by current phase differentials of lines connected the buses. A voltage differential relay detects a fault using the voltage induced from the current differentials of the lines. In applying HTS devices to power system, the magnitude of current injected into the bus decreases, and there are the differentials of current phase or induction voltage. So it seems that there is almost no problem in operation of the relay in the power system with HTS devices. However, if we install HTS-FCL to bus-tie in the real power system, we must consider the FCL protection and the protection area of the bus.

3.3. HTS Transformer and FCL protection

Differential and over-current relaying systems are used for the protection of large power equipments such as transformers. These systems operate by currents injected into the equipment. So the protection of the conventional power equipment is little affected by HTS power devices application. And we can use differential relaying as a protection of HTS devices such as HTS transformers, HTS-FCLs.

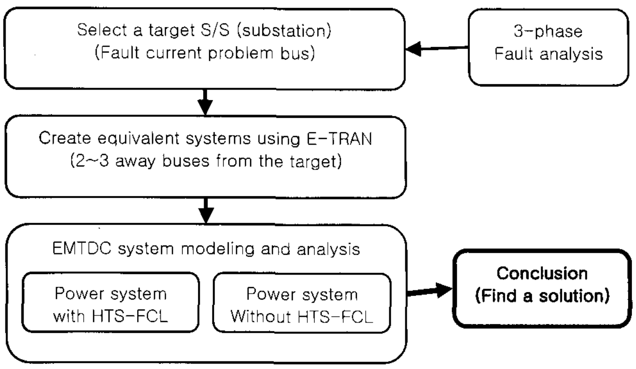

Fig. 1. Procedure of the real power system analysis.

3.4. FCL recovery and transmission re-colsing time

The recovery time of SFCL being developed in Korea has an uncertainty. Developers of SFCL estimate the recovery time to be 1 sec and more, even though considering the progress of SFCL technology. However, automatic reclosing time of circuit breaker is 0.3 sec in Korean power system. This will be operational problem that automatic reclosing action may be done before SFCLs recover in case of a power fault. To solve this problem, some studies on the new SFCL system have been done, reflecting the operation of a practical power system [17].

4. PROCEDURE FOR THE ANALYSIS

As the above basic study describes, there are some problems in the three step distance relaying system of 154kV back-up relaying system for applying HTS power devices. In this chapter, we carries out the more detailed study for the real power system using some power system analysis programs such as PSS/E, EMTDC, and E-TRAN. The target system is the 154kV Seoul power system of Korean power system in 2010. The procedure is as follows.

❍ (Step-1) Select a target substation

We select a target substation having a fault problem through the analysis result, after we do 3-phase fault analysis for a real power system. The substation having a fault problem means a substation having a fault current over the rating of a circuit breaker.

❍ (Step-2) Create equivalent systems

We consider the selected substation in (Step-1) and translate the power system data into a PSCAD/EMTDC data file using E-TRAN of the translation program for power system simulation. PSCAD/EMTDC is a transient analysis program and we have to use this program for a detailed power system analysis with HTS power devices. We convert 2~3 away buses from the target substation for modeling of HTS devices and protection systems.

❍ (Step-3) Analyze the equivalent system using PSCAD/EMTDC

We model HTS power devices and protection systems using EMTDC/PSCAD in the equivalent system of (Step-2). Test systems are two systems before and after applying HTS-FCL. And then we study the impact of HTS-FCL on the equivalent power systems in a fault.

5. CASE STUDY OF THE REAL POWER SYSTEM

5.1. (Step-1) Select a target substation

We did a fault analysis for Korean power system in 2010 using PSS/E and obtained buses(substations) having a 3 phase fault current over 50kA of 154kV circuit breaker rating in 154kV Seoul power system. Table 2 shows the results. In this study, we selected Sungdong-1 bus as a target substation for the detailed analysis, which is the most severe bus in a fault current problem.

TABLE II
BUSES WITH FAULT CURRENT PROBLEM IN SEOUL.

Faulted buses		Fault current
Bus number	Bus name	
1610	Sungdong-1	53.4 kA
1611	Wangshimni	52.7 kA
1670	Majang	52.4 kA
1710	Migeum-1	50.8 kA
1711	Migeum-1S	50.8 kA
1745	Heuikyung	50.7 kA
3660	Sinsiheung	50.2 kA
4510	Sinsungnam-1	52.1 kA
41711	D-Migeum-1	50.8 kA
44510	D-Sinsungnam-1	52.1 kA

5.2. (Step-2) Create equivalent systems

We considered Sungdong-1 bus and translated the PSS/E power system data into a PSCAD/EMTDC file using E-TRAN. The converted system is 154kV transmission power system in Seoul. For more reliable result, we converted 3 away buses from Sungdong-1 bus.

5.3. (Step-3) Modeling and analysis

We modeled the test system including HTS-FCL and protection system. We installed HTS-FCL at the bus-tie of Sungdong-1. Line connections of the bus considered the most effective case. The applied quenching impedance of HTS-FCL is 10 ohm. Distance relays are installed into Heungin, Majang, Gunja, Heuikyung, and Hannam buses. Fig 2 describes the test system with distance relays. In this system, we investigated the system impedance change by applying HTS-FCL.

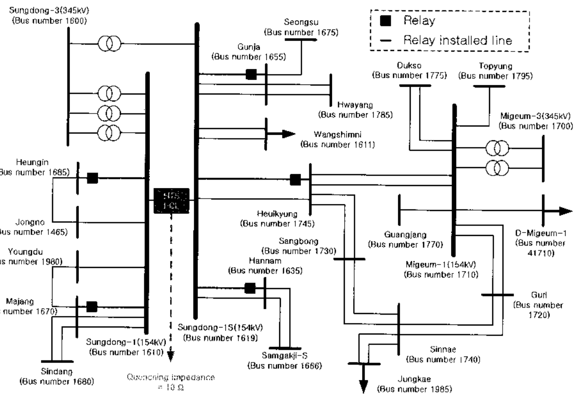

Fig. 2. Test system with distance relays.

5.4. Results and discussion

This paper describes the relay impedance measurements in Gunja and Heuikyung. These are results of the severe cases. Table 3 and 4 describe the results. When a fault occurs in zone-1, system impedance measured by relay is the same before and after applying HTS-FCL.

TABLE III
RELAY IMPEDANCE RESULTS OF GUNJA.

Fault location (Middle of the line)	**Relay impedance [ohm]**		**Zone**
	Before apply HTS-FCL	**After apply HTS-FCL**	
Gunja–Sungdong1S	0.03 + j0.28	0.03 + j0.28	Z-1
Sungdong1–Heungin	1.06 + j13.76	-384.04 – j74.65	Z-2 or Z-3
Sungdong1–Jongno	1.02 + j14.89	-379.23 – j72.34	
Sungdong1–Yongdu	0.76 + j6.29	-423.0 – j95.33	
Sungdong1–Majang	0.41 + j2.73	-446.5 – j110.5	
Sungdong1S–Wangshimni	0.24 + j1.58	0.07 + j1.12	
Sungdong1S–Heuikyung	-4.20 + j43.57	-1.61 + j8.78	
Sungdong1S–Hannam	0.95 + j9.18	-0.02 + j5.17	
Gunja–Seongsu	-0.07 - j0.50	-0.08 – j0.52	Z-4
Gunja–Hwayang	-0.08 - j0.80	-0.09 – j0.83	

TABLE IV
RELAY IMPEDANCE RESULTS OF HEUIKYUNG.

Fault location (Middle of the line)	**Relay impedance [ohm]**		**Zone**
	Before apply HTS-FCL	**After apply HTS-FCL**	
Gunja – Sungdong1S	0.04 + j0.36	0.04 + j0.36	Z-1
Sungdong1 – Heungin	0.25 + j2.34	33.73 + j6.80	Z-2 or Z-3
Sungdong1 – Jongno	0.27 + j2.48	34.04 + j6.93	
Sungdong1 – Yongdu	0.16 + j1.43	31.63 + j5.98	
Sungdong1 – Majang	0.11 + j0.99	30.59 + j5.56	
Sungdong1S – Wangshimni	0.20 + j2.04	0.04 + j1.40	
Sungdong1S – Heuikyung	0.10 + j0.84	0.08 + j0.79	
Sungdong1S – Hannam	0.20 + j1.79	0.06 + j1.30	
Gunja – Seongsu	-0.08 – j0.68	-0.24 – j0.91	Z-4
Gunja – Hwayang	-0.10 – j0.97	-0.42 – j1.46	

The reason is that the installation location of HTS-FCL is in zone-2 of protection system. This means that a distance relay normally operates in a fault if there is not HTS-FCL in the protective zone. When a fault occurs in zone-2 or zone-3, relay impedance changes. This is caused by an apparent effect and the impedance change of HTS-FCL. Especially, Table 3 and Table 4 shows the big change of the impedance in faults of some lines such as Sungdong1-Heungin,Sungdong1-Jongno,Sungdong1-Yongdu, and Sungdong1- Majang.

6. CONCLUSION

This paper is a study on 154kV protective relaying systems for applying HTS power devices such as HTS-FCL in Korea. We can confirm some problems in protective relaying systems. This study provides some considerations about the power protection with HTS power devices. The summary is as follows.

- **(Primary protection of 154kV transmission line)**
  The conventional protection system can be applied without big problems. To detect the exact fault location, however, directional-comparison tripping and blocking relay need to re-set the impedance of a distance relay considering HTS devices.
- **(Back-up protection of 154kV transmission line)**
  3 Step distance relay can fail in normal operation because of quenching impedance of HTS power devices. Therefore we have to do any action for solving the problem like re-setting the impedance of the relay including the quenching impedance of HTS devices.
- **(154kV bus protection)**
  The existed protection system can be applied without big problems. However, we have to modify the protection area of 154kV bus, when HTS-FCL is applied to power system by bus-tie.

This paper is the basic study on the power system protection for applying HTS power devices. We will study on the operation of a real protective relay in the power system with zero-phase sequence impedance using RTDS (Real Time Digital Simulator) in the near future.

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