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Planning of HVDC System Applied to Korea Electric Power Grid

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Abstract – This paper proposes pre-analysis on planning of high-voltage direct current (HVDC) transmission system applied to Korea electric power grid. HVDC transmission system for interface lines has been considered as alternative solution for high-voltage AC transmission line in South Korea since constructing new high-voltage AC transmission lines is challenging due to political, environmental and social acceptance problems. However, the installation of HVDC transmission system as interface line in AC grid must be examined carefully. Thus, this paper suggests three scenarios to examine the influences of the installation of HVDC transmission system in AC grid. The power flow and contingency analyses are carried out for the proposed scenarios. Power reserves in metro area are also evaluated. And then the transient stability analysis focusing on special protection scheme (SPS) operations is analyzed when critical lines, which are HVDC lines or high voltage AC lines, are tripped. The latest generic model of HVDC system is considered for evaluating the impacts of the SPS operations for introducing HVDC system in the AC grid. The analyses of proposed scenarios are evaluated by electromechanical simulation.

Keywords: Contingency analysis, Electromechanical simulation, Generic model, Generation rejection scheme, High-voltage AC transmission line, High voltage direct current, Overload capability, Power flow analysis, Power reserve, Special protection scheme, Transient stability

1. Introduction

In Korea electric power grid, metro-area consumes 40% of total generated power even though large-scale nuclear and thermal power plants for base load generation are in sea-side. As the result, the bulk power must be transmitted through interface lines from large-scale power plants in sea-side to the load in metro area. In present, high-voltage AC transmission systems such as of 765 kV and 345 kV lines are backbone of transmission system in South Korea. Although the overall load demands and generation capacities in the Korea electric power grid are increased in every year, constructing of new high-voltage AC transmission lines becomes problematic due to political, environmental and low social acceptance problems [1].

To figure out these problems, the installation of high-voltage direct current (HVDC) is considered as alternative solution as interface line in the Korea electric power grid [2]. HVDC system has ability to control active power with fast-acting power electronic devices resulting the enhancement of AC grid stability. Also, the efficiency of long-distance power transmission by HVDC might be preferable to AC transmission line because the maximum available transmission in AC cable is restricted by technical limitations. Furthermore, HVDC does not increase short-circuit current which may become critical problem in the AC grid. On the other hand, HVDC has disadvantages such as high costs, complexity and restricted install capacity [3]. Therefore, the impacts of HVDC system installation in the AC grid are evaluated by not only its own characteristics on location and operation but also interaction characteristics with AC power system. In other words, the installation of HVDC transmission system in AC grid must be carefully evaluated.

The special protection scheme (SPS) operation provides the necessary controls in a situation of contingency caused by tripping generation units or even big loads (which is called as the under-frequency load shedding), and thereafter reestablishing new stable condition of system [4]. If the capacity of the tripped generators is large, it might cause a cascading stability problem due to a severe mismatch between power generation and load demand. Due to its inherent characteristics of Korea electric power grid, the critical line trip leads to serious stability problem. Furthermore, HVDC transmission system as interface line in the AC grid is carefully analyzed since the fault in the adjacent AC grid would be more problematic. Therefore, the SPS operation analyses for planning transmission system of HVDC system must be analyzed in advance. In the analysis of SPS operation, the generic HVDC model

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is applied to evaluate its impacts on the AC grids because the analysis of SPS operation is focused on the electromechanical characteristics of the power system. As the results, the selection of generic HVDC model is significant. Therefore, the SPS operations are analyzed by considering the latest generic model of HVDC system when critical lines are tripped.

This paper is organized as follows: Section 2 describes the present condition of Korea electric power grid including pre-existing high-voltage AC transmission lines and proposes the scenarios for planning of HVDC transmission system by considering the construction of large-scale power plants in east-sea side. Then, Section 3 analyzes the static analyses for HVDC transmission system installation including power flow, contingency analyses and power reserve analyses in metro area. Thereafter, the analyses of SPS operations for the proposed scenarios are evaluated with the introduction of HVDC system by using the time-domain simulation based on the PSS/E® software in Section 4. Finally, conclusions are given in Section 5.

2. Planning of Transmission System for Constructing Power Plants in East-Coast Side

Large-scale power plants located at sea-side deliver the bulk power to the metro area through interface lines in the Korea electric power grid. The high-voltage AC transmission systems as interface lines are typically composed of 765 kV (thick) and 345 kV (thin) lines, as shown in Fig. 1. The circles with solid line and dotted line represent existing power plants and planned power plants, respectively. The size of circle is proportional to the capacity of power plant and its color represents the type of power plant. The black, red, and blue mean nuclear, thermal, and pumped-hydro, respectively. The load generations of Korea electric power grid are nuclear and thermal generation as shown in Fig. 1.

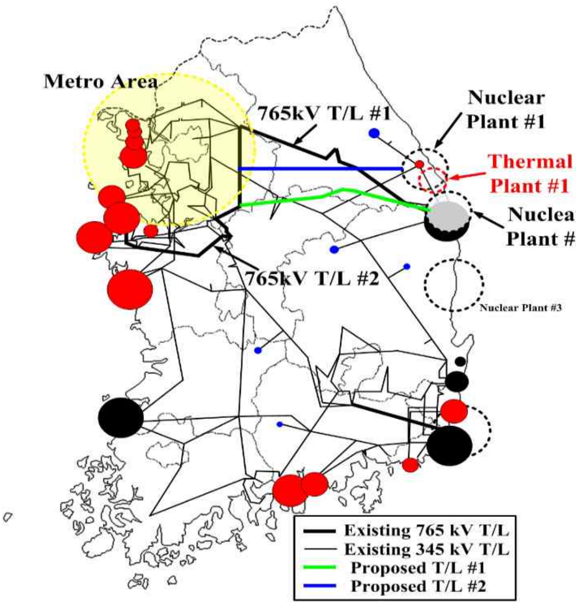

Fig. 1. Planned power plant in east-sea side and the proposed transmission for its installations in the Korea electric power grid

Two pre-exist 765 kV transmission lines has been installed to transmit the bulk power to metro area from east (765 kV T/L #1) and west (765 kV T/L #2) sea-side, respectively as shown in Fig. 1. In addition, most of planned nuclear and thermal power plants (dotted circles shown in Fig. 1) will be constructed in east-sea side. Due to the planned construction of power plants in east-sea side, new interface transmission systems (blue and cyan in Fig. 1) must be installed to deliver the increased bulk power from the planned generation plants.

Table 1 proposes three scenarios of interface transmission system for interconnecting between east-sea side planned power plant and metro area in the Korea electric power grid. SN 1 assumes the whole interface lines are composed only high-voltage AC transmission lines. Two 765kV transmission lines must be installed because of the capacities of two planned power plants. In other words, the proposed line #1 and #2 in Fig. 1 are supposed to 765 kV T/L #3 and #4 in SN 1, respectively. This scenario is base case to evaluate the effect of HVDC transmission system as interface line.

The effects of the HVDC as interface line are analyzed with two scenarios. The capacity of HVDC transmission system is selected as same as the transmitted power by 765 kV transmission line. As the result, the capacity of HVDC transmission system is 6 GW and its voltage level is selected as 500 kV for undergrounding. SN 2 assumes the whole interface lines as HVDC transmission systems. In other words, the proposed line # 1 and #2 in Fig. 1 are supposed to 500kV HVDC #1 and #2 in SN2, respectively. SN 3 in Table. 1 is a compromise plan SN 1 and 2. In SN 3, the proposed line #1 is supposed to 765kV transmission line and the proposed line #2 is supposed to 500kV HVDC system as shown in Fig. 1.

Table 1. Proposed scenarios of interface transmission systems for planned generations

Scenario	Proposed transmission system	Planned power plant
SN 1	765kV T/L # 3 (Proposed T/L #1)	Nuclear Plant #1
	765kV T/L # 4 (Proposed T/L #2)	Nuclear Plant #2
SN 2	500kV HVDC # 1 (Proposed T/L #1)	Nuclear Plant #1
	500kV HVDC # 2 (Proposed T/L #2)	Nuclear Plant #2
SN 3	765kV T/L # 3 (Proposed T/L #1)	Nuclear Plant #1
	500kV HVDC # 2 (Proposed T/L #2)	Nuclear Plant #2

3. Static Analysis of Planning Transmission System

3.1 Power flow analysis

Power flow analysis is a base analysis for inter-connecting transmission system in power system analysis. The power flow analysis is evaluated with practical data used in Korea Electric Power Corporation (KEPCO) based on the 6th basic plan of long-term electricity supply and demand [5]. In addition, the planned nuclear plants are assumed by considering the 2nd master plan for national energy [6]. Based on the above assumptions, all the proposed scenarios have no problems in respect of voltage and transmission line loading. In other words, the scenarios have no problems in terms of power flow analysis regardless of the interface flow by HVDC system.

Table 2. Interface power flows and interface line loadings of SN 1 in N – 1 contingency

SN 1	Base Case	N-1 Contingency			
		765 kV T/L #1	765 kV T/L #2	765 kV T/L #3	765 kV T/L #4
	Interface power flow [MW] (Line loading [%])				
765 kV T/L #1	2853.6 (39.1)	4209.9 (57.7)	2854.4 (39.2)	3385.8 (46.4)	3107 (42.6)
765 kV T/L #2	609.3 (8.4)	612 (8.4)	1107.5 (15.2)	576.5 (7.9)	509.1 (7)
765 kV T/L #3	2708.5 (37.2)	3295.9 (45.2)	2706.1 (37.1)	3608.7 (49.5)	3101.1 (42.5)
765 kV T/L #4	3095.4 (42.5)	3180.9 (43.6)	3092.3 (42.4)	3344.9 (45.9)	4694.1 (64.4)
345 kV T/L #1	117.4 (10.8)	118.5 (10.9)	114.5 (10.5)	120.3 (11.1)	117.1 (10.8)
345 kV T/L #2	1132 (52.1)	1139 (52.4)	1122.4 (51.6)	1135.6 (52.3)	1127.5 (51.9)
345 kV T/L#3	956 (44)	967 (44.5)	950.4 (43.7)	959.5 (44.2)	951.5 (43.8)
345 kV T/L#4	469.8 (21.6)	515.8 (23.7)	466.2 (21.5)	539.6 (24.8)	510.3 (23.5)

Table 3. Interface power flows and interface line loadings of SN 2 in N – 1 contingency

SN 2	Base Case	N-1 Contingency			
		765 kV T/L #1	765 kV T/L #2	HVDC # 1	HVDC # 2
	Interface power flow [MW] (Line loading [%])				
765 kV T/L #1	2818.6 (38.7)	5178.3 (71)	2816.1 (38.6)	3951.8 (54.2)	3874.7 (53.2)
765 kV T/L #2	431.1 (5.9)	376.4 (5.2)	784 (10.8)	349.5 (4.8)	223 (3.1)
HVDC # 1	6000 (100)	6000 (100)	6000 (100)	3000 (100)	6000 (100)
HVDC # 2	6000 (100)	6000 (100)	6000 (100)	6000 (100)	3000 (100)
345 kV T/L #1	74.4 (6.8)	81.5 (7.5)	68.5 (6.3)	83.4 (7.7)	87.1 (8)
345 kV T/L #2	1192.2 (54.9)	1198.8 (55.2)	1185.5 (54.6)	1188.3 (54.7)	1171.4 (53.9)
345 kV T/L#3	993.2 (45.7)	1003.6 (46.2)	989.3 (45.5)	986.9 (45.4)	972.2 (44.7)
345 kV T/L#4	462.6 (21.3)	575.6 (26.5)	459.7 (21.2)	600.6 (27.6)	593.4 (27.3)

3.2 Contingency analysis

In static analysis of power system, bus voltages and transmission line loadings in contingency are also evaluated. The bus voltages and transmission line loading are checked when interface lines are tripped. Thus N-1 contingency (one 765 kV transmission line trip) is simulated with all scenarios.

Table 2 to 4 show the interface power flows and its line loadings of the proposed scenarios against N-1 contingency. The interface line loadings are satisfied with its regulation in all scenarios. Also, the bus voltages in the contingency keep in the operating boundary not exceeding 5 % voltage deviation.

3.3 Power reserve analysis in metro area

In Korea electric power grid, interface power flow from sea-side power plants to metro area is essential for reliable operation. Furthermore, the proposed scenarios assume the additional nuclear power plants will be installed in east-sea side intensifying the characteristic of the Korea electric power grid. Therefore, the analysis of power reserve in metro area in the Korea electric power grid is also evaluated for introducing HVDC system as an interface line. Power reserve in metro area can be easily calculated by

Table 4. Interface power flows and interface line loadings of SN 3 in N – 1 contingency

SN 3	Base Case	N-1 Contingency			
		765 kV T/L #1	765 kV T/L #2	765 kV T/L #3	HVDC # 2
	Interface power flow [MW] (Line loading [%])				
765 kV T/L #1	2794.7 (38.3)	4886.4 (67)	2794.2 (38.3)	3287.8 (45.1)	3664 (50.3)
765 kV T/L #2	614.1 (8.4)	596.3 (8.2)	1123.1 (15.4)	509.3 (7)	560.8 (7.7)
765 kV T/L #3	2961 (40.6)	3156.2 (43.3)	2956.9 (40.6)	4631.6 (63.5)	3369.1 (46.2)
HVDC # 2	6000 (100)	6000 (100)	6000 (100)	6000 (100)	3000 (100)
345 kV T/L #1	72.1 (6.6)	79.1 (7.3)	74.7 (6.9)	81.6 (7.5)	80 (7.4)
345 kV T/L #2	1133.2 (52.2)	1141.7 (52.5)	1123.9 (51.7)	1131.1 (52.1)	1137.5 (52.3)
345 kV T/L#3	956 (44)	967.8 (44.5)	950.6 (43.7)	953 (43.9)	960.4 (44.2)
345 kV T/L#4	442.1 (20.3)	532.6 (24.5)	438.2 (20.2)	508 (23.4)	556.3 (25.6)

Table 5. Power reserve in metro area with the proposed scenarios

Scenario	Peak load demand [MW]	Installed capacity [MW]	Interface flow margin [MW]	Power reserve in metro area [MW](ratio)
SN 1	46,170	31,569	22,860	8,259 (17.89%)
SN 2	46,170	31,569	23,277	8,676 (18.79%)
SN 3	46,170	31,569	22,477	7,876 (17.06%)

$$P_{\text{Reserve}} = P_{IFM} + P_{\text{installed capacity}} - P_{L\_paek} \qquad (1)$$

where $P_{Reserve}$, P_{IFM}, $P_{installed\ capacity}$ and P_{L_peak} represents the power reserve in target area, interface flow margin from other areas, installed capacity of power plant in target area and peak load demand in target area, respectively [7]. Interface flow margin is maximal available interface power flow through interface lines by using the critical point of PV curve.

The interface power flow margin is calculated for each scenario shown in Table 5. It is clearly shown that the power reserves in metro area of all scenarios are enough for reliable operation of Korea electric power grid for preparing unexpected events.

4. SPS operation analysis of Planning Transmission System

The Korea electric power grid is characterized with bulk power transfer through interface lines. Thus, interfaces lines play important roles by transmitting power from east-sea side power plants to the load in the metro area. As the result, critical line trip might cause cascaded large-scale blackout in the Korea electric power grid. Therefore, the analyses of the SPS operations of critical line trips for the proposed scenarios are essential to evaluate reliable operation. Consequently, the dynamic stability of this study focuses on the SPS operation analysis for critical line trip of east-sea side.

4.1 Case study – SN 1

Table 6 shows the SPS operation analyses of critical line trip on SN 1.

In SN 1, the generated power from planned capacities is delivered by only AC transmission lines (765 kV T/L #3 and #4). As the results, most of SPS operations on critical line trip are stabilized without generation trip. When two lines of 765 kV T/L #3 are tripped, one generator must be tripped for stabilizing the power system. In other words, if the interface lines for planned capacity are established with only high-voltage AC transmission lines, the transient stability of critical line trips is guaranteed by one generator trip.

Figs. 2 and 3 show that the generator angles and bus voltages responses, respectively, when 765 kV T/L #3 two-lines are tripped with and without generation trip. If the proper number of generators is not tripped in the critical line trip, the power system loses its stability shown in Fig. 2(a) and 3(a). However, if the proper number of generators is tripped, the power system keeps stable as shown in Fig. 2(b) and 3(b). When the interface lines are established with only high-voltage AC transmission lines, the power transfer capability of high-voltage AC transmission system enables sudden increase of delivering power shown in Fig. 4.

Table 6. SPS analyses of critical line trip on SN 1

Scenario	Critical line trip	Stability
SN 1	765 kV T/L #1	Stabilized without generator trip
	765 kV T/L #3 (proposed)	
	765 kV T/L #4 (proposed)	Stabilized with 1 generator trip

4.2 Generic model of HVDC system for analyzing SPS operations

In general, dynamic analysis in electric system depends on area of consideration of time scales and frequency bands. The SPS operation with large-scale power system is analyzed with balanced Root-Mean Square (RMS) simulation focusing on electromechanical characteristics in terms of simulation speed. Therefore, the case studies

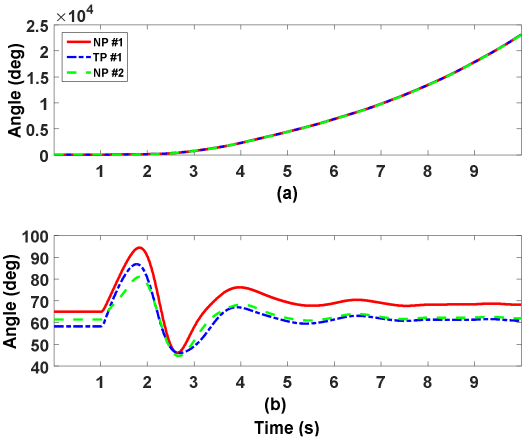

Fig. 2. Generator angle responses when two 765 kV T/L #3 lines are tripped: (a) without generator trip; (b) with 1 generator trip

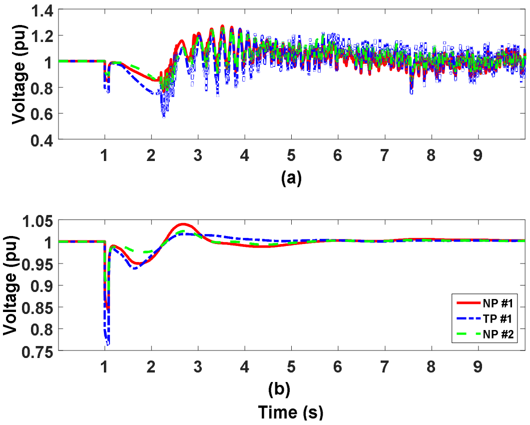

Fig. 3. Bus voltage responses when two 765 kV T/L #3 lines are tripped: (a) without generator trip; (b) with 1 generator trip

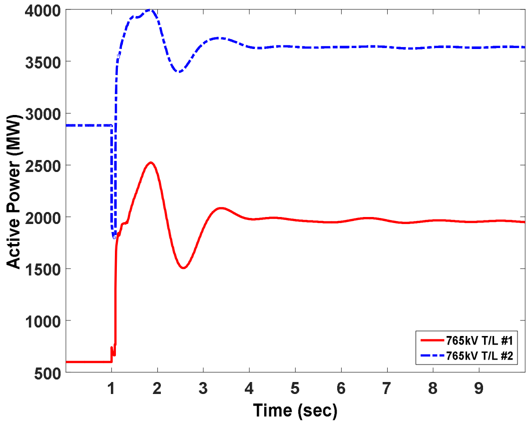

Fig. 4. Transmitted power responses with 1 generator trip when two 765 kV T/L #3 lines are tripped

carried in this section are simulated balanced-RMS simulation based program. However, balanced-RMS simulation is calculated with only symmetric component by omitting the internal dynamics of converter controller since the converter design is quite complex, nonlinear, and its bandwidth is beyond the electromechanical simulation. As the result, the generic HVDC model is used for evaluating the SPS operations considering HVDC system as interface line. The equations for normal regulating control of the converter are represented by (2) to (7) [8].

$$V_{dcr} = N_r\left(\frac{3\sqrt{2}}{\pi}E_{acr}\cos(\alpha) - \frac{3X_{cr}I_{dc}}{\pi} - 2R_{cr}I_{dc}\right) \tag{2}$$

$$\mu_R = \cos^{-1}\left(\cos(\alpha) - \frac{\sqrt{2}I_{dc}X_{cr}}{E_{acr}}\right) - \alpha \tag{3}$$

$$I_{acr} = \frac{\sqrt{6}N}{\pi}I_{dc} \tag{4}$$

where V_{dcr}, E_{acr}, I_{acr}, I_{dc}, N_r, R_{cr}, and X_{cr} are rectifier-side dc line voltage, open circuit voltage, AC line current, dc line current, number of bridges, resistance and reactance of converter transformer, respectively. And α and μ are rectifier firing delay angle and overlap angle, respectively.

$$V_{dci} = N_i\left(\frac{3\sqrt{2}}{\pi}E_{aci}\cos(\gamma) - \frac{3X_{ci}I_{dc}}{\pi} - 2R_{ci}I_{dc}\right) \tag{5}$$

$$\mu_I = \cos^{-1}\left(\cos(\gamma) - \frac{\sqrt{2}I_{dc}X_{ci}}{E_{aci}}\right) - \gamma \tag{6}$$

$$I_{aci} = \frac{\sqrt{6}N}{\pi}I_{dc} \tag{7}$$

where V_{dci}, E_{aci}, I_{aci}, I_{dc}, N_i, R_{ci}, and X_{ci} are inverter-side dc line voltage, open circuit voltage, AC line current, dc line current, number of bridges, resistance and reactance of converter transformer, respectively. And γ and μ are inverter margin angle and extinction angle, respectively.

Table 7. SPS analyses of critical line trip on SN 2

Scenario	Critical line trip	Stability
SN 2	765 kV T/L #1	Stabilized with 3 generators trip
	HVDC # 1 (proposed)	Stabilized without generator trip
	HVDC # 2 (proposed)	

This paper analyzes the SPS operations with the latest generic model of HVDC system, which provides not only detailed dc equivalent circuit but also various control algorithms to elaborate internal dynamics of HVDC system. Furthermore, voltage dependent current order limit (VDCOL) algorithm is implemented based on *V-I* characteristics of HVDC system. The latest generic model of HVDC system is different from former generic HVDC model, which is assumed to operate instantaneously when the disturbance occurs in the AC grid. In other words, if the voltage drops to predefined threshold, the HVDC operates blocking or bypassing by assuming the firing and extinction angle are updated directly. [9].

4.3 Case study – SN 2 and SN 3 without HVDC control

Table 9 summarizes the SPS analyses of critical line trip on SN 2 with the latest generic model of HVDC system.

In SN 2, the proposed transmission lines are assumed with the HVDC systems (HVDC #1 and #2) as interface lines. Therefore, 765 kV T/L #1 plays an important role in transmitting power from east-sea side power plants to metro area as shown in Fig. 1. Different from high-voltage AC transmission line shown in Fig. 4, sudden increase of transmitted power by the HVDC system is difficult without proper control in the HVDC system. As the result, the most severe case of critical line trip is 765 kV T/L #1 case in SN 2.

Figs. 5 and 6 show the responses of generator angle and bus voltage when 765 kV T/L #1 two-lines are tripped with 2 generators trip and 3 generators trip in SN 2, respectively.

The active and reactive power responses of HVDC system are shown in Fig. 7(a) and (b) when 765 kV T/L #1 two-lines are tripped with 3 generators trip. The rectifier and inverter of the generic HVDC model describe with the VDCOL characteristics of HVDC and detailed internal dynamics. The DC voltage and current also are shown in Fig. 7(e) and (f), respectively. The corresponding α and γ, firing angle for rectifier and extinction angle for inverter are shown in Fig. 7(c) and (d).

Table 10 summarizes the SPS analyses of critical line trip on SN 3 with the latest generic model of HVDC system.

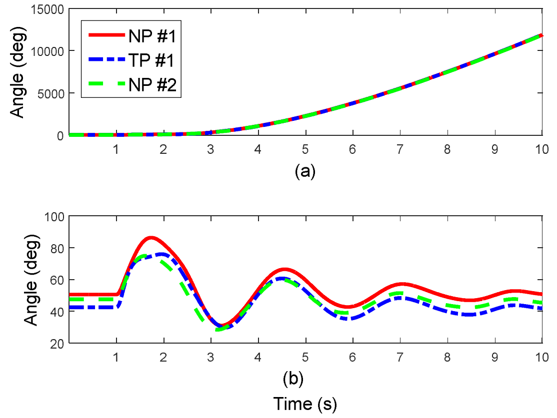

Fig. 5. Generator angle responses in SN 2 when 765 kV T/L #1 two-lines are tripped: (a) 2 generators trip; (b) 3 generators trip

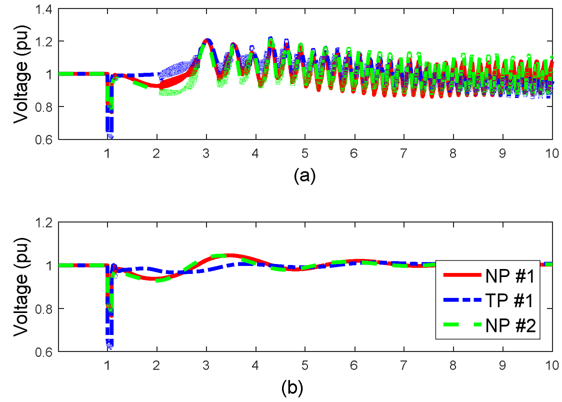

Fig. 6. Bus voltage responses in SN 2 when 765 kV T/L #1 two-lines are tripped: (a) 2 generators trip; (b) 3 generators trip

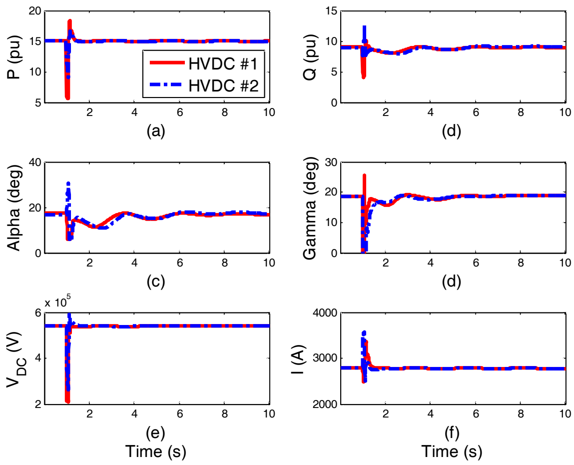

Fig. 7. HVDC responses when 765 kV T/L #1 two-lines are tripped with 3 generators trip: (a) active power; (b) reactive power; (c) alpha; (d) gamma; (e) DC voltage; (f) DC current

Table 10. SPS analyses of critical line trip on SN 3

Scenario	Critical line trip	Stability
SN 3	765 kV T/L #1	Stabilized without generation trip
	HVDC # 1 (proposed)	
	765 kV T/L #3 (proposed)	Stabilized with 1 generator trip

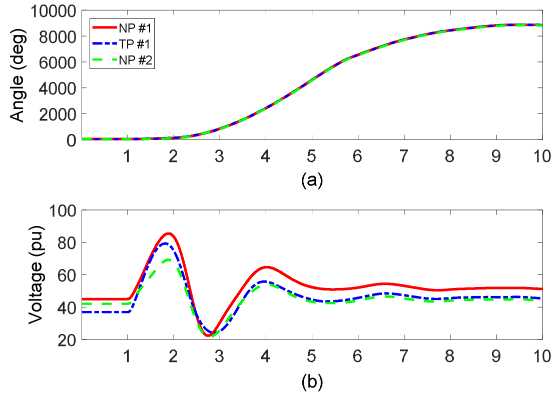

Fig. 8. Generator angle responses when 765 kV T/L #3 two-lines are tripped in SN 3: (a) without generator trip; (b) 1 generator trip

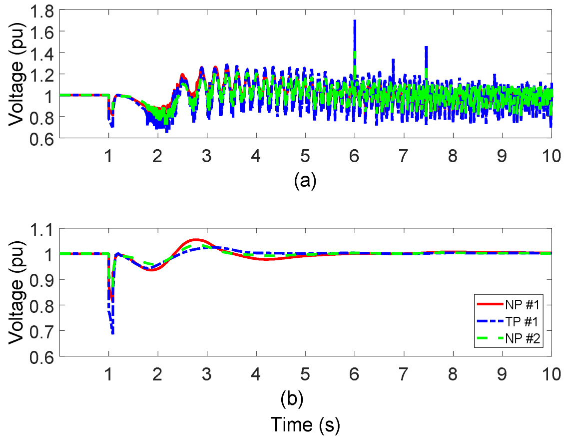

Fig. 9. Bus voltage responses when 765 kV T/L #3 two-lines are tripped in SN 3: (a) without generator trip; (b) 1 generator trip

In SN 3, the proposed transmission lines are assumed with one high-voltage AC transmission line (765 kV T/L #3) and one HVDC system (HVDC #2), respectively. Different from SN 2, SN 3 is a compromise plan of SN 1 and SN 2. Thus, 765 kV T/L #1 is less significant compared to SN 2 because 765 kV T/L #3 can increase when 765 kV T/L #1 two-lines are tripped. As a result, the most severe case of critical line trip is 765 kV T/L #1 case in SN3 since HVDC #1 cannot increase its transmitted power by HVDC system without proper control.

Figs. 8 and 9 show the responses of generator angle and bus voltage when 765 kV T/L #3 two-lines are tripped without generator trip and 1 generator trip in SN 3, respectively. It is verified that the number of tripping generators are reduced in SN 3 compared to SN 2.

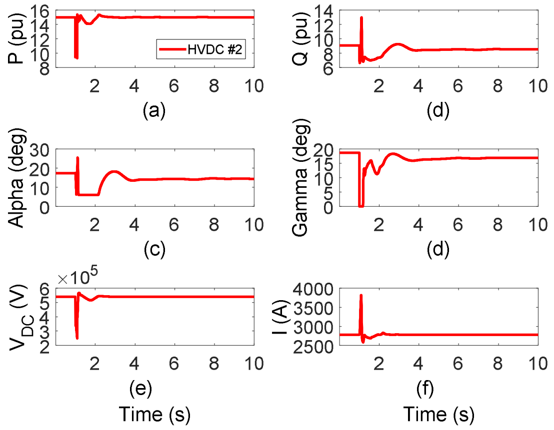

Fig. 10. HVDC responses when 765 kV T/L #3 two-lines are tripped with 1 generator trip: (a) active power: (b) reactive power; (c) alpha; (d) gamma; (e) DC voltage; (f) DC current

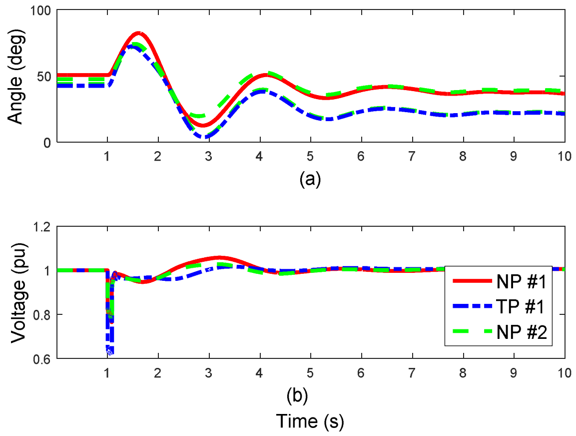

Fig. 11. (a) Generator angle; (b) Bus voltage when 765 kV T/L #1 two-lines are tripped with 2 generators trip by applying overload capability

Likewise Fig. 7, The HVDC responses in the most severe case in SN 3 are shown in Fig. 10 when 765 kV T/L #3 two-lines are tripped with 1 generator trip.

4.4 Case study – SN 2 with HVDC control

Furthermore, the HVDC system also has ability to control the active power easily with the help of fast-acting of power electronics. As the results, the proper control actions of HVDC system enable overload capability. Therefore, the number of generation trip can be reduced with proper control of HVDC system as an interface line. With the proper control of HVDC system, the number of generation trip is effectively reduced by increasing transmitted power after the fault like the high-voltage AC transmission line in SN 1.

Fig. 11 shows the responses of generator angle and bus voltage with the tripping of two generators by applying overload capability of HVDC model when 765 kV T/L #1 two-lines are tripped in SN 2. The number of generator trip is reduced by two generators owing to the HVDC overload capability.

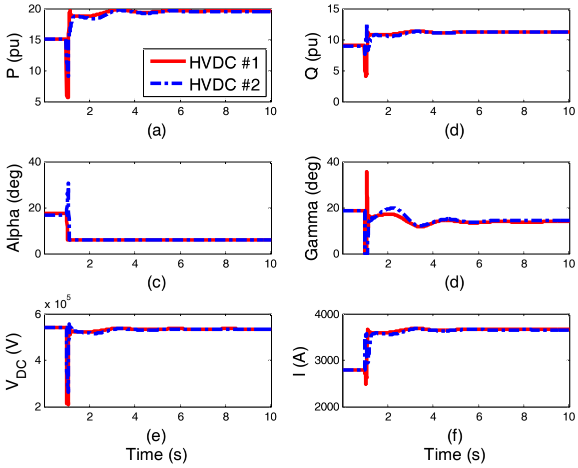

Fig. 12. HVDC responses when 765 kV T/L #1 two-lines are tripped with 2 generators trip by applying overload capability: (a) active power; (b) reactive power; (c) alpha; (d) gamma; (e) DC voltage; (f) DC current

The active and reactive powers of detailed HVDC systems are increased with the proper control of HVDC system as shown in Fig. 12(a) and (b). By controlling α, firing angle, for rectifier to its minimum its shown in Fig. 12(c), the DC currents of HVDC systems in Fig. 12(f) are increased to the aimed value resulting overload capability. Likewise, γ, extinction angle, for inverters is controlled as low value compared to its pre-fault condition as shown in Fig. 12(d). As the results, the reactive powers are increased to compensate bus voltage of adjacent grid after fault. However, DC voltages of HVDC systems keep its value since HVDC is operated with current control.

5. Conclusion

This paper analyzed the introduction of high-voltage direct current (HVDC) system as an interface line in the Korea electric power grid. Transmission line planning needs sufficient pre-studies for reliable and stable operation of power system. Especially, HVDC system as an interface line in AC grid requires more deliberate examination in advance. Therefore, the static analysis and special protection scheme (SPS) operation were investigated for its validities of the proposed scenarios. SN 1 represented as base case composed of high-voltage AC transmission lines as interface lines. SN 2 was established with two HVDC systems as and SN 3 was a compromise plan of SN 1 and 2, which means that one high-voltage AC transmission line and one HVDC system were assumed as interface lines, respectively. For the all the proposed scenarios, power flow, contingency analysis and power reserve analyses in metro area are verified. And then, SPS operations for critical line trip were analyzed by considering the proper number of generation trip. In particular, the overload capability of HVDC system with proper control was analyzed for reducing the number of generation trip.

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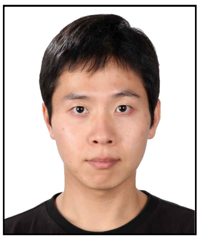

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