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Impact Examination on Power System Transient Stability Considering HVDC Overload Capability

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Abstract

Background/Objectives: The application of HVDC system is increasing due to economical large-capacity long-distance transmission, asynchronous linkage, and renewable energy source linkage, and HVDC operation point decision is becoming a research issue for power system engineers.

Methods/Statistical analysis: The operating point of the HVDC should be as close to the rated rating as possible in terms of plant utilization, but this would make the system vulnerable to additional power transfer requirements. In this paper, we studied the improvement of the power system transient stability by transmitting additional power through the overload control of HVDC system.

Findings: In this paper, we showed that large disturbance information such as AC line dropping of the system could be recognized through the communication system like SPS and triggered overload control to solve the unbalance of power by supplying additional power for a short time. The effectiveness of the proposed method was verified using the actual KEPCO transmission system in Korea and the planned HVDC system model.

Improvements/Applications: In the future, it is expected that the proposed method can be developed and applied to HVDC to be installed in Korea to improve both facility utilization and stability.

Keywords: *HVDC system, overload control, transient stability, N-1 contingency, transmission system*

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I. Introduction

In recent times, construction of large-capacity long-distance AC lines is becoming more and more difficult due to social problems such including landscape, environment, and land compensation problems. As an alternative, there is a HVDC system installation with a small right-of-way (ROW). The same power transmission requires much less area and quantity of tower towers of DC transmission than AC transmission lines. The DC voltage is about 70% smaller than the maximum value of the AC voltage, so that it is easy to insulate the device and the voltage is low, so that the number of insulators and the height of the steel tower installed in each device can be reduced. HVDC is economically advantageous for long distance transmission compared to AC transmission [1].

The HVDC consists of two converters called rectifiers and inverters connected by a DC link, which transfers power under the control of the converter. When appropriate control is applied, it increases the flexibility of the system as compared to AC lines that were not previously controllable. However, the HVDC system can have a significant adverse effect if not properly controlled in the system stability point of view. Because the power system has to be balanced not only at normal times but also when disturbances occur. When the disturbance occurs, it finds an appropriate new driving point without any control.

When the power system was introduced, the only dynamically controllable facility in the system was a generator. The power electronics-based facilities such as renewable energy resources (RES), energy storage system (ESS) have been increasing recently [2].HVDC and FACTS are facilities that provide flexibility in typical power transmission systems [3]. However, as explained above, proper control can help the operation of the power system.The control method of facilities for improving the stability of AC and DC system has been studied for a long time [4].Several researches to increase the flexibility of the system by using installed HVDC are actively being conducted [5].

The thyristor element that is the basis of the LCC type HVDC is robust and resistant to failure caused by overcurrent. Therefore, LCC HVDC can temporarily flow a current higher than the rated value, which is called an overload capability [6, 7].In this paper, we analyze the effect of the HVDC on the system stability according to how the HVDC operates when the nearby AC line accidents and trips occur in the grid installation case of large capacity LCC HVDC. In this case, we have analyzed through power system dynamic simulations that transient stability can be improved by applying overload control of HVDC.

II. HVDC control

General control configuration

The HVDC system consists of two converters and a DC link between them, as shown in Figure 1. In this case, a converter that absorbs active power from an AC system is called a rectifier, and a converter that supplies active power to the opposite AC system is called an inverter. Each converter operates normally in a steady-state mode such as constant voltage control and constant current control in accordance with its control purpose to transfer the required power stably [8].

At this time, real power, DC current or DC voltage becomes the control target,the rectifier changes the firing angle and the inverter changes the gamma anglerapidly to maintain the control.The transfer function of these control blocks and the steady state equations representing the circuitry of the HVDC system enable HVDC modeling for grid analysis.

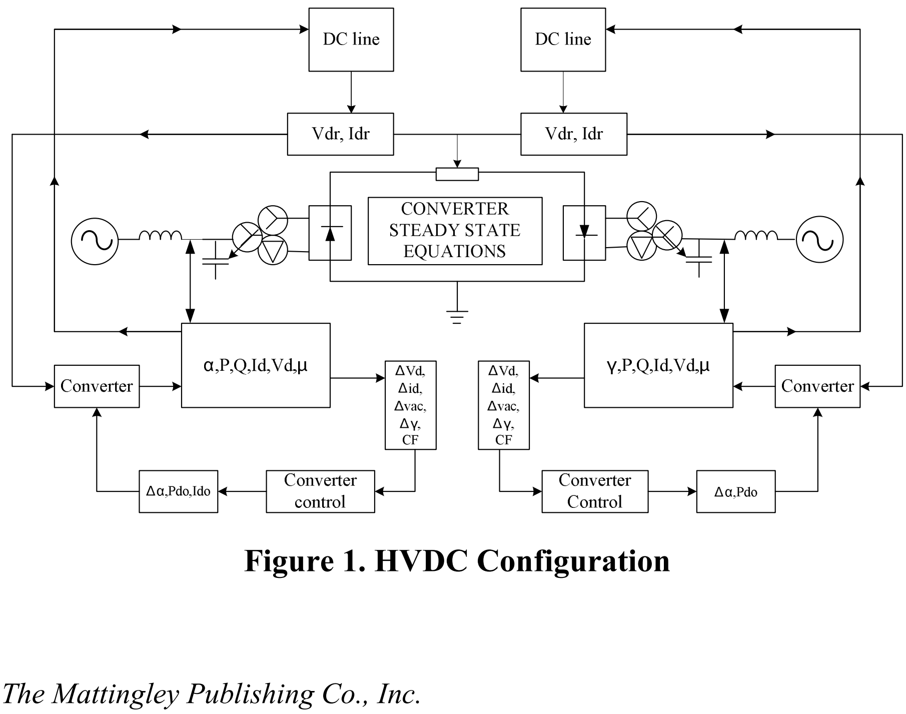

Figure 1. HVDC Configuration

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The active power and the reactive power determined by the internal variables of the HVDC system can be derived from the system parameterssuch as AC voltage (E_{acr}), DC current(I_{dc}) and converter transformer impedances (R_{cr} , X_{cr})in (1) and (2). The converter equation for rectifier side is as follows:

$$P_{acr} = N_r \left(\frac{3\sqrt{2}}{\pi} E_{acr} \cos\alpha - \frac{3}{\pi} X_{cr} I_{dc} - 2RcrIdc \times Idc \qquad (1)$$

$$Q_{acr} = P_{acr} \times \sin\phi_R \qquad (2)$$

$\sin\phi_R$, which is a correlation between active power and reactive power, can be obtained from the firing angle (α) and the overlap angle (μ_R) as follows.

$$\tan\phi_R = \frac{2\mu_R + \sin 2\alpha - \sin 2(\mu_R + \alpha)}{\cos 2\alpha - \cos 2(\mu_R + \alpha)} \qquad (3)$$

$$\mu_R = \cos^{-1}\left(\cos\alpha - \frac{\sqrt{2} I_{dc} X_{cr}}{E_{acr}}\right) - \alpha \qquad (4)$$

HVDC overload control

As shown in Figure 2, overload control is to temporarily increase the power transfer of HVDC by using the overcurrent resistance of the thyristor element.Therefore, when a nearby line is tripped and there is no additional power transmission line, HVDC can temporarily increase the power transmission to maintain the total power transfer.However, due to thermal problems, overload capability cannot be continuous, so after a certain time, the mismatch must be resolved by adjusting the power generation of the power transmission station or the power station [9].

The power mismatch ($p \times dt$)accelerate/decelerate generator speed, eventually, some generators may cause transient stability problems due to synchronous outage [10]. Consequently, the overload control can be kept the power mismatch below a certain level, the generator trip can be reduced by a special protection scheme.

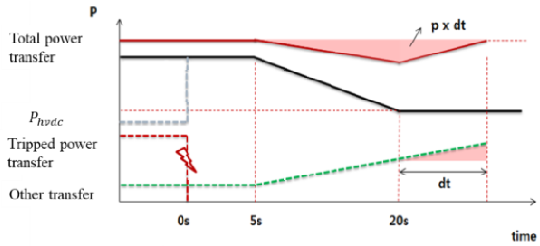

Figure 2. HVDC overload control

In case of a disturbance, a kind of auxiliary controller transmits a command as a master controller to the converters of both sides according to the condition of the system. The overload controller serves to change the setpoint so that both converters transmit power greater than the amount of active power normally delivered.

As shown in Figure 3, overload controllers can be added in addition to the general control loop.It operates by increasing the current order to a predefined overload operating point by detecting an accident from the AC system or an accident of the HVDC internal system.Therefore, the modification of the controller is not complicated, and if the heat capacity is kept well, the contribution to the system stability of HVDC can be greatly increased.

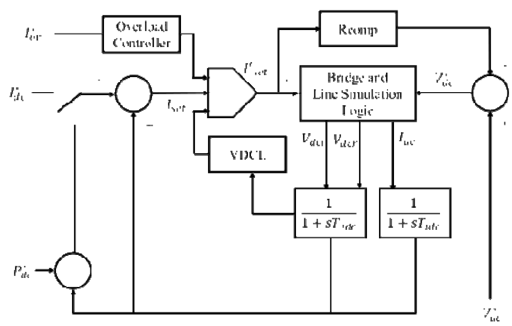

Figure 3. HVDC overload controlconfiguration

III. Case study

System configuration

In Korea's power system, an ultra-high voltage 765kV AC power transmission system has been responsible for the huge power flow as a back-bone power grid.However, the construction of additional high voltage AC lines has become difficult due to problems such as high fault current and social acceptability [11]. As an alternative, HVDC, which is advantageous in terms of right-of-way, was considered and planned.Especially, large-scale nuclear power plants are located on the east coast of Korea, and additional construction of transmission lines for power transfer is necessary.

In this paper, the steady state operating point is set to 3.5GW by modeling the planned 4GW HVDC system.The contingency scenario simulates a three-phase line-to-ground fault at the receiving end system and parallel 765kV line outage as shown in Figure 4. The 765kV two circuittrip is one of the most serious contingency scenarios in Korea.

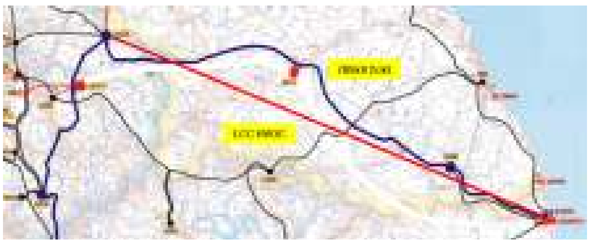

Figure 4. East Coast - Singapyeong HVDC project

Simulation results

In this paper, we applied overload control in case of the parallel 765kV AC transmission line trip contingency. As shown in Figure 5, HVDC system is blocked for a short time due to sudden voltage drop caused by AC accident at 0.5s simulation time. In this case, the blocking of HVDC causes temporary overvoltage about 1.2pu due to the remaining capacitors in the converter station bus.

After confirming that the AC system voltage has recovered, the HVDC can increase the transmission power at a constant ramp rate to reach 4.5 GW(2.25GW*2) depending on the overload control. The amount of power is not steady since the AC bus voltage fluctuation. The results show that the AC system voltage has a great influence on the stable power transfer of HVDC.

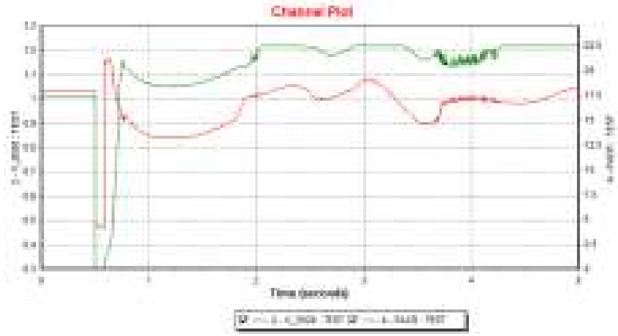

Figure 5. The AC bus voltage and active power transfer of HVDC

The system's angle spread is a measure of the maximum and minimum differences in the phase angles of the generators in the system. If this value increases greatly, it may lead to transient instability such as synchronous outage. Therefore, it is advisable to keep the angle spread as small as possible in case of an accident, and to reduce the angle spread by using overload control as shown in Figure 6.

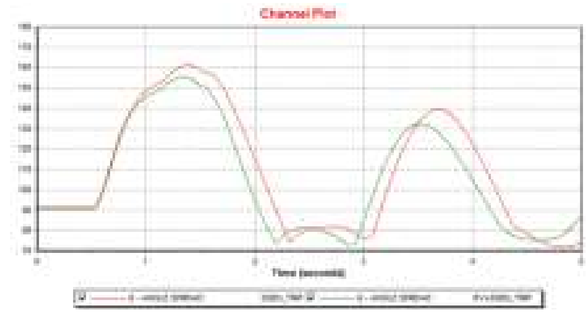

Figure 6. Angle spread of the system

The longer the holding time, the higher the amount of overload power can contribute to the transient stability, but this increases the manufacturing cost of the HVDC.Therefore, in the feasibility assessment, it is necessary to determine the appropriate overload capability through the application of the same simulation scheme and methodology.

IV. Conclusion

In this paper, it is proposed to apply HVDC overload control to contingency such as parallel AC line trip, and its effectiveness is proved by using real Korean power systemplanning data.HVDC system with overload capability shows the improvement of power transient stability by reducing the angle spread of the generators in the system through the dynamic simulation. It can be estimated that even a small rated HVDC installation can reduce the possibility of transient instability through overload control in an emergency.

As shown in the simulation results, the contribution to transient stability may vary depending on the overload capabilityand control design.Based on this study, it is possible to study how to design economically reasonable overload capability characteristics considering various system situations. The study on the various capability characteristics and the method to stabilize the stable control performance would be performed in the future work.

V. Acknowledgment

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