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New HVDC Interaction between AC networks and HVDC Shunt Reactors on Jeju Converter Stations

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ABSTRACT

This paper deals with the new HVDC interaction which was observed in the Jeju-Haenam HVDC system. The interaction is not from a system malfunction or controller loop problem but from the change of AC network scheme and the network operating condition. We have found that the interaction is caused by the voltage oscillation between synchronous compensator and HVDC shunt reactor. We analyzed the cause of the interaction and suggested a solution.

Keywords: HVDC, Reasonance

1. Introduction

Generally **"Interaction"** in a power system means the interaction with the generating unit excitation and prime mover controls, and with nearby HVDC converter controls. The interaction with a nearby HVDC converter first came to light on the Square Butte DC system in North Dakota, and it showed that the HVDC converter can exert a de-stabilizing influence on turbine-generator torsional mode of vibration. The sub-synchronous torsional interaction between an HVDC converter and a turbine-generator may be manifested in several forms:

- Interaction through the HVDC current regulator
- Interaction through HVDC supplementary controls
- HVDC converter mis-operation

The Jeju-Haenam 300MW HVDC system in Korea, which was completed by submarine in 1998, conveys relatively cheap electric power through underwater 100 km DC cables from the Haenam S/S to the Jeju S/S in Jeju Island. This 12 pulse bi-polar system normally conveys 150 MW which corresponds to 60% of the total load demand on Jeju Island. The HVDC system basically adopts inverter operation at the Jeju side in which current control is used as the main control and mean .γ control as the secondary control. At the Haenam side where the rectifier operation is adopted, voltage control is used as the main control and current control is used as the secondary control.

Reactive power compensation for the Jeju side is done by condenser banks in steady state and synchronous condensers provide transient reactive power compensation, but none is used at the rectifier side. In the design stage,

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the Jeju-Haenam HVDC was designed to supply full power to Jeju Island of zero inertia (no synchronous machines). But a synchronous compensator in the receiving system was introduced, since a conventional inverter cannot re-start after even a momentary interruption of DC power. However, several steam turbine-generator systems have been installed because of the excessively increasing demand for power on Jeju Island, and it led to the interaction between the HVDC system and a synchronous compensator. The interaction that was observed in the Jeju HVDC is the relation between the HVDC filter and synchronous compensator, which differs from the interaction reported until now.

2. Review of the Jeju HVDC System

2.1 Purposes of a synchronous Compensator

The purposes of a synchronous compensator are as follows:

2.1.1 To enhance the short circuit ratio of the AC network and the inertia of the AC network.

When a synchronous compensator is connected to the HVDC system, it is connected as in Figure 1. Figure 1(a) illustrates how to connect a synchronous compensator to the HVDC link. Figure 1(b) illustrates how to connect a phase modifier to the 3rd winding between the primary windings. In both cases, an inductance is connected parallel to the system, so the value of SCR of the entire system tends to increase. Since the synchronous compensator is a rotating device, the momentum of inertia of the system also increases.

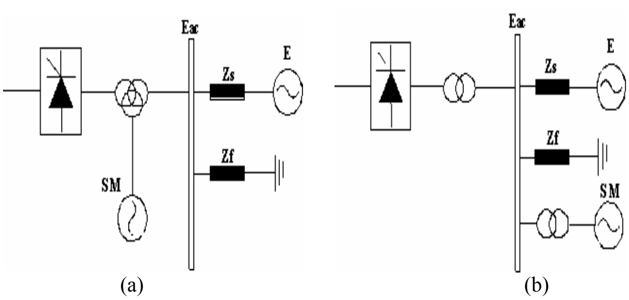


Fig. 1 System Connection for a Synchronous Compensator

2.1.2 To make turn-off voltage in a black-start condition

A conventional HVDC system using thyristor cannot be extinguished itself because of thyristor characteristics. Therefore, a synchronous compensator that can make turn-off voltage is needed.

2.1.3 Compensator for the dynamic reactive power

The HVDC converter draws a lagging reactive current from the AC system, of the order of 0.6 of real current, which must be supplied from another source. Where the AC system is large compared with the DC link, it may have an inherent capability to supply the remainder. But for other cases, s synchronous compensators must be added for this purpose.

2.1.4 To derive the frequency signal in a black-start condition

In the case of zero inertia, the accurate frequency signal is needed to operate the HVDC system in frequency mode. The frequency signal is not from an AC bus-bar but from a synchronous compensator shaft.

2.2 Switching Strategy of the Jeju-Haenam HVDC system During Synchronous Compensator Reactive Power Limiting Condition

The Jeju HVDC system absorbs the reactive power in the order of 70% of the real power and AC harmonic filters and shunt reactors provide part of this reactive power.

Figure 2 shows the AC filters and shunt reactors switching sequence according to the HVDC transferring power. In Figure 2, the switching hysteresis band is used to prevent a chattering at the filter switching.

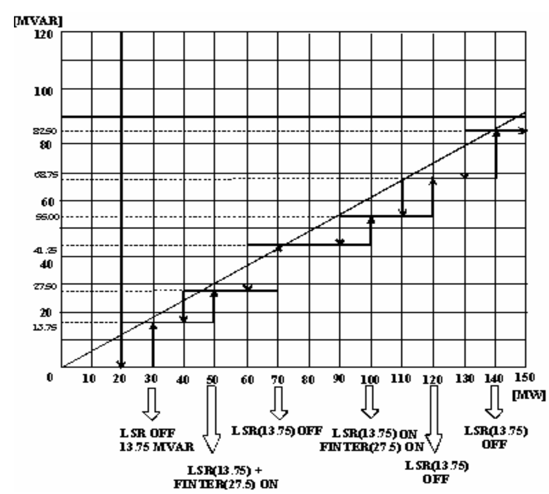


Fig. 2 Filter Switching Condition of the Jeju HVDC

Also, the AC filters and shunt reactors of the Jeju HVDC system are coordinated with a synchronous compensator. The switching strategy of the Jeju HVDC during the synchronous compensator reactive power limiting condition is as follows;

1. If the reactive power absorption exceeds 10[MVAR] then the master control of the HVDC system shall energize the shunt reactors associated with that synchronous compensator.
2. If the reactive power absorption exceeds 10[MVAR] and all associated shunt reactors are already energized then the master control shall de-energize one filter bank provided there are never less than 1×double filter + 1×High pass filter banks energized.
3. The reactive power absorption "corrective actions" shall be reversed by the master when the reactive power generation by the synchronous compensator exceeds +30 [MVAR].
4. If the reactive power generation by the synchronous compensator exceeds +40 [MVAR] then the master shall energize an additional filter bank by switching the next bank in sequence.
5. The reactive power generation "corrective actions" shall be reversed by the MC when the reactive power generation by the synchronous compensator is less than 0 [MVAR].

Figure 3 shows a Jeju HVDC network diagram and the numbers of Figure 3 are the switching sequence to energize the HVDC system and AC network. In Figure 3, the first switching breaker is for the synchronous compensator and the purposes of the synchronous compensator are to make turn-off voltage and to supply the electric power to the HVDC valve and HVDC control room.

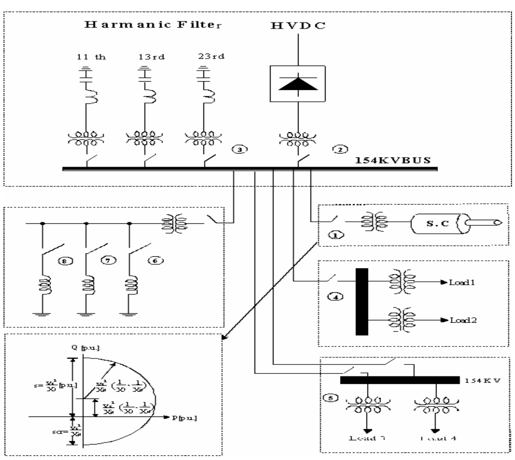


Fig. 3 Jeju HVDC Diagram in Black-Start Condition

3. Review of the Jeju HVDC System Interaction

3.1 Jeju HVDC system Interaction

The meaning of the HVDC interaction in this paper is the relation between the HVDC shunt reactor switching and a synchronous compensator reactive power limiting condition above stated.

In the Jeju HVDC design stage, HVDC was designed to supply the total power needs of Jeju Island, and other synchronous machines in Jeju Island were not considered. Due to the increasing power demand in Jeju Island, the additional generators have been installed. The purposes of the synchronous compensator were changed to supply not only the reactive power of the HVDC but also the reactive power of the AC network. Figure 4 shows a Jeju HVDC diagram with additional generators. The HVDC interaction between a synchronous compensator and shunt reactors has been observed. At that time, operating conditions of the AC network and the synchronous compensator are as follows;

* Total AC Power: 334[MW]
* HVDC: 140[MW]
* Synchronous compensator operating condition: 11[MVAR]
* Generators Power: 194[MW]

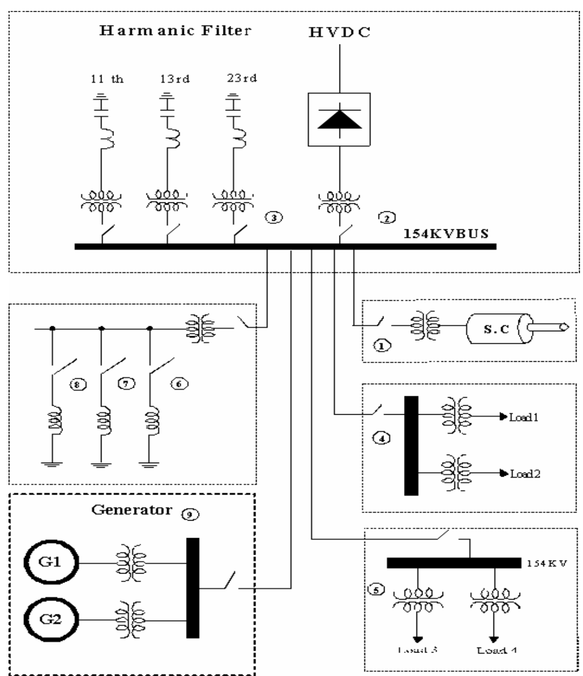
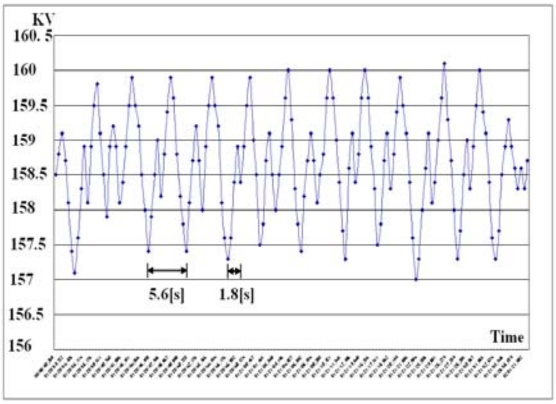
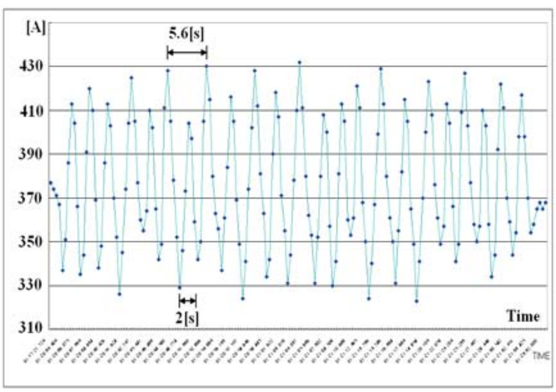


Fig. 4 Jeju HVDC Diagram in Modified Condition with Generators

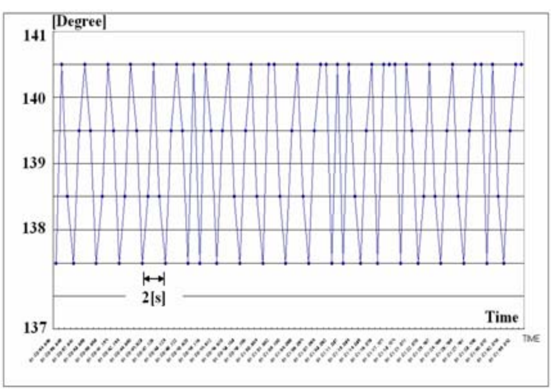
Figure 5 shows the interaction waveform from the Jeju HVDC. Figure 5 a) shows the AC voltage oscillation and the interaction frequency is 0.4[Hz] ~0.55 [Hz]. The interaction frequency depends on the response time of the shunt reactor, AC network impedance and the synchronous compensator. Also, in Figure 5 a), the voltage oscillation gap, ΔV is about 3kV and it is determined by the AC network impedance (Short Circuit Ratio: SCR).



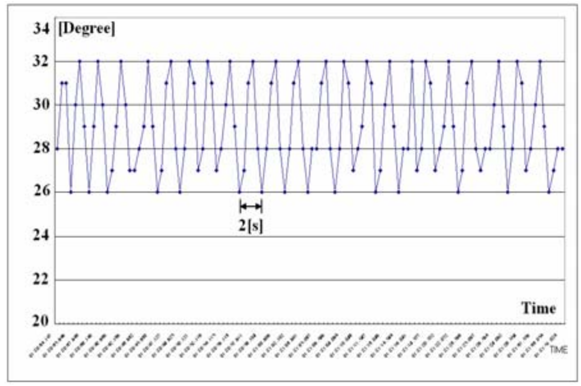
(a) 154kV Voltage



(b) DC Current



(c) Alpha



(d) Gamma

Fig. 5 HVDC interaction waveform in the Jeju HVDC (Each figures time cannot be corrected)

This phenomenon may cause a serious situation such as a sub synchronous resonance and fatigue at the turbine-generator. Figure 5 b) and c) are HVDC DC current waveform and alpha response waveform respectively. Figure 5 d) shows the gamma response waveform and the gamma value is 26 degree in steady state.

3.2 Suggested Solution and HVDC Operation Condition

In 2001, two thermal generators were installed on the Jeju inverter side. The capacity of the generators is 75[MW] respectively, which is large enough compared with the total load of the Jeju system. Since it caused the power share of HVDC to be below 50%, the purpose of a synchronous compensator needs to be changed and the shunt reactors are not needed. Therefore our suggestion is for KEPCO to remove the meaningless shunt reactor in order to prevent the interaction.

4. Conclusion

This paper deals with the new type of an HVDC interaction. The new HVDC interaction is due to the relation between a synchronous compensator and HVDC filters. This HVDC interaction can result in serious problems such as sub-synchronous resonance and fatigue of the turbine-generator system. To eliminate these phenomena, KEPCO (Korea Electric Power Company) adopts a new HVDC filter switching scheme which includes the removal of the shunt reactor.

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