VSC-HVDC를 통한 약한 계통에 연계된 해상풍력발전시스템의 전압회복능력

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Voltage Recovery Capability of Offshore Wind Farm Connected to a Weak Grid via a VSC-HVDC

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Abstract – *Large offshore wind farms using high voltage direct current transmission system (HVDC) have been considered and exploited in many countries in the world. The maintenance of the stable operation of wind farm and interconnected system is an important issue, especially in the case of fault. To ensure the stable operation after fault clearance, the PCC voltage must be restored as soon as possible and meet the grid code requirement. This paper will evaluate the PCC voltage recovery ability of a large offshore wind farm as it is connected to a weak grid via a VSC-HVDC*
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1. Introduction

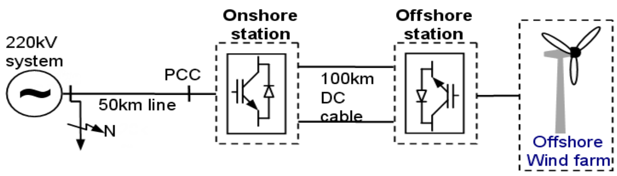
Nowadays, with the development of wind farm industry, beside onshore wind farms that have been exploited widely, offshore wind farms are also being considered and exploited efficiently because of the plenty of wind energy at offshore area.

Energy transmission from offshore station to onshore one is a big challenge for operators and developers. Many researchers focused on this issue. Some authors researched about application of a high-voltage alternating current system (HVAC) and others focused on HVDC system in offshore wind farm. Overall HVDC is the most promising choice for large offshore wind farms, over 100MW, with a long distance, over 50km.

Many studies investigated the FRT aptitude of offshore wind farm using HVDC for transmission [1], [2]. Almost previous references, wind farms are connected to a strong grid. Therefore, the PCC voltage is recovered immediately and authors only took care the over DC voltage on the DC link. However, in the case of a connected weak grid, after isolated fault, whether the PCC voltage can meet the grid code requirement or not. This need a consideration to ensure the stable operation of whole system.

This paper is going to evaluate the PCC voltage restoration potential of a large offshore wind farm interconnected to a weak onshore grid via a VSC-HVDC as short-circuit fault occurs on the onshore grid.

2. Configuration of investigated offshore wind farm



<Fig. 1> Configuration of studied system

The studied power system is shown in Fig. 1. It comprises a PMSG - based offshore wind farm. This offshore wind farm is consisted of 120 units of 2MW permanent magnet synchronous generator (PMSG) - wind turbine. In order to economize on the invested capital of converters, in this study, converter is not outfitted at each generator. The control of the power output of generators is still carried via the inverters of the VSC-HVDC system. The entire offshore wind farm is divided into 6 groups. At the offshore station, each group is connected to the HVDC system via a 2/110kV step-up transformer and a rectifier. At the onshore station, only one inverter is equipped to convert from DC voltage to AC voltage. The AC side of this inverter is connected to the PCC via a filter and two 110/220kV step-up transformers in parallel. This wind farm supplies power to the onshore grid via 50km 220kV overhead line (L=50km). The onshore grid is a weak grid whose short-circuit capacity is only fourfold compared to the rated power value of wind farm, SCR=4 and X/R=2.

3. Control strategy for VSC-HVDC system

3.1 Control strategy for rectifiers

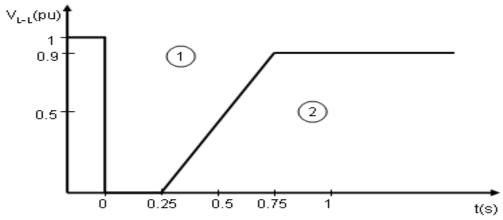
Since no converter is equipped at each generator, the rectifiers installed at the offshore station is controlled to get the maximum power point curve (MPPT) and unity power factor which leads to a minimum capacity of transformers put at the offshore station. In this control, the MPPT control is always priority.

3.2 Control strategy for inverter

The objectives of controller applied to the inverter are to maintain a constant DC voltage and a constant voltage magnitude at the PCC. The major purpose of maintenance a constant DC voltage is to ensure the entire active power generated by generators will be delivered to the onshore grid. This helps increase in the transmission efficiency of the VSC-HVDC system. Since this wind farm is connected to a weak grid that the PCC voltage depends on the power output of the wind farm, so the maintenance of a constant voltage at the PCC is also quite important. However, the PCC voltage is allowed to deviate in the 5% range of the rated value. Therefore, in this research, the constant DC voltage control should be prioritized to get the maximum of power output.

However, the onshore grid is very weak, the voltage at the PCC will be heavily reliant on the power output of the wind farm. For that reason, in this paper, the maximum of current used for the DC voltage control is only allocated to achieve 95% of the capacity of inverter (Imax) and thus at least 31% of Imax is used for accommodating the PCC voltage magnitude.

4. Voltage recovery requirement of the grid code



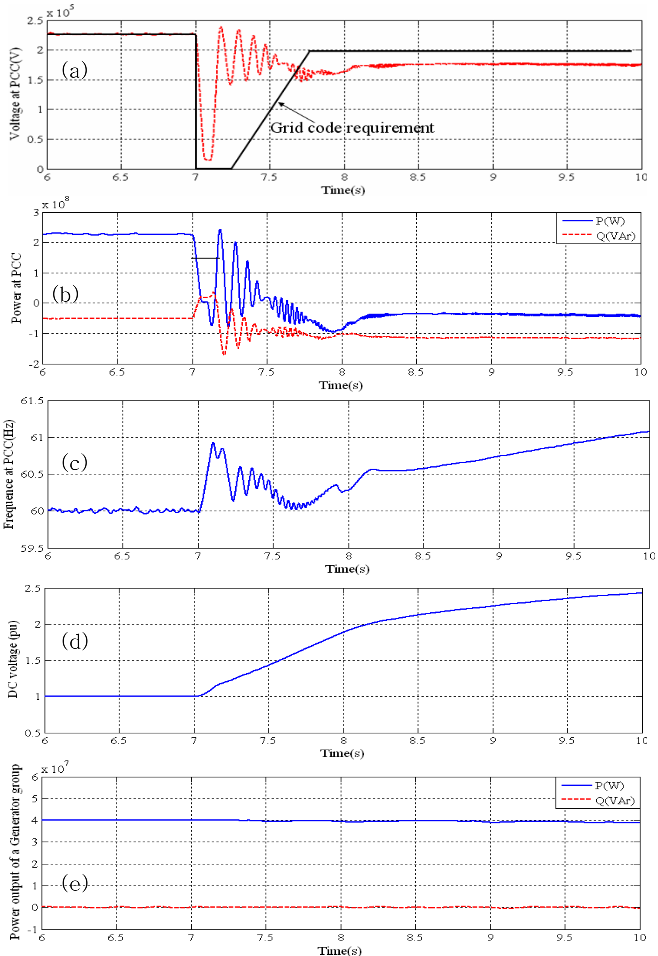
<Fig. 2> Voltage recovery requirement of the grid code

Fig. 2 indicates the grid code requirement for the PCC voltage magnitude of a large wind farm (S>100MW) in

Sweden as short-circuit fault occurs on the onshore grid [3]. According to this requirements wind farm has to maintain connecting to the onshore grid at voltages within the areas 1. If the PCC voltage is fell down in area 2, wind farm is required to disconnect from the grid in order to ensure the stable operation of the grid.

5. PCC voltage recovery capacity of the wind farm

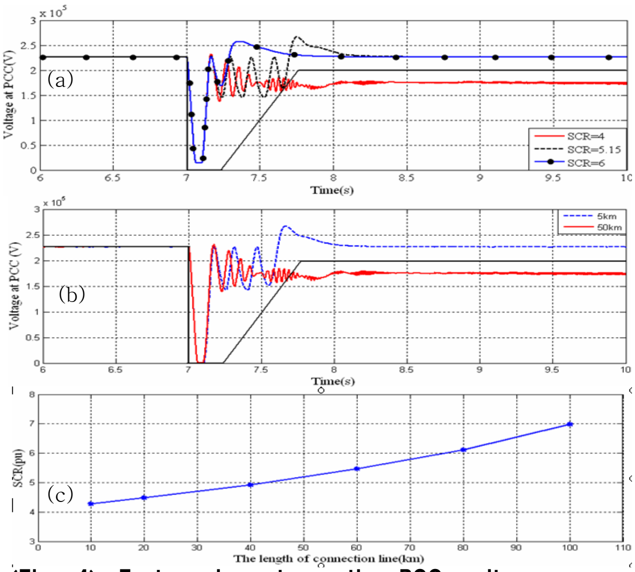
Fig. 3 indicates simulation results as the onshore station is connected to a weak system, SCR=4, with fault occurring on the onshore grid at 7s and clearing at 7.1s. Figures (a), (d) and (e) perform that before 7s, the PCC voltage and the DC voltage are maintained at the rated value. Active power output of a generator group is got the rated value while reactive power is maintained at zero. It is mean that the objectives of the controllers are achieved.



<Fig. 3> Simulation results: (a) voltage at PCC, (b) power at PCC, (c) frequency at PCC, (d) DC voltage, (e) power output of a generator group

During fault period, due to a low voltage at the PCC, active power cannot transfer to the onshore grid. Active power generated by generators are stored in the DC link and it boosts the DC voltage to around 1.07pu at 7.1s.

After fault clearance, the PCC voltage is instantaneously recovered to around 105% and following a long time of transient. By comparing with the grid code requirement, at 7.65s, the PCC voltage is fell in zone 2 and this wind farm is required to disconnect. Otherwise, the connected power system must supply a small part power to the PCC, Fig. 3 (b) and the frequency of whole system will be accelerate continuously, Fig. 3 (c). Furthermore, since the power output of generators still keeps at the constant after 7s, Fig. 3 (e), while the onshore station cannot deliver active power to the onshore grid, this makes equipments installed on the HVDC system suffer a high overvoltage, Fig. 3 (d). It is clear that with SCR=4, the PCC voltage cannot restore to retain and the unstable operation of whole system is unavoidable.



<Fig. 4> Factors impact on the PCC voltage recovery ability: (a) SCR vale, (b) Length (L), (c) Locus of critical point (L,SCR) of power system

Fig. 4 (a) and (b) show that with the same control strategies, the higher SCR or the shorter distance from the onshore station to the infinity bus of the power system the more early the PCC voltage can retain the pre-fault value. Each distance, there is a respectively critical SCR value and again so that the PCC voltage just satisfies the grid code obligation. Each couple of critical value is named a critical point. A locus of critical points is shown in Fig. 4 (c). From Fig. 4 (c), with a specific SCR value of power system and a specific distance (L), if (L, SCR) point is above this curve the PCC voltage completely satisfy the grid code requirement and whole system can operate stably after fault. Otherwise, the PCC voltage can not meet the grid code requirement.

6. Conclusion

The PCC voltage recovery ability of a wind farm is reliant on the SCR value and the distance between the onshore station and the infinity bus of the connected system. Results of simulation indicated that as the (L, SCR) point is located above the locus of critical point, whole system can stably operate after fault clearance. Otherwise, the PCC voltage cannot meet the voltage recovery requirement of the grid code and this wind farm cannot operate stably after fault clearance.

References

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