

Coordinated Fault Ride through Strategy for Offshore Wind Integration System

Rui Chen^{1,*}, Ke Jia¹, Tianshu Bi¹, Bohan Liu² and Yikai Sun³

¹North China Electric Power University, Beijing 102206, China

²State Grid AC Project Constr. Co., Ltd., Beijing 100082, China

³State Grid Zhejiang Economy Research Institute, Hangzhou, Zhejiang 310008, China

*Corresponding author e-mail: pinkpig2008@126.com

Abstract. The gradual depletion of fossil fuels has led people to start a new generation of energy changes. In recent years, offshore wind power has developed rapidly. This paper analyzes the steady-state operation control strategy of converters on both sides of VSC-HVDC transmission system in offshore wind power integration system. A coordinated fault ride through strategy is proposed to keep the system operate stably during AC grid side fault. The simulation results in PSCAD have verified the effectiveness of the proposed strategy, which will lay a theoretical foundation for the future research on offshore wind power integration system.

1. Introduction

With the rapid development of renewable energy, the cumulative installed capacity of offshore wind power in China has reached 1,630 MW by the end of 2016, which has shown an increase of 64% compared to last year [1]. In order to realize the long-distance transmission of large-scale wind resources, flexible HVDC transmission technology has been widely applied in offshore wind integration system [2].

In an offshore wind integration system, the wind farm is connected to the VSC-HVDC transmission system through the rectifier station. Then, it is incorporated into the AC grid through the inverter station. When a fault occurs on AC grid side of VSC-HVDC, the output power of the grid-side converter (GSVSC) will decrease. However, the output power of the wind farm will remain unchanged, which causes the input and output power of the VSC-HVDC transmission system to be unbalanced. As a result, the DC voltage will increase. In severe cases, the entire DC system may collapse. Therefore, it is necessary to study the coordinated fault ride through strategy of the VSC-HVDC transmission system to ensure the stable operation of the entire system during AC side fault.

The studies for the control strategies of the offshore wind power integration system can be separated into two parts. The first one is the studies of the control strategies of each part of the system. The second part is about the fault ride through strategy of the system. For the first aspect, reference [3] and [4] introduce the control strategy of PMSG. For the second aspect, [5-6] proposes different control strategies considering FRT requirements of HVDC, while various control strategies to reduce active power in HVDC system are evaluated in [7]. Most of the strategies are based on fast communication or coordination control to reduce the output power from wind farm, such as frequency-increase



method and voltage-decrease method, while reference [8] discusses the influence of two methods to the wind generators.

2. Coordinated Fault Through Strategy for VSC-HVDC

During a fault, the VSC-HVDC transmission system must have the ability to achieve fault ride through successfully to keep the stable operation of the offshore wind integration system. Thus, it is important to study the control of each part of the whole system during fault. The structure of the offshore integration system is shown as follows.

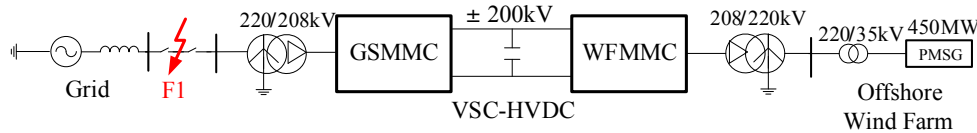


Figure 1. Structure of the offshore wind integration system.

The offshore wind farm consists of 90 PMSGs with a capacity of 900MW, while the DC voltage of VSC-HVDC is $\pm 200\text{kV}$.

2.1. Control Strategy of Grid Side VSC Converter

During a fault, the grid side VSC applies double closed loop vector control strategy based on the oriented grid voltage to make GSVSC a power balance point. Suppose that the three phases are symmetrical, the transient mathematical model of GSVSC in d, q synchronous coordinate system is

$$L \frac{d}{dt} \begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} -R & -\omega L \\ \omega L & -R \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} u_{sd} \\ u_{sq} \end{bmatrix} - \begin{bmatrix} u_{cd} \\ u_{cq} \end{bmatrix} \quad (1)$$

i_d , i_q are the output currents of GSVSC. u_{sd} , u_{sq} are grid side AC bus voltages. u_{cd} , u_{cq} are GSVSC side voltages. ω is the frequency of ac system.

When d-axis orientates at the grid voltage, using instantaneous reactive power theory, we can obtain the current inner loop uses PI controller to achieve a complete decoupling of d, q axis for the currents. The reference voltages of d, q axis can be expressed as:

$$\begin{cases} u_d^* = (K_p + \frac{K_i}{s})(i_d^* - i_d) \\ u_q^* = (K_p + \frac{K_i}{s})(i_q^* - i_q) \end{cases} \quad (2)$$

Then we can get the mathematical model of GSVSC, which is shown as below.

$$\begin{cases} u_{sd} = -Ri_d - \omega Li_q + u_{cd} \\ u_{sq} = -Ri_q + \omega Li_d - u_{cq} \end{cases} \quad (3)$$

For the outer control loop, this paper uses DC voltage controller to control system's active power. The overall control strategy of GSMC is shown in Figure.2.

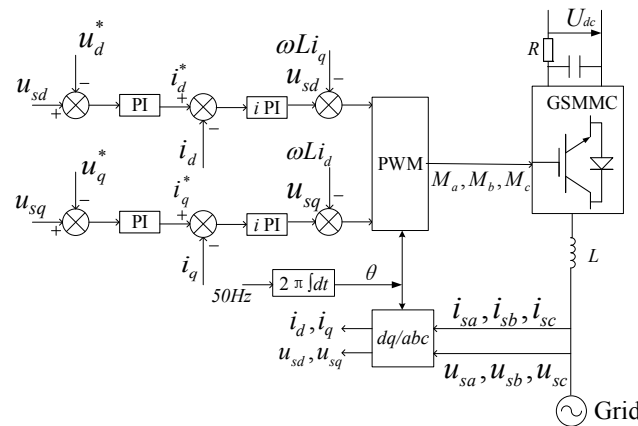


Figure 2. Control strategy of GSVSC.

2.2. Control Strategy of Wind Farm Side VSC Converter

As the wind farm cannot hold a stable frequency and voltage because of its control strategy, WfVSC often applies V-f control strategy to fix the wind farm's voltage and frequency. The voltage reference value can be calculated by the following expressions.

$$\begin{cases} u_{dref} = k_p (U_{ref} - U_{WF}) + k_i \int (U_{ref} - U_{WF}) dt \\ u_{qref} = 0 \\ \theta_{ref} = \int 2\pi f_0 dt + \theta_0 \end{cases} \quad (4)$$

Where u_{dref} , u_{qref} are the reference voltages in d, q axis. As the d -axis orientates at the grid voltage, $\theta_{passive}$ is the reference phase determined by this paper, θ_0 is the initial phase. f_0 is the fixed frequency of ac voltage. U_s is the wind farm side ac bus voltage, while U_{ref} is defined as its reference value.

When fault occurs on AC side of the VSC-HVDC transmission system, in order to achieve fault ride through successfully, the WfVSC will reduce the voltage at the AC outlet of the wind farm. Then, the output power of the wind farm will be reduced and the accumulation of active power on the VSC-HVDC transmission line will be eliminated. As a result, the offshore wind integration system will continue to operate stably during AC side fault.

When the output DC voltage of WfVSC $U_{DC} \leq U_{DCmax}$, the WfVSC operates under normal Vf control. When $U_{DC} > U_{DCmax}$, the AC reference voltage of the converter will decrease and the AC voltage of the wind farm will track the reference value through PI controller. The AC reference voltage of d -axis can be expressed as

$$u_{dref} = U_{ref} - \Delta U = U_{ref} - k(U_{DC} - U_{DCmax}) \quad (5)$$

From equation (4) and (5), the control strategy of WfVSC is set up as follows.

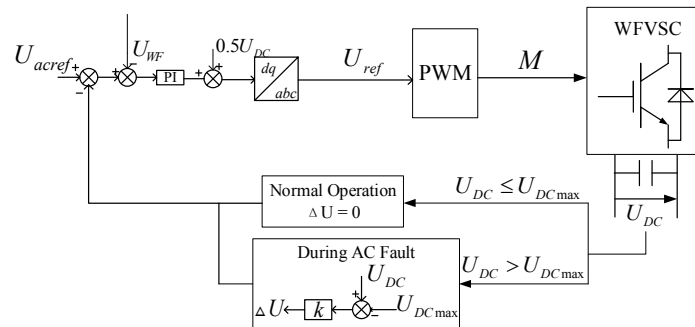


Figure 3. Control strategy of WfVSC.

3. Simulation Results

In order to verify the proposed coordinated control strategy, a simulation system is built in PSCAD/EMTDC. The performances of the offshore wind integration system when phase A is grounded are shown below.

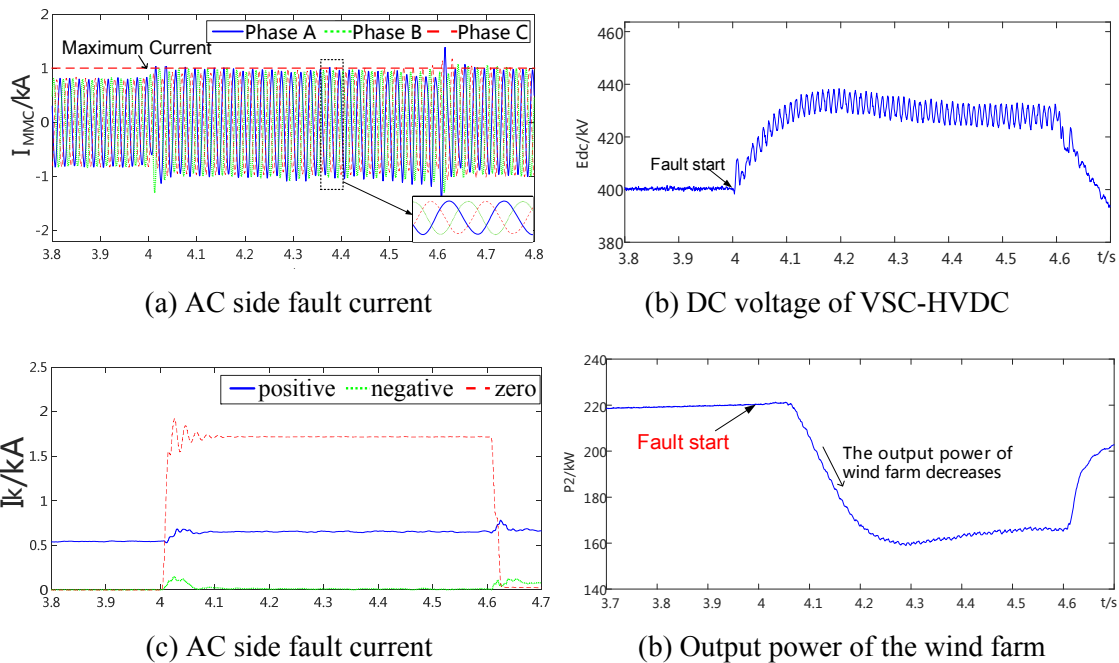


Figure 4. Performance of the offshore wind integration system during phase A-to-ground fault.

From the above figures, it can be seen that when fault occurs on the AC side of VSC-HVDC, the wind farm side converter will reduce the output power of the wind farm through the step-down method. Thus, the continuous rise of the DC voltage under the condition that the power cannot be delivered will be limited. At the same time, the grid side converter eliminates the asymmetry of fault current by applying the negative-sequence current suppressed control strategy, reducing the double-frequency fluctuation of the DC voltage and active power. As a result, the system will operate stably during the fault.

4. Conclusion

The control strategies of offshore wind power integration system are discussed in this paper. A coordinated fault ride through strategy is proposed to keep the system operate stably during AC grid side fault. After setting up the system model in PSCAD, the simulation results have verified the

effectiveness of the proposed strategy, which will lay a theoretical foundation for the future research on offshore wind power integration system.

Acknowledgments

This work was financially supported by Science and Technology Project of State Grid Zhejiang Electric Power Co., Ltd. (5211JY16000U).

References

- [1] National Electricity Industry Statistics from January to November, 2017. China Electricity Council, <http://www.cec.org.cn/guihuayutongji/tongjixinxi/>
- [2] Terry Chi Young Ho, Li Ran, A. García-Cerrada, J. L. Zamora-Macho and P. Brogan, "Voltage source converter AC voltage controller design and dynamic response for a large offshore wind farm network," 2013 International Conference on Renewable Energy Research and Applications (ICRERA), Madrid, 2013, pp. 470-475.
- [3] E. Muljadi, N. Samaan, V. Gevorgian, Jun Li and S. Pasupulati, "Short circuit current contribution for different wind turbine generator types," IEEE PES General Meeting, Minneapolis, MN, 2010, pp. 1-8.
- [4] X. Wu, Y. Guan and W. Ning, "Reactive power control strategy of DFIG-based wind farm to mitigate SSO," in The Journal of Engineering, vol. 2017, no. 13, pp. 1290-1294, 2017.
- [5] Wei Yue, Chengyong Zhao, Yi Lu and Gang Li, "Study and Simulation of VSC-HVDC under AC Power System Faults," 2010 5th International Conference on Critical Infrastructure (CRIS), Beijing, 2010, pp. 1-6.
- [6] R. Teixeira Pinto, S. F. Rodrigues, P. Bauer and J. Pierik, "Grid code compliance of VSC-HVDC in offshore multi-terminal DC networks," IECON 2013 - 39th Annual Conference of the IEEE Industrial Electronics Society, Vienna, 2013, pp. 2057-2062.
- [7] C. Feltes, H. Wrede, F. W. Koch and I. Erlich, "Enhanced Fault Ride-Through Method for Wind Farms Connected to the Grid Through VSC-Based HVDC Transmission," in IEEE Transactions on Power Systems, vol. 24, no. 3, pp. 1537-1546, Aug. 2009.
- [8] L. Xuan, S. Qiang, L. Wenhua, R. Hong, X. Shukai and L. Xiaolin, "Fault ride-through control and its impacts on wind generators in a VSC-HVDC system," 2013 IEEE International Symposium on Industrial Electronics, Taipei, Taiwan, 2013, pp. 1-6.