Review of low voltage ride-through technology of doubly-fed induction generator

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Abstract: In recent years, with the increasing of wind power development, the demand for low voltage ride-through (LVRT) technology was proposed to ensure the safe and reliable operation of the power system. The key issue of LVRT strategy for HVDC system has been unable to meet the requirements of countries; the most important is the demand of low voltage ride-through, these characteristics, synchronous interconnection, demonstration project in 2013, Zhoushan VSC-MTDC and Luxi back–back asynchronous network project in 2016[3–5]. The characteristic of short-circuit current is a basis of the resistance setting, and the voltage of the power grid and the DC voltage also be considered [9, 10]. In the protection of the crowbar circuit, a reactive power can be generated continually by DFIG; however a large amount of reactive power will be absorbed by wind power system, which affects the recovery of voltage. There will be a risk of repeated input for crowbar circuit when crowbar is withdrawn before the fault clearance. On the other hand, a large amount of reactive power will be required when crowbar circuit is withdrawn after the fault clearance. Therefore, it should be possible to reduce the operating frequency and input time for crowbar circuit [11]. During the power grid failure, the active power of the stator is out of control, and the surplus power can be sent out by adding the chopper circuit to provide an energy channel and avoid overvoltage of direct current [12, 13].

1 Introduction

With the development of large-scale new energy, the influence caused by wind power paralleling in the grid has become a research focus. In response to this problem, the corresponding standard was set up by different power grid operators on the situation of their countries; the most important is the demand of low voltage ride-through (LVRT) ability for wind farm.

As one of the main wind turbines, the stator of doubly-fed induction generator (DFIG) is connected to the power grid directly under the traditional AC grid connection mode, so wind power system is sensitive to the fluctuation of the grid voltage.

Along with the progress of power system technology in recent years, VSC-HVDC technology has been applied more and more, especially in the field of offshore wind farm. Compared with AC transmission, these characteristics, synchronous interconnection, isolation between large area power grids, and the fast control of active power provide strong support for network interconnection and transmission reliability. The traditional two-terminal VSC–HVDC system has been unable to meet the requirements of reliability, flexibility and economy for the appearance of some application scenarios such as multi power supply and multi drop point reception and so on. Thus, the multi-terminal VSC-HVDC transmission system arises at the historic moment[1, 2].

At present, there have been 30 flexible DC transmission projects that were put into operation, and five of them were built in China, including flexible DC power transmission project in Shanghai Nanhui operated in 2011, Nanao VSC-MTDC demonstration project in 2013, Zhoushan VSC-MTDC transmission project in 2014, Xiamen VSC-HVDC project in 2015 and Luxi back–back asynchronous network project in 2016 [3–5]. VSC-HVDC technology has been concerned by national and domestic scholars from the above list, which further promotes the development.

Under this background, the existed LVRT technologies for DFIG when the wind farm is connected to AC network are summarised. Then relevant literatures are analysed and evaluated about LVRT in light of power surplus for two-terminal system and DC voltage control for multi-terminal system when integrated with VSC-HVDC, respectively. In the end, the coordinated control strategy of multi-terminal VSC–HVDC system under the fault and LVRT technology for islanded system are prospected in this paper.
The main control methods used in VSC-HVDC are direct control and vector control, in which vector control can avoid overcurrent through the effect of the current limiter. In this paper, vector control is applied to the wind farm side modular multilevel converter (WFMMC), providing stable AC voltage and frequency supply, and can transmit the wind power to the DC network. The control strategy is more complex [28].

3.2 LVRT strategy for DFIG integrated with two-terminal VSC-HVDC system

Fig. 2 is a schematic diagram of two-terminal VSC-HVDC system. The operation characteristics of wind power system vary with the network synchronisation modes; therefore, it is necessary to continue the study of LVRT for DFIG based on VSC-HVDC. The main problem is the overvoltage of direct current system caused by unbalance of active power when fault happens at PCC for the system of DFIG connected to the two-terminal VSC-HVDC. Frequency increase and voltage magnitude reduction are currently the main strategies, controlled by the compensation of reference value provided by the WFMMC according to the decline of fault voltage to solve this problem [15, 16]. The objective of first method is to store some mechanical power temporarily in the form of generator rotor kinetic energy and reduce the electromagnetic power generated by DFIG. The other is to reduce the power transmitted from DFIG to VSC–HVDC system. Those methods have different influence on different wind turbines. Voltage magnitude reduction is adopted to reduce the damage to the rotor converter of DFIG with a strong LVRT ability; otherwise, frequency increase is chosen to guarantee voltage stability [17–19]. However, the above methods only have an obvious effect for LVRT under the condition of weak fault. In the case of serious fault, the unbalanced power should be consumed with the DC chopper. However, there is a need for large cooling system because of large amount of heat production to match nominal capacity. Based on the design of MMC, the DC chopper circuit can be designed and coordinated with these methods of frequency increase and voltage magnitude reduction [20].

3.3 LVRT strategy for DFIG integrated with multi-terminal VSC–HVDC system

Fig. 3 is a schematic diagram of four-terminal VSC-HVDC system. The operation characteristics of multi-terminal VSC–HVDC system are directly determined by the stability of DC voltage whose control strategies include master/slave control and voltage droop control [21, 22]. Master converter station is set to control DC voltage by master/slave controller in master/slave control. Once the master converter station fails to run out, control strategy of slave converter station will switch to the constant current voltage control mode. Though the control method is simpler, its requirement for communication between the converter stations is higher than voltage droop control and the system is difficult to be controlled in the event of a failure. The voltage droop control strategy requires multiple converter stations to participate in the balance of power and the regulation of DC voltage. The method responds quickly and does not need communication, so it is more suitable for the coordinated control of active power of VSC-MTDC to realise LVRT. The determination of droop sparsity is essential for voltage droop control [23], and the smaller of DC droop coefficient is, the greater deviation of power allocation in the side of DC network will be caused by the DC line voltage drop under the condition of neglecting the resistance of the DC line [24, 25]. At the same voltage level, the total loss of the system can be reduced by a reasonable droop coefficient [26]. The flexibility of traditional voltage droop control with fixed coefficient is relatively poor under the complex working conditions. In view of this situation, fuzzy logic inference can be utilised to adjust droop coefficient by detecting DC voltage deviation and power margin and improve operation characteristics of the system [27].

These control strategies proposed in the above literatures are all based on the pseudo-bipolar wiring mode, and the system adopting the real bipolar wiring mode makes it possible to realise power conversion strategy. Therefore, for the multi-terminal VSC–HVDC system, the power of fault end can be converted by other ends to balance the power in system, so as to ensure that the converter station does not be locked. Nevertheless, the realisation of the power conversion function needs the coordination of the upper control system to get the power reference value, that is to say the strategy is more complex [28].
4 Conclusion

Relevant literatures are studied about LVRT strategy when the wind farm is connected to AC network and VSC-HVDC, respectively. The summary of the research and directions of prospects is as follows:

(1) According to the present research, DFIG has basically had LVRT capability by increasing the crowbar and chopper. However, the switching strategy and the choice of resistance are still not perfect, so there is a need for further study.

(2) The research of coordinated control method of VSC-MTDC is mainly aimed at maintaining DC voltage under normal conditions but is still at a preliminary stage for coordinated control strategy under fault conditions.

(3) Most of the researches focus on grid side failure for wind farm connected to VSC–HVDC system. During the sending end station failure of islanded system, the voltage and frequency of the wind farm will be out of control. In this regard, the insufficient reactive power can be provided through WFMMC to provide the voltage support.

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6 References

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