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Research on Subsynchronous Oscillation Mechanism of Large-scale Wind Power Outgoing

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Abstract

The integration of large-scale wind power into the power grid through series compensation AC transmission mode can improve the power transmission capacity, but at the same time it may bring about subsynchronous oscillation problem, causing fan disconnection or equipment damage. The integration of large-scale wind power into the power grid through series compensation AC transmission mode can improve the power transmission capacity, but at the same time it may bring about subsynchronous oscillation problem, causing fan disconnection or equipment damage. When the series compensation is high, electrical resonance with a frequency lower than the rated frequency may be generated due to disturbance in the line. If the natural torsional vibration frequency of a shaft system of the generator is complementary to the electrical resonance frequency, torsional vibration amplification, namely subsynchronous resonance (SSR), will be generated, damaging the shaft system of the generator. With the large-scale use of series capacitor compensation technology and technology in the construction of ten million kilowatt wind power base, the problem of system oscillation caused by wind power has gradually emerged. The subsynchronous oscillation will not only affect the power quality, but also cause the damage of the unit shafting. Therefore, it is urgent to study the subsynchronous oscillation in large-scale wind power transmission.

Keywords

Large-scale wind power; Subsynchronous resonance; resonant frequency.

1. Introduction

Wind energy is a kind of pollution-free renewable energy with abundant reserves. In recent years, with the shortage of fossil fuels, more and more attention has been paid to it. The growth rate is the fastest among all renewable energies. Wind power has the characteristics of intermittence, fluctuation and randomness. As wind power only uses wind energy to generate electricity and cannot adjust the intensity of wind, it is generally considered that the power generation capacity of wind power is uncontrollable compared with conventional power sources such as hydropower and thermal power without considering "power limitation". The reverse distribution of resources and load centers in our country makes it inevitable for large-scale wind power to be transmitted over long distances. Series compensation technology can greatly improve the stability limit of the system and thus improve the transmission capacity, and is widely used in high voltage transmission lines [2]. The reverse distribution of energy and load centers in China determines that large-capacity and long-distance wind power transmission must be vigorously developed. When the series compensation is high, electrical resonance with a frequency lower than the rated frequency may be generated in the line due to disturbance. If the natural torsional vibration frequency of a shaft system of the generator is complementary to the electrical resonance frequency, torsional vibration amplification, namely subsynchronous resonance (SSR), will be generated, damaging the shaft system of the generator and further endangering the operation of the power grid [3]. In-depth research on the issue of sub-synchronous oscillation in large-scale wind power transmission is conducive to the safe and stable operation of China's power network.

In the large-scale wind power transmission process, transmission via series compensation and high-voltage direct current transmission (HVDC) may cause sub-synchronous oscillation of the wind turbine, but the mechanism and related characteristics are not the same [3]. The series capacitor compensation device may cause sub-synchronous oscillation in large-scale wind power transmission systems. Series capacitance compensation technology can economically and effectively increase the transmission capacity of long-distance transmission lines and improve the stability of power systems. With the large-scale use of series capacitor compensation technology and technology in the construction of multi-kilowatt-scale wind power bases, the system department oscillation problems caused by wind power have gradually emerged [5]. Installing a series capacitor compensation device on a long-distance AC transmission line can not only reduce the reactance of the transmission line, reduce the electrical length of the transmission line, but also reduce line losses, increase the transmission capacity of the power grid, and increase the static stability limit of the system [6]. In recent years, China has paid more and more attention to the large-scale development and utilization of wind power. The distribution characteristics of wind energy resources and power loads in our country determine that series capacitance compensation technology in long-distance wind power transmission will be widely used, which makes large-scale wind farms face more severe The problem of subsynchronous oscillation [7]. The sub-synchronous oscillation will not only affect the power quality, but also cause damage to the shaft system of the unit. Therefore, in-depth research is needed on the issue of sub-synchronous oscillation in large-scale wind power transmission.

2. Subsynchronous Oscillation Mechanism of Wind Turbine

2.1. Subsynchronous Control Interaction

The subsynchronous oscillation mechanism of wind turbines is similar to that of thermal power units, but slightly different. The existing literatures are mainly summarized as induction generator effect (IGE), subsynchronous control interaction (SSCI) and subsynchronous shafting torsional oscillation effect (SSTI) [8]. The structural characteristics of wind power units determine that the subsynchronous oscillation problem when series compensation or HVDC transmission is adopted is not exactly the same as that of thermal power units. In addition to subsynchronous resonance and subsynchronous oscillation caused by devices, subsynchronous oscillation may also be caused by inverter control in wind turbine generator set. At present, the common wind turbines include squirrel-cage asynchronous wind turbines, doubly-fed induction wind turbines and permanent magnet direct-drive wind turbines, which differ greatly in structure from conventional thermal power units. SSCI is the interaction between converter and series compensation line of wind turbine. SSCI has nothing to do with the torsional vibration frequency of the generator shafting. The oscillation frequency depends entirely on the converter control and the structure of the electrical transmission system, so there is no fixed oscillation frequency. However, due to the essential differences between wind power units and thermal power units in terms of organization and grid connection, the research results of conventional thermal power units in subsynchronous oscillation analysis, modeling and suppression cannot be directly applied to subsynchronous oscillation analysis caused by wind power. The induction generator effect results from the apparent negative resistance of

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the rotor of the synchronous generator to the subsynchronous frequency current lower than the system power frequency.

2.2. Torsional Vibration of Subsynchronous Shafting

The induction generator effect is a self-excited phenomenon that only considers the dynamic behavior of the electrical system and has nothing to do with the turbogenerator shafting. The control strategy of DFIG includes maximum wind power tracking control, pitch angle control and vector directional control. Among them, the maximum wind power tracking control is to change the rotor speed by controlling the electromagnetic torque according to the blowing wind speed of the current wind turbine, maintain the optimal tip speed ratio, and realize the maximum utilization of wind energy. The full-power converter transfers all the power from the wind turbine generator set to effectively isolate the generator from the power grid. Therefore, the electrical frequency of the generator can change with the change of wind speed, while the grid frequency is constant, realizing variable speed operation of the wind turbine [9]. At present, the commonly used wind turbine generator shaft system is much shorter than the turbine generator shaft system, so the elastic coefficient is relatively small, and the natural torsional vibration mode frequency is lower, generally lower than 5Hz. To excite the torsional vibration mode, a higher electrical resonance frequency, i.e. a higher degree of series compensation, is required. In the construction of the model, a new type of low-carbon economic dispatch target is proposed, which takes into account the economy of electricity production and the low-carbon nature of system emissions, so as to realize the simplification of multi-objective problems. A simulation system including a large-scale wind farm is taken as an example for simulation analysis. The specific parameters of the wind farm are shown in Table 1.

Table 1. Parameters of wind farm

Rated wind speed (m/s)	Cut-in wind speed (m/s)	Cut-out wind speed (m/s)	Rated output of wind farm (MW)
36	5	15	550

The coordinated operation of carbon capture power plant and wind power can make full use of surplus wind power and increase the capture energy consumption to treat the stored rich liquid during the trough period. The coordinated operation of carbon capture power plants and wind power can improve the system's ability to absorb wind power and obtain certain carbon emission reduction benefits. As shown in Table 2, the optimized operation results of the system before and after the carbon capture power plant is configured. Fig. 1 shows system load and wind power output.

Table 2. System optimization operation results before and after the carbon capture power plant is configured

	Including carbon capture power plants	Carbon-free capture power plant
Generation cost	316.24	328.96
Carbon cost	235.68	210.77
Wind power rejection rate	5.64	0
Capture efficiency	1.28	18.56
Comprehensive cost	551.92	539.73

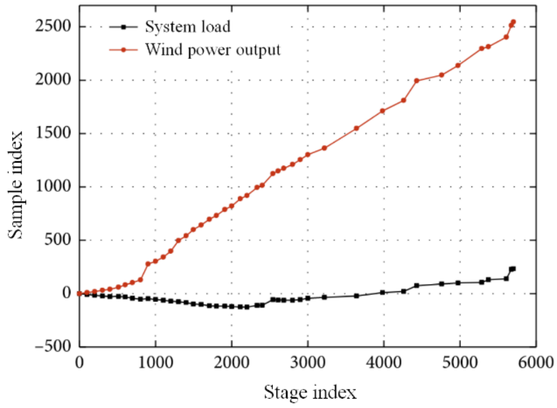

Figure 1. System load and wind power output

Different from the subsynchronous oscillation phenomenon of traditional thermal power units, the subsynchronous control interaction of wind power units is not related to the shafting of the units, and the oscillation frequency and characteristics are only affected by the controller parameters and transmission system parameters, and are not related to the natural modal frequency of the shafting of wind power units.

3. Analysis of Subsynchronous Oscillation in Large-scale Wind Power Transmission

SSTI is caused by unreasonable parameter setting of power electronic device controllers such as HVDC and FACTS. The fast control or response of power electronic controller to power and current at subsynchronous frequency will affect the phase difference between generator electromagnetic torque and rotating speed. The wind turbine is directly connected with the generator, so that the gearbox is omitted, the maintenance cost of the wind turbine is reduced, and the working life and reliability of the wind turbine are improved. As an important low-carbon emission reduction technology, wind power plants can quickly adjust the carbon emission intensity through the flexible operation mode of storing solution, thus adjusting the solution storage amount, capture energy consumption, net output and corresponding operation cost. There will be a serious transition process when the power system fails, recloses and non-synchronous recloses are carried out, and the transient energy in the generator set may contain complementary components of frequency and natural torsional vibration frequency of the shafting.

Similar to the research on subsynchronous resonance of steam turbine units, the research on torsional vibration interaction between fan and power grid must establish a more accurate shafting model. It is generally believed that the shafting two-mass model can already meet most simulation accuracy requirements [10]. SSCI problem is a new type of oscillation with different subsynchronous oscillation types with the development of wind power. SSCI is caused by the interaction between the wind turbine controller and the fixed series compensation. It is mainly determined by the parameters of the wind turbine controller and the transmission system, and has nothing to do with the natural modal frequency of the shafting. Penetration factor is an important parameter to characterize wind power output. The partial derivative relation between penetration factor and shape parameter S and relative wind speed is difficult to be obtained by analytical method. Fig. 2 shows the change of penetration factor with relative velocity under different shape parameters. Fig. 3 is a probability density function of wind speed under different shape parameters.

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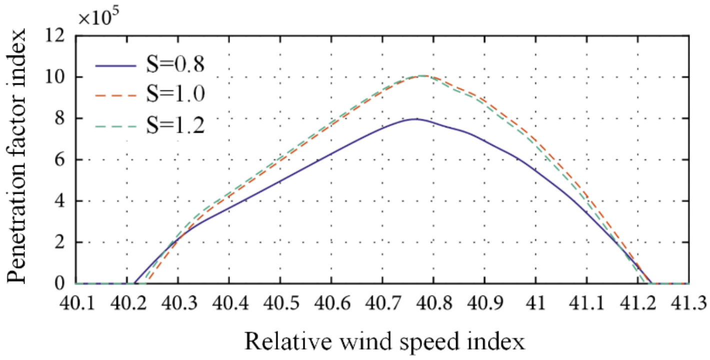

Figure 2. Penetration factor changes with relative speed under different shape parameters

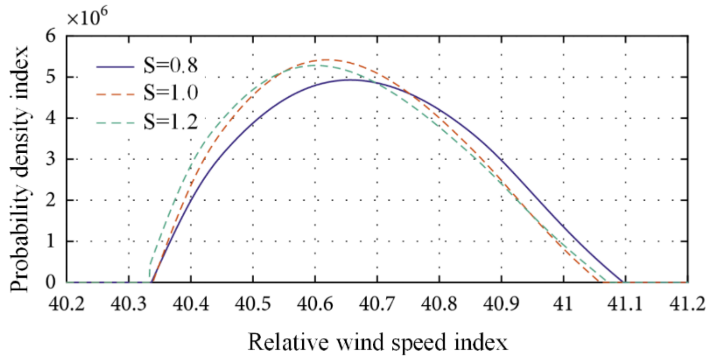

Figure 3. Probability density function of wind speed under different shape parameters

The resonance current generated by system disturbance will induce corresponding subsynchronous current on the generator rotor, thus causing changes in rotor current. The converter controller will adjust the output voltage of the inverter after sensing this change, causing the change of the actual current in the rotor. Aiming at the contradiction between the coal consumption and the utilization rate of wind power when the wind power is connected to the power grid, the coal consumption that wind power can save for the power grid is taken as a measure of the value of wind power, and a power grid dispatching decision model taking into account the capacity of wind power is constructed. Permanent magnet direct-drive wind turbines use high-cost materials such as full-power converters and permanent magnet materials, while the generator is complicated in structure and heavy in weight, which all limit its development. The frequency scanning method can be used to calculate the equivalent impedance of the wind turbine looking at the grid and the wind turbine looking at the grid. Through this method, the system operating conditions with potential subsynchronous oscillation threat can be screened out, and devices or operating conditions that have no effect or little effect on subsynchronous oscillation problem can be excluded. If the equivalent reactance is equal to zero or close to zero, the equivalent resistance at this frequency point is negative and the risk of subsynchronous oscillation of the system is high.

4. Conclusions

Compared with traditional thermal power generation units, the structure and grid connection of wind power generation system are essentially different, and the wind farm group is composed of various types of wind power generation units, which makes the subsynchronous oscillation problem of large-scale wind power base transmission very complicated. Analysis of Multi-machine Synchronous Oscillation of Large-scale Wind Power Transmission System via HVDC. Most of the existing researches focus on the subsynchronous oscillation problem of thermal power units when they are sent through HVDC, and pay less attention to wind power, especially the subsynchronous oscillation problem that may occur in the currently most widely used DFIG in the system sent through HVDC. This paper introduces the research background of subsynchronous oscillation in large-scale wind power transmission, the classification and research methods of power system subsynchronous interaction, and the research status of wind farm subsynchronous oscillation. The effects of series capacitor compensation device, wind speed and line series compensation degree on subsynchronous oscillation characteristics of doubly-fed wind power transmission system are analyzed through simulation. With the construction of large-scale wind power bases in our country, how to evaluate the subsynchronous oscillation of wind power units, which suppression strategies to adopt and how to coordinate the suppression strategies have become urgent problems to be solved.

5. References

[1] Wang Xuewei, Xie Huan, Liu Qing, et al. Study on the influence of SVG on the subsynchronous oscillation of wind power [J]. North China power technology, 2017 (6): 37-41.

[2] Deng Wangbo, Wang Haiyun, Chang Xiqiang, et al. Analysis of factors affecting subsynchronous oscillation of large-scale direct driven wind farms [J]. High voltage electrical appliances, 2019 (6): 218-224.

[3] Guo Xiaolong, Li Yu, Li Jue, et al. Discussion on the standard of subsynchronous oscillation monitoring function expansion of PMU device [J]. Smart grid, 2016, 4 (9): 924-928.

[4] Wu Yang, Xiao Xiangning, Luo Chao, et al. Influence of direct driven fan on subsynchronous oscillation of thermal power units and its suppression method [J]. Modern electric power, 2019 (5): 31-38.

[5] Dai Jinshui. Analysis of subsynchronous oscillation damping characteristics of large offshore wind farms connected to grid via VSC-HVDC [J]. Electrical application, 2015 (8): 51-56.

[6] Zheng Chao, Li Yuan. Influence of large-scale photovoltaic grid connection on the sub synchronous oscillation characteristics of pyroelectric generator [J]. Power construction, 2016, 37 (9): 62-69.

[7] Qi Xin, Chang Fujie, Meng Jinyou, et al. Analysis and Research on subsynchronous oscillation propagation based on wide area information [J]. Control engineering, 2017, 24 (12): 2456-2461.

[8] Lu Jingjing, Xiao Xiangning, Zhang Jian, et al. Mechanism and experiment of subsynchronous oscillation suppression by dynamic stabilizer with weak damping [J]. Power system automation, 2015 (4): 135-140.

[9] Zhang Min, Shen Jian, Hou Mingguo, et al. Discussion on online identification and alarm of subsynchronous oscillation by phasor measurement unit [J]. Power system automation, 2016, 40 (16): 143-146.

[10] Wang Lin, Guo Xiaolong, Zhang Feng, et al. Research and analysis of Subsynchronous Oscillation Based on a variety of online monitoring devices [J]. Xinjiang electric power technology, 2017 (3): 47-51.