Analysis of SSO in DFIG grid with series compensation

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Abstract. Doubly fed induction generator (DFIG) has become the most widely used type of wind power generation due to its superior technical performance. Series compensation technology is widely used in large-scale and long-distance wind power transmission system because of its high cost performance and significant improvement of transmission capacity. However, it may cause subsynchronous oscillation (SSO). This paper first introduces the definition and harm of subsynchronous oscillation, and then analyzes the advantages and disadvantages of series compensation technology, as well as the mechanism and suppression measures of subsynchronous oscillation of DFIG connected system through series compensation. Through modeling and simulation analysis, the suppression effect of additional subsynchronous damping controller (SSDC) on subsynchronous oscillation of DFIG control system is verified.

1. Introduction

Subsynchronous oscillation is a special dynamic behavior caused by the coupling of mechanical equipment and electrical equipment in the power system. As a result, it will produce continuous or even increased oscillation in the relevant variables of mechanical system and electrical system. The continuous oscillation of electrical system seriously threatens the stability of the system, while the oscillation in mechanical system will lead to the loss of shaft life of steam turbine generator set. Serious subsynchronous oscillation and torsional vibration of power system will lead to serious damage of rotor shafting of large turbo generator, causing major accidents and endangering the safe and stable operation of power system.

In recent years, the development of renewable energy has become a national strategic trend. Wind power has been developed on a large scale in China. At present, China has become the country with the largest capacity and fastest development of wind power. DFIG is widely used because of its mature technology and high power generation efficiency. Most of the wind resources in China are far away from the load center, so it is imperative to send the new energy to the outside. Because the long distance transmission line is inductive, the series capacitor on the line can compensate the equivalent inductance of the line, shorten the equivalent electrical distance of the line, reduce the voltage phase difference between the two ends of the line and the voltage loss of the line, and improve the transmission capacity of the line. Therefore, series compensated capacitor transmission technology, which has the advantage of long-distance and large capacity transmission, has become the main measure to realize large-scale wind power transmission\[^1\].

Although series compensation technology has many advantages and has been widely used, after the transmission line series capacitor, the inductance and capacitor in the line will be in series, which will cause the electrical resonance problem, and the line with series compensation capacitor and its
connected power generation equipment are coupled and affected each other, which may cause subsynchronous oscillation [2].

This paper introduces the mechanism and suppression measures of subsynchronous oscillation of wind turbine series compensated grid connection. Based on the IEEE first standard model, the model of DFIG output through series compensation line is established, and SSDC is used to verify the suppression effect of improving electrical damping on subsynchronous oscillation of DFIG.

2. SSO mechanism and suppression methods of DFIG with series compensation

2.1. Mechanism of SSO in DFIG with series compensation
DFIG series compensation transmission system consists of three parts: doubly fed induction motor, converter and series capacitor. The main reason for SSO of wind farm connected to grid through series compensation is that the converter in DFIG controls the excitation current rapidly, which leads to negative damping of the system. The resonance current caused by small interference in the wind power grid connected system will induce the corresponding subsynchronous current on the generator rotor, and then cause the adjustment of the rotor current. The change of rotor current detected by the rotor side converter will adjust the output rotor excitation voltage of the converter, and then affect the stator and rotor currents of the generator. If the output voltage is helpful to increase the rotor current, the oscillation amplitude of resonance current will be intensified, which will lead to the instability of the whole system.

In principle, the subsynchronous oscillation principle of DFIG is more complex than that of traditional thermal power. DFIG is not only directly connected to the power grid through generators, but also connected to the grid through power electronic equipment. Therefore, the subsynchronous oscillation caused by DFIG and series compensation capacitor not only has the characteristics of conventional thermal power, but also couples the role of power electronic control. Its mechanism is more complex than that of similar thermal power problems and its containment is also challenging [3, 4].

2.2. SSO suppression measures of DFIG with series compensation
According to the mechanism of subsynchronous oscillation, it can be divided into three types: avoiding resonance point, improving damping and blocking subsynchronous electrical quantity.

- avoiding resonance point
  The essence of the subsynchronous oscillation caused by series compensation is that the resonant points of the electrical part and the mechanical part complement each other in frequency, so the method of avoiding the resonant points can be used to suppress the subsynchronous oscillation. It mainly includes changing the operation mode of the system and connecting FACTS devices in series.

- improving damping
  The damping of the oscillation mode is increased to suppress and alleviate subsynchronous oscillation. Supplementary excitation damping controller (SEDC), SSDC, and SSO dynamic stabilizer are all of these control devices. Their principle is basically the same, which is to generate damping torque on the generator rotor by detecting the subsynchronous oscillation signal, adjusting or injecting the corresponding electrical quantity through proper phase shifting and gain, and finally restraining the subsynchronous oscillation.

- blocking subsynchronous electrical quantity
  Because the subsynchronous oscillation is generated by the interaction between the power grid and the generator and its rotor, in addition to increasing the damping capacity, the subsynchronous oscillation can also be effectively suppressed by blocking the corresponding subsynchronous electrical quantity. Such methods include blocking filter, bypass filter, etc. [5].
3. Series compensation model of DFIG

3.1. Topology of DFIG
DFIG is a new type of generator developed on the basis of synchronous generator and asynchronous generator. It is mainly composed of wind turbine, gearbox, AC excited double induction generator and back-to-back power converter. The back-to-back power converter includes rotor side converter (RSC) and grid side converter (GSC). The topology is shown in Figure 1.

![DFIG Topology](image)

Figure 1. Topology of DFIG

DFIG converts the mechanical energy transmitted from gearbox to generator spindle into electrical energy, which is transmitted to power grid through generator stator and rotor. The stator is directly connected with the power grid, the rotor is connected with the power grid through the converter, and the power electronic converter is used for AC excitation. When the wind speed changes, the speed response of the induction motor changes. At this time, as long as the AC excitation frequency is adjusted correspondingly, the variable speed constant frequency operation of the doubly fed fan can be realized.

There are three working modes of doubly fed induction machine: when the rotor's mechanical rotation angular speed is lower than the synchronous speed, it is in subsynchronous operation, at this time, the converter inputs active power to the rotor and gives positive sequence excitation, then the converter absorbs energy from the grid; when the rotor's mechanical rotation angular speed is higher than the synchronous speed, it is in supersynchronous operation, at this time, the converter absorbs active power from the rotor and gives negative sequence excitation, then the converter is in subsynchronous operation. When the mechanical rotation angular velocity of the rotor is equal to the synchronous speed, it is in the synchronous operation state. The converter controls the motor to keep generating state in subsynchronous and supersynchronous state.

3.2. DFIG simulation modeling of series compensation
In this section, the model of DFIG output through series compensated line is established on the basis of IEEE first standard model, and the topology is shown in Figure 2.

![DFIG Series Compensation Model](image)

Figure 2. DFIG series compensation model

When DFIG is sent out through series compensated line, the self-excited oscillation of subsynchronous resonance component of line current may be caused when the system is subject to small disturbance. On the basis of this model, the subsynchronous oscillation phenomenon of DFIG
when it is sent out through series compensated line is simulated to verify the suppression effect of improving electrical damping on subsynchronous oscillation of wind turbine. DFIG is set to operate at the wind speed of 10m/s and the speed of 1.1pu. When the system operates normally to 2s, a single-phase ground fault is set at the power supply side, which causes subsynchronous oscillation of the system. At this time, the active power waveform of DFIG is shown in Figure 3

![Figure 3. Oscillation waveform of A-phase current in case of disturbance](image)

In this paper, the applicability of SSDC to suppress subsynchronous oscillation is verified. A damping control link is added to the RSC control system to produce an additional positive damping to suppress the subsynchronous oscillation. In RSC control system, the additional control loop can provide a positive virtual resistance for DFIG small disturbance impedance. The input of the additional loop should be rotor current and the output should be rotor voltage. If the virtual resistance is directly connected in series with the DFIG impedance, the voltage generated by the additional circuit will be superimposed on the reference value of the rotor winding voltage. The RSC controller with virtual resistance control loop is shown in Figure 4. In the figure, \( F(s) \) is the transfer function of the band-pass filter. The function of the filter is to isolate the low-frequency component and the fundamental component of the current, and only let the subsynchronous frequency current flow. \( K_R \) is the virtual resistance value.

![Figure 4. RSC control structure diagram with additional virtual resistance circuit](image)

When the subsynchronous oscillation occurs in the system, the additional damping control is started immediately. The waveform of DFIG output power after the additional damping is shown in Figure 5. It can be seen from the figure that SSDC has a certain inhibitory effect on the subsynchronous oscillation of DFIG of wind turbine group.
4. Conclusion and Prospect

In this paper, a series compensation capacitor model of DFIG is established, and the subsynchronous oscillation is caused by a small disturbance. On this basis, the practicability of the additional subsynchronous damping controller (SSDC) for suppressing the subsynchronous oscillation of DFIG is verified, which also verifies the effectiveness of the series compensation model of DFIG.

Although there are a lot of researches on subsynchronous oscillation at home and abroad, because it involves the complex interaction of mechanical and electrical systems, its phenomena and characteristics, suppression measures and other aspects of the power system make it difficult to analyze its mechanism, and there are still many problems to be solved. There is also a lack of standard and unified comparison method for the suppression effect of different suppression measures on subsynchronous oscillation, which hinders the effective solution of subsynchronous oscillation.

With the development of smart grid and the wide application of high-power power electronic technology and devices, the generation mechanism, manifestation and suppression measures of subsynchronous oscillation in modern power system will continue to attract the deep attention of power industry and science and technology circles, and carry out more extensive research to lay the foundation for the further development of smart grid.

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