Studies of Sub-synchronous Oscillation Caused by the Series Compensation Transmission in System with Large-Scale Wind Power

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Abstract. In recent years, the technology of wind power developed very rapidly. In order to solve the issue of wind power consumption and improve the utilization of wind power. Large-scale wind power transmission is imperative. Series compensation technology is currently one of the economic and effective measures to solve large-scale wind power transmission. However, after the series compensation, sending wind power will cause sub-synchronous oscillation. In this paper, firstly, the structure and characteristics of three common wind turbines are introduced, and then they are summarized according to the characteristics of various turbines. The generation mechanism, related characteristics, and suppression measures of subsynchronous oscillations caused by series complement sending. The analysis method of the subsynchronous oscillation of the current large-scale wind power sending system is described. Finally, the part that needs further research is explained.

Introduction

Wind energy is one of the most commercially viable renewable energy sources at home and abroad. The large-scale development and utilization of wind energy is an important part of China's energy strategy. Among the nine large-scale wind power bases in China, except Jiangsu and Shandong, the remaining power generation bases’s capacity for wind power absorption is limited and long-distance wind power transmission are imperative. Series compensation technology can improve the transmission capacity and the stability of long-distance transmission systems, so this is one of the economic and effective ways to solve the problem of large-scale wind power transmission. Similar to the thermal power generating units, the wind turbines may also cause sub-synchronous oscillation (SSO) when they are sent through series compensation. This may cause the unit to be disconnected from the grid or damage the equipment. However, due to the fact that the wind turbine's own structure and grid connection are fundamentally different from traditional thermal power generating units, combined with the complexity of the wind farm and its system, the new subsynchronous oscillation problem caused by large-scale wind power transmission through series compensation will be even greater. SO, the research on this topic is also very challenging and innovative.

According to the object of interaction, the subsynchronous oscillation phenomenon of wind turbines can be classified into three types: Sub-Synchronous Resonance (SSR) and Sub-Synchronous Control Interaction (SSCI) and Sub-Synchronous Torsional Interaction (SSTI).

Firstly, this paper will introduces the structure and characteristics of three common wind turbines, and then summarizes the subsynchronous oscillations caused by the series compensation according to the characteristics of each unit. The generation mechanism, related characteristics, and suppression measures are described. What’s more, the analysis methods of subsynchronous oscillations in the current large-scale wind power delivery system are also introduced in this paper. Finally, try to explain the shortcomings in the current research work and the direction in which follow-up needs to be further studied.
The Structure and Characteristics of Common Units

There are mainly three types of aircraft currently used in the field of wind power generation, cage-type asynchronous wind turbines, Doubly Fed Induction Generator (DFIG) and permanent magnet synchronous wind turbines. The type of the unit is different, and the types of subsynchronous oscillations caused by the series compensation are also different.

Cage-Type Asynchronous Wind Turbine

The cage-type asynchronous wind turbine generator is used earlier and its structure is relatively simple. It consists by a wind turbine with a fixed pitch, a gear box, a cage-type asynchronous generator, a soft starter, and a parallel reactive compensation capacitor, as shown in Figure 1. The stator circuit of the cage-type asynchronous generator is directly connected to the grid, and the large power converter is omitted; the rotor of the cage asynchronous generator is connected with the wind wheel through the shaft of the unit. The unit shaft system mainly includes three parts: high speed shaft, gear box and low speed shaft. The presence of the gearbox increases the flexibility of the shafting. The shafting stiffness is approximately 0.15 to 0.40, and the natural oscillation frequency of the shafting system is very small, typically 1 to 2 Hz. The cage asynchronous generator runs near the rated speed, and it operates at constant speed and constant frequency during normal operation, so its wind energy conversion efficiency is low. At present, there are a certain number of cage-type asynchronous wind turbines in wind farms, but with the development of technology, they will gradually be replaced by more efficient new generation turbines.

Doubly Fed Induction Generator (DFIG)

As shown in Fig. 2, the DFIG consists of a wind turbine, a gearbox, an asynchronous generator, a Rotor Side Converter (RSC), and a Grid Side Converter (GSC). Its generator stator circuit is directly connected to the grid and the rotor circuit is also connected to the grid through the converter. Since the stator and rotor circuits can feed the grid, it is called double feed. DFIG's shafting and cage asynchronous wind turbines have similar shafting and low natural oscillation frequency. In addition, through converters and various types of control, DFIG can achieve decoupled control of active and reactive power, ensuring the variable speed and constant frequency operation of the unit at different wind speeds and capturing wind energy more efficiently. With its high wind energy conversion efficiency and excellent dynamic adjustment characteristics, DFIG has become the mainstream wind turbine.
**Permanent Magnet Synchronous Wind Turbine**

As shown in Fig. 3, a permanent magnet synchronous wind generating set consists of a wind turbine, a permanent magnet synchronous generator, a machine-side converter and its control system, a grid-side converter and its control system, and a filter circuit, and its generator. The stator is connected to the grid via AC/DC/AC or AC/AC inverters, and the wind turbine is directly connected to the generator. Since the gear box is omitted, its shafting stiffness is greater than the two units above, but at the same time it also reduces the maintenance cost of the unit and improves the unit operating reliability working life. Permanent-magnet synchronous wind turbines adopt permanent magnet excitation and have high conversion efficiency. In addition, the permanent magnet synchronous wind turbine can achieve maximum wind energy tracking and decoupled control of active and reactive power through the control of the stator-side inverter, and its access to the power grid has good stability and good low-voltage ride-through capability. Permanent-magnet synchronous wind turbine generators are also one of the mainstream wind turbine generators. However, due to factors such as high cost of permanent magnet materials, complicated generator structure, and heavy weight, their development has received certain restrictions.

![Figure 3. Permanent magnet synchronous wind turbine.](image)

**Subsynchronous Oscillations Caused by Large-Scale Wind Power Transmission through Series Compensation**

In recent years, research on the subsynchronous oscillations caused by wind power transmission through series transmission has mainly focused on the SSR phenomenon caused by the torsional vibration and series compensation grids of wind turbine generators. The state of Texas in September 2009, after the subsynchronous oscillation of the wind farm, the problem of SSCI between the converter control and the series compensated transmission line of the DFIG has drawn wide attention.

**Subsynchronous Resonance (SSR)**

At present, relevant researches have been carried out on the mechanism, analysis methods and suppression measures of the SSR caused by the use of series compensation for external transmission of wind turbines. The paper [1-3] discusses the mechanism of SSR occurring when the cascade asynchronous wind turbine adopts the series-assist transmission method. The influence factors of the SSR of the cage-type asynchronous wind turbine are studied by the time-domain simulation method, and the higher the series compensation is indicated. The higher the output active power, the more severe the subsynchronous resonant divergence, and gives the relevant suppression measures and their simulation results. Literature [4-6] established the DFIG model and used time-domain simulation and eigenvalue analysis to study the main factors that lead to SSR in DFigure. The study indicates that the lower wind speed, the higher the string compensation degree and the higher the resonant frequency. The more severe the SSR of the DFIG, the greater the proportional coefficient of the current tracking control of the rotor side converter (RSC), and the worse the system damping. However, in the above studies, the SSR phenomenon will only be triggered when the line total string compensation is above 50%, which is inconsistent with the string complementarity in the actual project, and the analysis method is relatively single; furthermore, the analysis of multiple wind turbines on the grid has not been conducted in the study. The influence of SSR has not been
explained in terms of the mechanism of SSR leading to SSR and how the above factors affect its characteristics.

**Subsynchronous Control Interaction (SSCI)**

For the three types of wind turbines commonly used in current wind farms, the cage-type asynchronous wind turbines are directly connected to the grid due to their stator loops, and there are no power electronic devices in the system. Therefore, there is no SSCI problem when using series compensating wind turbines. The study in [7] also shows that there is no SSCI problem for cage-type asynchronous wind turbines. The stator of a permanent magnet synchronous wind turbine generator is connected to the grid through a frequency converter. Although there is a power electronic device, the generator and the grid are not directly coupled, and the resonant current cannot enter the generator. Therefore, when a series compensator is used to send wind power, there is no SSCI problem.

**Subsynchronous Oscillation Analysis Method for Large-Scale Wind Power Delivery System**

At present, among the proposed subsynchronous oscillation analysis methods for wind farms, several typical analysis methods are frequency sweep analysis, eigenvalue analysis, complex torque coefficient and time domain simulation. Each has its own advantages, disadvantages, and scope of application.

**Frequency Sweep Analysis**

Frequency sweep analysis method is a tool used for subsynchronous oscillation analysis of series compensation system. It can filter system operating conditions with potential resonance risk. It is an approximate linear method. When using this method to analyze the problem, the relevant systems to be studied need to be simulated with a positive sequence network; other generators in the network other than the generator to be studied are simulated using sub-transient reactance equivalent circuits, for the analysis containing fixed The SSR problem in the series compensation system is very effective. Its advantages are less raw data needed, simple calculation method, clear physical concept, and the disadvantage is that the results obtained are approximate, and can only be used as a tool for screening possible SSCI systems. It is impossible to accurately and quantitatively study phylogenetics. SSCI's detailed features.

**Eigenvalue Analysis**

The eigenvalue analysis method is a method to analyze the dynamic response of the system by establishing a small disturbance linearization model of the system and solving eigenvalues, eigenvectors, etc. The oscillation mode and its damping characteristics can be analyzed; the participation factors that are strongly correlated with the SSCI can be found for monitoring; the sensitivity analysis can be performed on the state variables.

In order to take effective preventive measures. The advantage is that a large amount of useful information can be obtained, and the eigenvalue change situation before and after the implementation of the suppression strategy is easy to obtain; the disadvantage is that only the positive sequence network is used to describe the system, and the order of the matrix of the eigenvalues is high, and the dimension may be generated. “Disaster” is difficult to apply to a multi-machine power system. Generally, the engineering needs to be simplified after the multi-machine system is simplified.

**References**


