Full-Scale Electromagnetic Transient Modeling and Oscillation Suppression of a Wind Farm with SVG

Jierui Yang*,Zhen Li, Zhaofeng Zhang, Bin Wang, Xuepeng Mou

Grid Planning Research Center of Guizhou Power Grid Co., Ltd

Abstract. With the gradual depletion of the earth's resources and people's attention to environmental issues, the access of renewable energy has been paid more and more attention by countries around the world. Wind is one of the pollution-free energy sources, and wind power generation is forming a boom in the world, because wind power generation does not need to use fuel, nor does it produce radiation or air pollution. The power of wind power generation is characterized by volatility and intermittence. When there is disturbance in the system, the wind farm is likely to oscillate and challenge the stability of the power grid. Therefore, the wind turbine generator must be connected to SVG system to realize dynamic reactive power compensation function, so as to ensure the stability of its operation in case of fault. In addition, the cause of wind turbine oscillation needs to be analyzed in detail to ensure its stability.

1. Introduction

The principle of wind power generation is to use the wind to drive the wind turbine blades to rotate, and then increase the speed of rotation through the booster engine to promote the generator to generate electricity. According to the windmill technology, the wind speed (the degree of the wind) is about three meters per second, and power generation can start. Due to the dependence on wind speed, which is an unstable energy source, the power of wind power generation is characterized by volatility and intermittency. A large number of asynchronous power sources based on power electronic equipment and their access form a new type of power system, which makes the interaction between large wind farms and adjacent power electronic equipment and the power grid very complex. When there is disturbance in the system, the wind farm is likely to oscillate and challenge the stability of the power grid. Therefore, the wind turbine generator must be connected to SVG system to realize dynamic reactive power compensation function, so as to ensure the stability of its operation in case of fault. In addition, the cause of wind turbine oscillation needs to be analyzed in detail to ensure its stability. The research of many suppression measures is mainly carried out from two aspects: first, with the help of external equipment, the oscillation suppression is achieved by lifting the damping of the system at the grid side [1-8], such as the use of static synchronous compensator (STATCOM) and static var compensator (SVC); Second, through DFIG's own converter, add corresponding damping control to realize oscillation suppression, such as additional damping control, virtual resistance and other suppression strategies [9-11]. In addition, there are other suppression methods, such as auto-disturbance rejection technology [12], sliding mode control, etc. [13-16]. The auto-disturbance rejection controller improves the anti-interference ability of the doubly-fed Wind turbine, thereby reducing the torque fluctuation [17]. However, the oscillation frequency of the system has significant time-varying characteristics, which may reduce its control effect. Reference [18] uses sliding mode control to suppress the system subsynchronous oscillation, and the control effect is good, but its parameter setting and control link are relatively complex. Literature [19] proposes to reduce the PI parameters of the rotor-side converter to achieve oscillation suppression, but in practice, the system needs to have good dynamic response ability, and the change of parameters may affect the performance of the system. In order to improve the above problems, this paper proposes a wind farm oscillation control method with dynamic reactive power compensation device (SVG), which realizes the oscillation suppression of the wind turbine model by adjusting the SVG and the built-in parameters of the wind turbine. At the same time, because the wind turbine is connected to SVG, it also ensures that the stability of its operation can be maintained in case of failure.

2. Full-scale electromagnetic transient modeling of wind farm

This paper builds a wind turbine model based on the actual situation. The modeling idea of this full-scale wind turbine model is to build a wind turbine model, and then build a gearbox component to connect the induction generator, and then connect it into the system.

* fengji0314@163.com

2.1Build wind turbine model based on actual situation

The wind turbine model simulates the working conditions of the wind turbine in actual operation according to the specific wind energy utilization coefficient, wind speed and generator speed. The internal part of the wind turbine is composed of wind source elements and relevant speed regulators that simulate the wind speed output.

As a preferred scheme for the oscillation control method of wind farms with SVG described in this paper, the characteristics of this wind turbine simulation model are:

The wind speed signal v_w input to the Wind turbine is generated by the wind source element. The wind speed of the wind source adopts the mode of parallel internal input and external input. The external wind speed input can be adjusted during the operation process, and the parameters affecting the Wind turbine output such as the swept area of the wind wheel and air density can also be set independently to achieve the purpose of full-scale simulation by fully simulating any actual operation condition. The wind power transmitted from the wind turbine to the generator set in the model is expressed as:

$$P_{out} = 0.5\rho A v_w^3 \eta_{GR} C_p(\lambda, \beta) \tag{1}$$

Where, P_{out} is the power output of the wind turbine, in watts; ρ is the air density, unit: kg/m3; A is the swept area of the wind turbine, in cubic meters; v_w is the wind speed, unit: m/s; η_{GR} is the gearbox efficiency coefficient; C_P is the wind energy utilization coefficient, he is the pitch angle β Speed ratio to blade tip λ Function.

The basic working principle of the full-scale wind turbine model to realize grid connection is: before the generator speed is established, the grid connection is realized through the anti-parallel thyristor. At this time, the system provides active power and reactive power for the generator, while the wind turbine provides torque, driving the generator to increase speed. The trigger angle of the crystal box tube decreases gradually with the increase of the generator speed. Therefore, the generator speed can rise steadily through the above method, and thus the impact current interference stability can be avoided.

2.2Connect the built wind turbine model with the three-phase AC power supply

This model focuses on dual PWM converter and its control. The mathematical model of grid-side converter can be expressed as:

$$\begin{bmatrix} \frac{d_{id}}{d_t} \\ \frac{d_{iq}}{d_t} \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & 0 \\ 0 & \frac{R}{L} \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} x_1 \\ x2 \end{bmatrix} \tag{2}$$

$$x_1 = \frac{(v_d - e_d)}{L + \omega i_q} \tag{3}$$

$$x_2 = -\frac{e_q}{L - \omega i_d} \tag{4}$$

According to the above three formulas, we can get

$$e_d = -Lx_1 + v_d + \omega L i_q \tag{5}$$

$$e_q = -Lx_2 + \omega L i_d \tag{6}$$

Where, R and L are the connection impedance and inductance of the converter; i_d and i_q are the actual current of the d axis and the q axis respectively; v_d is the D-axis component of the system voltage; e_d and e_q are the D-axis and Q-axis components of the converter output voltage, respectively.

When the connection resistance R is ignored, if the output reference voltage of the converter is calculated according to the above formula, DQ decoupling control can be achieved. The wind farm model proposed in this paper is shown in Figure 1.

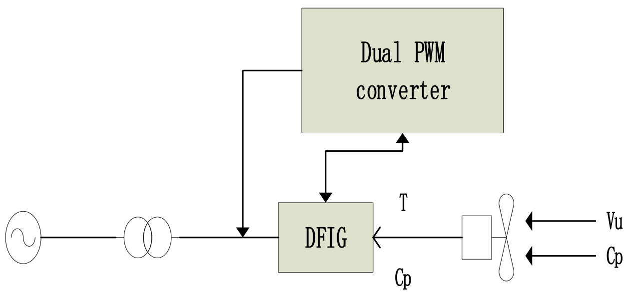

Figure 1. Structural drawing of wind turbine.

3. SVG access and oscillation suppression method

3.1Verify the effect of accessing SVG

According to the wind turbine model built in the above steps, connect SVG components into the wind turbine system and verify whether it works. The SVG system is based on a static synchronous voltage source. Its specific working principle is to connect the self-commutating bridge circuit with the power grid through a series reactance (including the leakage reactance of the transformer and other reactance), and properly adjust the amplitude and phase of the output voltage at the AC side of the bridge circuit according to the input system's reactive power rate and active power command, Or by directly controlling its AC side current, the system can absorb or send reactive current that meets the system's needs, and realize the purpose of dynamic reactive compensation. After SVG is connected, debug the program until no error occurs, and observe whether the voltage and power output waveform is stable.

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3.2Analyze the influence of various control parameters on oscillation

The relationship between Wind turbine response to system disturbance and Wind turbine side parameters is analyzed. In the case of system disturbance, since the stator side of the doubly-fed wind turbine generator unit is directly connected to the system side, the disturbance amount will exist in the stator of the wind turbine generator unit, so the instantaneous electrical parameters collected by the control system inside the unit will change accordingly, resulting in changes in the output voltage and current at the rotor side. At the same time, due to the coupling interaction between the stator side and the rotor side, the corresponding voltage and current changes will also occur at the stator side, and then will be superimposed with the original disturbance generated at the system side, making the situation more complex. If the wind turbine generates obvious oscillation at this time, there may be situations that can not restore the steady state, or even cause voltage collapse in serious cases. The current inner loop control parameters in the converter at the rotor side of the doubly-fed wind turbine are the key to affect the oscillation of the wind turbine system in the face of disturbance. The current is expressed as:

$$i_{re} = aK_D(1+\frac{1}{sT_D}) \tag{7}$$

Where, i_{re} refers to the disturbed current fed back by the doubly-fed unit to the system side, a is constant, T_D is the integral time constant, and K_D is the inner loop gain.

According to the specific relationship between parameters and oscillation, the design of relevant simulation can be completed. It can be seen that due to the mathematical relationship between the integral time constant T_D and the inner loop gain K_D of the rotor-side inner loop control, these two parameters can control the mutual excitation of the double-fed wind turbine system after the disturbance. Therefore, the idea of control variable is adopted, and in the simulation scenario where the disturbance will cause oscillation:

[1] Keep the value of parameter K_D unchanged, and appropriately increase the value of T_D. Because of the existence of positive correlation mathematical relationship, the interaction between the reaction and the system is weaker, that is, the system should be able to restore stability faster.

[2] Verify that the value of parameter K_D is properly reduced while keeping the parameter T_D unchanged, and observe the corresponding situation.

Analyze the possible influence of the relevant control parameters of the connected SVG side on the oscillation of the wind turbine when the system is disturbed, and analyze the relationship between the SVG response to the system disturbance and the SVG parameters. Because the inner loop control strategy of the static var generator is similar to that of the doubly-fed wind turbine generator, there are also control parameters P_{gain} and time constant T_{const} in the SVG to jointly control the excitation acting on the system, so the same analysis method is adopted to study. Under the system disturbance, the instantaneous voltage collected by the control system inside SVG will change, resulting in the change of the trigger pulse signal output by the AC voltage control loop, and the SVG will induce the disturbance current, which will be superimposed with the original disturbance and play an additional role in the oscillation. The disturbance current is expressed as:

$$i_{ref} = G\frac{1+P_{gain}}{1+T_{const}} \tag{8}$$

Wherein, i_{ref} refers to the disturbed current fed back by SVG to the system side, G is the parameter of the control loop, here it can be regarded as a constant, and T_{const} is the integral time constant.

The simulation design is completed according to the specific relationship between parameters and oscillation. It can be seen that because there is a certain mathematical relationship between the integral time constant T_{const} of the control loop and the inner loop gain P_{gain}, these two parameters can control the mutual excitation of the SVG reacting on the system after the disturbance. Therefore, the idea of control variable is adopted, and in the simulation scenario where the disturbance will cause oscillation:

[1] Keep the value of parameter P_{gain} unchanged, and appropriately increase the value of T_{const}. Because of the existence of positive correlation mathematical relationship, the interaction between the reaction and the system is weaker, that is, the system should be able to restore stability faster.

[2] Verify that the value of parameter P_{gain} is properly reduced while keeping the parameter T_{const} unchanged, and observe the corresponding situation.

4. Simulation verification

Based on the power system computer-aided design/DC electromagnetic transient simulation (PSCAD/EMTDC) platform, build the simulation wind turbine unit grid-connection model, debug and run until no error is reported. After SVG is connected, debug the program until no error occurs, and observe whether the voltage and power output waveform is stable. The output voltage of the simulated wind turbine generator unit connected to SVG is 690V, which is connected to the 220kV bus through the step-up transformer, and the output of the wind turbine generator unit is about 200MW; SVG capacity is 300MVar and voltage is 25kV; The short circuit capacity of the system is 476.3MVA, and the short circuit ratio is about 2.13. The simulation model diagram is shown in Figure 2.

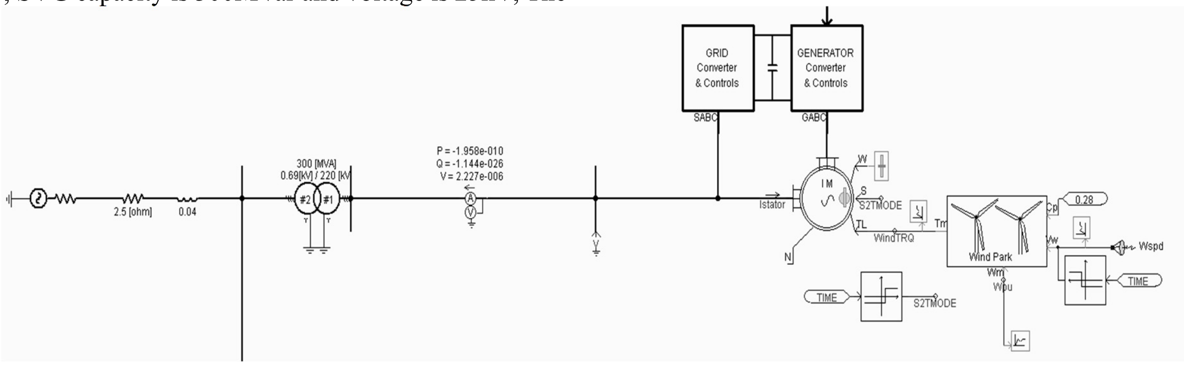

Figure 2. Structure diagram of wind turbine simulation model.

After the SVG is connected to the wind turbine and the commissioning is successful, a short time fault condition is set at the wind turbine connection point to record the voltage and power changes of the system before and after the SVG is connected, and on this basis, analyze whether the SVG realizes its function. After the SVG is connected, a short time three-phase short circuit fault is set at the grid connection of the Wind turbine, and the simulation waveform of the Wind turbine side affected by the fault before and after the SVG is connected is observed and compared. If SVG is connected correctly, SVG will output reactive power in case of failure at grid connection, and maintain the voltage and active power at the Wind turbine side to recover to the state of stable operation in a very short time. According to the simulation results, adjust the appropriate parameters to ensure that SVG can function normally. The results are shown in Figure 3 and Figure 4. Figure 3 shows the voltage change when the system encounters a fault before connecting to SVG, and Figure 4 shows the voltage change after connecting to SVG; The reactive power release of SVG is shown in Figure 5. It can be clearly seen that the wind turbine generator after SVG is connected can recover to the original operating state faster in the face of failure.

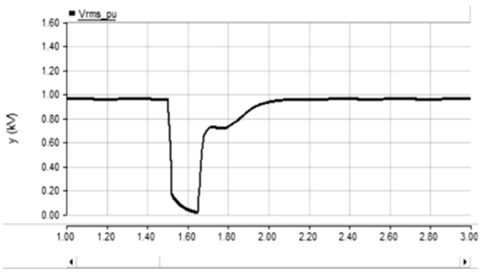

Figure 3. The system encounters fault voltage changes before SVG is connected.

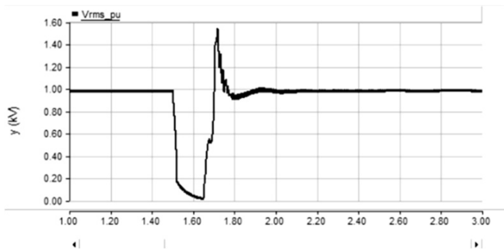

Figure 4. The system encounters fault voltage changes after SVG is connected.

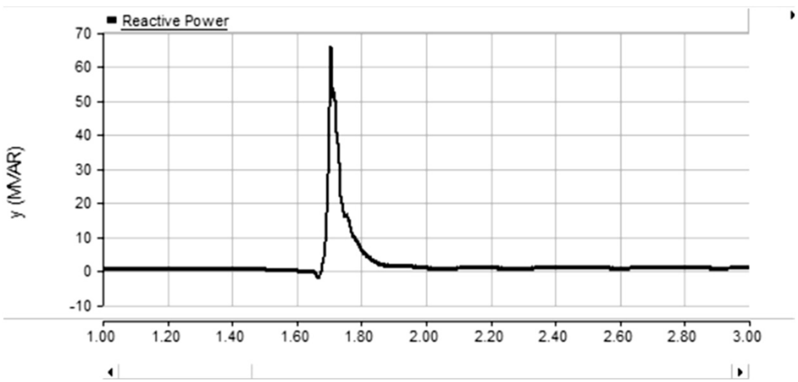

Figure 5. SVG output.

Simulation of SVG wind power system oscillation suppression model design. First of all, according to the analysis of the actual situation, the short circuit current of the system is appropriately reduced, thus reducing the short circuit ratio of the wind farm, and reducing the short circuit ratio to about 1.5. At this time, the system is more unstable than the original, and it is easier to observe the oscillation. Set the load disconnected at the grid-connected side of the wind turbine at a certain time, observe the voltage oscillation at the grid-connected point, and consider the influence of the control parameters of the converter at the rotor side of the doubly-fed wind turbine and the STATCOM control parameters on the stability of the grid-connected system based on the system. The oscillation is shown in Figure 6. It can be clearly observed from the figure that the wind turbine system oscillates for a long time in this scenario.

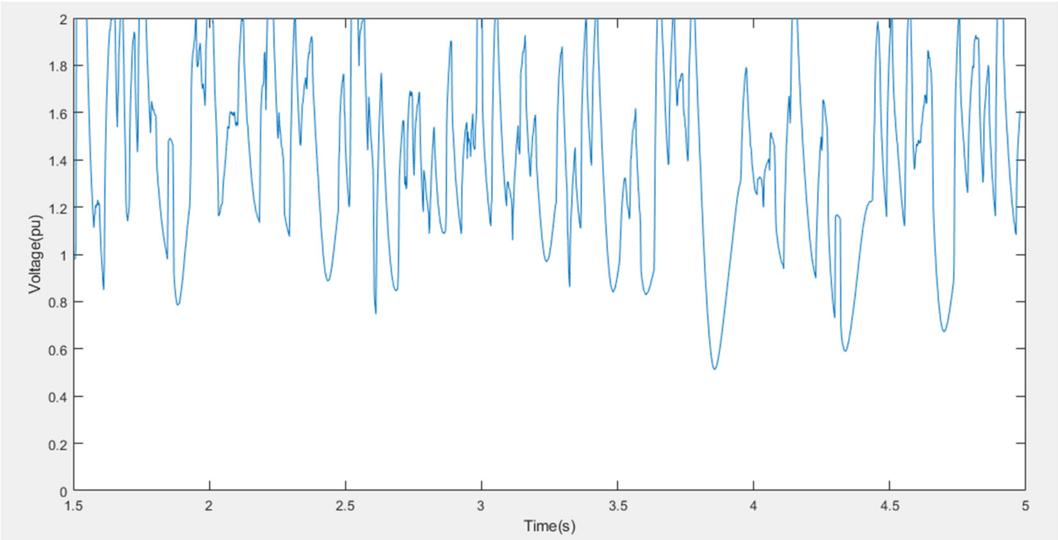

Figure 6. Voltage oscillation of wind turbine generator unit in case of disturbance.

Record the parameter at this time, K_D =0.1; T_D =0.2; P_{gain} =10; T_{const} =1;

Adjust the value of K_D to 0.005 and keep the other parameters unchanged. The results are shown in Figure 7. It can be observed that the system oscillation has improved significantly and recovered to stability in a short time.

Adjust the value of T_D to 0.5 and keep other parameters unchanged. The results are as shown in Figure 7. It can be observed that the system oscillation has improved significantly and recovered to stability in a short time.

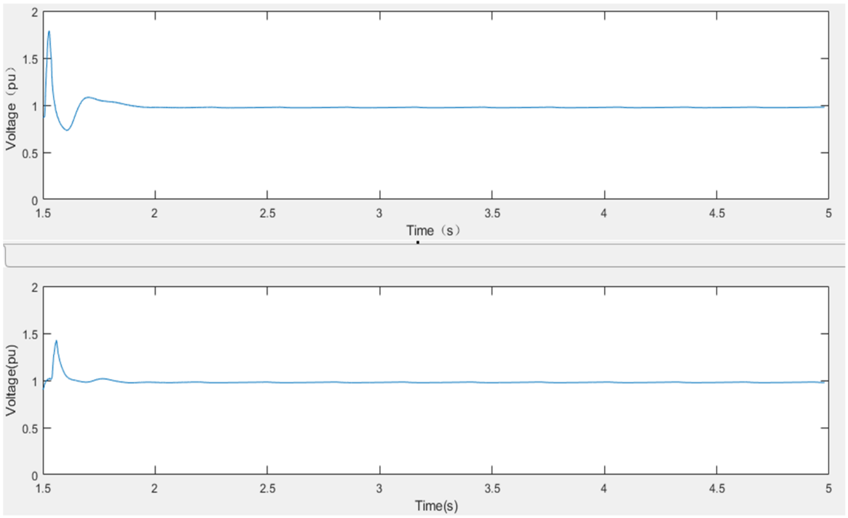

Figure 7. Influence of Adjusting Parameters of Doubly-fed Wind Turbine on Oscillation Suppression.

Adjust the value of T_{const} to 2, and keep other parameters unchanged. The results are shown in Figure 8. It can be observed that the system oscillation has been significantly improved, and it will be stable in a short time.

Adjust the value of P_{gain} to 2 and keep other parameters unchanged. The results are shown in Figure 8. It can be observed that the system oscillation has been significantly improved and recovered to stability in a short time, and the system oscillation amplitude is the smallest in this scenario.

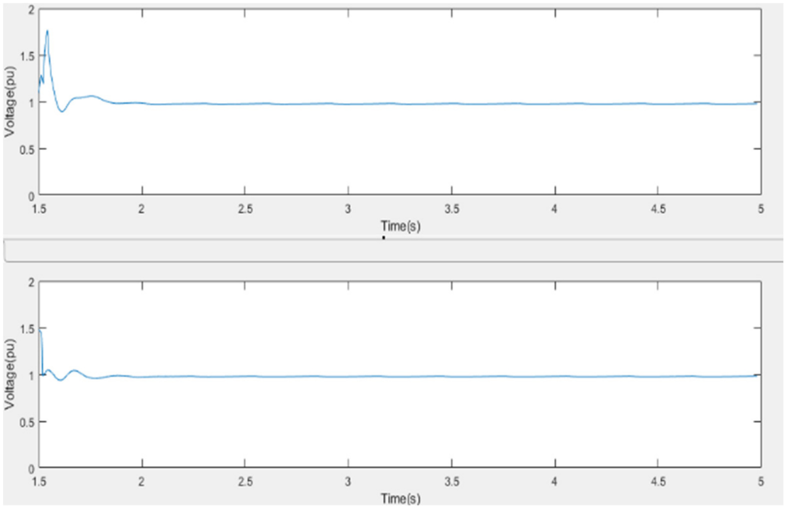

Figure 8. Influence of adjusting SVG control parameters on oscillation suppression.

Through practical verification, the control parameters of the doubly-fed wind turbine and SVG will have an impact on the oscillation of the system under disturbance, and the specific simulation results also verify the rationality of the previous analysis.

The wind farm modeling with SVG designed in this paper and the analysis of the oscillation influence factors based on this model enable the wind farm to recover to the stable operation state as soon as possible when encountering faults and system disturbances after connecting to the large power grid, which is helpful for understanding the stability of the new energy system grid connection, and provides a feasible analysis method.

5. Conclusions

This paper proposes a wind farm oscillation suppression method with SVG to realize SVG access to wind turbines and analyze how to improve stability and avoid oscillation under disturbance. It can realize that wind turbines can rely on SVG to achieve dynamic reactive compensation to maintain stability in the face of failure, and can effectively improve the stable operation ability of wind turbines according to the analysis of the factors affecting oscillation, so as to maintain stable operation in the event of disturbance, Reduce the impact of oscillation on wind turbines as much as possible, and provide a feasible analysis method for improving the grid connection stability of new energy systems.

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