

Equivalent Power Smoothing and Frequency Compensation for Large-scale Wind Power Equipment

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Abstract. Grid-side power converter is the key interface of the larger-scale wind power system connecting to the grid, with the continuous improvements of the penetration rate of the large-scale wind power equipment, the connected grid converter device plays more and more prominent influences on the large grid. Learning from the synchronous generator mathematical model in the traditional power system, a large-scale wind power equipment virtual synchronous generator (Virtual Synchronous Generator, VSG) is proposed to equivalently realize the power smoothing and frequency compensation. Firstly, the virtual speed governor and the virtual excitation governor with the individual characteristics of power electronic device are designed to guarantee the low harmonic distortion of the grid current, and at the same time have the functions of responding the grid voltage amplitudes] and frequency fluctuation event, and can be capable of improving the grid stability to a certain degree. And meanwhile simulate the rotational inertial of the synchronous generator, improve the inertial and damping characteristics of the grid interface and decrease the impact of the large-scale wind power generator system to the traditional grid. And at last, perform the verification and analysis to the feasibility and effectiveness of proposed method on basis of 110kW wind power generator set as well as the lithium battery energy storage unit.

Introduction

With the increasingly serious energy crisis and the requirements of the national “energy conservation and emission reduction”[1-2], wind power generation technology industry has been rapidly developed in worldwide. However, because the wind power has randomness and intermittent, with the gradually increase of the proportion taken by wind power installed capacity in the grid, the influences produced by the large-scale wind power field on the stability of the system has been gradually increased. And because the frequency variation caused by the system load variation will also become more radical, which makes it easy for the grid to lose its stability. As the bridge between the generation (consumption)system and the grid, the pros and cons of the grid interface power converter topology as well as its control strategy directly determine the operation mode and performance of the wind power system. In order to effectively respond to the increasing wind generation system, and make it as member of the green grid family, scholars from various countries execute depth studies focusing on how to improve the dynamic and static performances of the grid interfaces.From the documents checked at present, there are mainly the indirect and direct current controls, direct power control, as well as the control strategy[5-7] taking the model predictive control as the representative on basis of the modern control theory. Throughout the above-mentioned control strategies, the traditional wind power system grid interface control scheme still can’t satisfy the increasing “intellectual grid”demands.

Grid interface virtual synchronous generator control

As is shown in Figure1, the purpose of the large-scale wind power generation system grid interface adopting VSG control is to realize that the grid interface actively adjusts the grid active and inactive powers it takes in according to the grid frequency and voltage, to reach the aim of active interactions with the grid, and meanwhile satisfy the load power requirements.

Virtual speed governor

Learning from the synchronous generator frequency-active power adjustment theory of the traditional system to design the grid interface virtual synchronous generator speed governor as is shown in Figure 1. Realize the adjustment of the active power order of the wind power generation system grid interface through the adjustment of the virtual prime mover torque T_m .

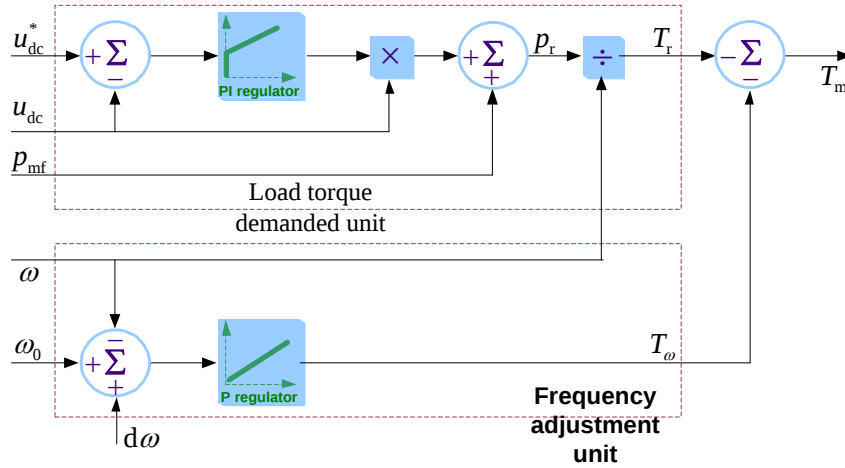


Figure 1 Virtual speed governor

As is shown in Figure1, the virtual prime mover torque $T_m = T_r + T_\omega$, which including the load demanded torque T_r and the frequency deviation torque T_ω . In which, $T_r = p_r / \omega$ adjusted by the load torque demanded unit, p_r includes the virtual synchronous generator DC-bus voltage proportion integration, governor output and load real-time power demand value p_{mf} introduced in order to improve the responding speed of the grid interface to the active power of the wind generation system load transition process. T_r can be expressed as,

$$T_r = \left[\left(k_{dcP} + \frac{k_{dcI}}{s} \right) (u_{dc}^* - u_{dc}) + p_{mf} \right] / \omega \quad (1)$$

In this formula, k_{dcP} and k_{dcI} are respectively the proportional coefficient and integration coefficient of DC bus voltage PI governor of virtual synchronous generator.

The frequency deviation torque T_ω is realized by the frequency adjustment unit designed according to the traditional generator system frequency-power droop characteristics. Simulate the droop characteristics by adopting the proportion governor,

$$T_\omega = k_\omega (\omega_0 - \omega) \quad (2)$$

In this formula, ω_0 is the grid rated angle frequency, k_ω is the frequency response coefficient. In Figure 1, the input variable of frequency adjustment unit $d\omega$ is the phase deviation signal of the virtual pre-connected grid.

Virtual excitation control

The traditional synchronous generator adjusts the inactive power output and motor terminal voltage through the excitation controller. The virtual excitation system should be capable of automatically adjusting the virtual excitation current to make the grid interface connected grid provide the corresponding inactive power while operating, and at the same time, effectively controlling and stabilizing the terminal voltage in order to improve the stability of the grid system. In which, the inactive power adjustment unit introduces the the proportion governor to simulate the traditional generator system voltage-inactive power droop characteristics, the output is,

$$\Delta E_Q = k_Q (Q_n - Q) \quad (3)$$

In this formula, Q_n is the inactive power order of the grid interface, Q is the transient inactive power of the grid interface output, k_Q is the inactive power adjustment coefficient. In which, Q can be calculated according to the transient inactive power theory,

$$Q = u_{g\beta} i_{\alpha} - u_{g\alpha} i_{\beta} \quad (4)$$

In this formula, $u_{g\alpha}$, $u_{g\beta}$ and i_{α} , i_{β} are respectively the components of the grid interface PCC voltage and current on the $\alpha\beta$ coordinate axis.

In order to stabilize the virtual synchronous generator voltage, introduce the voltage adjustment unit equivalent to the synchronous generator automatic excitation effect, and its output is,

$$\Delta E_U = k_U (U_n - U) \quad (5)$$

In this formula, U_n is the expected value of the grid interface end, U is the actual value of the grid interface end, and k_U is the voltage adjustment coefficient.

$$\Delta i_f = \left(k_{ifP} + \frac{k_{ifI}}{s} \right) (\Delta E_Q + \Delta E_U) \quad (6)$$

In this formula, k_{ifP} and k_{ifI} are respectively the proportion coefficient and integration coefficient of the PI governor of the virtual excitation current. In this article, it introduces the proportion-integration controlling strategy which can realize the steady-state static difference-free tracking of inactive power and terminal voltage when the grid interface connected grid is running, restrain the inactive responding impact in the dynamic progress.

Use the excitation current derivation signal Δi_f , virtual EMF unit to simulate the excitation relation between synchronous generator EMF desired amplitude E_r and the excitation current i_f as in shown in formula (5),

$$E_r = k_E \omega (i_{fn} + \Delta i_f) \quad (7)$$

In this formula, i_{fn} is the virtual excitation current rated value, k_E is the excitation current adjustment coefficient.

According to the above analysis, it can be seen that, the virtual synchronous generator controlling scheme is completely different from the traditional controlling strategy in the aspect of inactive power adjustment. It guarantees the inactive power tracking, and at the same time can be capable of participating in the grid voltage adjustment, and provide necessary inactive power supports to the grid it connecting to according to the voltage derivation.

Experiment result and analysis

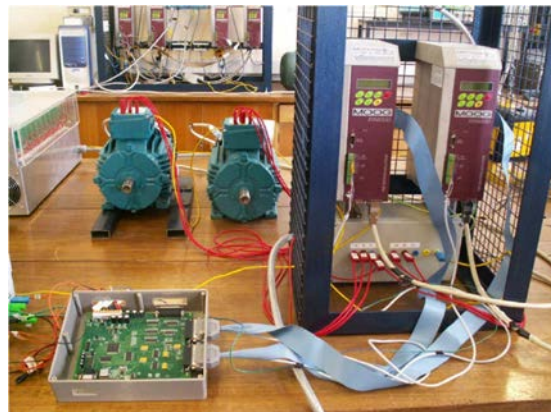
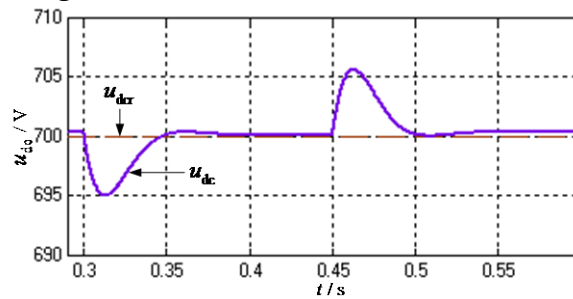


Figure 2 System diagram of experiment platform

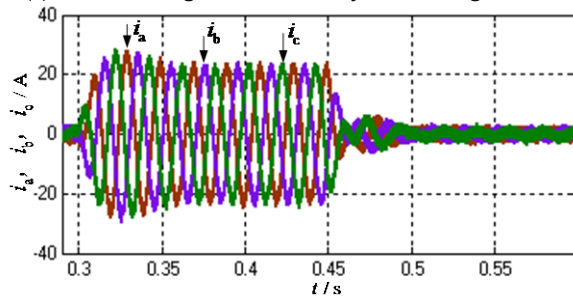
In order to verify the effectiveness of the grid interface virtual synchronous generator controlling scheme of B2B wind generation system proposed in this article, in which: wind generation unit. Rated capacity is 25 kW, rated wind speed is 13 m/s, storage battery capacity is 18 kVA. The

virtual synchronous generator controlling algorithm parameter $R_a=0.01\ \Omega$, $X_s=0.25\ \Omega$, $J=0.12\ \text{kg}\cdot\text{m}^2$. In order to realize the flexible start of grid interface, through the Software Phase-locked Loop in Figure 7 to obtain the space position angle θ_g of u_g , and at the same time, direct the d axis to the u_g vector direction, and through controlling the d,q axis component $u_{dr} = u_g \cos \theta_g$, $u_{qr} = u_g \sin \theta_g$ of u_g , the synchronous tracking of u_g can be realized.

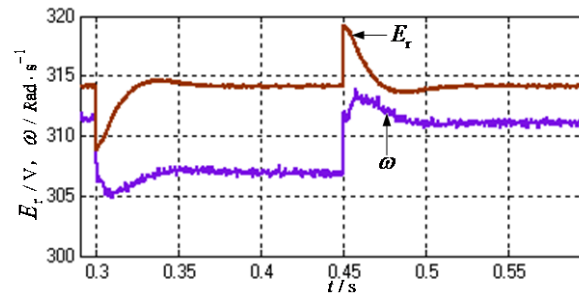
At 0.3s in Figure3, the DC-side bus connecting with 50Ω resistance to simulate the working conditions of sudden increasing load of the wind generation system, at 0.45s, cut off the resistance to simulate the working conditions of sudden reducing. From Figure 3(a) it can be seen that, during the sudden load change process, DC-bus voltage u_{dc} has fluctuation, and under the effect of load power frontward control, it will restore to 700v after 0.05s adjustment process. Figure 3(b) is the grid interface current in the load sudden change process, from which it is easy to discover that, under the effects of inertia and damping, the current of three-phase interface changes smoothly, and reduces the influences to grid on the basis of satisfying the load demands. Figure 3(c) shows the responding situation of the EMF E_r and rotational angle speed ω of the virtual synchronous generator. From this it can be seen that, E_r and ω both have significant inertial characteristics in the dynamic process to guarantee the grid interface run more stable and reliable. The mechanical torque and electromagnetic torque of the virtual synchronous generator shown in Figure 3(d) are both negative, the virtual synchronous generator absorbs energies from the grid. When the load suddenly increases, the virtual speed governor adjusts the mechanical torque T_m order, and under the effect of the virtual synchronous generation technology, the electromagnetic torque T_e changes accordingly, which results the decrease of the rotational angle speed ω , and this is consistent with the droop characteristics between the traditional synchronous generator system active power-frequency. During this process, the torque response changes smoothly under the effects of inertia and damping, realizes the flexible and soft inertial buffering function of the grid interface as the bridge between the grid and load. In order to avoid the inactive power injection of the wind generation system grid interface to the grid, the inactive power order Q_n is set as 0Var. From Figure3 (e) it can be seen that the grid interface can respond quickly to the load active power demand, and provide necessary power supports and inactive compensation to the grid according to the inactive power order. At the same time, the proposed controlling strategy can provide necessary damping and inertia to the system to make the grid interface have the controlling performance comparable to the synchronous generator.



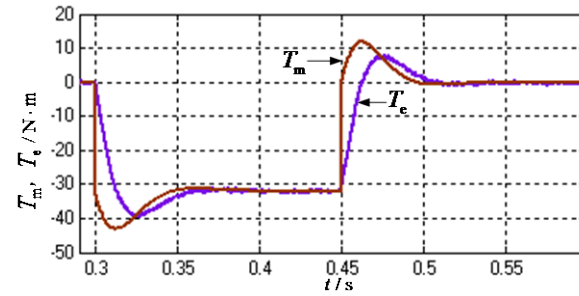
(a) DC bus voltage of the virtual synchronous generator



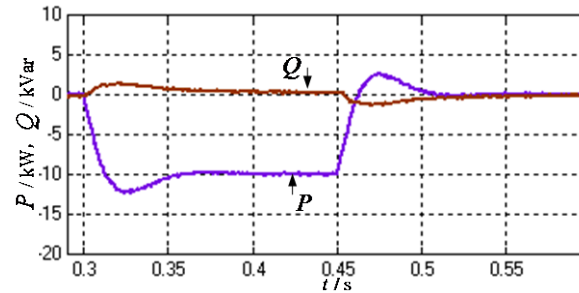
(b) three-phase current of the grid interface



(c) EMF and power angle characteristics of the virtual synchronous generator



(d) Mechanical torque and electromagnetic torque of the virtual synchronous generator



(e) Active and inactive powers of Grid interface

Figure 3 experiment result of VSG connected grid

Conclusion

In this article, it introduces the virtual synchronous generator concept and researches a large-scale wind power system grid interface controlling method which can actively participate in the adjustments of grid voltage and frequency. Based on the experiment verification of 110 kW wind power generation experimental prototype, the following conclusions can be obtained: the virtual synchronous generator controlling technology adopted by the large-scale wind power generation system grid interface has good load power demand characteristics, and improves the adaptability of the grid to the wind generation system. The virtual grid interface adopted by the grid has the external characteristics of the traditional synchronous generator, and can provide necessary inertia and damping to the system mode switch, and provide necessary active and inactive power supports to the grid abnormal events and greatly improve the stability of the large-scale wind power connected grid system.

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