# RESEARCH ON THE VIRTUAL SYNCHRONOUS GENERATOR CONTROL STRATEGY OF GRID-CONNECTED PERMANENT-MAGNET DIRECT-DRIVEN WIND POWER SYSTEM

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*Renewable energy, distributed generation, and micro-grid technology have been widely concerned for a long time. The traditional grid-connected inverter control strategy does not take into account the problem of inertia which is short and fast to cause the frequency change. The virtual synchronous generator control strategy is adopted to simulate the synchronous generator characteristics, which enhanced the inertia and damp of the system. For the micro-grid of wind power grid-connected, the storage battery is arranged on the AC side of the permanent magnet direct-drive wind turbine, and the model of the virtual synchronous generator is established. Thus the grid-connected performance of large-scale wind farm is improved. Here, the effect of moment of inertia in the virtual synchronous generator and the grid-connected regulation of virtual synchronous generator are verified by using PSCAD/EMTDC. The simulation results show that the grid-connected inverter controlled by the virtual synchronous generator is approximately equivalent to the synchronous generator in external characteristic. The grid-connected inverter based virtual synchronous generator control has a beneficial to adjust frequency and voltage, and can enhance the standby inertia of new energy and grid power generation.*

Key words: *grid-connected wind power, inverter, energy storage, virtual synchronous generator, frequency and voltage regulation*

## Introduction

As a clean renewable energy of wind energy, which is developing rapidly in the industry. However, due to the randomness and intermittence of wind energy, the wind turbine has an impact on the stability of the power grid. At the same time, the frequency caused by the change of system load changes will become more intense, it is also easy to lose stability for the grid.

Distributed power generation and micro-grid technology has long been widely concerned, in order to improve the power supply based on power electronic inverter interface to maintain the stability of the power system. In recent years, grid-connected inverter controlled by virtual synchronous generator (VSG) strategy, due to its voltage and frequency support effect

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for active power distribution network included the distributed power supply, have more and more widely applications in the distributed power generation system and micro-grid. Based on the rotor motion equation of the synchronous generator, primary frequency modulation characteristic and the delay characteristic of the reactive power adjustment of synchronous generator, the control of the distributed inverter power supply is constructed. The method of simulating synchronous motor control can make the grid-connected inverter of micro-grid or other independent system has the same grid-connected and island characteristics to traditional synchronous generator, which can made the grid-connected inverter have some good characteristics, such as self-synchronization, large impedance and large inertia. So that the grid-connected inverter based VSG control has the similar active and reactive power adjustment capability compared to the synchronous generator, and can simulate the inertia and damping characteristics of synchronous generators, to overcome the lack of inertia of traditional grid-connected inverter impact on the grid, and can effectively enhance the capacity of the grid to accept renewable energy.

The output of the single grid-connected inverter based on VSG control is compared with the output of traditional synchronous motor and the inverter output based on the droop control, respectively, which shows that the grid-connected inverter based on VSG control can simulate the synchronous motor inertia characteristics. The virtual inertia is actually provided by a distributed power storage device [1]. The distributed energy sources such as photovoltaic in the micro-grid are intermittent and unstable, so that the inverter based on VSG can not maintain the DC bus voltage stability and can not provide stable and sufficient energy buffering response to power fluctuation of distributed energy sources. Therefore, the VSG control grid-connected inverter with energy storage unit is proposed, which is used in the grid-connected distributed energy sources. However, the literature does not study a specific distributed energy source [2]. The energy storage unit based on VSG control and the photovoltaic grid-connected system are studied. Through the establishment of VSG model, with reference to synchronous generator control theory, the design of the frequency controller and excitation controller is carried out. The VSG-controlled energy storage system is connected in parallel with the photovoltaic grid-connected system, and the results show the effect of the moment of inertia in the VSG and the grid-connected regulation of VSG. It verifies the feasibility of the photovoltaic grid-connected system based on VSG [3-5]. In order to make the wind turbine show the frequency regulation characteristics of the conventional wind turbine, a new generator set based on the energy storage system is proposed, in which the VSG control strategy is used to study the power system frequency regulation of the wind farm. The results show that the VSG-controlled energy storage system adopted by wind farm can effectively support the frequency of the power system, so that the frequency regulation characteristics of wind farm performance is consistent with that of conventional generator sets. Thus it can improve the dynamic frequency characteristics of power system including wind power system [6, 7]. However, the previous study is carried out based on doubly-fed wind turbine, this paper study on the wind power system consisted of permanent magnet direct drive wind turbine, and the energy storage system based on VSG control is arranged in the AC side. It can make wind power to deliver smooth power to the power grid, and to show the synchronous generator characteristics to the large grid, which effectively improves the grid-connected performance of the wind power system [8-12].

In order to maintain the stable operation of the VSG, it is necessary to increase the energy storage link to provide energy buffering for the VSG adjustment process. At the same time, it can maintain the DC bus voltage stability and ensure the stability of power supply during the micro-grid load and distributed energy sources change. Firstly, this paper mainly studies the

VSG which introduces the energy storage unit. Secondly, the storage power demand when the distributed energy sources fluctuate is analyzed. Lastly, the energy storage battery is arranged on the AC side of the permanent magnet direct drive wind turbine is studied with the power system electromagnetic transient simulation software PSCAD/EMTDC. Especially the VSG control strategy of the inverter of the energy storage system is adopted to study the regulation characteristics of the permanent magnet direct drive wind turbine, the power system frequency, and voltage stability when the load fluctuates.

## The VSG control strategy

As shown in fig. 1, the energy storage battery is arranged on the AC side of the wind turbine, by the control strategy design of the inverter based energy storage battery, then the wind turbine will send the smooth power to the grid and it can reduce the influence of grid frequency caused by wind turbine [13]. At the same time, the inverter has the same external characteristics relative to grid, which can adjust the output power according to the system load fluctuation, to realize the frequency and voltage regulator of the synchronous generator, and it can improve the stability of the system effectively, and is beneficial to the acceptance of the wind power generator.

The VSG control strategy consists of two parts: the upper power control and the bottom voltage and current double loop control. The overall control strategy of distributed inverter power supply based on VSG control is shown in fig. 2.

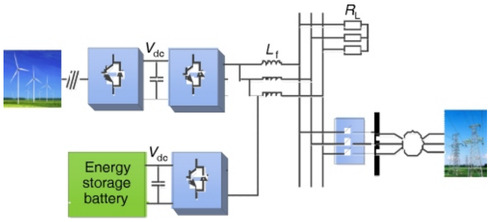


**Figure 1. The VSG block diagram**

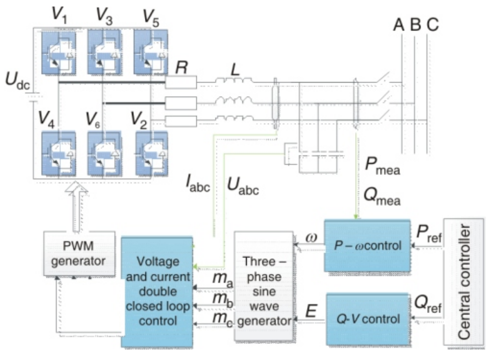


**Figure 2. The side of energy storage battery inverter control block diagram**

## Wind power grid-connected system based battery energy storage

### *Active power-frequency control*

Because the synchronous generator rotor has certain inertia, its frequency will not change in a short time. According to its rotor motion equation, the virtual inertial control is introduced into the distributed inverter control algorithm to simulate the synchronous generator rotor motion characteristics. So the active power-frequency control equation of distributed power is:

$$\begin{aligned} & 2H\frac{d\omega}{dt} \quad P_{mec} \quad P_{out} \quad K_d(\omega \quad \omega_{grid}) \\ & \frac{d\varphi}{dt} \quad \omega \end{aligned} \tag{1}$$

where $H$ is the virtual inertia time constant, $\omega$ $\omega_{grid}$ – the angular frequency of inverter power supply and the common bus, respectively, $P_{mec}$ – the inverter power supply input power and $P_{out}$ – the inverter power supply output power, $K_d$ – the damping coefficient, and $\varphi$ – the phase angle. The control block diagram is shown in fig. 3.

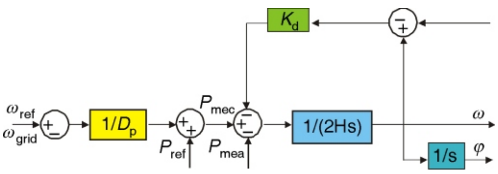


**Figure 3. Active power-frequency control block diagram**

The frequency regulation control link is:

$$P_{mec} \quad P_{out} \quad \frac{1}{D_p}(\omega_{ref} \quad \omega_{grid}) \tag{2}$$

where $D_p$ is the active power of the droop coefficient, and $\omega_{ref}$ – the reference value of angular frequency.

According to eqs. (1) and (2), it can be found that the transfer function of active – frequency control is:

$$[(\omega_{ref} \quad \omega_{grid})\frac{1}{D_p} \quad P_{ref} \quad P_{mea} \quad K_d(\omega \quad \omega_{grid})]\frac{1}{2Hs} \quad \omega \tag{3}$$

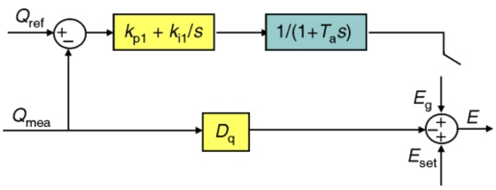


**Figure 4. Reactive power-voltage control block diagram**

### *Reactive power-voltage control*

When the distributed inverter power supply works in different modes including grid-connected and autonomous modes, the goal of reactive power-voltage control is different. In the grid-connected mode, the control purpose is to transmit the specified reactive power to the grid. While In the autonomous mode, the output reactive power is depended on the load. The main purpose is to control the output voltage of the inverter.

In fig. 4, $D_p$ is the sagging coefficient of reactive power, $k_{p1}$ and $k_{i1}$ are the proportional integral coefficients, $T_a$ – the time constant of the delay link, $E_g$ – the output signal of the reactive power controller, $E_{set}$ – the voltage reference voltage of the distributed inverter power supply. So the reference voltage of the distributed inverter power supply can be expressed:

$$E \quad E_{set} \quad D_q Q_{mea} \quad (Q_{ref} \quad Q_{mea}) \; k_{p1} \quad \frac{k_{i1}}{s} \quad \frac{1}{1 \quad T_a s} \tag{4}$$

here $D_p$ have determined the system drop characteristics of reactive power-voltage. When the distributed inverter power supply is operated in the autonomous mode, the reactive power controller should be stopped, that is $E_g = 0$, to maintain the reactive power-voltage drop control, and to ensure the stability of the output voltage of the inverter power supply by changing the reference voltage.

## System simulation verification

In view of the advantages of PSCAD/EMTDC in electromagnetic transient simulation and wind power modeling, so this simulation based on PSCAD simulation environment.

In the model, the side of permanent magnet direct drive wind turbine adopts the power control, and the grid side adopts the voltage control. The VSG control strategy is used into the side of inverter based on energy storage battery. The VSG control of wind turbine simulation shown in fig. 5. The parameter configuration is shown in tab. 1.

### *The simulation of load power variation*

This section studies the wind turbine and energy storage batteries supply power to the load separately, in order to verify that it adjusts its output and the moment of inertia based on

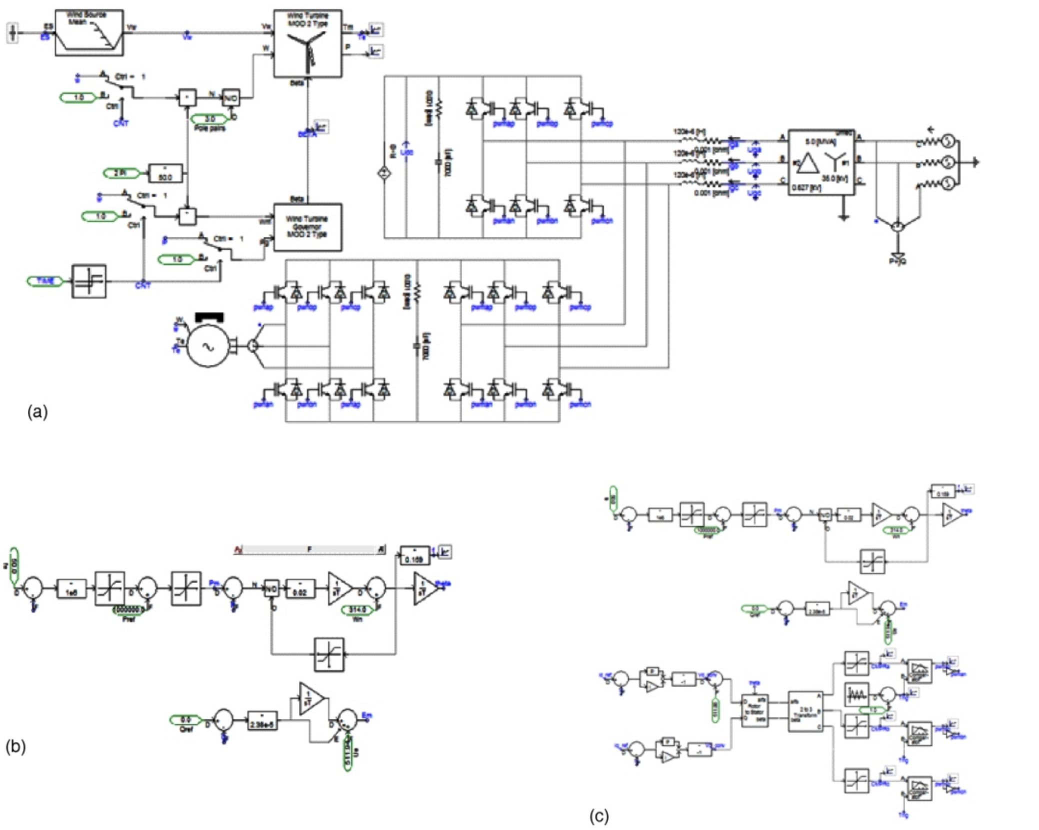

**Figure 5. Simulation of wind turbine controlled by VSG; (a) simulation of the main circuit diagram, (b) active power-frequency control and reactive power-voltage control, (c) simulation of voltage and current double loop control**

load changes. In 0.5 second when the load active power reduced by 40 kW, reactive power remains unchanged, and in 1.5 second, the active power increased by 40 kW, reactive power remains the same. The system simulation results are shown in fig. 6. Subscript load corresponds to the load power, VSG represents the power provided by the wind turbine and energy storage battery together.

Figure 6(a) shows the frequency variation of the system when the moment of inertia and fig. 6(a) shows that when the same change of load power, the system response time will increase with the increase of the moment of inertia, and the frequency of the change will be more gentle. The reason is that when introduction of the moment of inertia, the output of mechanical power of the VSG

**Table 1. System parameters**

| | |
|---|---|
| Rated capacity of wind turbine | 140 kW |
| Energy storage battery capacity | 100 kVA |
| Filter inductance | 0.12 mH |
| Moment of inertia | 0.2 kgm$^2$ |
| Current inner loop control parameter, $K_p$ | 0.3 |
| Current inner loop control parameter, $K_i$ | 0.01 |
| Voltage inner loop control parameter, $K_p$ | 1 |
| Voltage inner loop control parameter, $K_i$ | 100 |

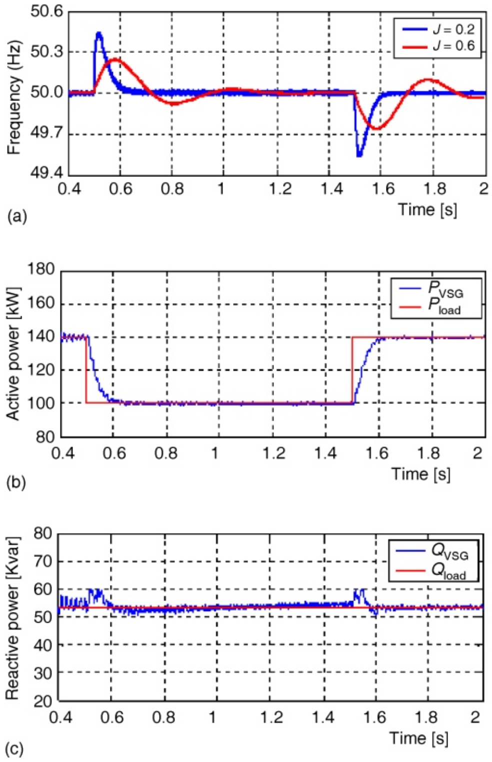


**Figure 6. The VSG technology to maintain system stability; (a) system frequency at different inertia, (b) system active power, (c) system reactive power**

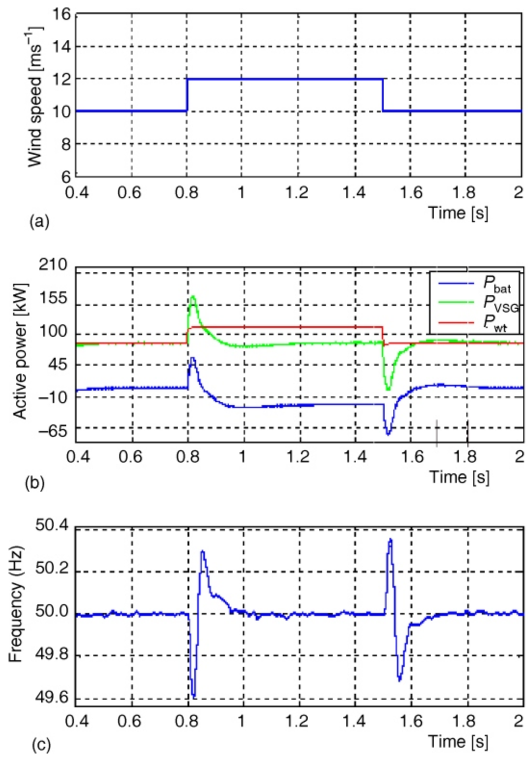


**Figure 7. Energy storage battery stabilizes wind farm output power; (a) wind speed, (b) system active power, (c) system frequency**

can not make real-time change with the sudden change of the load power. The power supply and demand imbalance will result the torque difference on the rotor shaft. When the torque difference is constant, speed change rate is inversely proportional to the moment of inertia. So in order to improve the stability of the system, it is useful to increase the moment of inertia appropriately, to ease the fast and frequent change of system frequency caused by load inputting and removing frequently.

It can be seen from fig. 6(b) and (c) that the output power of the wind turbine and the energy storage battery can track the change of the load power better, indicating that the energy storage battery can stabilize the output power of the wind turbine according to the load power. In fig. 6(c), the change trend of reactive power is consistent with the change trend of frequency, that is, when the frequency increases, the reactive power output increases, and when the frequency decreases, the reactive power output decreases as well. At the same time, the process of change shows the characteristics of inertia.

### *Simulation of wind power generation fluctuation*

The system carries a load of 100 KW. Figure 7(a) is the wind speed waveform. In fig. 7(b), $P_{bat}$, $P_{wt}$, and $P_{VSG}$ correspond to the output power of the energy storage battery, the output power of the wind turbine and the output power of the energy storage battery and wind turbine together.

It can be seen from fig. 7(a) that the wind speed increases from 10 $ms^{-1}$ to 12 $ms^{-1}$ at 0.8 second, and in fig. 7(b), due to the change of wind speed, the fluctuating power is fed into the system, which will have an impact on stability of grid. The energy storage battery based on VSG control strategy can quickly absorb or release the power fluctuation of the wind turbine, which makes the wind turbine generator system to inject the active smoothing into grid. Figure 7(c) shows that, in the case of wind speed changes, adopting VSG technology to control the energy storage battery, it can maintain the stability of the system frequency.

## Conclusion

In this paper, by designing the control strategy of the energy storage battery of the wind turbine, the wind turbine with the energy storage system is equivalent to the VSG, so that the wind turbine has the characteristics of friendly grid connection and show the synchronous generator characteristics to grid, and the output power of the wind turbine is smooth, Which can effectively reduce the influence of the wind turbine on the grid frequency. It can adjust the output according to the fluctuation of the system load and maintain the power balance of the system automatically, so as to stabilize the system voltage and frequency.

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## Nomenclature

$D_p$ – droop coefficient
$H$ – virtual inertia time constant
$K_d$ – damping coefficient
$P_{mec}$ – input power of inverter power supply
$P_{out}$ – output power of inverter power supply

*Greek symbols*

$\varphi$ – phase angle
$\omega_{ref}$ – reference value of angular frequency
$\omega$ – angular frequency of inverter power supply
$\omega_{grid}$ – angular frequency of the common bus

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