Simulation Research on Wind Storage Joint Control of Wind Turbine Based on VSG

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Abstract. The fluctuation of wind energy has an impact on the stability of active power output and system frequency, resulting in the decline of power quality. In addition, the large-scale wind power generation which is connected to the power grid reduces the inertia of system. The use of VSG control can effectively deal with the lack of inertia response ability of traditional synchronous generators. In the state of large-scale distributed wind power generation connected to the power grid, the ability of wind turbines to suppress the power oscillation of the system can be enhanced. In order to improve this ability, the VSG control strategy is introduced into the control of network test converter, and the virtual inertia control technology is used to respond to the system frequency modulation. The voltage loop and current loop control strategy are adopted for the Generator side rectifier. Meanwhile, the energy storage control of the battery system is introduced. Realize the regulation of wind power active power. In the MATLAB / Simulink, a combined wind energy storage system is built to verify the correctness of the proposed scheme. Finally, the maximum wind energy tracking, the enhancement of system frequency regulation ability and the stabilization of active power output fluctuation are realized. It can effectively restrain the reduction of economic benefits after long-term operation of wind farm.

1. Introduction

In the large-scale grid connected operation of wind power, most of the grid connected wind turbines use permanent magnet synchronous generators. Compared with doubly-fed wind turbines, PMSG is completely decoupled from the grid, and system control is more flexible. Compared with the traditional generator set, this kind of dual PWM converter to achieve MPPT control wind power generation will cause the system's inertial response ability to decline. When the system frequency oscillates, it cannot provide support. [1] The fluctuation of wind energy leads to the instability of wind turbine output power, which leads to the decline of power grid quality.

Considering how to better support the system inertia and respond to the frequency changes, so as to enhance the ability of the system to maintain power grid frequency stability. At present, virtual synchronous machine is a very important technology to solve the stability problem of new energy grid connection. Based on the grid connection characteristics of traditional synchronous generator, the strategy of simulating the nature of synchronous generator is adopted in grid side converter in reference [1], so as to support the system when frequency fluctuation occurs. Reference [2] uses the most basic virtual synchronous machine, analyses the principle, researches the related technology, analyses the control principle of wind turbine to realize frequency modulation, and designs the related control algorithm. Finally, through the experimental verification, it is proved that the effectiveness of the technology implementation can meet the functional requirements of power grid for wind power to participate in frequency modulation. In the chapter of literature [3-4], the control strategies that have
been developed to respond to wind power frequency regulation and suppress power fluctuation are summarized. The basic control technology includes pitch angle control, MPPT control, additional power control loop strategy and virtual synchronous machine control method. In reference [10], a VSG control with energy storage is added, and an adaptive control strategy is proposed to enhance the smoothness of the output power by combining the frequency characteristics of the synchronous machine in the transient process.

At present, in addition to the above, energy storage system has been widely concerned. Energy storage technology can release and absorb power timely according to system changes. In reference [6], hybrid energy storage was used, lithium battery was used to balance the low frequency part of power, and super capacitor was used to balance the high frequency part. The load is supplied with high power quality to keep the DC bus voltage constant. Literature [7-9] studies the control of wind accumulation energy system. The research shows that the accumulation energy module has fast response and strong absorption capacity of instantaneous power release, which is suitable for stabilizing the system of thermal power unit, suppressing the fluctuation of active power, and improving the frequency regulation capacity.

To sum up, this paper adopts a joint control strategy considering wind storage. To achieve maximum wind energy tracking, dual PWM control strategy is adopted, virtual synchronous generator (VSG) control is introduced into network test, and constant voltage control strategy of machine side converter is designed. The energy storage system and its operation mode are designed to stabilize the DC bus voltage and regulate the system frequency, which can stabilize the numerical fluctuation caused by the output power and fluctuation caused by variable wind speed, and realize the power and frequency regulation of the wind farm. At the same time, the system model using only VSG control is established, and compared with the simulation results, it is proved that the joint control of wind storage system has advantages. It is proved that the control system can stabilize the wind power fluctuation and adjust the system frequency. In this way, the long-term operation of the wind farm will not reduce the economic benefits.

2. Mathematical Model of Wind Turbine

2.1. The Operating Characteristics

PMSG system consists of wind turbine and generator, and the power source is provided by wind turbine. According to aerodynamics:

\[ P = 0.5 \rho v^3 C_p (\lambda, \beta) \]  

(1)

The capture of wind energy is related to the characteristics of wind turbine and its control strategy. CP parameter represents the utilization efficiency of wind energy. The calculation formula of CP coefficient is

\[ C_p(\lambda, \beta) = C_1 \left( \frac{C_2}{\lambda} - C_3 \beta - C_4 \right) e^{\frac{-C_3}{\lambda}} + C_5 \lambda \]  

(2)

\[ \lambda = \frac{\omega w}{v} \]  

(3)

\[ \frac{1}{\lambda_i} = \frac{1}{\lambda_i + 0.08 \beta} \frac{0.035}{\beta^3 + 1} \]  

(4)

According to Bates theory, \( C_{p_{max}} = 0.593 \), the actual value is generally about 0.4. \( \rho \): Air density. \( \omega \): Wind turbine speed. \( R \): Sweep area radius.\( A \): The windward swept area of wind turbine blade. The values of \( C_1-C_6 \) are 0.5176, 116, 0.4, 5, 21 and 0.006795 respectively. \( V \) is the air flow rate, 11.5.

2.2. Permanent Magnet Synchronous Motor Drive System Model

The permanent magnet synchronous generator is directly connected with the wind turbine through the
The mathematical model of the transmission system can be divided into a single mass block, two mass blocks and six mass blocks. This paper mainly studies the wind-storage cooperative control, so the elementary block model is selected to model the transmission system. The dynamic equation of single mass drive is:

\[
\frac{d\omega}{dt} = \frac{1}{J_c}(T_m - T_e - B\omega) 
\]

Tm: mechanical torque of the wind turbine; B: generator friction coefficient; Jc: equivalent moment of inertia of the permanent magnet synchronous power generation system; Te: electromagnetic torque of the generator. \(\omega\): the speed of generator, equivalent to the wind turbine speed.

3. PMSG Control Model

The control block diagram of permanent magnet synchronous generator is shown in Figure 1. The grid connection is carried out through dual PWM structure. The VSG based control strategy is adopted for the grid test transformation to provide inertia response for the system, and the constant voltage strategy is adopted for the generator side converter control. In order to better ensure the voltage stability of DC bus, it is incorporated into battery system at DC side. The Battery energy storage is used in the DC side to form the cooperative control of wind energy storage.

![Permanent magnet synchronous generator system with energy storage](image)

**Figure 1.** Permanent magnet synchronous generator system with energy storage

3.1. VSG control in Network Measurement

The traditional second-order model of synchronous generator is used as the reference object to simulate the electromagnetic and mechanical motion of synchronous generator:

\[
J\omega \frac{d\omega}{dt} = P_m - P_e - D(\omega - \omega_{ref}) \\
\frac{d\theta}{dt} = \omega - \omega_{ref}
\]

J: the moment of inertia; Pm: mechanical power; \(\theta\): Electric angle; D: Damping coefficient; Pe: electromagnetic power;

The stator voltage equation:

\[
\dot{E} = E_s sin\theta = \dot{V} + jR_L + jX_L
\]

\(\dot{E}\): electromotive force in the stator; \(\dot{V}\): stator terminal voltage; RL/XL: generator electronic resistance and synchronous impedance.

VSG control can be subdivided into active frequency controller and reactive voltage controller. In order to simulate the frequency regulation characteristics of traditional synchronous generator, a virtual governor is designed:

\[
P_m = P_{ref} + R_w (\omega_{ref} - \omega)
\]

According to formula 8, the active power and frequency have droop characteristics. The function of J is to control the frequency of inertia time effectively when the active power fluctuates.
The VSG virtual excitation regulator is established by simulating the excitation device of synchronous machine. In this way, the reactive voltage equation is deduced as follows:

\[ U_{\text{ref}} = U_n + k(Q_{\text{ref}} - Q) \]  

\( U_{\text{ref}} \): output voltage reference value; \( U_n \): rated voltage; \( k \): Reactive power coefficient.

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**Figure 2.** Power frequency controller adjustment block diagram

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**Figure 3.** Block diagram of excitation controller adjustment

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To sum up, the signal generated by the exciter and frequency regulator is combined to form a voltage signal input to realize inverter control of the inverter.

### 3.2. The Constant Voltage Control of Motor-Side Converter

The above VSG control strategy is applied to the network test control. Therefore, different from the traditional machine side control strategy using speed loop control strategy, this paper uses voltage loop outer loop control network test converter. The vector control of rotor field orientation based on \( i_d = 0 \) is adopted in the machine side. The following figure is the control block diagram of motor side.

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**Figure 4.** Motor side controller adjustment block diagram

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The electromagnetic torque equation of PMSG:

\[ T_e = 1.5p_n \Psi_i_q \]
The above formula shows that under the rotor field oriented control with \( id = 0 \), the stator q-axis current determines the electromagnetic torque output of the generator. At the same time, the reactive power of the generator can be regulated and stabilized by the d-axis current. The stator voltage equation of motor side is as follows:

\[
\begin{align*}
U_{ds} &= R_i i_{ds} - L_d \omega_j j_{ds} + L_d \frac{di_{ds}}{dt} \\
U_{qs} &= R_i i_{qs} + L_d \omega_j j_{ds} + \omega_j \Psi + L_q \frac{di_{qs}}{dt}
\end{align*}
\] (11)

Where \( U_d, U_q \): generator dq axis stator voltage component; \( i_d, i_q \): generator dq axis stator current component; \( R \): generator stator winding resistance; \( L_d, L_q \): inductance at the dq axis of the stator winding; \( \Psi, \omega_j \): Permanent magnet flux linkage and generator angular velocity.

4. Energy Storage System

There are two ways of cooperative control of wind energy storage: decentralized access and centralized access. Distributed mode means that the energy storage is connected to the DC side converter of the unit, and the unit can be regulated by DC power. Centralized means that the device is connected to the AC bus of wind turbine to control the active power of wind turbine by AC.

There are three types of energy storage system, namely electromagnetic system, electrochemical energy storage and mechanical system. At present, the most mature technology is electrochemical energy storage, namely battery energy storage. It is applied to DC side through Bidirectional DC-DC converter. Bess system has the characteristics of fast response, flexible configuration of power and battery capacity. DC / DC bi-directional converter is the key to realize bi-directional power flow in bess system. The half bridge converter is usually used. The polarity of the converter remains unchanged under the working state, and the charging and discharging process is determined by the current direction:

(a) Charging schematic diagram                           (b) Discharge schematic diagram

![Charge discharge schematic diagram](image)

\( \text{Figure 5. Charge discharge schematic diagram} \)

The general battery equivalent model is used in this simulation, which is commonly used in lead-acid batteries and lithium batteries. Based on the SOC of battery in running state and the change of terminal voltage. The mathematical expressions of lithium battery in charging mode and discharging mode are as follows:

\[
\begin{align*}
U_{ch} &= U_o - R_{ch} \frac{Q_{max}}{0.1Q} i_t - r_{ch} \frac{Q_{max}}{Q} i_c + Me^{N_i} \\
U_{disch} &= U_o - R_{ch} \frac{Q_{max}}{Q} i_t - r_{ch} \frac{Q_{max}}{Q} i_c + Me^{-N_i}
\end{align*}
\] (12)

\( U_{ch} / U_{disch} \): the no-load voltage of the battery. \( U_o \) is the rated voltage. \( R_{ch} \): polarization resistance. \( M \): the amplitude of the exponential region. \( N \): the reciprocal of exponential time constant. \( Q_{max} \): the maximum capacity of micro battery. \( i_t \): low frequency current. \( i_c \): the actual available capacity of the battery.

5. Matlab Simulation

In conclusion, the grid connected model of 2MW wind energy storage cooperative control system is established. 5m/s to 13 m/s for 5s, and the original wind speed will be restored after 3s. The system simulation waveforms are as follows, including generator output active power, DC bus voltage and system frequency.
As shown in FIG. 6, the graph in the right column in the figure above uses VSG only. In the state of variable wind speed, the output power has fluctuation, but the two kinds of control always change with the wind speed to maintain the MPPT state. Therefore, the DC bus voltage and frequency are mainly compared. Compared with the control without energy storage, there will be short-term fluctuations under the transient condition of variable wind speed under the control of wind storage, but the fast regulation is stable, and the overall stability is basically at 1200V. The response of no energy storage control is slow, and then tends to be stable. The lowest frequency of the wind storage system is 49.8hz, and the highest frequency is 50.2hz. It can be seen from the figure that the lowest frequency of the wind storage system is increased by about 0.3, and the highest frequency is decreased by about 0.4.

It is obvious from the figure that although VSG control is used only, it can continuously provide inertial capability for the unit, but its response speed is slow. At the same time, it is easy to cause fault problems under long-term operation, such as sudden increase of speed. There will also be the problem of a second drop in frequency. The method adopted in this paper not only effectively suppresses the power fluctuation, enhances the frequency modulation ability, but also effectively suppresses the sudden change phenomenon by using the energy storage, maintains the stable operation of the unit, reduces the
occurrence of fault accidents, maintains the power grid quality, and protects the economic benefits of
the wind farm in the actual production and long-term operation.

6. Conclusion
In this paper, through the analysis of the traditional permanent magnet wind turbine control, VSG control
is used in the network measurement rectifier, and constant voltage control is used in the DC side rectifier.
The battery energy storage module is connected to the DC side. The simulation results show that the
method can effectively restrain the fluctuation of system frequency, quickly provide inertial response
and stabilize the frequency. When the output power changes, it can improve the power regulation of
wind farm and restrain the fluctuation of wind turbine power. Through the comparison of the two kinds
of control, it is found that the wind energy storage system can better realize the voltage stabilization of
DC bus at 1200V, effectively enhance the frequency regulation ability of the system after large-scale
wind power grid connection, maintain the power quality of the power grid, and play a certain role in
protecting the economic benefits of the wind farm after long-term operation.

References
[1] Cheng Zhilong, Li Lan, Wu Lei, Guo Xiaoxiao. 2020, Frequency regulation of grid connected
direct drive permanent magnet wind power generation based on VSG[J]. Electrical measurement
and instrumentation, 57 (18): 103-109.
[2] Wang Jianwei, Qi Xiaoxiao, Yu Yongjun, Luo Zhongyou. 2019, Research on wind power
frequency modulation technology based on the principle of virtual synchronous machine [J].
Machinery and electronics,37(02):67-70
[3] Li Kaikai. 2018, Research on virtual inertia control strategy of 1.5MW permanent magnet direct
drive wind turbine [D]. Shenyang University of technology.
[4] Hu lang. 2018, Research on power control and frequency modulation technology of doubly fed
wind turbine [D]. Hubei University for nationalities.
[5] Chu Xin, Gao Guige.2019, Frequency modulation control strategy for wind power grid
integration based on hybrid energy storage [J]. Magnetic materials and devices, 50 (06): 52-56.
[6] Guo Ronan, Guo Yingjun, sun hexu, an Conghui. 2019, Bus voltage control strategy for DC
microgrid based on hybrid energy storage [J]. Hebei Industrial Science and technology, 36 (06):
384-389
[7] Y. Lingang, W. Xiaohe, W. Zhaohui, D. Xue, Y. Wenbin and G. Yuan, 2021,"Research on control
strategy of virtual synchronous generator based on energy storage wind farm," 2021 IEEE 5th
Advanced Information Technology, Electronic and Automation Control Conference (IAEAC), pp.
240-244,
[8] R. Heydari, M. Savaghebi and F. Blaabjerg, 2020, "Fast Frequency Control of Low-Inertia
Hybrid Grid Utilizing Extended Virtual Synchronous Machine," 2020 11th Power Electronics,
Drive Systems, and Technologies Conference (PEDSTC), pp. 1-5,
[9] Yan Xiangwu, Cui Sen, song Zijun, sun Xuweii, Sun Ying. Inertia and primary frequency
regulation strategy of doubly fed wind turbine based on super capacitor energy storage control
[J]. Power system automation, 2020,44 (14): 111-120.
[10] Li Cuiping, Bi Liang, Li Junhui, Li Yuanyuan. 2020, Energy storage VSG adaptive control
strategy for auxiliary wind power response to primary frequency regulation of power grid [J].
Jilin electric power, 48 (04): 1-6