PMSG Wind turbine grid-connected pre-synchronization technology based on virtual impedance

Zi Shu Meng1,a, Yong Geng Lu2,b*

1Shanghai Dianji University Power systems and their automation systems, Pudong new area, Shanghai, China
2Shanghai Dianji University Power systems and their automation systems, Pudong new area, Shanghai, China
aemail: 693185308@qq.com
bCorresponding author: be-mail: luyg@sdju.edu.cn

Abstract. With the integration of large-scale wind power, the inertia of the whole grid system is reduced. Therefore, virtual synchronous machine (VSG) technology has become a new strategy for wind power integration. In view of the fact that the VSG grid connected control of permanent magnet direct drive wind turbine does not consider the constraints of grid connection conditions, a scheme combining VSG technology with pre synchronization technology is proposed in this paper. VSG technology is still used in the PWM control of grid connected inverter. However, considering that there is no deviation between the phase angle of output voltage and the phase angle of grid voltage, it is impossible to judge whether the grid connection conditions are met or not when there is no deviation between the phase angle of output voltage and that of grid voltage.

1.Introduction

In recent years, with the large-scale application of distributed generation, a large number of power electronic devices are connected to the power grid, so that new energy cannot provide inertia to the power grid, so the stability of the power grid is affected.

Virtual synchronous generator (VSG) is essentially a grid-connected inverter control method using power electronics to simulate the traditional generator. Due to the vulnerability of power electronics, the output voltage of the VSG before grid-connection should be the same as the amplitude, phase and frequency of the grid voltage, otherwise there will be a current shock during grid-connection or damage to the power electronics. Literature [1-2] analyses the pre-synchronization process of traditional droop control, but the pre-synchronization time is relatively long. Literature [3] is a micro-grid connection/isolated island seamless switching technology with master-slave control. A pre-regulator is added in front of the voltage loop regulator, and a method of software phase locking is proposed. Literature [4] considers the influence of LC filter on grid connection and the pre-synchronization unit is divided into two PLL units. It uses proportional integral (PI) regulation control to realize phase difference closed-loop control. In reference [5], a dual phase-locked loop was added to the virtual power and voltage frequency control loop for synchronous control, so that the voltage amplitude and phase angle of VSG before grid connection are the same as those of power grid. But the structure is complex, and it is difficult to ensure its accuracy in the case of weak current network. In reference [6], since the phase Angle difference between VSG and power grid is 0 and cannot be controlled by the controller, a
strategy of making the difference between the voltage angle of VSG output and the power grid voltage angle through PI control is proposed.

In view of the lack of research on VSG grid-connected permanent magnet direct drive wind turbine (PMSG), this paper proposes a PMSG wind turbine grid-connected pre-synchronization technology based on virtual synchronous machine. The control mode of machine side converter remains unchanged. The grid side converter is controlled by VSG. Before VSG grid-connection, virtual impedance pre-synchronization technology is used to ensure the grid-connection voltage meets the requirements.

2. VSG-controlled PMSG wind turbine mathematical mode

The control of direct drive wind turbine is mainly the control of the converter. Mainly through PWM control to achieve this function. The difference is that the former is to ensure that the wind turbine can absorb wind energy to the maximum extent and convert it into electric energy. The role of the latter is to control the grid-connected voltage and current to meet the grid-connected requirements.

As the structure of the grid-side converter is similar to that of the machine test converter, the grid-side converter is taken as an example. Figure 1 shows the structure diagram of PMSG grid side converter:

![Figure 1. Structure diagram of PMSG grid side converter.](image)

To facilitate the research, we studied the grid-side converter in the two-phase rotating $dq$ coordinate system:

$$
\begin{align*}
L_{gd} \frac{d i_{gd}}{dt} &= e_{gd} - i_{gd} R_{gd} + \omega_{g} L_{gs} i_{gs} - u_{gd} \\
L_{gs} \frac{d i_{gs}}{dt} &= e_{gs} - i_{gs} R_{gs} - \omega_{g} L_{gs} i_{gd} - u_{gs} \\
C \frac{d U_{dc}}{dt} &= \frac{3}{2} (S_{gs} i_{gs} + S_{gd} i_{gd}) - i_{dc}
\end{align*}
$$

The Voltage oriented control strategy is adopted, and the output power of the grid-side converter is expressed as follows:

$$
\begin{align*}
P_{g} &= -\frac{3}{2} (e_{gs} i_{gd} + e_{gd} i_{gs}) = -\frac{3}{2} E_{g} i_{gd} \\
Q_{g} &= -\frac{3}{2} (e_{gs} i_{gs} + e_{gd} i_{gd}) = -\frac{3}{2} E_{g} i_{gs}
\end{align*}
$$

3. Permanent magnet wind turbine VSG control

3.1 VSG induction

Virtual synchro control is essentially an inverter control strategy, and the main circuit uses a two-level inverter with LC filter. See Figure 2.
3.2 Design of virtual frequency modulator

The $P-f$ control is mainly realized by virtual frequency modulator. By changing the mechanical torque injected by the prime mover, the rotor speed of the PMSG generator is adjusted, and the active power of the generator is controlled to affect the frequency variation of the system. Actively support the frequency of the grid by changing the angular velocity, $\omega$, and the output phase of the VSG, $\theta$. The relationship between the angular velocity of the power grid and the VSG converter is:

$$\omega = \omega_{ref} + \frac{1}{JS + D} \frac{P_{set} - P}{\omega}$$  \hspace{1cm} (3)$$

In the formula, $P_{set}$ is the given value of active power, that is, the rated mechanical power of the analog traditional synchronous generator, and $P$ is the electromagnetic power actually output by the converter. By the formula (4) know system angular velocity variation $\Delta \omega$ has positive correlation with power difference:

$$\Delta \omega = \omega - \omega_{ref} = \frac{(T_m - T_s)}{D}$$  \hspace{1cm} (4)
3.3 Virtual exciter control

The function of virtual exciter is to simulate the primary voltage regulation characteristic of synchronous generator by using the reactive-voltage control link. The output port voltage and its internal potential can be expressed as:

$$\begin{align*}
    v_d &= -R_i i_d + \omega L_i i_q - L_i \frac{di_d}{dt} + \omega M_j i_f \\
    v_q &= -R_i i_q - \omega L_i i_d - L_i \frac{di_q}{dt} + M_j \frac{di_f}{dt}
\end{align*}$$

(5)

The virtual impedance is used to modify the parameter variation of the actual impedance by changing the size of the excitation current to adjust the port voltage. Excitation current including no-load excitation current $i_{f0}$ and virtual exciter current increment $\Delta i_F, m$ for reactive power droop coefficient, introducing integral element in the control to eliminate the error of the reactive power control. Therefore, the excitation current expression can be expressed as:

$$i_F = i_{f0} + m(Q_{ref} - Q)K_s$$

(6)

Due to the instantaneous power theory, the reactive power $Q$ output by wind turbine is expressed as:

$$Q = \frac{(v_a - v_b)i_c + (v_b - v_c)i_a + (v_c - v_a)i_b}{\sqrt{3}}$$

(7)

Due to the instantaneous power theory, the reactive power $Q$ output by wind turbines can be expressed as: since the control bandwidth of active and reactive power determines that the power generated by the stator voltage component and the stator current component of the same phase sequence can only be controlled, feedforward compensation is added to eliminate the disturbance caused by the negative sequence component and the transient component. The modified internal potential can be expressed as:

$$\begin{align*}
    e_d &= \omega M_j [i_F + (v_{dref} - v_d)G_{d}]
    e_q &= sM_j [i_F + (v_{qref} - v_q)G_{q}]
\end{align*}$$

(8)

The potential and voltage in THE VSG can be adjusted by changing the size of the virtual excitation current.

4. PMSG Wind turbine presynchronous grid connection method based on virtual impedance

A typical VSG control strategy is under the condition that the output voltage phase Angle is $\theta$ and the grid voltage phase Angle is $\theta_{grid}$. If the angular velocity $\theta_{grid}$ has been tracked to the angular velocity of the grid, the requirements of the grid cannot be met by improving the VSG controller. Therefore, this section proposes a PMSG grid-connected pre-synchronization strategy based on virtual impedance. The scheme is shown in Figure 3.
The PMSG wind turbine is used as the input power source of the whole system, which is connected to the grid after the back to back converter. VSG pre-synchronization technique is applied to back-back converters.

The amplitude and phase information of the voltage and current output by the rotor side inverter is obtained through sampling and three-phase decomposition, and the phase locked loop PLL is used as the input value of the pre-synchronization algorithm. The amplitude and phase information of the grid voltage is calculated through voltage and current sampling as the reference value. Through calculation and PI control, the grid-connection information is obtained to determine the timing of grid-connection.

The phase Angle of the pre-synchronization module is measured by using a micro synchronous vector measurement device ($\mu$PMU). The $\mu$PMU acquisition signal comes from the set unified clock signal. In this paper, according to the grid-connected voltage signal, the unified time is 0.3 seconds after. The precision of pre-synchronous measurement can be improved. The pre-synchronization is completed at 0.4 seconds, and the response time is faster.

5. Pre-synchronous simulation effect
In order to test whether the pre-synchronization strategy designed in this paper can satisfy the seamless switch of the system from isolated island to grid connection, the pre-synchronization control device is added to the PMSG wind power system in this paper. The simulation results of voltage and current before and after pre-synchronization are shown in Figure 4 and Figure 5 respectively:

Figure 4. Voltage comparison before and after pre-synchronization
The pre-synchronous grid-connection current is out of sync with the grid frequency, so it cannot be grid-connected the pre-synchronous device starts at 0.3 seconds, when the isolated island operation switches to the grid-connected system, the grid-connected voltage is stable, and the waveform is consistent with the grid, which can meet the grid-connected requirements. It shows that the pre-synchronization technology provided in this paper can not only track the grid-connected voltage current and grid voltage current, but also improve the distorted waveform.

The current waveform is uniformly stable before pre-synchronization, but there is no grid connection due to frequency un-synchronization. After 0.3 seconds, the pre-synchronization device detected that the system operating frequency was consistent with the grid, so it started to connect to the grid. Before the grid connection, the current before the grid connection is 0, after the grid connection, the grid connection current is stable in a very short time. Therefore, the pre-synchronous device designed in this paper meets the practical requirements.

6. Conclusions
This paper focuses on how to combine the pre-synchronization device of virtual synchronous control, because both of them are the control strategy of grid side inverter, and the phenomenon of repeated sampling will occur in the process of fusion. Therefore, it is difficult to improve the pre synchronization algorithm and VSG algorithm. The PMSG wind turbine model, pre-synchronization module and virtual impedance control module are built with Matlab / Simulink software. Finally, the pre-synchronization technology and virtual synchronization algorithm are successfully combined through the test. It provides an idea for the large-scale application of permanent magnet synchronous generator.

Acknowledgments
In the writing of this paper, I would like to thank those who supported me and helped me. I would like to thank my tutor, Professor Yong Geng Lu, and other teachers in the tutor's lab for their help. They gave me a lot of suggestions in the process of my simulation, helping me to find the errors in the simulation, and gave me guidance on the paper writing. I want to thank the students for their encouragement and help. Without them, I can't write the article well.

References
[1] Wang K., Wang Z.Z., Chai J.Y., (2015) Analysis of pre-synchronization process of synchronous control inverter power grid connection. Automation of Electric Power Systems., 39:152-158
[2] Nie Z.Q., Liang H., Luo H., (2016) A seamless switching technique based on nonlinear droop control for single mode microgrid. Power System Technology., 40:1371-1378.
[3] Chen J., Chen X., Feng Z.Y., (2014) Seamless switching control strategy for grid-connected/isolated operation mode of microgrid system. Proc Chin Soc Elect Eng., 34:3089-3097.

[4] Yang L., Yang C., Lv Z.P., (2014) Pre-synchronous grid-connection based on synchronous inverter. Power Syst Technol., 38:3103-3108.

[5] Wei Y.L., Zhang H., Sun K., (2016) Virtual synchronous generator pre-synchronization method based on virtual power. Automation of Electric Power Systems., 40:124-129,178.

[6] Qi J., Li Y.C., Tong H., (2020) Second order decoupling strategy of pre-synchronous VSG power based on dynamic virtual current feed forward. Power Syst Technol., 44:3556-3564.