An Improved Grid-connected Pre-Synchronization Method based on Virtual Synchronous Generator Control in Power Conversion System

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Abstract. In this paper, an improved grid-connected pre-synchronization control strategy based on virtual synchronous generator (VSG) is proposed. The system starts to operate as a current source and doesn’t change the output active power at the moment of grid connection. The voltage magnitude control and the phase angle control of pre-synchronization module on the basis of VSG can provide a certain output voltage on the premise of minimizing the rate of change of voltage and surge current caused by the voltage drop, which will achieve seamless switching of microgrid connection to the grid. However, there is a problem that the frequency fluctuation is introduced to reduce the rate of change of voltage and suppress the surge current caused by the voltage drop in the microgrid system. In this paper, an improved pre-synchronization control strategy based on VSG is proposed, and it will actively adjust the output active power to maintain the stability and balance of the system, so many scholars have studied the control strategy of pre-conversion system (PCS). In addition, the system adds a pre-synchronization control module on the basis of VSG, so it always plays an important role in the grid-connected pre-synchronization process by calculating the phase angle error and the slope control module which is introduced to ensure the stability of the system. Finally, the framework of a new power system mainly based on renewable energy generation will actively support the power grid in order to maintain the safe and stable operation of the system. The effectiveness and feasibility of the proposed scheme is verified by simulation. As the interface between the energy storage system and the power grid, the virtual synchronous generator (VSG) is considered as one of the most promising solutions, because it can provide the phase and frequency support on the basis of GFL and GFM, which is a certain output voltage and frequency support in the microgrid system. As the technological development of renewable energy technologies, the renewable energy generation is an inevitable trend for future development of the power system. As the interface between the energy storage system and the power grid, the virtual synchronous generator (VSG) is considered as one of the most promising solutions, because it can provide the phase and frequency support on the basis of GFL and GFM, which is a certain output voltage and frequency support in the microgrid system. As the technological development of renewable energy technologies, the renewable energy generation is an inevitable trend for future development of the power system.

1. Introduction

The grid-connected microgrid system has been widely studied in recent years. Many scholars have proposed different schemes to improve the performance and stability of the microgrid system, such as fuzzy logic control, sliding mode control, and artificial neural network control. In addition, the system adds a pre-synchronization control module on the basis of VSG, which can provide a certain output voltage and frequency support in the microgrid system. As the technological development of renewable energy technologies, the renewable energy generation is an inevitable trend for future development of the power system.
2. Grid-connected power conversion system

Cf, PLL is used to automatically acquire the grid phase \( \theta_g \) and the d-aixs grid voltage \( u_{gd} \). The equivalent resistors \( R_f \) and \( R_g \) are very small, which can be ignored. The system parameters are shown in Table 1.

3. Detailed Description of VSG

In order to mimic the frequency regulation characteristics of the SG, the droop characteristic between active power and frequency are simulated in the VSG control, which is mathematically described as shown in (1).

\[
P_{o} = P_{ref} + k \cdot (\omega - \omega_o)^2
\]

where \( P_o \) is the measured active output power of converter and \( P_{ref} \) is the active power reference, \( k \) is the active power-freqency droop coefficient, \( \omega \) and \( \omega_o \) are the fundamental angular frequency and the VSG's output angular frequency respectively.

In order to change the overly stiff external characteristics of the converter, the rotor motion equation of the SG is algebraically realized to further add virtual inertia and damping to the control system, as shown in (2).

\[
\begin{align*}
J \frac{d\omega}{dt} &= T_m - T_e - T_e \frac{P_{ref}}{\omega_o} - P - D \omega - \omega_o \\
\frac{d\delta}{dt} &= \omega
\end{align*}
\]
grid synchronous angular frequency, which can be replaced by $\omega_g$ in general. By substituting (2) into (1), the active frequency output characteristic equation of the VSG can be modeled as

$$P_{kD} \omega + \omega = P + \omega_g$$

Substituting $K_p = k_p + D$ into (3) to simplify the control system, the corresponding control block is shown in Fig. 2.

By adjusting parameters, the frequency of the regulation process is determined by $k_p$, the inertia of the entire adjustment process is determined by $J_s$. As a consequence, the phase information of the reference voltage can be dynamically adjusted.

### 3.2. Reactive Power Control Loop

The excitation system is able to regulate the excitation electromotive force of the SG, so as to adjust the output reactive power and ensuring the stability of the machine terminal voltage. The reactive power control is determined by the droop control theory that

$$u_{ref} - u_o = -k_q Q_{ref} - Q_o$$

where $u_{ref}$ denotes the VSG’s output voltage amplitude, $u_o$ is the rated voltage amplitude (i.e. $u_g$), $k_q$ is the reactive power-voltage droop coefficient, $Q_{ref}$ and $Q_o$ are the measured reactive output power of converter and the reactive power reference respectively. In order to mimic the SG's regulation between reactive power and voltage, the reactive power control model are consequently written as Eq. (5) according to the Eq. (4), the corresponding control block is shown in Fig. 3.

With the single closed-loop control of voltage magnitude, the output voltage magnitude $u_m$ of PCC is consistent with the VSG's output voltage amplitude. Then combine the $u_m$ and $\theta$ to form the control waveform used to modulate the converter switch. This process ensures the control of the PCS, thereby improving the reliability of the system.

### 4. The Improved Grid-Connected Pre-Synchronization Method

It is indispensable to regulate the voltage and frequency on both side of PCC to keep synchronization when PCS is connected to the grid, so as to realize the seamless connection and coordinated operation of the whole system.
As shown in Fig. 4, the equivalent circuit of grid-tied PCS. The vector relationship of the grid voltage and PCS output voltage is described in Fig. 5. Apparently, if both of them are not synchronized, the voltage deviation $\Delta U$ will lead to surge current $i$ at the moment of grid connection. The corresponding algebraic relationship is shown in (6).

It can be seen that the larger the $\Delta U$, the larger the surge current. Therefore, a reasonable pre-synchronization method needs to be adopted to ensure that the voltages on both sides of PCC remain synchronized before the PCS is connected to the grid.

The block of improved pre-synchronization method based on VSG proposed in this paper is shown in Fig. 6. The $\Delta U$ is determined by the amplitude and phase of voltage, so the pre-synchronization control consists of a phase regulator and a voltage magnitude regulator. When output voltage of the VSG is synchronized with the grid voltage, the pre-synchronization switch SW will be disconnected, the $u_{gd}$ and $\Delta \omega$ is switched to $u_0$ and $\Delta \omega$ respectively. The system is then operating in grid-connected mode. It is noteworthy that a slope control unit is introduced in pre-synchronization module to reduce the rate of change of the voltage, so as to further prevent the surge current due to the excessive voltage drop at the time of grid-connected switching.
5. Results and Discussion

The PCS based on virtual synchronous generator control is built using MATLAB / Simulink to verify the performance of the control strategy proposed in this paper. The main parameters of the control system are as follows:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtual inertia</td>
<td>( J = 2 ) kg·m(^2)</td>
</tr>
<tr>
<td>Droop coefficient</td>
<td>( K_p = 557, K_q = 0.023 )</td>
</tr>
<tr>
<td>Reference active power</td>
<td>1725 kW</td>
</tr>
<tr>
<td>Reference reactive power</td>
<td>300 kVar</td>
</tr>
</tbody>
</table>

The system is connected to the grid at 0.3 s, and the output waveform of PCS are shown in Fig. 7. It can be seen that when the system without the pre-synchronization control strategy, the current amplitude increases to several times of the rated current at the moment of grid connection in Fig. 7(a), and the excessively high current will threaten the safety of the system. Fig. 7(b) shows the output waveform under the proposed in this paper, the output voltage of the converter can be synchronized with the grid voltage within 0.25s, so the output current can be smoothly stabilized at the moment of grid connection.

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6. Conclusions

In this paper, the basic principle of VSG is analyzed, and the active power control loop are designed separately. Based on Virtual Synchronous Generator, the Presynchronous Control Strategy of Virtual Synchronous Generator and Its Applications in Microgrid Operation Modes is proposed, which quickly realizes the voltage synchronization control. Therefore, it can be concluded that the experimental results are consistent with the theoretical analysis, the proposed converters: Inverters That Mimic Synchronous Generator have a better stability and dynamic performance.

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