Application of VSG technology based on flexible parameter adjustment in PV unit grid-connected inverter

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Abstract—As a clean and effective renewable energy source, PV has been widely used in power systems. The application of VSG technology can effectively improve the system inertia reduction problem caused by the grid connection of PV and energy storage units. The virtual inertia and damping coefficient in VSG control have the unique advantages of being flexible and controllable. This paper designs a control strategy in which the virtual inertia and damping coefficient can be flexibly adjusted according to the system frequency, which further improves the operating performance of the PV and energy storage units based on VSG control. The frequency quality of the system is maintained. Finally, the effectiveness of the proposed flexible parameter adjustment strategy was verified through the simulation platform, which played a role in popularizing the application of the proposed strategy in engineering.

1. Introduction

The coordinated cooperation of PV units and energy storage devices can reduce the power fluctuations caused by the intermittent output of PV units to the system, and effectively realize the large-scale grid connection of PV devices [1-2]. Applying the virtual synchronous generator (VSG) control strategy to the grid-connected converter where the new power supply is connected to the grid can make the inverter power supply have inertia and damping characteristics when it is connected to the grid, and realize the friendly grid connection of the PV and energy storage units [3-6]. The numerical change of the inertia and damping coefficient in the VSG control equation has an important impact on the system frequency. This article uses flexible adjustments to further improve the application effect of the VSG technology in the grid-connected PV units.

This article first introduces the basic principles of VSG control. The influence of the virtual inertia and damping coefficient value changes on the VSG control strategy is analyzed, and the virtual inertia and damping coefficient flexible adjustment control strategy is formulated. Through the system frequency change, the inertia and damping coefficient are dynamically adjusted. Finally, the control effect of the proposed strategy is verified by simulation to improve the engineering applicability of the control strategy.

2. Basic Theory of VSG Control

PV and energy storage units are connected to the AC grid through inverters, and VSG control is applied to the grid-connected converters, which can make the PV and energy storage units have output characteristics similar to synchronous generators. This article focuses on the study of the rotor motion
equation in the VSG control, and improves the control effect of the VSG technology by changing the inertia and damping coefficient. The rotor motion equation in VSG control is shown in equation (1):

\[
\begin{align*}
T_m - T_e &= J \frac{d\omega}{dt} + D (\omega - \omega_n) \\
\omega &= \frac{d\theta}{dt}
\end{align*}
\]

In equation (1), \(T_m\) and \(T_e\) respectively represent the mechanical torque and electromagnetic torque of the VSG unit; \(J\) represents the moment of inertia of the VSG unit; \(D\) represents the damping coefficient of the unit; \(\omega, \omega_n\) respectively represent the actual angular frequency and rated angular frequency of the system Value; \(\theta\) represents the phase angle of the VSG unit. Among them, \(T_m\) and \(T_e\) are calculated by mechanical power \(P_m\) and electromagnetic power \(P_e\). The expressions of \(T_m\) and \(T_e\) are shown in equation (2):

\[
\begin{align*}
T_m &= \frac{P_m}{\omega_n} \\
T_e &= \frac{P_e}{\omega_n}
\end{align*}
\]

3. Flexible adjustment strategy of virtual inertia and damping coefficient

The size of the virtual inertia affects the rate of change of the system frequency. Under the same power disturbance, the greater the virtual inertia of the distributed power supply, the smaller the rate of change of the system frequency. Based on the above analysis ideas, the size of the virtual inertia in this article is adjusted by an exponential control equation. The expression of the virtual inertia is shown in equation (3):

\[
J_f = \begin{cases} 
J_0, & |\Delta f|/dt < M_f \\
J_0 + k_1 (|\Delta f|/dt)^{k_2}, & |\Delta f|/dt \geq M_f
\end{cases}
\]

In equation (3), \(J\) represents the virtual inertia in VSG control, \(J_0\) represents a constant with a small value; \(f\) represents the frequency of the system; \(k_1\) and \(k_2\) represent the adjustment coefficients of the virtual inertia of the system when a power disturbance occurs. \(M_f\) represents the threshold value when the value of the virtual inertia \(J\) is switched. Through the analysis of equation (3), it can be obtained that when the system is operating normally, the system frequency change rate is small, and the virtual inertia \(J\) maintains a small value \(J_0\). When a power disturbance occurs in the system, the amplitude of the frequency change rate \(|df/dt|\) is greater than the switching threshold \(M_f\). At this time, the virtual inertia in the system changes dynamically with the frequency change rate, which brings greater inertial support to the system and slows down system frequency changes.

The damping coefficient is also an important parameter that affects the control effect of the VSG control. After the load disturbance occurs, a larger damping coefficient can effectively suppress the frequency offset amplitude. Therefore, flexibly adjusting the amplitude of the damping coefficient according to the magnitude of the load disturbance has positive significance for the rapid recovery of the system frequency after the load disturbance. The control expression of the damping coefficient in this paper is shown in equation (4):

\[
D_f = \begin{cases} 
D_0, & |\Delta f| < M_D \\
D_0 + k_0 |\Delta f|, & |\Delta f| \geq M_D
\end{cases}
\]

\(D_0\) represents a constant with a small value, \(k_0\) represents the adjustment coefficient of the damping coefficient, and \(M_D\) represents the switching threshold of the damping coefficient in the VSG control. \(|\Delta f|\) represents the offset value of the system frequency. It can be obtained from equation (5) that when the system is operating normally, the amplitude of the frequency offset is small, and the damping...
coefficient maintains a small value at this time. When a power disturbance occurs in the system, the increase in the amplitude of the frequency offset will be greater than the switching threshold $M_D$. The value of the damping coefficient in the system is dynamically adjusted with the amplitude of the frequency offset, and is maintained near a larger value. It can suppress the frequency offset and reduce the effect of system oscillation. The flow chart of the flexible adjustment strategy for inertia and damping coefficient proposed in this paper is shown in Fig. 1.

![Flow chart](image)

**Fig.1 Virtual inertia and damping coefficient flexible adjustment control flow chart**

### 4. Analysis of simulation results

In order to verify the control effect of the flexible parameter adjustment control strategy used in this article, this article built an AC system as shown in Fig. 2 in Matlab/Simulink.

![System diagram](image)

**Fig.2 Multi-terminal AC system with PV and energy storage units**

In Fig.2, the PV power station and the storage battery form a VSG power generation unit based on virtual synchronous generator control. Among them, the $G_1$ unit represents the traditional generator set in the power grid and has the capability of secondary frequency regulation. The power shortage caused by load disturbance in the system is finally stabilized by the $G_1$ unit changing its own power output. The
load $P_L$ represents the power consumption in the system, and the power disturbance in the system is simulated by changing the value of $P_L$ during the simulation process.

4.1 Flexible adjustment of virtual inertia and optimization results

Firstly, the optimization effect of the flexible adjustment of virtual inertia is simulated and verified. At the beginning of this simulation, the system is operating normally, the VSG unit runs at a rated power of 3kW, and an active load disturbance of 3kW appears in the system at 5s. Fig.3 also shows the system in operation results of the VSG unit under the same operating conditions under the flexible virtual inertia control and constant inertia control.

Observe Fig.3(a), which can be obtained, compared with the constant inertia strategy. When the virtual inertia adopts a flexible adjustment strategy, the virtual inertia in the system changes dynamically with the frequency change rate. After load disturbance occurs, it can provide greater inertial support for the system. Further observation of Fig.3(b) can be obtained. When the VSG unit uses the virtual inertia flexible adjustment strategy, compared to the constant inertia control, the VSG unit can provide greater inertia support for the system at this time. After the disturbance occurs, the active power output of the
VSG unit increases greatly, which can make up for the instantaneous power shortage in the system to a greater extent. Compared with Fig.3(c), it can be seen that when the virtual inertia flexible adjustment strategy is adopted, the active power output of the VSG unit increases greatly. The frequency change of the system can be slowed down, and the maximum offset in the frequency change is reduced, which improves the frequency quality of the system.

4.2. Optimization results of flexible adjustment of inertia and damping

The following simulation will verify the control effect when the damping coefficient is flexibly adjusted. In the simulation of this section, the virtual inertia adopts the adjustment strategy shown in equation (4). The damping coefficient adopts the regulation strategy shown in equation (5) and the control strategy with constant damping value respectively. Fig.4 shows the change of each parameter in the VSG unit when the damping coefficient adopts two kinds of control. Fig.4(a) shows the change curve of the damping coefficient under different controls after the occurrence of power disturbance. When there is no flexible adjustment, the damping coefficient in the VSG unit is constant. When using flexible adjustment, after the power disturbance occurs, the frequency deviation in the system is relatively large, and the size of the damping coefficient can be flexibly adjusted along with the frequency deviation. Analyzing Fig.4 (b), it can be seen that after the damping coefficient is also flexibly adjusted, the frequency quality of the system has been further improved. The maximum offset value of the frequency is reduced, and the response speed in the frequency recovery process is also accelerated. Appropriate adjustment of the damping coefficient improves the frequency quality of the system after the power disturbance occurs. Observing Fig.4(c), it can be seen that after adopting the coordinated regulation control strategy, the active power of the VSG unit changes more smoothly, and the fluctuation range is small. The adaptive increase of the damping coefficient reduces the power oscillation in the system.
5. Conclusion

Based on the results and discussions presented above, the conclusions are obtained as below:

1) When the virtual inertia is adjusted flexibly, the VSG unit can provide greater inertia power to the system after the load disturbance occurs. This effectively slows down the frequency change rate and maintains the frequency quality of the system after the load disturbance occurs.

2) When the damping coefficient changes dynamically with the frequency offset value, the frequency offset value after the load disturbance can be further reduced. At the same time, it reduces power fluctuations and improves the power quality of the system.

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