Primary frequency modulation characteristics of photovoltaic power station suitable for grid connection certification

Changqing Yao¹, Qing Yan¹, Zhaodong Liu²*, Changlai Zhou¹, Yuanyuan Li¹, Enren Liu¹, Chao Zhang²

¹ State Grid Shandong Electric Power Research Institute, Jinan 250003, China
² College of Electrical Engineering and Automation, Shandong University of Science and Technology, Qingdao 266590, China

*Corresponding author’s e-mail: liuzhaodong1224@163.com

Abstract. Photovoltaic power station can participate in the primary frequency modulation of the power system for grid connection certification. The primary frequency modulation capability of photovoltaic power station is analyzed when the light intensity changes. According to theoretical and simulation analysis, by changing the control mode, the photovoltaic power station operated by load reduction can quickly respond to the drop and increase of frequency and reduce the change of frequency after disturbance. Overall results show that the photovoltaic power station with primary frequency control can reduce the frequency of system changes, implement the support for the frequency of the system, and make corresponding adjustment to improve the safety of power grid.

1. Introduction

Frequency reflects the basic state of the balance between supply and demand of active power in power system, which is an important index of power quality. In order to maintain the safe and stable operation of the power system, the frequency deviation of the power system must be controlled within a certain range [1-3]. With the continuous progress of new energy technology and the gradual saturation of other energy utilization forms, solar photovoltaic power will become the mainstream energy utilization form around 2050, with immeasurable development potential [4, 5]. In recent years, there have been photovoltaic power stations with extremely large capacity (several hundred MW) at home and abroad.

In large power grids, photovoltaic capacity is much smaller than that of conventional power plants and has little influence on the frequency of the system. However, when a large-scale photovoltaic power station is connected to an isolated power grid, the system inertia may be reduced and the frequency modulation capability is insufficient. When a system accident leads to a large frequency disturbance, the frequency stability is difficult to guarantee. At this time, the frequency adjustment of the photovoltaic power station participating in the system will have important practical significance. The conventional primary frequency modulation function is to automatically control the increase or decrease of the active power of the generator set through the control system of the generator set, limit the substantial change of the power grid frequency, and ensure the frequency quality and safe operation of the power system [6]. The primary frequency modulation capability of photovoltaic power generation system can be developed by referring to the primary frequency modulation characteristics of conventional units.
In view of the above problems, the grid-connected photovoltaic power station in this paper adopts the power difference control mode [7], which enables the photovoltaic power station to operate under the floating load reduction level according to different lighting parameters and has a certain capacity of up-regulating and down-regulating active power output. On this basis, the active power output of photovoltaic power station is dynamically connected with the system frequency to participate in the primary frequency modulation of the system. In order to verify the effectiveness of the proposed method, an isolated power network model with photovoltaic power station was built in Matlab for simulation verification. The results showed that the primary frequency modulation of the photovoltaic power station participating system could support the system frequency stability.

2. Power control of photovoltaic power station

The photovoltaic grid-connected system studied in this paper is shown in figure 1, which mainly consists of photovoltaic cells, maximum power tracking (MPPT), inverter, power grid and local load. In the figure, PV represents photovoltaic cells. Due to the instability of photovoltaic cell output, the maximum power output is realized through the maximum power tracking system, which is then fed into the dc bus after being filtered by LC filter. The inverter of the latter stage adopts one-way full-bridge inverter, the dc side is connected to the dc bus, and the ac side is connected to the local load and the ac power grid after being filtered by the inductor filter L4, so as to realize the voltage stabilizing control of the dc bus, and provide the dc inverter to the load and power grid as an AC.

![Figure 1. topology of grid-connected system](image)

By simulating the droop characteristics of the synchronous generator, a measure to control the inverter is called droop control [20]. Since the connection between DG and the micro grid depends on the inverter, in the isolated island mode, the inverter can be regarded as parallel, and the output power of each inverter unit is shown as follows.

\[
P_n = \frac{U U_n}{X_n} \delta_n\]

\[
Q_n = \frac{U U_n - U^2}{X_n}\]

where, U is the voltage of grid-connected system; Un is the output voltage of the inverter; Xn is the inverter power output reactance; \(\delta_n\) is the Angle between Un and U.

According to equation (1), the output of active power is related to the power Angle, and the output of reactive power is related to the output voltage Un of the inverter itself. Different voltage amplitudes can be obtained by directly controlling the output voltage of the inverter cell, and different phases can
be obtained by changing the output frequency of the inverter cell, i.e.

\[ f' = f_n + \frac{\Delta f}{\omega} \]

(2)

In order to make the micro grid smooth switch, the VF droop control will be further improved. The improved VF droop control can keep the voltage and frequency stable, and constantly change the output power of the inverter to the micro grid to meet the changing load demand, but also can make the voltage and frequency fluctuation do not exceed the operating allowable value. Its control block diagram is shown in figure 2 below.

![Control Block Diagram](image)

Figure 2. Improved VF sag controller principle block diagram

3. Power frequency static characteristics of photovoltaic power station

The power difference control is adopted to make the photovoltaic power station operate in the load reduction mode. The following will discuss the determination of the specific load reduction capacity of the photovoltaic power station and the setting of the static power frequency characteristics of the photovoltaic power station. In this section, the power-frequency static characteristics of photovoltaic power station will be set by referring to the power-frequency static characteristics of conventional units.

3.1 Power frequency static characteristics of conventional units

The load power in the power system is provided by the generator set. When the active load of the system changes, the active power provided by the generator set should change accordingly to ensure that the frequency deviation is within the allowable range. The relationship between the output active power and frequency of the generator set becomes the power-frequency static characteristic of the generator set [10]. The power-frequency static characteristic coefficient of the generator set is as follows:

\[ k_G = \frac{-\Delta P}{\Delta f} = \frac{-\Delta P}{f_N} \]

(3)

A negative sign indicates a change in active power as opposed to a change in frequency. Where: \( f_N \) is the rated frequency of the system; \( P_{GN} \) is the rated active power of the generator set; \( \Delta P_G \) is the change of prime mover power when the frequency offset is \( \Delta f \).

In the process of primary frequency modulation of the system, each generator unit naturally distributes unbalanced power according to the set static characteristic coefficient of power frequency in response to the change of frequency, and jointly shares the frequency modulation pressure of the power grid.

3.2 Power frequency characteristics and load reduction level setting of photovoltaic power station

Photovoltaic system in a frequency modulation to reduce running efficiency reserved spare capacity in the first place. In order to determine a FM spare capacity needed for the photovoltaic power station, this definition of photovoltaic power station for reducing load level \( \sigma \% \), photovoltaic power station, it decreases transport line active power output \((1 - \sigma\%)\). Can be represented as lightening of
where, $P_m$ is the maximum power of photovoltaic power station; $\Delta P$ is the load reduction power of photovoltaic power station.

What needs to be taken into special consideration is that the actual environmental parameters (mainly illumination) have a great influence on the output of photovoltaic power station, so the setting of load reduction level needs to take into account the influence brought by the change of photovoltaic environmental parameters (mainly illumination). In view of this, the load reduction level of photovoltaic power station is set as follows

$$\sigma\% = \frac{\Delta P}{P_m} \times 100\%$$

where, $S$ is the light intensity.

According to the above setting of load shedding level, the load shedding level of photovoltaic power station will affect its participation in primary frequency modulation. When the light is weak, the load reduction level of photovoltaic power station decreases, which reduces the standby capacity to participate in primary frequency modulation, and its ability to participate in primary frequency modulation will be weakened. When the light is stronger, the load reduction level of the photovoltaic power station increases, which increases the standby capacity to participate in the primary frequency modulation, and its ability to participate in the primary frequency modulation will also become stronger.

4. Example verification and performance evaluation

The photovoltaic power station was initially maintained at 20% load reduction. At 10s, the illumination changed from 1000 to 800, which reduced the system frequency. The system simulation results are shown in figure 3.
segment, and the real power variation of primary frequency modulation is calculated, and the real power variation \( \Delta P \) of primary frequency modulation is obtained from the end of the primary frequency modulation action segment.

\[
\Delta P = P_2 - P_1 = P(r_x) - P(T_1)
\]

(8)

The stable time \( T_2 \) of the primary frequency modulation is also obtained from the stable segment after the end of the primary frequency modulation action segment. In the end, \( T_2 \) and \( \Delta P \) were respectively calculated to obtain the response time of this primary frequency modulation \( T_R \), illumination intensity inequality rate \( \delta \) and stability time \( T_s \) through the formula, so as to obtain the primary frequency modulation performance of the photovoltaic power station.

Figure 4. Evaluation results of primary frequency modulation

As can be seen from figure 3, at 10s, due to the weakening of illumination, the reduction of photovoltaic output leads to the system's active power shortage and the system frequency drops. It can be seen from figure 4 that when the photovoltaic power station does not participate in the primary frequency modulation, the power gap caused by the reduction of its output will all be borne by the primary frequency modulation of the conventional thermal power plant. After the photovoltaic power station in a frequency modulation, when light reduced, photovoltaic power station will adjust its level of lightening and according to the setting of power frequency static characteristic coefficient of secondary active power, make active gap decreases to a certain extent, thus make the system frequency drop obtained certain inhibition, the frequency of the system falls value decreases, and the frequency stability is enhanced.

5. Conclusion

In this paper, the photovoltaic power station adopts the power difference control mode, and sets the floating load reduction level and power frequency static characteristics of the photovoltaic power station, so that the photovoltaic power station can participate in the primary frequency modulation of the system after it is connected to the isolated power grid. The primary frequency modulation capability of photovoltaic power station is analyzed when the light intensity changes. According to theoretical and simulation analysis, by changing the control mode, the photovoltaic power station operated by load reduction can quickly respond to the drop and increase of frequency and reduce the change of frequency after disturbance. Overall results show that the photovoltaic power station to participate in primary frequency control, split the primary frequency control pressure of the conventional power plants, to reduce the frequency of system changes, implement the support for the frequency of the system, at the same time for the dispatching departments according to the actual parameters of power grid frequency modulation is analyzed, and make corresponding adjustment, to improve the safety of power grid.

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