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Steady-State Analysis of Grid-Connected New Energy Power Plants

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Abstract: In order to ease the fossil energy crunch, new energy sources need to be fully utilized. Clean energy sources such as wind, light, and nuclear energy are important tools to solve environmental and energy problems. However, in the process of researching new energy farms, there are some problems when they are integrated into the power system. In order to ensure the stability of new energy power plants, it is necessary to conduct an in-depth analysis of the grid connection technology of new energy farms. In the study, it is necessary to learn about the specific problems of the stability of the grid connection of new energy power plants, and to clarify the specific application of the grid connection technology of new energy power plants from the application principle and advantages of the grid connection technology of new energy power plants. Through simulation experiments, the positive effect of grid connection technology of new energy power plants in improving the stability of power systems was determined.

Keywords: New energy power plant; Grid connection technology

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1. Introduction

In light of China's rapid economic development, the level of industrialization is improving continually, and the current production and life demand for electric energy is increasing. If we simply rely on traditional thermal power generation, it cannot meet the demand for electric energy for social development, and it may cause serious environmental and energy problems. Therefore, it is necessary to pay attention to the promotion and application of new energy generation technology. The application of new energy generation technology in power systems is becoming more and more common. Compared to traditional power generation technology, new energy generation technology is cleaner, more environmentally friendly, and has a positive effect on promoting the sustainable development of the power industry. However, there are some problems in the integration of new energy power farms with the existing power system for grid integration, which leads to the stability of the power system being affected. Therefore, it is necessary to control the light intensity and inverter and filter of the grid-connected system to enhance the stability of power system and play a positive role of new energy power field.

2. Transient stability analysis of grid-connected new energy power plants

In this study, we mainly discuss the transient stability of new energy sources after they are connected to the grid. The specific requirement of transient stability is that after the new energy sources are connected to the grid, the generators are to operate synchronously, and at the same time, new energy should be spent or returned to the original operating state. When the new energy power plant is connected to the grid, there will be a large disturbance. The main part of an actual transient function curve is mainly the first or second pendulum being able to keep up with the control speed. The main perspective in the analysis of the stability requirements of the grid-connected transients of new energy farms is explained below.

(1) If the disturbance of the system itself is a common fault, its impact on the stability of the grid connection is relatively small, and the requirements for transient stability are relatively high. After the disturbance, it is necessary to ensure a continuous and stable power supply to users, and at the same time to maintain the stability of the power supply system. For example, in a 220 kV system, if it is a multi-line circuit, a single-phase permanent fault occurs in one return, and the circuit breaker will trip forever after reclosing starts [1].

(2) In the process of connecting new energy plants to the grid in disturbed areas, the main requirement for transient stability in weak areas of the grid, such as when a single contact line fails, is to allow for partial and load loss while ensuring system stability.

(3) If faults occurring in the network are more serious, larger disturbances will be produced, which will have a great impact on the stability of the power supply system. Therefore, it is necessary to ensure that various feasible measures, such as three-phase short circuits, are applied on the basis of the system being able to keep up with the control speed, thus ensuring the transient stability of new energy farms connected to the grid. According to the relevant power system safety guidelines in China, if the fault is a single-phase ground fault on the busbar, it can be regarded as a transient stability problem that occurs at the disturbance site in the weak area of the network. An in-depth analysis of the problem of increasing base work angle triggered by each larger disturbance suffered by the system is required. After the first swing, decaying oscillations occur and the pivot voltage continues to recover slowly. Large disturbances are usually caused by the removal of line or unit reclosing faults and short circuits.

3. Influence mechanism of photovoltaic grid connection on transient stability of power grid

In the process of grid connection of photovoltaic power farms, the specific impact on the stability of the grid state is the system voltage dip in which photovoltaic power supply variable speed constant velocity (VSCV) has the characteristics of low voltage and high current. The high current injected into the supply line will lead to transient reactive load at the bus, and the voltage of the system cannot be recovered quickly. In this case, the system will experience a long period of low voltage state. In terms of energy conservation, the output power of the inverter side of the photovoltaic power will also be reduced after the system voltage drops. However, because of the U-I characteristics of the photovoltaic power cell itself, the power is prompted to remain unchanged. At this time, the energy is stored in the direct current capacitor, and the voltage of the direct current capacitor rises rapidly, along with the photovoltaic power array output voltage. Because the Voltage Source Converter controller has a certain direct current voltage difference, it will cause the output current to rise to boost the output power, so that the direct current capacitor voltage drops until the steady state, and the reactive power on the line rises as the output alternating current continues to increase. As a result, the voltage of the converging bus will gradually decrease, and the characteristics of transient reactive load will appear [2].

After the photovoltaic power plant is connected to the distribution network, it will also have a great impact on the stability of the state power angle of the unit, which is mainly manifested in the aspects below.

(1) Inertia coefficient (H)

In the case of the same disturbance, the larger the inertia coefficient (H), the more the peak power angle of the unit will decrease, and the trend of this change will gradually slow down, and the risk of power angle instability is relatively small. However, the smaller the H value, the peak power angle of the unit will increase further, and this change will not slow down with time, but become faster and faster, leading to a higher risk of power angle instability.

(2) The specific scale of photovoltaic grid connected

The scale of photovoltaic grid connected is mainly evaluated through the penetration rate. The higher the penetration rate, the more obvious the characteristics of low voltage and high current in transient state. As a result, the duration of transient low voltage at the bus of grid-connected system will be prolonged. On the other hand, the smaller the output electromagnetic power of the unit, the more the increase of accelerated energy in the characteristic curve of transient work angle, and the risk of instability will be increased.

(3) Photovoltaic control mode

The Voltage Source Converter, as an important element of the photovoltaic power generation unit, controls the active and reactive power exchange of the alternating current grid and can realize the transition from direct current to alternating current power. The controller is generally designed using a two-loop control structure with direct-quadrature-zero (dq0) coordinates. The outer-loop control allows effective control of direct current voltage reactive power or alternating current voltage and is able to obtain the current value of the inner-loop current access controller. The direct current side voltage controlled by the inverter can ensure the tracking effect of the photovoltaic control power at the maximum operating power point. If the system is disturbed by disturbances affecting light intensity or ambient temperature, the control system can adjust the output alternating current voltage phase shift angle according to the deviation of the direct current voltage to ensure that the direct current voltage is dynamically balanced between the battery input power at the target setting and the inverter output power [3].

4. Application analysis of transient stability of grid connection technology for new energy power plants

4.1. Experimental design and analysis

In this study, experimental analysis of the stability of new energy generation fields was carried out with solar photovoltaic arrays. Photovoltaic arrays have non-linear characteristics, and parallel circuits can be designed according to the power. Photovoltaic cells include diodes, parallel resistors, and other components. The photovoltaic cell’s light energy is more closely linked to the light intensity and time. When the current passes through the diode, there is little resistance, but the characteristics of photovoltaic cell cannot be manifested. When designing the photovoltaic array model, the power under different light intensity and time needs to be calculated to obtain the maximum power value. For the maximum power when the photovoltaic array is grid-connected, the reference voltage of the photovoltaic array in operation was analyzed comprehensively to form a three-phase photovoltaic grid-connected system with direct current voltage feedback control. The grid-connected stability of the photovoltaic array was controlled through closed-loop control system. When calculating the maximum power of the photovoltaic array, it is necessary to analyze the initial current value of the photovoltaic array and obtain the light intensity and time under the maximum power to design the reference current value under maximum power. Simulation analysis was also performed on the main points of inverter and harmonizer improvement for direct current voltage feedback grid-connected technology in packaged photovoltaic module control system. Lastly, the application value of direct current voltage feedback control technology was verified using experimental validation to provide a reference for steady-state research under stability construction in the process of grid connection of new energy power farms.

4.2. Simulated analysis

The power system simulation software Simulink was used for this research and to build a simulation model as shown in **Figure 1**. In the simulation process, the specific impact of the new energy side fluctuations was not analyzed. In order to improve the reliability of the simulation results, the new energy was controlled using the photovoltaic module control system and direct current voltage feedback.

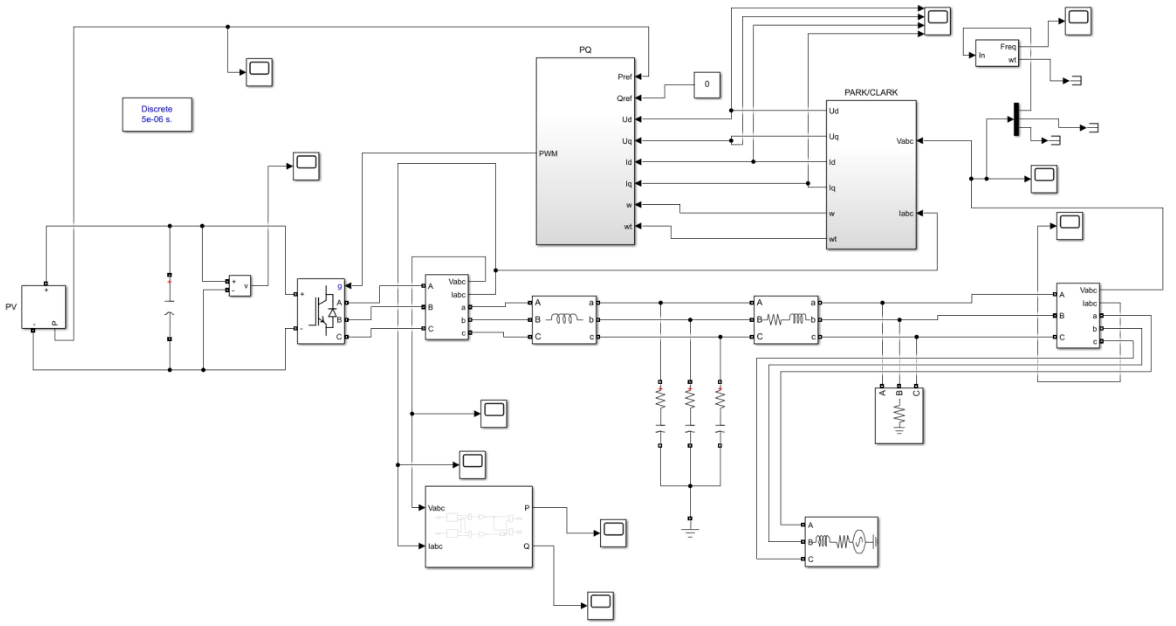

Figure 1. Simulation model

A photovoltaic array consists of several photovoltaic modules and panels. The relationship between the output voltage, V, and the output current, I, of the photovoltaic cell can be expressed through the equation below.

$$I = I_{ph} - I_o\{\exp[\frac{q(V + IR_s)}{AKT_\theta}] - 1\} - \frac{V + IR_s}{R_{sh}}$$

To determine the specific influence of illumination intensity, inverter, and filter on the transient characteristics of the new energy when the synchronous motor is applied to the grid connection technology, the effective value of phase voltage of the grid was set to 220 V and 50 Hz in the simulation design. In this condition, the following conclusions were obtained through simulation analysis:

(1) Light intensity changes

In the simulation experiment, the H value was set at 50e-7s and the damping coefficient at 0.001. A total of 4 simulation experiments were completed, and the results are shown in **Figures 2** and **3**.

The output current, voltage and power of the photovoltaic cell model were different at different light intensities and temperatures. At the same temperature, as the light intensity increased, the output current of the cell model increased and the maximum output power increased, as shown in Figure 2. Under the same light intensity, the output voltage and the maximum output power decreased with the increase of temperature. This indicates that reasonable control of light time helps in improving the transient stability of synchronous motors of new energy farms to the grid [4].

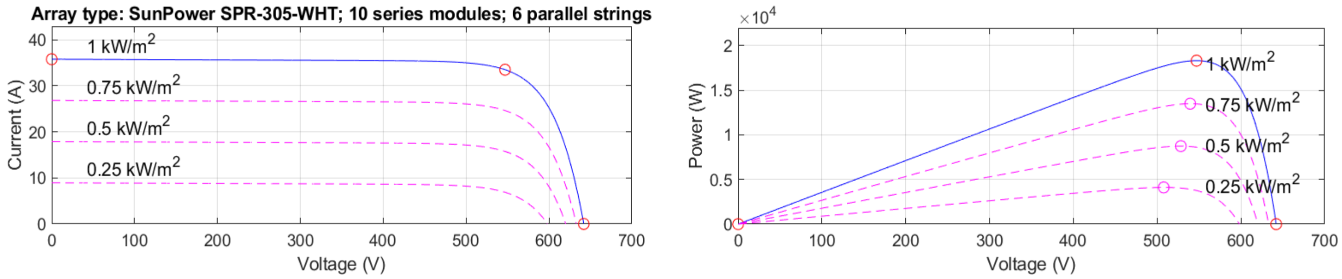

Figure 2. Output current and power under different light intensities

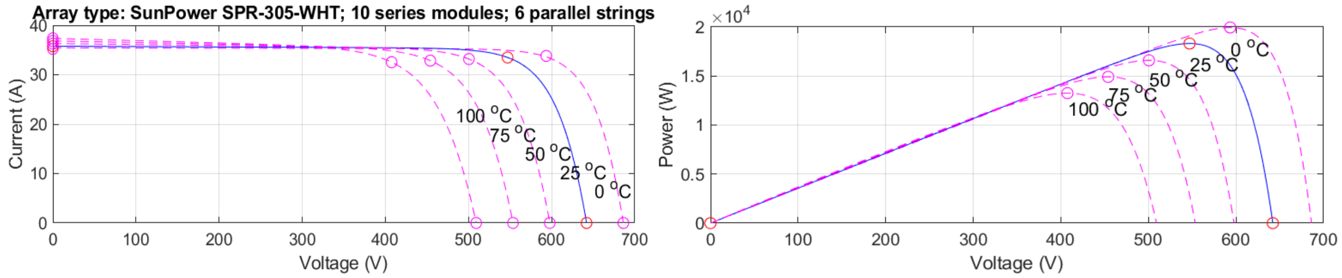

Figure 3. Output current and power at different temperatures

(2) Inverter

A three-phase full-bridge inverter was designed in this study. This is because compared to a half-bridge inverter, a full-bridge inverter has higher output power and smaller switching losses. Its structure is shown in **Figure 4**. A total of four simulation experiments were completed and the results are shown in **Figure 5**.

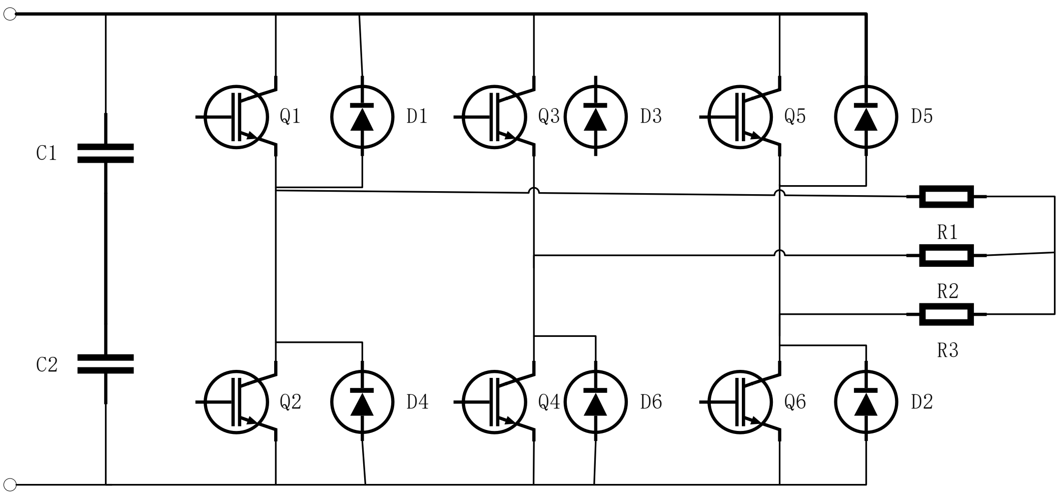

Figure 4. Full bridge inverter

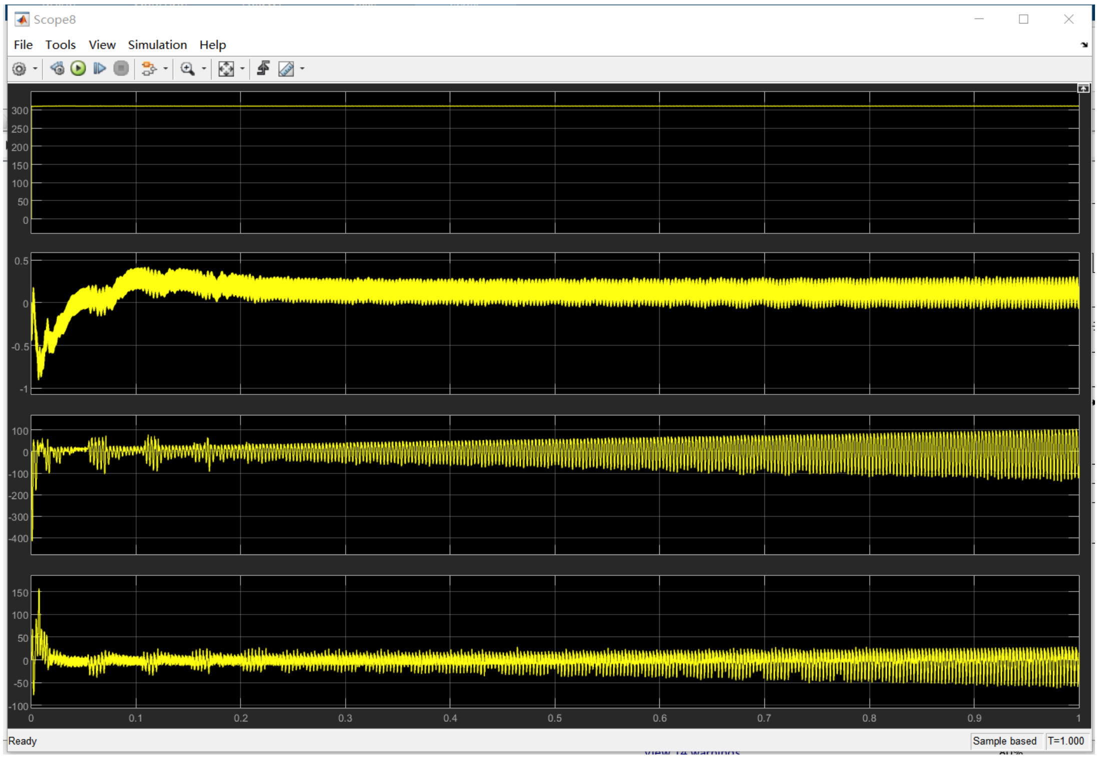

Figure 5. Output power

The analysis of the simulation experiment results can be determined in the case that the light intensity changes. In using the three-phase full-bridge inverter circuit, insulated-gate bipolar transistor (IGBT) was selected as the switching device, and the driving signal provided by the Pulse Width Modulation (PWM) drove the switching of the IGBT transistor to finally convert the direct current to alternating current, and the specific amplitude of the light intensity was reasonably controlled in the actual operation to ensure the stability of the power system.

(3) Filters

The high harmonic distortion rate during the experiment was mainly due to the nonlinear access of devices such as inverters. These power electronic devices generate high amplitude, short pulse currents that cause severe distortion in various waveforms of the line. In the photovoltaic grid modeling, LCL filters were selected to filter high harmonics, but the current filtering effect was not ideal because grid parameters and control parameters also had an impact on the harmonic characteristics of distributed photovoltaic power generation. Hence, the simulation could have been improved in several ways. The first point is to add a tripping signal on the direct current supply to simulate the environmental changes of distributed power generation in actual operation. The second point is to change the parameters of the line and electronic blocks, such as the PID block, to reduce the distortion of the system. The third point is to increase the power factor by increasing the capacitance value or reactive power compensation block to compensate the large amount of reactive power absorbed by the components. The fourth point is to add energy storage devices to make up for the shortcomings of photovoltaic power generation due to environmental constraints that lead to unstable power generation to ensure the stability of power generation.

4.3. Experimental verification

In order to verify and analyze the stability characteristics of the new energy grid connection, a photovoltaic-driven grid connection system was constructed. Besides, in order to determine the transient characteristics of grid-connected photovoltaic power plants, the application effects of photovoltaic grid-connected and direct current voltage feedback control grid-connection was compared and studied. The transient stability of the grid-connected system under load variation was compared in the experiments. Two experiments with different loads were carried out in the experimental platform built. The load conditions of the grid-connected system in the experiments were the same. The experimental results were as follows: the direct current voltage feedback-controlled grid-connected inverter was a three-phase full-bridge inverter. In the grid-connected, the harmonizer set in the grid-stabilized system designed in this paper enhanced the power factor through the reactive power compensation block to avoid the rapid increase of reactive power from negatively affecting the transient stability of the grid-connected system. The maximum offset of the operating frequency of the grid-connected photovoltaic power plant with direct current voltage feedback control was one-third of that when the photovoltaic is directly connected to the grid. The overall operating frequency of the grid was relatively stable in direct current voltage feedback-controlled grid connection, and the inertial response and damping level of the grid connection were improved, which ensured the transient stability of the grid connection of the new energy farm.

5. Measures to improve the transient stability of grid-connected new energy power plants

In the process of connecting a new energy power plant to the distribution network, measures should be taken to ensure the grid-connected transient stability.

(1) Effective control of power quality

At present, new energy farms mainly consist of wind and solar energy power plants, and there are a few disadvantages in using these two new energy sources. Firstly, the power output of the power generation system at different times is differ greatly, which will directly affect the safe operation of the power grid. In order to reduce the probability of power system failure, the installation of real-time power quality monitoring devices when the new energy is connected to the grid can provide comprehensive monitoring of voltage fluctuations, voltage deviations, harmonic changes, and other conditions in the power system. If it does not meet the usage requirements, active voltage filters and reactive power compensators can be installed to improve the power quality [4].

(2) The need to promote the effective application of advanced technologies

In the process of development of new energy industry in China, the corresponding power generation and transmission technologies are still immature, and relevant researchers need to strengthen the in-depth study of new energy generation technologies. We can use advanced technologies to improve the quality of power generation in new energy farms. For example, in the development of photovoltaic power generation technology, mechanical automatic control devices can be used to adjust the working point of solar panels to ensure that the power generation is in a relatively constant state. In addition, energy storage devices can be used to control the output power, so as to achieve the goal of power regulation. The requirements for batteries in for energy storage devices are relatively high, and the topology of the common distribution network can be improved according to the scale of new energy devices connected to the grid, to ensure that the power system can quickly make the correct response after a fault occurs when the new energy power plant is connected to the grid, and to improve the stability and safety of the supply and distribution system.

(3) Strengthen the management of grid connection

There are some differences in the way new energy power plants are connected to the grid, which makes it difficult to manage new energy power plants after they are connected to the grid. In order to improve the stability and safety of the power system, technicians can build an information management platform to supervise the specific situation of new energy farms after they are connected to the grid, strengthen the data collection and analysis of the power grid, and set up a special supervisory team to carry out large-scale monitoring of the power grid, so as to timely discover any problems during the operation of the power grid to ensure the safety and stability of the power grid.

6. Conclusion

In conclusion, through the analysis of the stability of new energy grid-connection, it is clear that the application of synchronous motor to grid-connection technology in the process of grid-connection of new energy power plants can greatly improve the frequency stability of new energy power grid and play a positive role in ensuring the reliability and safety level of the power system. However, further research should be carried out on the advantages and disadvantages of synchronous motor on grid-connected technology in different scenarios using different new energy power plants, so as to improve the application level of synchronous motor on power grid technology.

Disclosure statement

The author declares no conflict of interest.

References

[1] Guan F, Li Y, Wang H, 2021, A Method to Improve the Operational Stability of New Energy Synchronous Motor-To-Grid System, CN112271757A, China National Intellectual Property Administration.

[2] Chen J, Zhang Y, Sun B, et al., 2020, A Starting Control Method for New Energy Synchronous Motor Pair Grid-Connected, CN110829898A, China National Intellectual Property Administration.

[3] Huang L, Xin H, Ju P, et al., 2020, Synchronous Stability Analysis and Unified Synchronous Control Structure of Power Electronic Grid-Connected Equipment. Power Automation Equipment, 40(9): 16.

[4] Yang X, Chen H, Zhang Y, et al., 2019, Virtual Synchronous Generator Power Decoupling Method Based on Single Rotation Angle Virtual Power, CN109256805A, China National Intellectual Property Administration.