Impact and Improvement of Distributed Photovoltaic Grid-Connected on Power Quality

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Abstract. With the large-scale access of distributed photovoltaics to the distribution network, its intermittent and random characteristics bring power quality problems such as voltage exceeding the upper limit, broadband oscillation, and three-phase unbalance to the distribution network. The grid connection method and related standards and specifications of distributed photovoltaic grid connection, analyze the main impact of distributed photovoltaic grid connection on the power quality of distribution network, and propose countermeasures.

Keywords: Large-scale distributed PV · Distribution network · Power quality

1 Introduction

With the access of large-scale distributed photovoltaics, the network structure and power supply mode of the distribution network have undergone great changes, and the distribution network has evolved from a one-way passive network to an active network that interacts with supply and demand. The output fluctuation, intermittency, randomness and other characteristics of photovoltaic power generation may lead to the problems of voltage bidirectional over-limit, voltage fluctuation and flicker, three-phase unbalance and harmonic over-standard. In this paper, based on the current main grid-connected methods of distributed photovoltaics and related standards and specifications of distributed photovoltaics, selected practical cases, analyzed the main impact of distributed photovoltaics on the power quality of distribution grids, and proposed countermeasures.

2 Status of Distributed Photovoltaics

2.1 Distributed Photovoltaic Grid Connection Method

At present, the domestic distributed photovoltaic access to the distribution network is divided into four methods: 220 V low-voltage single-phase access, 380 V low-voltage three-phase access, 10 kV access and 35 kV/110 kV centralized access. Distributed photovoltaics with a capacity of 8 kW and below generally use low-voltage 220 V single-phase access. Distributed photovoltaics with a capacity of 8 kW-400 kW generally use

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low-voltage 380V three-phase access, as shown in Fig. 1. Distributed photovoltaics with a capacity of 400 kW–6 MW are generally connected by 10 kV, and the schematic diagram is shown in Fig. 3. Distributed photovoltaics with a capacity of 6 MW–50 MW are centrally connected with a voltage level of 35 kV/110 kV. The schematic diagram is shown in Fig. 4. (Fig. 2)

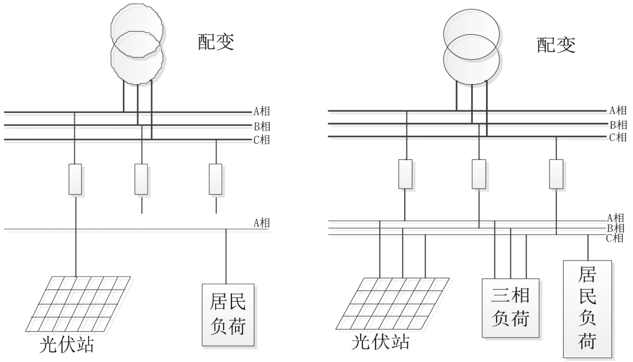

Fig. 1. Schematic diagram of photovoltaic low-voltage single-phase and three-phase connection

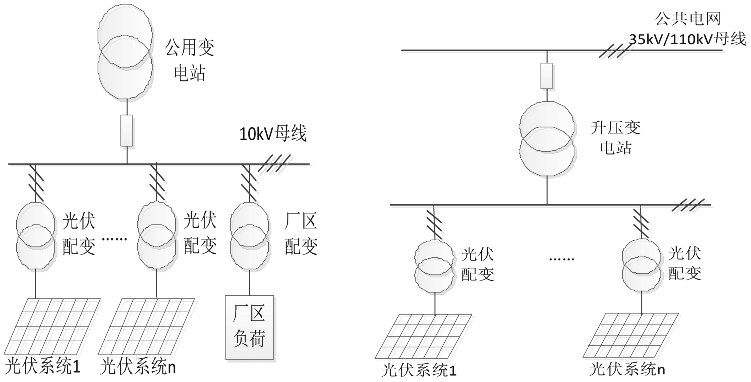

Fig. 2. Schematic diagram of photovoltaic 10kV distributed and centralized access

2.2 Standards and Specifications Related to Distributed Photovoltaic Grid-Connection

In terms of standards and specifications for access to the distribution network, industry standards [1] stipulate that it is necessary to carry out an evaluation of the carrying capacity of distributed power generation access to the power grid to provide a basis for distributed power and power grid planning, design, construction, and operation to ensure the safe and stable operation of the power grid and promote distribution. The healthy and orderly development of the power supply. The evaluation of the carrying capacity of the distributed power grid connected to the power grid includes thermal stability evaluation, short-circuit current check, voltage deviation check, and harmonic check. The national standard [2] stipulates the quality of the power generated by the distributed power source, and the indicators include harmonics, voltage deviation, voltage unbalance, voltage fluctuation and flicker, etc., which should meet the relevant national standards. The distributed power supply connected through the 380V voltage level shall provide the power grid enterprise with the equipment inspection report issued by the unit or department with corresponding qualifications before the grid connection. The distributed power supply connected through the voltage level of 10 (6) Kv–35 kV shall provide the power grid enterprise with an operation characteristic test report within 6 months after the grid-connected operation. The inspection content shall include but not be limited to the following: power control and voltage regulation, power quality, operational adaptability, etc.

For the operation requirements specification of distributed photovoltaic operation, the national standard [3] makes requirements for low-voltage household photovoltaics: when a large number of photovoltaic power generation systems are distributed in the power supply area of the same distribution transformer, the annual power generation exceeds the annual power consumption 50%, it is advisable to carry out a special research on the power quality and reactive voltage in the power supply area as a whole from the perspective of the system. The inverter of the photovoltaic power generation system should have the ability to adjust the power factor within the range of 0.95 leading to 0.95 lagging. If necessary, it should have the method predetermined by the State Grid Corporation, according to the voltage of the grid connection point within its reactive power output range. Ability to work.

The national standards [4] for the operation of industrial and commercial rooftop photovoltaic or photovoltaic power plants are as follows: distributed power sources connected to 380 V, 10 kV–35 kV power grids, if they transmit electricity to the public power grid, they should have the ability to control active power (change), and should have the ability to execute the power grid. The ability to schedule agency orders. For distributed photovoltaics that do not transmit electricity to the public grid, their operation and management parties control their active power by themselves. The reactive power and voltage control of distributed power sources should have the functions of supporting constant power factor control, constant reactive power control, and reactive voltage droop control. The power factor at the grid connection point should be adjustable within the range of 0.95 (leading) to 0.95 (lag) when it is connected to a 380 V distributed power supply connected to the grid via a converter. The distributed power supply connected to the grid of 10 kV–35 kV through the converter should have the ability to ensure that the power factor at the grid-connected point is continuously adjustable within the range of 0.98 (leading) to 0.98 (lag); within the range of its reactive power output It should have the ability to adjust reactive power output and participate in grid voltage regulation according to the voltage level of the grid connection point. Its adjustment method, reference voltage, voltage adjustment rate and other parameters can be set by the grid dispatching agency.

For grid-connected inverters [5], the industry standard stipulates that when the inverter is running, the total harmonic distortion rate of the current injected into the grid is limited to 5%. Under normal operating conditions of the inverter, when the output active power of the inverter is greater than 50% of its rated power, the power factor should not be less than 0.98 (leading or lagging), and when the output active power is between 20% and 50%, the power The factor should not be less than 0.95 (lead or lag). When the inverter is in normal operation, the negative sequence three-phase current unbalance should not exceed 2%, and should not exceed 4% in a short time. When the inverter is in normal operation, the DC current component fed to the grid should not exceed 0.5% of its output current rating.

3 The Main Influence of Distributed Photovoltaics on Power Quality of Distribution Network

With the large-scale access of distributed photovoltaics to the distribution network, its intermittent and random characteristics mainly bring power quality problems such as voltage exceeding the upper limit, broadband oscillation, and three-phase unbalance to the distribution network.

3.1 High Voltage Problem

In the distribution network that is not connected to distributed photovoltaics, the voltage distribution is only affected by load fluctuations, and the voltage of the distribution line gradually decreases with the direction of the power flow. After the distributed photovoltaic is connected, the load is balanced on the spot, so that the power flow of the distribution network changes. When a large number of distributed photovoltaics are connected, the phenomenon of power flow return may occur, raising the back-end voltage of the line. Especially when the line is lightly loaded, the voltage of the distribution line is basically close to the upper limit, and the distributed photovoltaic cannot be absorbed locally, and the back-end voltage of the line may exceed the upper limit. In addition, in order to ensure that low voltage does not occur at the end users of peak loads, some lines have high voltage problems even without distributed photovoltaics at light loads. After distributed photovoltaic power generation, the high voltage problem will be particularly aggravated, and in serious cases, users' household appliances will be damaged. At present, most distributed photovoltaics themselves do not have reactive power-voltage control capability, and the problem of voltage exceeding the upper limit is more difficult to control.

Case 1: A commercial photovoltaic user with a total installed capacity of 1.9 MW is connected to the power grid through a 10 kV dedicated line, and the voltage and power of the grid-connected point are tested. The test waveform is shown in Fig. 1. It can be seen from the figure that the larger the photovoltaic power, the higher the corresponding grid-connected point voltage, and the smaller the safety margin of the voltage. This photovoltaic inverter has a reactive power adjustment mode. Under the premise of not affecting the active power of photovoltaic power generation, that is, within the allowable range of the photovoltaic inverter capacity, by adjusting the reactive power (absorption) of the photovoltaic inverter, it can effectively reduce The voltage level of the photovoltaic 10 kV side, so that the voltage safety margin on the distribution grid side is guaranteed within an appropriate range.

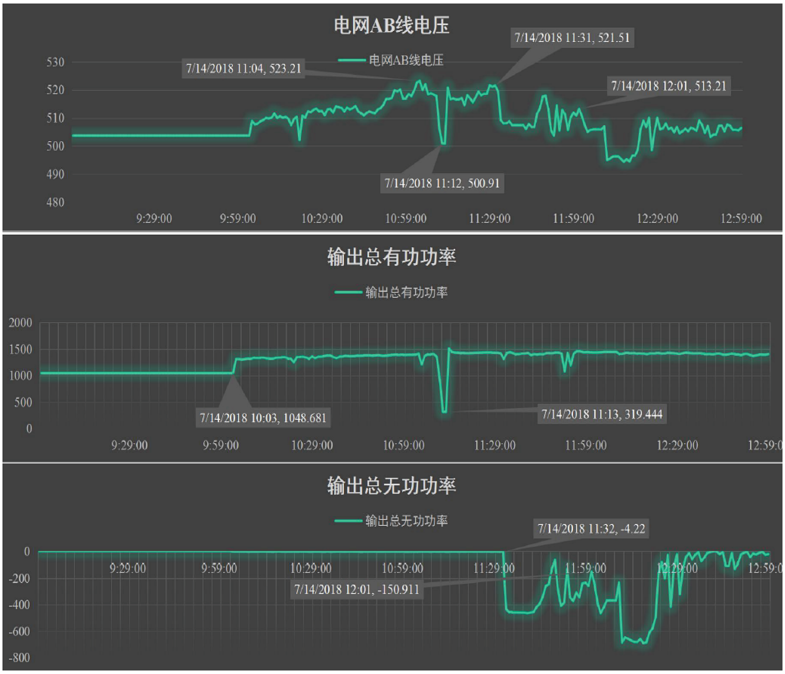

Fig. 3. Test waveform of voltage and power of a commercial photovoltaic user

3.2 Harmonic Problem

The harmonics of distributed photovoltaics are mainly caused by the modulation of inverter PWM switching and the dead zone effect of switching devices. According to the working principle of power electronic switching devices, the harmonic frequency generated by PWM switching modulation is related to the modulation carrier frequency (switching frequency), and is mainly distributed in the vicinity of the multiplication frequency of the carrier frequency, which is a high-frequency harmonic. The sub-harmonics are mainly 19th, 23rd, 41st and 43rd; the switching frequency is 2000 Hz, and the higher harmonics are mainly 38th, 42nd, 79th and 81st. The harmonic frequencies generated by the dead-time effect of the device are mainly low-order harmonics such as the 3rd, 5th, and 7th. The harmonic spectrum generated by distributed photovoltaics is relatively wide, and the potential risk of broadband oscillation with the distribution network is relatively large, especially in the scenario where multiple distributed photovoltaic inverters are connected to the grid, the grid-connected line is a cable line, and the diameter of the grid-connected line is large. Small and distant scenes.

Case 2: A village poverty alleviation photovoltaic power station is a joint establishment model of 4 villages, including 4 sets of 60 kW photovoltaic units with a total installed capacity of 240 kW, which are connected to the grid through a 400 kVA distribution transformer.

Since the village's photovoltaic poverty alleviation power station has been connected to the grid, it has basically operated normally, and faults have occasionally occurred,

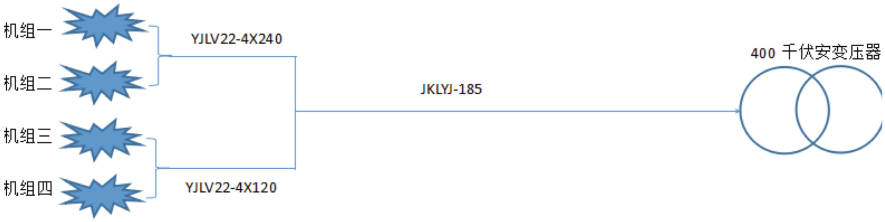

Fig. 4. Schematic diagram of village poverty alleviation photovoltaic power station

but it is within the controllable range. After the transformation of the rural grid, the grid connection of the power station was abnormal. When the power of a single inverter increased to 40 kW, 2 inverters out of the 4 inverters were automatically disconnected from the grid and could not generate full-load power. Through the on-site power quality test, it is found that the output voltage of a single inverter is normal, the power quality is good, and it meets the requirements of grid connection; when two inverters are connected to the grid, harmonic resonance occurs with the grid, and the power quality of the common connection point is poor. The harmonics were seriously exceeded, causing another inverter to be disconnected from the grid (Fig. 5).

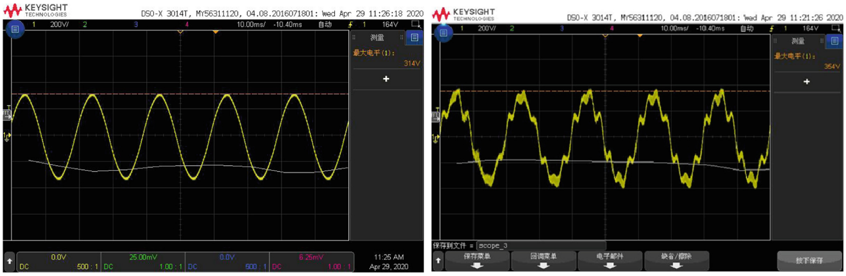

Fig. 5. The voltage waveform when one inverter is connected to the grid and the voltage waveform when two inverters are connected to the grid

Case 3: A 49 MW photovoltaic power station has 98 500 kW photovoltaic inverters, consisting of 49 10 kV distribution transformers (1 distribution transformer with 2 inverters). During the operation of the photovoltaic power station, the inverter will occasionally trip abnormally under certain working conditions, and the noise of the 110 kV grid main transformer is too large. After on-site testing, it was found that the total harmonic distortion rate of 110 kV voltage when all inverters were connected to the grid was seriously exceeding the standard (the maximum was 12.1%, and the national standard limit was 2%). The impedance of the grid-connected line resonates, generating a large 23rd harmonic voltage (7.87 kV), causing multiple inverters to be disconnected from the grid and increasing the noise of the main transformer (Figs. 6 and 7).

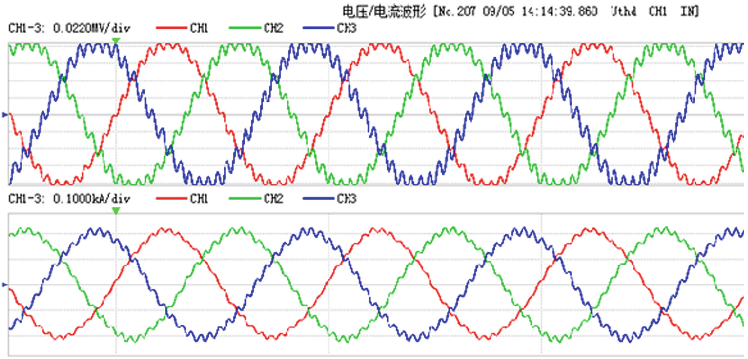

Fig. 6. Grid voltage and current waveforms when all inverters are connected to the grid

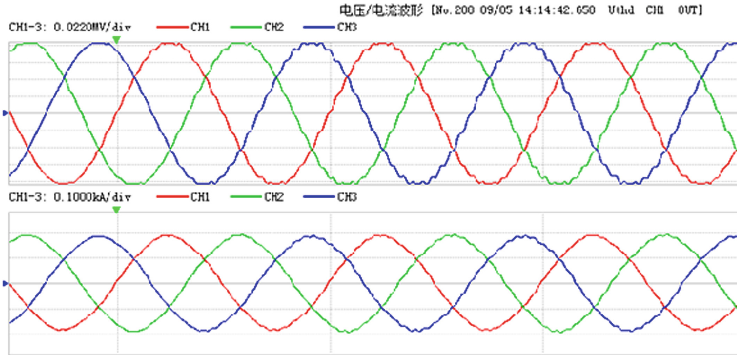

Fig. 7. Grid voltage and current waveforms after abnormal inverter off-grid

3.3 Imbalance Problem

After a large number of single-phase household photovoltaics are randomly connected to the station area, the power flow of the power grid flows in both directions, and the load and power supply in the station area will have randomness and volatility, which will further increase the problem of unbalanced three-phase load in the station area.

Case 3: The capacity of a distributed poverty alleviation photovoltaic distribution transformer is 200 kVA, and the electricity load is mainly household appliances. The annual maximum power consumption is about 120 kW. A total of 78 kW of single-phase poverty alleviation distributed photovoltaics are connected to the Taiwan area. After on-site testing, the unbalance of three-phase current in the platform area exceeded 50% when the poverty alleviation photovoltaics were launched.

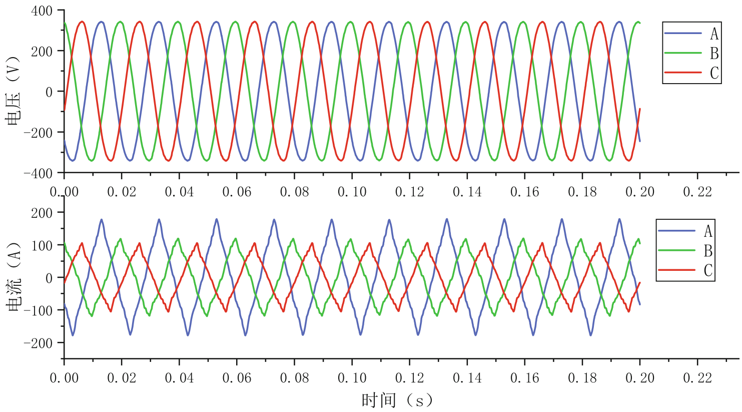

Fig. 8. The voltage and current waveforms of the low-voltage side of a distributed poverty alleviation photovoltaic station area

4 The Main Influence of Distributed Photovoltaics on Power Quality of Distribution Network

4.1 Distributed Photovoltaic Access Does not Fully Consider the Carrying Capacity of the Distribution Network

At present, the calculation of the carrying capacity of distributed photovoltaics by the power grid basically only conducts regional consumption analysis from the aspect of photovoltaic output and load level matching. For small-capacity rooftop photovoltaics, poverty alleviation photovoltaics, household photovoltaics, etc., it is basically in the state of "connecting all connections" and "disorderly control", and does not fully consider the carrying capacity of a single distribution line (including short-circuit current, voltage deviation, harmonics, etc.). Carrying capacity check), especially for lines with weak grids and poor power quality, the connection of distributed photovoltaics will further deteriorate the power quality of the lines. Typical problems include high voltage and harmonics of photovoltaic power distribution lines. Wave resonance amplification, etc.

4.2 The Unreasonable Selection of Distributed Photovoltaic Inverters Has Insufficient Adaptability to the Distribution Network

The selection of equipment such as distributed photovoltaic inverters (such as inverter withstand voltage range, inverter adaptive control strategy) basically does not consider the actual operation of the connected distribution network, and most of them are standardized and unified selection., The adaptability of photovoltaic inverters to the power grid is insufficient, mainly manifested in problems such as high-voltage inverter off-grid, broadband resonant inverter off-grid and even damage. For example, in Shaoyang area, poverty alleviation photovoltaics on small hydropower grid-connected lines were disconnected from the grid due to high voltage problems, and in Hengyang area, severe harmonic distortion occurred, resulting in limited photovoltaic output.

4.3 Insufficient Power Quality Monitoring and Coordination Management Capabilities of Distribution Network-Distributed Photovoltaics

At present, the distribution network only realizes the monitoring of voltage, and other power quality such as harmonics are basically not monitored. When power quality problems occur, it is difficult to realize real-time control and immediate disposal. Under long-term operation, it is easy to cause hidden dangers or damage to the distribution network (For example, harmonics will increase the noise of distribution transformers and cause serious heat generation). The distribution network has limited power quality self-adjustment ability, except for the adjustment of the distribution gear and the switching of the reactive power compensation device. As a power electronic device, distributed photovoltaics have certain advantages in "reactive power regulation", but they are basically in a state of "invisible, uncontrollable, and unadjustable", and they do not have the ability to adjust reactive power and voltage adaptively, much less It has the ability to coordinate and control with the distribution network.

4.4 Insufficient Acceptance Management of Distributed Photovoltaic Access to Distribution Network

Most of the distributed photovoltaics connected to the 380V voltage level did not provide equipment inspection reports to power grid companies in accordance with the standard requirements before grid connection, and the power grid companies did not carry out equipment sampling inspections; distributed photovoltaics connected to the 10 kV voltage level are currently The testing of grid-connected operation characteristics such as reactive power voltage and power quality has not been carried out, which also does not meet the relevant standards. Therefore, it may lead to the connection of photovoltaic inverters that do not meet the standard requirements, such as excessive harmonic generation levels and insufficient reactive power regulation capabilities, to the distribution network.

5 Main Measures

5.1 Carry Out Special Research on Power Quality Problems of High-Proportion Distributed Photovoltaic Distribution Networks and Pilot Projects

For the same distribution network line or station area, when the annual photovoltaic power generation exceeds a certain proportion of the annual electricity consumption (the national standard is 50%), a special study on the power quality and reactive voltage in typical regions is carried out. Strengthen the governance of power quality problems in high-proportion distributed photovoltaic areas, and comprehensively consider the technical and economic characteristics of measures such as on-load voltage regulating transformers, capacitors/reactors/SVG, energy storage devices or photovoltaic inverter reactive power regulation. Copy the economical and practical solutions that can be promoted to further improve the flexibility of the distribution network, which not only improves the acceptance capacity of distributed photovoltaics, but also ensures the safe and reliable operation of the distribution network. It is recommended to give priority to the extreme scenarios of high probability full-time reverse transmission of photovoltaic power generation at the station level and substation level, and carry out an overall research on the qualitative and quantitative comprehensive evaluation of the influence of the reactive voltage and power quality operation of the distribution network.

5.2 Improve the Power Quality Coordination Control Level of the Distribution Network and Distributed Photovoltaics

At present, the level of informatization and automation of the distribution network is rapidly improving year by year, and the reactive voltage and power quality control methods in the distribution network are increasingly abundant (such as distribution transformers, smart capacitors, line voltage regulators, and SVG, etc.). At the same time, the new loads represented by distributed energy, energy storage and electric vehicles can have the technical ability to participate in the reactive power and voltage regulation of the distribution network through functional transformation, which can effectively enhance the flexibility and interactivity of the operation of the distribution network. Therefore, various controllable resources such as distributed energy, distribution network, new loads, and energy storage (“source-grid-load-storage”) should be coordinated to overcome the multi-time-scale reactive voltage and power quality of complex distribution networks with source-grid-load-storage coordination. Active control technology achieves multi-level coordination of vertical high-voltage-medium-voltage-low-voltage distribution network, horizontal day-a-day-real-time distribution network multi-time scale coordination, and realizes economical, efficient and reliable operation of distribution network and maximizes distributed energy. Digestion.

5.3 Strengthen the Whole Process Management of Distributed Photovoltaic Access to the Distribution Network

In terms of grid access evaluation, equipment performance sampling inspection, grid connection inspection and acceptance, operation and maintenance, etc., the process and whole-process management of distributed photovoltaic access to the distribution network shall be strengthened. In particular, strengthen the early source control of distributed photovoltaic access, establish an access distribution network evaluation method that fully considers factors such as voltage, harmonics, line loss, and heavy overload, and refine access capacity, matching equipment selection, etc. Establish a sampling inspection platform for power electronic equipment such as photovoltaic inverters, and improve the quality inspection and acceptance of grid-connected 10 kV distributed photovoltaic power.

6 Conclusion

This paper comprehensively analyzes the main grid-connected methods of distributed photovoltaics and the relevant standards and specifications of distributed photovoltaics in the country and the industry, selects actual cases on site, analyzes the main impact of distributed photovoltaics on the power quality of the distribution network, and discusses the current Problems existing after distributed photovoltaics are connected to the distribution network, and targeted solutions are proposed.

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