

# Countermeasures for Distributed Photovoltaic Grid Integration Problems and Exploration of Relay Protection Methods

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**Abstract.** Photovoltaic power generation technology is progressing and developing in modern society. It also causes some problems in keeping the electrical grid safe to operate. In this paper, the impact of distributed photovoltaic power generation on the low-voltage power grid during the grid connection is analyzed, and related countermeasures for relay protection are proposed. This paper examines the effects of electricity quality on the power grid and suggests prioritizing access to low-voltage energy to prevent negative consequences. Distributed photovoltaic power generation systems after being grid-connected may appear to be the phenomenon of the islanding effect. In addition to the aforementioned issues, connecting large-scale distributed PV to the power grid can significantly impact its operation, hence requiring that the PV power generation system's relay protection configuration conform to the power grid standards. Low-voltage grid connection does not mean complete safety; high-frequency modulation of inverters may cause harmonic problems, and unstable generating capacity during cloudy and rainy weather can affect grid operation and electricity quality. The paper analyzes the causes of electricity quality and islanding effect and proposes countermeasures for the corresponding problems. In terms of relay protection, the article proposes solutions including the addition of protective components and enhanced information exchange between the grid and distributed PV. The research findings enhance distributed PV power generation system's reliability and grid operation stability by offering valuable guidance and reference for future research and practice.

**Keywords:** Distributed Power; photovoltaic power generation; electricity quality; islanding effect; relay protection.

## 1. Introduction

As environmental problems and energy security become increasingly serious, countries have begun to actively develop new energy technologies to meet these challenges. Currently, nations worldwide are striving to attain the shared objectives of "carbon neutrality" and "green carbon emissions". The overhaul of the power supply framework, in which renewable energy sources have taken the lead, is the prevailing trend. Among them, wind energy, solar energy, and other clean energy are mainly used in distribution, this method can reduce economic costs and optimize the energy structure. Currently, the development of distributed power supply in China is still in the primary stage, this power generation method is characterized by power under normal circumstances output power is relatively small, resulting in a low degree of pollution, power generation, and coexistence of electricity. In distributed power systems, a significant form of power generation is via photovoltaics. The inverter then converts this into electrical energy, which can be stored and managed by the controller and battery. Distributed power is long-lasting and capable of autonomous operation, making it effective in fulfilling power distribution needs and enhancing the stability of the power grid. Although photovoltaic power plants offer numerous advantages and largely enhance power supply capacity, the distribution network and relay protection equipment will be affected by the significant number and size of distributed PV power plants connected to the grid. In recent years, many scholars have been on how to solve the distributed photovoltaic connected grid caused by the adverse effects of many studies, the main idea is to optimize the distribution network relay protection strategy, the use of "longitudinal protection strategy" to accurately and timely removal of short-circuit faults occurring in any location of the transmission line. This paper primarily examines the problems of

power quality and islanding effect in distributed photovoltaic grid-connected systems and proposes countermeasures and relay protection strategies to address them. Reduce the problems of China's modern photovoltaic power grid and put forward the corresponding program for better construction and development of the field to provide feasible strategies.

## **2. Distributed Photovoltaic Power Generation System**

### **2.1. Distributed Photovoltaic Power Generation System Overview**

Distributed photovoltaic power generation system refers to the construction and operation at the near site or where the user is located. It is a photovoltaic power generation facility characterized by self-generation and self-consumption on the user's side. Excess power enters the power grid and is characterized by the balanced regulation of the distribution grid system. Within the new photovoltaic energy grid-connected transmission system, the system is categorized into a new photovoltaic energy grid-connected transmission system without battery storage and a new photovoltaic energy grid-connected transmission system with battery storage. The battery-less power generation system must be equipped with PV arrays, grid-connected inverters, controllers, etc. The battery storage PV new energy grid-connected transmission system is to add PV batteries into the battery-less energy storage system. In distributed photovoltaic power generation, when connected to the grid, the voltage of the DC power output from the photovoltaic battery is stabilized, and then this stabilized voltage is boosted to a certain value by a boost circuit on the DC side, and then the DC power is converted to AC power by a single-phase or three-phase inverter. If all the indexes can meet the requirements of grid connection, then it can be grid-connected control [1]. To minimize the undesirable effects of grid integration, the use of low-voltage grid integration is generally preferred if either high or low voltage can satisfy the grid access requirements [2].

## **3. Impact of Distributed PV Grid Integration on Low Voltage Grids**

### **3.1. Electricity Quality Standard Requirements and Impacts**

The main indicators of electricity quality are voltage, frequency, and waveform. The test work of electricity quality includes the power supply capacity, grid connection method, and converter type. The problems are summarized in four main areas. Voltage fluctuations and flicker, harmonics, voltage three-phase unbalance, voltage reduction, and power supply interruption. In the distributed power photovoltaic power generation system on the grid, the voltage and power have certain requirements, the current and voltage of the low-voltage grid before the grid is relatively stable, and the power is also a regular change [3].

It was found that the DC power generated by distributed PV power generation is modulated into AC power by inverters before it can be connected to the distribution grid, but the high-frequency modulation of inverters may cause harmonic problems [4]. In the case of simultaneous operation of the main grid and the PV system, even though the output power remains consistent in terms of voltage, harmonics are amplified and persist because of the long duration of continuous operation. The efficiency and stability of distributed photovoltaic power systems may be impacted by weather conditions, including precipitation and cloudy or overcast skies. Such conditions can cause voltage fluctuations or flicker effects on the low-voltage grid during grid connection. To mitigate these effects, appropriate measures must be taken. The operation of the distribution system will also become cumbersome after the grid connection, and it needs to do a good job of gathering, distributing, and transmitting electric energy, which greatly increases the workload of the whole grid [5].

### **3.2. Solutions for Electricity-related Impacts**

If the local government chooses to coordinate and manage the construction work, analyze the project conditions and circumstances specifically [6]. In the planning to choose the appropriate power

management devices, meet the requirements of the IEC 61000-4-30 standard power quality online monitoring device, and install harmonic suppression devices in the parallel network points, so that the harmonic voltage to meet the requirements of GB/T 14549-1993 "power quality utility grid harmonics" [4]. The aforementioned component will be installed at one end of the distributed photovoltaic power generation system. Before grid connection, the system's functions will be tested according to a 10MW installed capacity standard. The effectiveness of the control's harmonic requirements is expected to exceed 60%, indicating a high level of power supply stability for the system [6]. In addition, the concept of a large-capacity battery is proposed, which requires the system to store electricity in the battery after completing photovoltaic conversion [8]. In the case of normal power generation, it is not possible to rely on battery power to ensure the stability of the transmission of a distributed photovoltaic power generation system. The battery capacity must be equal to or greater than the total amount of power generation of the system for 16-32 hours to meet the basic requirement of temporary power transmission [8].

## **4. Islanding Effects Caused by Distributed Photovoltaic Systems**

### **4.1. Causes of the Island Effect**

The operations of the system are in parallel with the larger grid, and when the larger grid fails, the equipment will still supply power to the distribution grid, which creates an island effect. The system's continuous supply of power to localized grids can, firstly, lead to a waste of power, and secondly, for unplanned localized power supply, there is a risk of injury to staff engaged in the overhaul and maintenance of the grid [7]. At the same time, when one end of the distributed photovoltaic power generation system fails, under the premise of grid-connected operation, the power in the large power grid may also enter the distributed photovoltaic power generation system, resulting in the distributed photovoltaic power generation system end of the work of the system abnormally, and if the low-voltage grid is a single-phase distributed power generation system, it will lead to the system of the three-phase loads of the under-phase power supply.

### **4.2. Island Effect Solutions**

The key point in preventing the islanding effect is the monitoring of grid outages, where detected problems are analyzed and dealt with accordingly. The primary methods of detection can be categorized as active and passive detection. Active detection is done by controlling the inverter so that certain disturbances in the inverter output power, frequency, or phase cannot be detected under normal conditions. When the islanding effect occurs, the disturbances that lose their grid-balancing effect become cumulatively larger, allowing them to be detected [8]. Active detection methods are specifically frequency offset methods, voltage drift methods, grid impedance estimation methods, and modern remote monitoring and detection methods. The frequency offset method is used to determine if islanding has occurred by attempting to interfere with the system's frequency of motion through active frequency shifts. The voltage drift method applies positive voltage feedback. When the grid is disconnected, the voltage drop at the common connection point causes a drop in the inverter's output voltage and power. In case of an islanding effect, the voltage value keeps dropping, and the system can detect this occurrence [8]. In addition to active detection, passive detection is also widely used, which is the real-time monitoring of electrical signal anomalies at public connection points. The main detection methods are over/under frequency and over/under voltage detection, sudden voltage phase change detection, and harmonic detection. The harmonic detection method is to detect the harmonic distortion of the voltage at the common connection point after the grid has been disconnected and determine whether the distortion has increased and exceeded the 5% threshold to know whether there is an islanding phenomenon. The voltage phase mutation detection method is that under normal conditions, the inverter's output current and the grid voltage share identical frequency and phase, without any phase shift. After the loneliness effect occurs, a brief phase shift occurs between the voltage from the common connection point and the inverter output current, and

the controller cuts off the inverter output after detecting the shift [8]. Whichever of the above detection methods detects that the grid is in a state of power loss, disconnect the grid-connected inverter from the grid stop the operation of the inverter within 2s, and store the excess power with a large-capacity battery. If the battery is at full capacity, the power generation is stopped. The problem of the islanding effect is solved by this method.

## **5. Analysis of the Impact of Distributed Photovoltaic Grid Integration in Distribution Relay Protection**

### **5.1. Impact of Distributed Photovoltaic Grid Connection on its Relay Protection**

The distribution grid may be significantly impacted by the widespread integration of distributed photovoltaic sources into the local transmission grid, threatening the safety and stability of the grid and causing serious safety problems for the relay protection (current protection, voltage protection, frequency protection) in the grid. Most of these problems can be attributed to bidirectional flow and oscillation of currents, problems with voltage, and frequency stability. After the distributed PV is connected to the grid, the current may flow from the load to the feeder. At the same time, due to the simultaneous access of the transmission system to many distributed PV power sources of the same type of output power, it will be more likely to cause oscillations in the grid, triggering the grid's relays, and subjecting other normally working systems to potential safety hazards [9]. After the distributed PV is connected to the grid, the possible reverse current will cause a reverse voltage to drop on the grid lines, causing the voltage of each load node on the lines to rise, which ultimately leads to the equipment in the grid operating at voltage overruns, resulting in potential safety hazards [9]. At the same time in the power grid, more frequent frequency changes or fluctuations in the power system can have many adverse effects on the user, the generation system, and the entire power system. During operation, large random fluctuations in the distributed PV power supply can cause a great impact on the system balance, thus further affecting the system's primary and secondary frequency regulation and other operating characteristics [9].

### **5.2. Relay Protection Strategies for Distributed Photovoltaic Grid Integration**

China's conventional grid structure is ray-shaped, and relay protection devices are configured according to its structure, therefore, in the ray-shaped grid system, there is and exists a power supply to the fault current, so the main idea of the protection strategy is to solve the fault by bypassing the circuit breaker within the system [1]. Therefore, the so-called "longitudinal protection strategy" is proposed to remove accurately and promptly the short-circuit position at any location in the transmission line [10]. The next step is the optimization of the relay protection equipment in the transmission line, based on the following considerations: the original relay protection equipment, taking into account the actual situation and economic conditions, is equipped with directional discrimination equipment, to avoid erroneous protection actions, and the construction of a constant communication system to transmit the transmission line fault information on time [10].

To avoid distributed photovoltaic unreasonable integration into the distribution network, thus causing the instability of the frequency of the distribution network, to maintain the proper function of the distribution network, any impact must be considered in conjunction with the real-life implementation of flexible access to high-frequency inverters. This approach, known as "flexible access" [11], should be utilized for the distribution network. In addition, the so-called "flexible access" is used to reasonably select the access methods such as "dedicated access" and "branch access" [11], and the flexible use and adjustment of these methods can improve the protection of the power grid, thus reducing the adverse effects of distributed PV on the relay grid.

## 6. Conclusion

Role in promoting urbanization and socio-economic construction. Distributed power PV is designed to cost less, long service life, and have no pollution, but it also has a certain impact on the low-voltage power grid. To give full play to the effective role of distributed power photovoltaic power generation, the impact of photovoltaic power generation is to take timely countermeasures. Continuously improve and optimize the technology of distributed power PV power generation access to the distribution network, actively carry out experiments and make perfect evaluation, use reasonable technical testing means to solve the islanding effect problem, to promote the progress of distributed power PV power generation, and realize the long-term sustainable development of China's socio-economic.

## Authors Contribution

All the authors contributed equally, and their names were listed in alphabetical order.

Minglei Li is responsible for Abstract, Distributed Photovoltaic Power Generation System, Impact of Distributed PV Grid Integration on Low Voltage Grids and Islanding effects caused by distributed photovoltaic systems.

Tianruiqi Li is responsible for the Introduction, Analysis of the impact of distributed photovoltaic grid integration in distribution relay protection, and Conclusion.

## Reference

- [1] Fangzhu Wu, Liumin Lu. Analysis of the impact of low voltage distributed photovoltaic access on power quality in station area[J]. Electrical Engineering,2022, (07).
- [2] J Zhang. Analysis of distributed photovoltaic grid integration [J]. Light Source and Lighting,2023, (04).
- [3] YF Miao. Impacts and countermeasures of distributed power photovoltaic power generation on low-voltage power grids[J]. Electrical technology and economy, 2023, (06).
- [4] Dewei He. Analyzing the impact of distributed photovoltaic on distribution network [J]. Rural electrification,2021, (10).
- [5] Jiaqi Xie, Li Zhang. Impacts and countermeasures of distributed power photovoltaic power generation on low-voltage power grids[J]. China High-Tech,2023, (13):81-82+85.
- [6] Jimei Li. Impact and countermeasures of distributed power photovoltaic power generation on low voltage grid[J]. Communication Power Technology, 2020, 37(04):226-227.
- [7] Hui Xu, Bin Ran. Impact of distributed power photovoltaic power generation on low-voltage grid and countermeasures[C]//Shaanxi Power Grid Energy Saving and Power Quality Technical Society.Proceedings of Grid Energy Conservation and Power Quality Technology,2018:3.
- [8] Liangliang Zhu. Research on islanding detection of grid-connected photovoltaic power generation system[J]. Times Automotive,2021, (11).
- [9] Yuan Zhang. Analysis of relay protection impacts of distributed photovoltaic power generation connected to the grid [J]. Electrotechnology, 2022, (19): 129-131+134.
- [10] Y. Liu, M. Zhang. Distribution network relay protection strategy under distributed power grid-connected conditions [J]. Light Source and Lighting, 2022, (10): 228-230.
- [11] Du Liang. Analysis of the impact of grid-connected photovoltaic power plant on distribution network relay protection [J]. Electronic Technology, 2022, 51 (11): 298-299.