

Survey of the Current Status of Integrated PV System

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Abstract. This paper briefly introduces the integrated condition of PV integrated systems. The principles and characteristics of two significant forms of PV-integrated systems (distributed PV-integrated systems and large-scale centralized PV-integrated systems) are described in detail. Analyzed are the following issues brought on by the two PV-integrated systems linked to the grid: issues with power quality (harmonics, frequency, voltage amplitude), the islanding effect problem, the problems of reliability and stability of the PV-integrated system, etc. Feasible countermeasures are put forward for the above problems. Inadequate and possible improvements to existing technology are mentioned in this paper. The major causes of each sort of issue brought on by PV-integrated power production systems connected to the electrical grid, the state of domestic and international research, and the solutions are all reviewed. The future trend of large-scale industrial application of PV power generation technology has been prospected.

Keywords: Photovoltaic Systems, Integration, Harmonics, Frequency and Voltage Fluctuation, Islanding Effect.

1. Introduction

According to statistics, China's carbon dioxide emissions in 2020 were estimated to be 10.3 billion tons, of which 9.5 billion tons came from coal, oil, and natural gas emissions. So about 92% of the emissions are generated by the above three materials. The two major problems of energy shortage and environmental pollution have a very prominent impact on the sustainable development of the world economy. Vigorously promoting renewable and wind energy is one of the most effective ways to solve these two problems. Renewable solar energy is pure, secure, and never-ending. In China, distributed PV power generation is an important rising strategic sector. Promoting the use of PV power generation vigorously has significant strategic implications for optimizing the energy structure, benefiting the environment, and changing how urban and rural areas use energy. At present, more than 80% of the total installed PV capacity in China is large-scale ground-based power plants. However, in recent years, China has introduced policies to encourage the construction of PV power plants. At the same time, it has actively promoted the application of PVs in other industries such as agriculture, aquaculture, mining, ecological governance, etc. And promoted the diversification of PV power generation modes. Governments all around the world are implementing an energy policy that fully exploits and utilizes solar energy. The use of solar energy to generate electricity can solve the needs of special application areas shortly as a supplement to conventional energy sources. In the long run, solar power will be applied on a large scale to gradually replace traditional fossil fuels. PV power generation has a promising future as a substantial source of fresh energy. Expert predictions state that by 2030, PV power generation will make up 5% to 10% of all global electricity production.

PV power generation systems can be divided into off-grid PV power generation systems and integrated PV power generation systems, and the investment in integrated PV power generation systems is reduced by 25% compared with off-grid PV power generation systems. Integrating the PV systems into the large grid in the form of microgrids and supporting each other with the large power grid is an important technical way to improve the scale of PV power generation. In today's large number of PV power generation equipment that needs to be connected to the grid today, in addition to further improvement in economic policies and regulations, whether the two parts of the PV systems can be safely and efficiently operated after the PV system is integrated to the large power grid at the technical level is also the key to determining whether PV power generation technology can be

industrialized on a large scale. At present, in addition to some mature technologies in the research and development, manufacturing, and control of power generation equipment, most of the research involving the impact of integrated PV systems on the large power grid, as well as the system optimization, coordination, and control of the large power grid after grid operation, has just started. Generally speaking, the integrated PV system and other power generation systems may bring the same problems to the large power grid. However, compared with other power sources, PV power generation is different in the time period, geographical location, and the way of grid connection with large power grids. Furthermore, the characteristics of power generation systems and control systems also have their own characteristics. Therefore, we can learn from the research results of other power grids, but it is still necessary to study the problems and countermeasures that the large power grid may face after the PV system is integrated. Because PV power generation is very different from traditional thermal power generation and hydropower generation in terms of inherent characteristics and acceptance methods, problems in power quality, islanding effect, stability, and reliability usually occur in integration. By introducing the principle and characteristics of PV-integrated power generation, this paper expounds on the impact of the PV system on many aspects of the power grid after integration.

2. The Characteristics of Photovoltaic Systems and Integration

2.1. Photovoltaic Power System

The photovoltaic power system mainly uses the photovoltaic effect. The photovoltaic effect, a physical and chemical phenomenon, is the generation of voltage or electric current in the material following exposure to light. The solar cell produces electromotive force at both ends, converting sun energy into electrical energy. Solar panels, batteries, controllers, DC distribution cabinets, inverters, and AC distribution cabinets typically make up a PV power-producing system. Figure 1 displays the PV system's schematic diagram. The basic components of the PV system are solar cell arrays and inverters among others. Solar cell modules are joined in series and parallel to form the solar cell array, which increases the array voltage to meet input voltage requirements. Photovoltaic modules are used to convert solar energy into DC power. The inverter will then gather the DC electricity after it has passed through DC distribution cabinets and converted it to AC power.

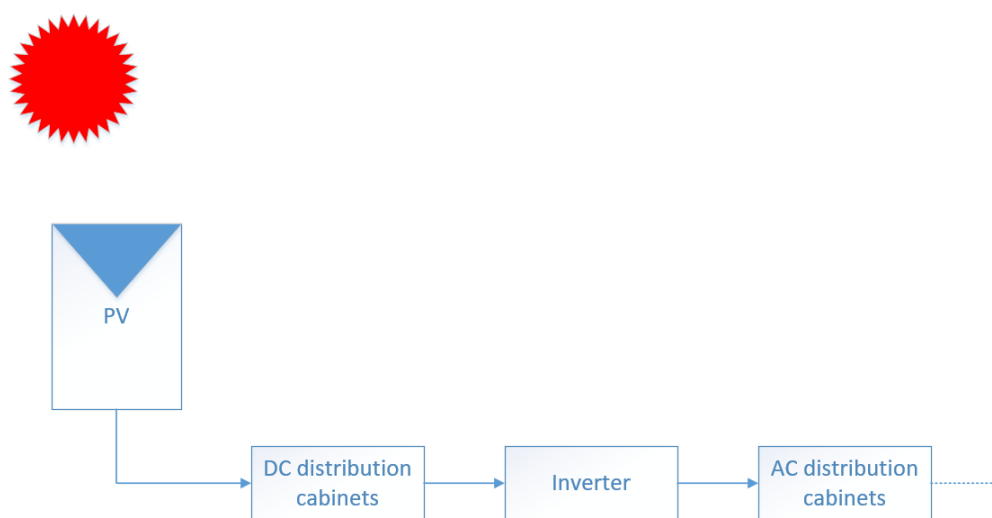


Figure 1. The schematic representation of the photovoltaic power generation system's component parts

Solar energy as typical renewable energy, Ambient temperature, solar light intensity, and weather conditions has a strong influence on PV power generation systems, which causes the biggest feature of PV power generation systems---stochastic volatility. To maximize the output of the power generating system, the primary energy power on the input side can only passively track the maximum

power point under the current illumination conditions because active regulation is not possible within the technical range. The input side of the current PV integrated inverter is a voltage source, and the output side is controlled by a current source. This is known as voltage source current control. By adjusting the output current to follow the voltage at the grid connection point, integration can be accomplished. The output is roughly all active power, with a power factor close to one. In addition, inverters are the primary source of harmonic production in PV power generation systems [1]. The PV power generation system produces DC as its output. And in order to bear the load, DC must be inverted into a high-quality, power-frequency alternating current. The PV integrated power generation system will include multiple types of integrated inverters connected to the same integration point (each with a different protective principle) as a result of the PV power generating capacity's ongoing growth. That will lead them to interfere with one another. The anti-islanding detection time will also increase noticeably and may even fail to identify when the load and power generation are balanced.

2.2. Integration of Photovoltaic Power Generation System

The following principles should be followed when synchronizing generator sets parallel operating:

(1) When the parallel circuit breaker is closed, the inrush current should be as small as possible. The instantaneous value of inrush current generally does not exceed 1-2 times the rated current of the generator to be paralleled.

(2) After the generator sets paralleled to the grid, it should be able to quickly enter the synchronous operation state. The transient process should be short to reduce the disturbance to the power system [2].

The quasi-synchronous parallel approach is typically used to start the generator sets when the power system is operating normally. The basic prerequisites for PV power generation system integration are:

(1) The frequency of the system voltage and the sine wave current that the inverter produces is the same.

(2) There is no phase angle difference between the sine wave voltage the inverter outputs and the grid voltage.

(3) The sine wave voltage produced by the inverter has the same amplitude as the grid voltage.

There are two forms of PV power generation systems integration: Centralized integration and Decentralized integration.

The characteristics of Centralized integration: The huge grid receives the generated electricity straight away. The unified deployment of the large power grid provides users with electricity, and circuit interchange with the large power grid is one-way. Voltage control and reactive power are simpler to implement than centralized integration. Participation in grid frequency regulation is also made simpler. Due to the fact that centralized PV integrated power generating systems are typically installed in arid regions with plentiful and reliable solar energy resources, long-distance high-voltage transmission lines are required for their integration into the grid. That makes it a source of grid disturbance that cannot be disregarded. It is impossible to disregard issues like voltage drop, line loss, and reactive power adjustment. The 380V three-phase AC power after the inverter is connected to the 380V bus before the booster, then connected to the grid after the booster. The step-up ratio is 0.4/10.5kV. The centralized large-scale system for generating solar power typically has an access voltage level of 10KV. Additionally, centralized integration necessitates greater expenditures for auxiliary hardware. When many PV power generation units are coupled to the grid, protection and automation equipment need to be installed or replaced. The reverse flow phenomenon caused by PV power sources requires new voltage control strategies. For large-scale PV power facilities, which are often located far from the load point, this integration option is appropriate. This is how desert PV power systems are linked to the grid.

The characteristics of Decentralized integration: The electrical load receives direct access to the generated electrical energy. By connecting to a large grid, it is possible for the power exchange with

the big grid to be bidirectional as the excess or insufficient electricity is controlled. Small-scale PV power generation systems can use this integration approach. The low-voltage distribution network is often connected to the decentralized PV integrated power generation system with a voltage level of 0.4kV. Together with other innovative energy sources, the decentralized integration of the PV power generating system can be connected to the big power grid as a micro-grid and supported by the large power grid [3]. The scale of PV-integrated power generation systems can be increased in a major technical way in this manner. Urban PV power generation systems usually use this method, especially PV systems integrated with buildings.

3. The Impact of PV System Integration on the Grid

3.1. Research Status of PV System Integration

The PV cell array's output power is directly correlated with environmental conditions. The solar cell's volt-ampere characteristic curve is nonlinear. When the maximum power production is calculated under the conditions of sunshine and temperature, the MRRT controller can compute the corresponding operating voltage of the PV array. Through such kind of controller, the PV power generation system can adapt to changes in the environment. It is an autonomous optimization method with better dynamic performance. The traditional CVT control strategy can obtain more power, but the ability to stabilize the terminal voltage is poor. A voltage regulation control link can be added to the outer loop of MRRT control to improve this defect, thereby improving the stability of the power system. The PV cell array's DC electricity is converted into AC power by the inverter. The output voltage of the PV cell array on the input side should be compatible with the inverter's operating point. Additionally, the conditions for AC integration on the output side must be met. The inverter will inject high-order harmonics on the AC side, and the harmonic content should be reduced by optimizing the inverter control method and filtering. There is no reactive power generated or consumed in the process of PV energy conversion. However, it needs to consume reactive power during the inverter process. That's one of the significant differences from other conventional power generation systems. Reactive power compensation equipment is therefore required in the PV energy production system in order to regulate the integration point's power factor. The regular operation of the system with integrated solar power generation may be impacted by the disturbance of the big power grid. To prevent harm to the PV power generation system and to prepare for integration, later on, it is especially significant to promptly identify when the PV power generation system enters islanded operation mode. At present, the problems of PV-integrated power generation research are mainly carried out around these characteristics: Maximum Power Point Tracking (MRRT), Inverter topology, and control method [4]. Filtering (reducing harmonic content), reactive power compensation (power factor control), islanding detection, and their coordination. Focus on the design and application of PV-integrated power generation system equipment with an inverter as the core.

3.2. Power Quality Problem in Integrated PV System

The reactive current of the load may have an impact on the caliber of the power source at the end of the grid because the PV-integrated power generating system can only produce active power. Corresponding reactive power compensation equipment needs to be added.

The main grid's power quality issues following the connection of the PV-integrated power generating system are described below.

3.2.1. Harmonics

Harmonic pollution will become a problem that can no longer be disregarded as the percentage of PV energy production systems in the power grid rises.

The enormous number of power electronic components found in PV inverters will unavoidably result in harmonic pollution of the power grid when DC is transformed into AC. Additionally, the harmonics considerably increase when a light load is output by an integrated inverter. The total

current harmonic distortion rate (THD) will surpass 5% when the rated output is less than 20% [1]. There might also be power resonance of higher harmonics if the grid has many harmonic sources. As a result, reducing the total harmonic content of the line current is as important as guaranteeing the inverter's own reliability. Therefore, it's essential to monitor and analyze harmonics in PV systems in a quick and accurate manner.

3.2.2. Frequency and Voltage Fluctuation

The frequency and voltage quality of the distribution network, high-voltage transmission network, and their control will be affected to some extent by the two types of PV integrated power generating systems.

The local loads are served by the decentralized PV integrated power generation systems, which are often situated close to customers. Integration can be utilized to achieve power compensation and external transmission, decreasing reliance on the grid and the line losses brought on by power transmission [5]. In addition, it can function autonomously under specific circumstances when combined with new energy sources like gas turbines and wind turbines to create a smart microgrid. The required protection settings must be reset because the distribution network's power flow direction is subject to change at any time. The feeder's usual voltage-regulating equipment performance is also impacted, adding to the system's complexity.

The voltage drop between the photovoltaic arrays and the substation will change gradiently when the power flow is reversed. It can be corrected by adjusting the voltage regulating switch of the transformer, and it needs to be used in conjunction with the PV system and reactive power compensation device.

3.3. Islanding Effect

The PV-integrated inverter continues to send power to the grid when the power system is disrupted by electrical problems or natural events thanks to the islanding phenomena. This creates an island of self-sufficient power that the utility cannot control called the Islanding Effect. The occurrence of isolated islands in the PV integrated system will have serious consequences, causing major harm to the safety of users' electrical equipment and maintenance personnel. When islanding occurs, if the frequency and voltage in the island exceed the allowable range, it might harm the user's device. The power failure of the power grid may cause the PV system to overload and be easily burned. The lines connected to the PV system are still electrifying, posing danger to maintenance personnel. In order to avoid the islanding effect, the power supply of the system to the grid must be quickly cut off when the power grid is turned off.

3.4. Reliability and Stability of PV Integrated System

The PV-integrated system will have the following effects on the stability and dependability of the system's power supply after it is linked to the primary grid.

Power generation from the PV system will fluctuate and be erratic, which will lead to unstable output power and, to a certain extent, affect the system's ability to reliably supply power. Increase the difficulty of traditional power generation and operation planning, and increase the difficulty of control of section exchange power. The site selection, configuration capacity, and connection to the grid of PV power plants, as well as the removal of faulty PV cell components, will also affect the reliability of the system. When more PV power production systems are placed into operation, the dynamic stability of the system may be affected when the capacity for power generation increases in proportion. The number of power points in the extensive grid has significantly expanded since the system was connected to the public grid. The power points are scattered and the scale of a single point is small, which significantly increases the difficulty of coordinated power control. Conventional reactive power scheduling and voltage control strategies are difficult to adapt to. It may have a certain impact on power grid peak regulation, safety backup, voltage stability, frequency safety, stability, etc. Increase the difficulty of large power grid operation control. Therefore, the adjustment and control

capabilities of the original conventional power supply to the operation of the enormous power grid are weakened after the large-scale connection of the Photovoltaic arrays to the public power grid, which creates new issues for the control of the safe and stable operation of the large power grid.

4. Solutions to Impact on the Integrated PV System

4.1. Solutions for Improving Power Quality

To increase the efficiency of the integrated device, raise the quality of the integrated PV system's electricity, and maximize its financial returns. Two control strategies for PV-integrated inverters were put forth in the reference [6] and were based on the current detection method and the notion of instantaneous reactive power. In addition to improving power quality, it realizes the flexible combination of inverter-integrated power generation, dynamic reactive power compensation, and active filtering. Since the DC side lacks a system for storing electricity, the reference [7] is directed at the unified power quality regulator, which is typically unable to make up for the load's power interruption. The alternating day and night of sunlight cause the PV-integrated power generation device to only work intermittently, thus affecting the utilization efficiency of the equipment. Due to the shortcomings of the energy system's regular operation, a new unified power quality regulator structure and control strategy are proposed, which can simultaneously achieve comprehensive power quality management, PV-integrated power generation, and power interruption compensation.

Harmonics: The following two factors serve as the primary means of control:

- 1) The inverter uses an active power factor adjustment circuit and a harmonic suppression circuit to deal with higher harmonics.
- 2) Processing of incoming high-order harmonics and distortion currents at the power supply equipment side.

The existing methods for suppressing harmonics of integrated inverters mainly include the group control technology method and the comprehensive compensation control method. The monitoring and analysis of harmonic parameters are effectively realized by the method of the Windowed Difference Radix 2FFT Algorithm which is mentioned in the reference [8] This method is also used to detect and analyze the harmonics of the PV integrated model.

In addition, the country has also set a series of standards for the harm caused by harmonics. For instance, the harmonic current component (RMS) of the connected public integration points should meet the requirements of GB/T14549-1993 "Power Quality Shared Power Grid Harmonics" Regulation, according to the national grid company of China's PV solar energy system access system technical regulations and distributed power grid access technical regulations[9].

The centralized integrated PV system is typically situated in isolated desert regions, necessitating a step-up transformer connected to the grid at medium or high voltage. In accordance with the applicable State Grid Corporation of China rules: Distributed power sources greater than 8MW should be dispatched. Therefore, large-scale PV stations should also be equipped with corresponding secondary equipment like ordinary power plants. Large-scale centralized PV systems should include a specific amount of reactive power adjustment equipment because the power factor of PV is close to 1.

4.2. Anti-islanding Effect Strategy

Power failures must be detected in order to have the anti-islanding effect, and the quicker the discovery, the better the result. Both passive and active detection techniques are frequently used. The grid voltage's frequency and phase are continuously detected using the passive detection technique. Judging whether the power grid is out of power by frequency and phase anomalies. The passive detection approach benefits from straightforward concepts, straightforward use, and no harmonic impact on the power supply. However, in the situation of load matching, passive islanding detection techniques are insufficient to identify islanding. To this end, active detection methods must be used. The active detection method is to send out interference signals to the power grid parameters in real-

time and to judge whether the power grid is out of power by detecting the feedback signal. Active Frequency Drift, Active Frequency Drift with Positive Feedback [10], and Slip Mode frequency Shift are the three basic active detection techniques. The theory behind the active detection method is to add a few power disruptions, and these disruptions will reduce the system's output power quality.

The reference [11] Proposes a new type of over/under voltage and power disturbance method. The precise approach involves measuring the voltage amplitude and frequency at the point where the inverter connects to the grid in order to determine whether the islanding effect is there. At the same time, to prevent the misjudgment phenomenon caused by the load dead zone in the islanding detection, an active islanding detection method is adopted in the experiment. That is, the power disturbance is introduced to reduce the occurrence of the misjudgment phenomenon. The reference [12] Proposes a method combining the improved 2N periodic perturbation method and the key electric quantity detection method based on AFD offset. The technique can successfully shrink the non-detection zone and increase the accuracy of island detection in the zone of detection. The detection technique and parameter optimization of a single inverter are the major topics of the reference [13] on the current anti-islanding research of PV inverters. The mutual influence between AFD and AFDPF in the multi-level integrated working mode and the variation law of the islanding detection blind area is deeply analyzed by using the phase principle of islanding detection and the blind space theory in the coordinate system of load quality factor and resonant frequency. The relationship between islanding detection reliability and working conditions under multi-machine integration is revealed.

4.3. Enhance Grid Stability and Reliability

Due to the reliability and stability difficulties the PV system connected to the main network has caused, research has been done both nationally and globally. Strong unpredictability is a feature of PV power generation, hence a model for PV power generating reliability must be developed in order to measure reliability. In the references [14], several appropriate dependability calculation models have been put out. Analysis of the impact on system stability is becoming more and more crucial as PV-integrated systems become more and more integrated into the power grid. In this regard, the reference [15] uses PSS/E to analyze the stability problems brought by the PV-integrated system after it is connected to the system. The source [16] discusses the "penetration rate" of grid-connected solar power generating systems and the potential effects of a "high penetration rate" on the electrical grid. The reference [17] analyzes the influence of enormous photovoltaic arrays integration into the grid on oscillation stability. The dispersed penetration of the photovoltaic arrays into the electricity grid is noted as being more advantageous for the oscillation stability of the system than the centralized integration. In addition, the reference [18] proposes the removal conditions of faulty PV modules based on the influence of faulty modules on the overall output of PV power plants. However, it does not consider the withstand voltage of PV cell modules and the influence of the location distribution of faulty modules. The reference [19] suggests a connection between the reactive power released by the solar photovoltaic plant, the access point's voltage, and the PV power station's fault characteristics. To suggest the cut-off circumstances for the PV cell components, solve the reactive power of the PV power station and the grid's power flow. Given the stability problems that may be caused when the PV system is put into operation in large quantities, the reference [20] discusses the use of battery energy storage, load transfer, to lessen the power fluctuation issue brought on by the centralized PV integrated system's technologies, and operation below the maximum power output point, were contrasted. In addition, the fluctuation of high-power sources can also be controlled through flexible AC transmission technology, high-voltage DC transmission, and energy storage technology, which can ensure system stability and power quality. Hydro storage with pumps, battery energy storage, and storage of compressed air energy are the three primary types of energy storage device technologies. Among them, the way of energy storage battery is the most used. To enable continuous and balanced power transmission of PV power generation, the capacity of the battery for storing energy and the power generation of solar energy and wind turbines are usually equipped with more than 1. That is, when the power generation power is 1KW, the capacity of the energy storage battery needs to be

greater than 1KW·h. However, large-scale PV power stations are limited by investment, and generally do not have power storage facilities. The size and direction of its transmission power vary greatly between day and night, which can be solved by selecting an on-load voltage regulating transformer.

5. Conclusion

PV-integrated power generation will cause problems such as reliability, quality of power, stable power, and the islanding effect of the power grid system. These problems are mainly caused by the random output characteristics of PV power generation. This paper expounds on the above problems and solutions to a certain extent, but there is still a lack of corresponding research and experimental verification methods, and the understanding of the mechanism of PV systems affecting large power grids still needs to be deepened. It is essential to improve the theory and method of fresh electric distribution system planning including PV power generation and other new energy sources. The current power grid operation control theory and technology cannot fully meet the new requirements after the massive integration of photovoltaic energy production. This paper proposes that all circles should increase their efforts to support the research on the massive integration of photovoltaic energy production. Create favorable conditions for actively exploring possible problems and actively researching countermeasures. To guide and standardize the orderly development of PV systems, take advantage of renewable energy. Do not interfere with the major power grid's ability to operate safely and reliably, realize the coordinated development of the large power grid, and distributed renewable energy power generation such as photovoltaic energy production. All in all, the PV industry, as an emerging industry, is continuing to develop rapidly. With the advancement of PV technology in the industry and the active guidance of macro-control policies of various countries, as well as international support, the PV industry will be a global environment-friendly, safe, and long-term recyclable energy source.

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