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Research on anti-islanding detection technology strategy

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Abstract: In recent years, the conditions and environment of China's economic development have undergone or are about to undergo many major changes. At the same time, China's electricity consumption ranks the first in the world with a huge volume and a considerable annual net increment. It is necessary to dialectically understand the profound impact of the new normal of economic development on the growth of China's electricity demand. Faced with the ever-increasing power demand, the power industry is still heavy to ensure steady supply, and the proportion of power consumption will also gradually increase. The central position of power in the energy field is gradually promoted, and the power security guarantee has gradually become one of the core elements of the new energy security strategy: in the actual operation of the power grid, there will be some unstable operation, and the local power grid accident can easily expand into a large-scale blackout. This will not only threaten the daily consumption of electricity, but also affect the national economy to a certain extent. The proposed distributed generation system solves this problem, but it also brings new problems. The appearance of island effect brings more harm to power grid operation. Aiming at the harm of island effect, this paper puts forward the detection technology strategy of related island effect.

Keywords: Anti-islanding; Detection technology; AFD; Detection method.

1. Definition and research significance of island effect

The so-called island effect refers to the distributed grid-connected power generation system of various users when the power supply of the power company jumps off due to fault accidents or power outage maintenance. (Such as: photovoltaic power generation, wind power generation, fuel cell power generation, etc.) Isolated island effect is a unique phenomenon of grid-connected power generation system, which has considerable harm. It will not only harm the whole distribution system and the user's equipment, but also cause the life safety of the transmission line maintenance personnel [1].

The research on islanding effect can be divided into two kinds: anti-islanding effect and utilization islanding effect.

Table 1. IEEEStd.1574 Allowed island effect detection times

state	Voltage amplitude after grid tripping	Voltage frequency after grid tripping	Allowable detection time/s
A	0.5Vn②	fn③	0.16
B	0.5Vn≤V≤0.88Vn	fn	2
C	0.5Vn<V<0.88Vn	fn	1
D	1.2Vn≤V	fn	0.16
E	Vn	f<fn-0.7Hz	0.16
F	Vn	f>fn+0.5Hz	0.16

The above table is applicable to power generation units with rated power ≤30KW. For power generation units with rated power >30KW, the range of voltage and frequency and the detection time of island effect are field adjustable

V refers to the rated value of grid voltage amplitude. For single-phase mains in China, it is AC 220VAC.f refers to the rated value of grid voltage frequency. For single-phase mains in China, it is 50Hz.

2. Mechanism, cause and harm of island effect

2.1. Mechanism and causes

The photovoltaic grid-connected system is connected to the local load and connected to the power distribution network through the gate switch. Its topology is shown in Figure 1. When the power grid is cut off, an island is formed.

Islanding can be the result of one or more of the following [2]:

(1) The power grid detects a fault, leading to the switch on the grid side jumping, but the distributed generation device does not detect the fault and continues to operate

(2) Accidental interruption of normal power supply due to failure of power grid equipment;

(3) Power supply interruption caused by network maintenance;

(4) Staff's mis operation or deliberate destruction;

(5) Natural disasters.

Figure 2 is the power diagram of the grid-connected photovoltaic power generation system. The inverter works in the sine wave control mode of unit power factor, and the local load is represented by a parallel RLC circuit.

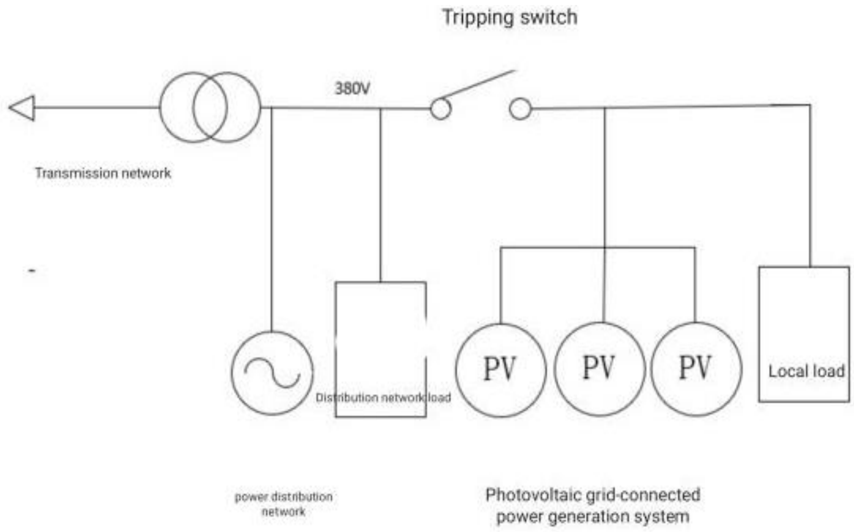

Figure 1. Grid topology for island problem study

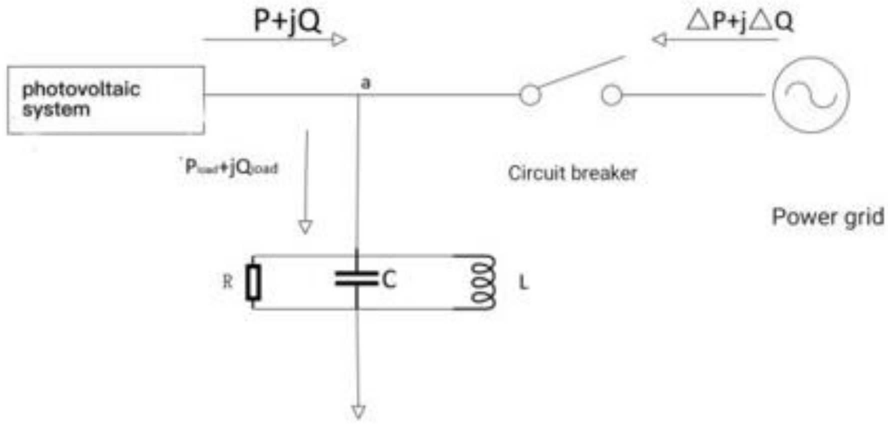

Figure 2. Schematic diagram of grid-connected power of photovoltaic power generation system

When the power grid runs normally, the active power and reactive power provided by the inverter to the load are P and Q, the active power and reactive power provided by the grid to the load are △P and △Q,namely Pload=P, Qload=Q, then when the switch K on the network side jumps due to line maintenance or fault, the voltage and frequency of the common coupling point a will not change much, and the inverter will continue to supply power to the load. The formation of photovoltaic grid-connected power generation system and the surrounding load constitute a self-powered island.After the island system is formed, the voltage va(instantaneous value) at point a is determined by the Ohm's law response of the RLC load and monitored by the inverter control system[3]. At the same time, in order to keep the output current i synchronized with the terminal voltage (Va), the inverter will drive the frequency of i to change until the phase difference between i and va is 0, that is, the frequency of i reaches a (and only) steady-state value, that is, the inevitable result of the resonant frequency f0, Qload=Q of the load. The reactive power balance relationship formed by grid tripping can be described by the phase balance relationship, that is, θload+θinv=0, where θinv is the phase Angle of the inverter output current ahead of the terminal voltage determined by the adopted anti-island scheme, θload is the load impedance Angle, in the case of parallel RLC load, θload=tan-1[R((ωL)-1-ωC)].

Therefore, the sufficient and necessary conditions for the occurrence of island effect are as follows:

(1) The active power provided by the photovoltaic grid-connected power generation device matches the active power of the load

(2) The reactive power provided by the photovoltaic grid-connected power generation device matches the reactive power of the load, that is, the phase balance relationship is satisfied: θload+θinv=0.

2.2. Harmfulness

After the occurrence of hazardous island phenomenon, voltage fluctuations, frequency fluctuations and harmonics may occur at the same time, or none of them may occur. The following problems will arise when the island is generated [4]:

(1) If the operation is non-three-phase, there is a large harmonic content and the frequency is unstable, the island phenomenon will be expanded.

(2) The voltage phasor of the island will drift relative to the main network, which may interfere with reclosing when the grid recovers quickly.

(3) If the island phenomenon is not eliminated before reclosing, it will lead to asynchronous grid connection. When the island voltage is connected to the grid at the same time that the grid voltage phasor is different, a large current will be generated at the interface, resulting in damage to the inverter.

(4) It will cause safety hazards to personnel conducting maintenance work in isolated island power grid.

(5) The three-phase load may be supplied by the single-phase grid-connected system, which will cause the three-phase load to operate without phase and cause harm.

3. Anti-island detection strategy

Isolated island effect is a unique phenomenon of grid-connected power generation system, which has considerable harm. It will not only harm the whole distribution system and the user's equipment, but also cause the life safety of the transmission line maintenance personnel. Therefore, it is very important to solve the island problem and we should seek effective ways to prevent the island effect. Islanding detection technology can be divided into active detection, passive detection and grid detection in grid-connected inverters. Passive detection has no interference on the power grid and no influence on the output power quality; However, when the load matches the output power of the inverter, there is a large detection blind area. And the detection time is long, need to combine with the active detection [5].

Island effect detection is one of the indispensable protection detection methods for grid-connected inverters. Detection of isolated island is an important factor to be considered in the safety of grid connection. It is very important to adopt appropriate and effective detection methods. In this section, various anti-islanding strategies are analyzed, and active frequency drift method (AFD) is selected as the anti-islanding detection scheme of this project.

3.1. Passive detection method

The passive method uses the voltage, frequency, phase or harmonic change of the inverter output terminal when the power grid is cut off to detect the island effect. However, when the output power of photovoltaic system is balanced with the local load power, the passive detection method will lose the detection ability of island effect, and there is a large non-detection zone (NDZ). The passive anti-islanding scheme of grid-connected inverters does not require additional hardware circuits or separate protective relays [6].

(1) Over/under voltage, over/under frequency detection scheme

All grid-connected inverters should adopt over/under voltage, over/under frequency protection scheme. Often when the remote switch trips due to fault or maintenance, if the output power (active power, reactive power) of grid-connected inverter does not match the load demand power, that is, $\triangle P \neq 0$ and $\triangle Q \neq 0$, the voltage or frequency will be offset. Once it exceeds the normal range, At this time, the over (under) voltage protection setting point and over (under) frequency protection setting point of the grid voltage stipulated by the software and hardware of the system can be used for detection. When the local switch is tripped (that is, the grid-connected switch of the inverter), the inverter will stop running, so as to prevent the generation of the island. However, when the load matches the output power of the photovoltaic system or $\triangle P$ is very small, the protection circuit cannot detect the occurrence of the island because the voltage fluctuation is small and does not exceed the normal range. When the inverter is working, the working range of voltage and frequency should be set reasonably to allow the normal fluctuation of the grid voltage and frequency [7]. Generally, for the 220V and 50Hz power grids, the working range of voltage and frequency is $194V \leq V \leq 242V$ and $49.5Hz \leq f \leq 50.5Hz$ respectively.

This method is simple, easy to implement and low cost. Its function is not only limited to detecting the island effect, but also can be used to protect user equipment. Other anti-island schemes that generate abnormal voltage or frequency also rely on over/under voltage and over/under frequency protection schemes to trigger the grid-connected inverter to stop working. However, there is a large non-detection area, and the response time of this scheme is unpredictable.

(2) Phase jump detection scheme

The phase jump scheme detects the island effect by monitoring the phase difference between the terminal voltage and the output current of the grid-connected inverter. In order to realize the operation of unit power factor, normally the grid-connected inverter always controls its output current to be in the same phase as the grid voltage. The sudden change of the phase difference between the grid-connected inverter terminal voltage and the output current means that the main grid trip and can no longer maintain the grid-connected inverter terminal voltage. The phase of the terminal voltage has jumped to the impedance Angle of the load [8].

After the power grid is cut off, that is, island occurs. The voltage at point a will depend on the product of the output current and load of the photovoltaic power generation system. Because the frequency and phase of the output current of the photovoltaic power generation system are controlled by the phase-locked loop, the current and voltage are synchronized only at the voltage crossing point, and outside the crossing point, the current frequency and phase are determined by the sinusoidal table inside the system, and the current waveform is sinusoidal wave. As shown in Figure 3, before the power failure, the phase difference between the current and voltage at the zero-crossing point is zero. After power failure, isolated island occurs. As the current is a sinusoidal wave with constant frequency and phase, if the load is inductive, the voltage will advance ahead of the current, resulting in sudden voltage phase change. Similarly, capacitive load will also lead to voltage phase mutation. Therefore, by detecting the magnitude of the phase difference between voltage and current, the occurrence of island can be judged.

However, it is difficult for this scheme to choose the threshold value that will not lead to mis operation. If the closing value is set too low, it will lead to false tripping of grid-connected inverter. When the load impedance Angle is close to zero, that is, the load is approximately resistive, the method fails due to the limitation of the set threshold.

Voltage harmonic detection scheme

The principle of voltage harmonic detection scheme is that the grid-connected inverter monitors the totalharmonicdistortion (THD) of voltage va. If THD exceeds the range, the grid-connected inverter stops running.

As shown in Figure 2, when the PV power generation system is connected to the grid, its output current harmonics will flow into the grid through the common coupling point a. Since the network impedance of the power grid is very small, the total harmonic distortion rate of the voltage at point a is usually low. Generally, the THD of va at this time is always lower than the threshold value (THD of grid-connected inverters is generally required to be less than 5% of the rated current).

After the power grid is disconnected, the PV power generation system output current harmonics into the load. Because the harmonic current and load impedance generated by grid-connected inverter are usually much larger than the grid impedance, so the voltage at point a (the product of harmonic current and load impedance) will produce a large harmonic, so it can be determined whether the PV system is in an isolated state by detecting voltage harmonics or harmonic changes.

Theoretically, the voltage harmonic detection scheme can detect the island effect in a large range, without dilution effect when the system is connected with multiple inverters, and the island effect can be detected even in the case of power matching. However, in practical application, due to the existence of nonlinear load and other factors, the power grid voltage harmonics are large, and the action threshold of harmonic detection is not easy to determine, so this method has limitations.

3.2. Active Detection Method

The active island detection method means that the output power, frequency or phase of the inverter is disturbed by controlling it. When the power grid is working normally, these disturbances cannot be detected due to the balancing effect of the power grid. Once the power grid fails. The disturbance of the inverter output will accumulate rapidly and exceed the allowable range, thus triggering the island effect detection circuit. This method has high detection accuracy and small non-detection area, but the control is more complex, and the quality of the output power of the inverter is reduced. At present, the anti-islanding strategies of grid-connected inverters are combined with passive detection scheme and an active detection scheme [9].

(1) Output power perturbation method

The principle of output power perturbation method is that the inverter through the output current perturbation, so that its output power changes, and then the output voltage changes. The active current perturbation method is essentially an output power perturbation method. In the case of no current perturbation, the output current of the inverter is controlled to follow the given signal vg (generally the signal of the power grid or the sine of the same frequency and phase with the power grid). At this time, iinv=vg. When the interference signal is added, the reference signal of the current is the difference between sinusoidal signal vg and interference signal vgi, then iinv=vgd= vg-VG. In the grid-connected case, if the output of the inverter matches the power consumed by the load, the voltage at point a does not change when the power grid is cut off without adding disturbance, which will lead to the occurrence of isolated island. In the case of adding current disturbance, the voltage at point a depends on the output current of the inverter and the local load when the grid is cut off.

(2) The main advantage of this scheme is that the undetectable area is very small for a single grid-connected inverter whose local load impedance is greater than that of the grid. If the load matches the output power of the grid-connected inverter during grid tripping, the output variation scheme will interfere with the matching condition and lead to undervoltage protection.It will not inject harmonics into the power grid, but it will affect the output power of the inverter, but also produce dilution effect, and the influence is greater when the number of grid-connected inverters increases in local areas. This means that the output variation scheme is only applicable to the small system of a single grid-connected inverter, and cannot work effectively in the small system of multiple grid-connected inverters or the large system of a single grid-connected inverter.

(3) Reactive power compensation detection method

Reactive power compensation detection method is also an output power disturbance scheme, using adjustable reactive power output to achieve island detection. When the system is connected to the grid, the load terminal voltage is clamped by the grid voltage, and is basically not affected by the reactive power output of the inverter. When the system enters the island state, once the reactive power output of the inverter does not match the load demand, the load voltage amplitude or frequency will change. Because the inverter output reactive current can be adjusted, and the load reactive demand is constant under certain voltage amplitude and frequency conditions, the inverter output set as partial reactive power compensation or wave compensation to the load can avoid the reactive power balance of the system under the island condition, so as to make the load voltage or frequency continuously change to reach the detectable threshold, and finally determine the existence of the island.

(4) Sliding mode frequency shift detection method

Sliding mode frequency shift detection is a scheme that applies positive feedback to the phase of the output current-voltage of grid-connected inverter to make the phase offset and then the frequency offsetThe frequency of the grid is not affected by the feedback.

In this scheme, the phase of the output current of grid-connected inverter is defined as the function of the deviation between the frequency f of the previous cycle and the frequency fg of the grid, i.e

(5) Active Frequency drift detection (AFD)

AFD is a common detection method of output frequency disturbance island effect. Working principle of AFD method:

By controlling the inverter, the system makes a certain error △f between the frequency of the output voltage finv and that of the grid voltage (within the allowable range of the grid connection standard); When the power grid works normally, the inverter will work normally in a small range due to the corrective action of the phase-locked loop circuit. In the next power frequency cycle of the inverter, the system will take the finv as the baseline, and then add the set frequency error △f to control the finv, resulting in further increase of △f. This process is repeated until the finv exceeds the requirements of the grid connection standard, and the island protection action is performed. Figure 3 shows the control schematic diagram.

However, for parallel RLC loads, AFDs have detection blind spots. Set load impedance Angle <0, that is, the load is resistively capacitive. In the KTH cycle after the island occurs, if the hysteresis of the load impedance Angle and the advance action of △f cancel out, and the frequency and voltage do not exceed the preset threshold. Then, the system will not be able to detect the island occurring. Similarly, for the negative frequency offset and >0, there will be a similar problem. In order to avoid the decrease of the effect of ADF detection method due to the load properties, the inverter output voltage can be periodically and continuously disturbed in both positive and negative directions to eliminate the balancing effect of the load properties on the direction of a single frequency disturbance.

FIG. 4 shows the control principle of the improved AFD island detection scheme. In the figure, cf1 and cf 2 -- two disturbance signals in different directions; cf1 = 5%, cf2 = -5%; △f 1, △f 2 -- error between fi and f g after the perturbation signal is applied. The grid-connected inverter based on DSP control is easy to implement the scheme. Although AFD can reduce the non-detection area of island effect, the current harmonics introduced by this method will reduce the output power quality of PV system. In addition, when multiple PV systems are connected to the grid, if the frequency shift direction is not consistent, their effects will cancel each other.

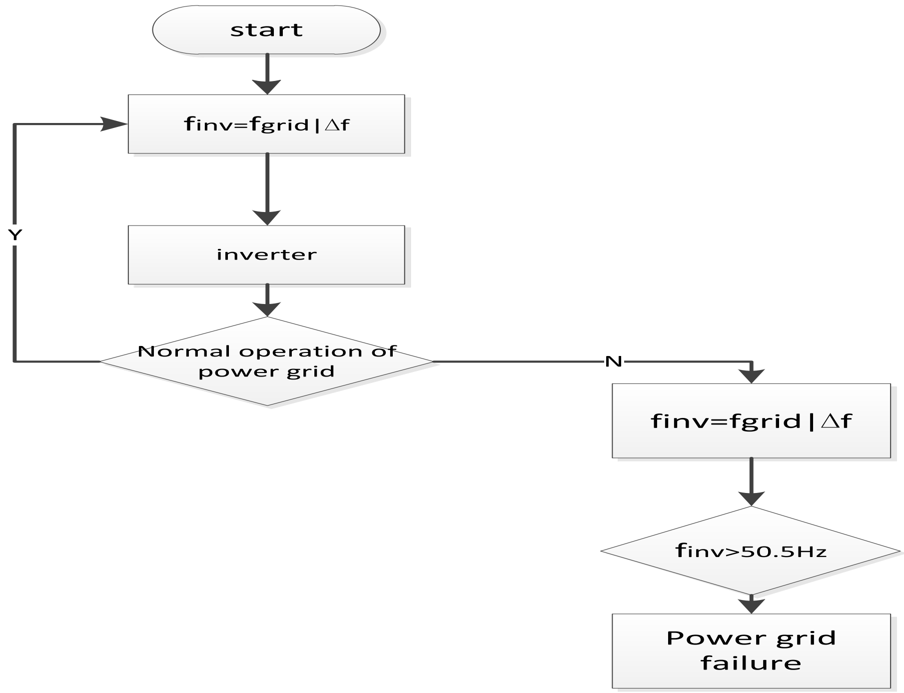

Figure 3. Control principle of AFD island detection method

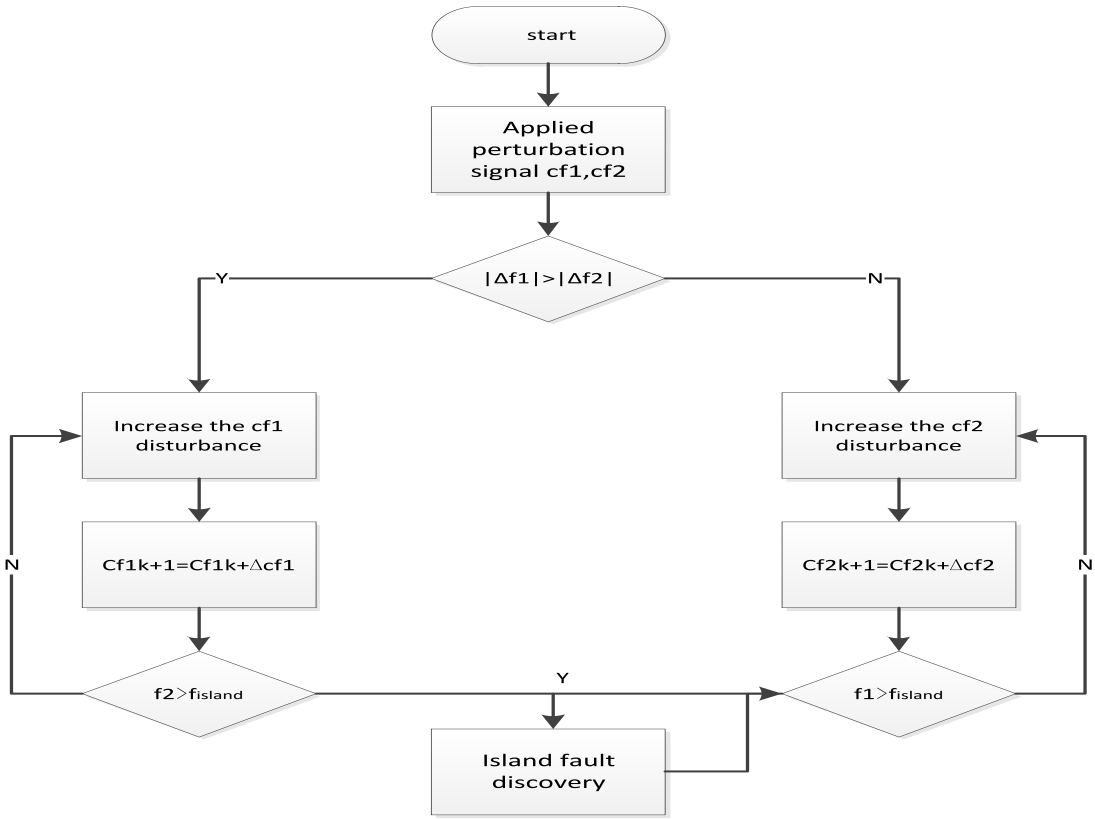

Figure 4. Detection method of periodic disturbance island effect

(6) Frequency jump detection

Frequency jump detection is a modification of the active frequency shift detection method, in which dead zones are inserted into the output current waveform in a preset pattern, but not every cycle, but every few cycles. When the grid is connected, frequency hopping causes the output current of the grid-connected inverter to be iinv, occasionally distorted, but the grid controls the voltage waveform of the va. After grid tripping, the frequency hopping scheme can prohibit the island effect by driving the frequency shift as in the active frequency shift scheme, or it can detect the island effect by detecting the frequency of the voltage va consistent with the output current waveform of the grid-connected inverter.

When a single grid-connected inverter adopts the frequency hopping scheme, the scheme has relatively effective island detection performance if sufficiently complex current wave shape is adopted. This scheme, like impedance measurement and active frequency shift schemes, has dilution effects in systems with multiple grid-connected inverters, unless the current waveform changes synchronizes.

(7) Voltage feedforward positive feedback disturbance detection method

In this detection method, the voltage of point a is fed forward, and the output is taken as the given current amplitude disturbance after a preset algorithm.

Set it to the default value every other cycle; When isolated island occurs, the positive feedback effects of peak voltage at point a and peak voltage of power grid U m under different conditions are analyzed as follows:

U a > Um If an island occurs at time t, the peak current will increase in the next period because U a = Um. As a result of positive feedback, the voltage at point A keeps rising. When the voltage peak exceeds the preset threshold, the system will detect the occurrence of the island. If △U works, that is, △U changes from 0 to U d, which further increases the voltage at point a until it exceeds the preset voltage threshold.

U a < Um If an island occurs at time t, the peak current will decrease in the next period because U a < Um. As a result of positive feedback, the voltage at point A continues to drop. When the voltage peak exceeds the preset threshold, the system will detect the occurrence of the island. If △U works, that is, △U changes from 0 to △U d, further reducing the voltage at point a until it exceeds the preset voltage threshold.

U a = Um It is assumed that an island occurs at time t. Due to the voltage equilibrium state, the PV system cannot detect the island. If △U acts every one cycle, i.e. △U =△Ud, the output current of PV system decreases, and then the peak value of voltage at point a is U a < Um, and the following working process is the same as U a < Um.

The grid-connected inverter based on DSP control is easy to implement the scheme, and the undetectable area is small. However, this scheme also has two shortcomings, one is that the positive feedback with gain slightly reduces the output power quality; Second, for the photovoltaic grid-connected inverter, the working efficiency of the inverter is reduced. Usually, the photovoltaic grid-connected inverter always controls its work at the maximum power point, but when this scheme is adopted, the small change of va amplitude will make the inverter reduce its power output, thus deviating from the maximum power point.

(8) The main monitoring unit equipped with a switching device connected in series is actually an automatic isolation device (ENS), which integrates a variety of island protection schemes. The automatic isolation device consists of two independent, parallel main monitoring units, each unit is equipped with a switching element connected in series, and the two switching elements are controlled separately. Each individual unit monitors the grid by continuously monitoring voltage, frequency, and impedance. The reliability of the scheme is improved by redundant design and automatic testing before each grid connection. The redundant design and periodic self-testing of grid-connected inverters at startup allow users to install the equipment without the need for periodic checks to determine if the anti-island circuit is still active, and it also has the advantage of an impedance measurement scheme. It is predictable that hundreds of devices connected to the same feed line will not interfere with each other. However, because ENS needs to determine impedance by injecting current pulses into the grid, it can also cause power quality degradation and some system problems. In a system connected with multiple grid-connected inverters, if the number of ENS connected to the same branch is large enough, it will eventually interfere with each other and lead to false tripping. Now most grid-connected inverters using this equipment need to adjust the time of current injection to reduce mutual interference. In addition, redundant designs and hardware circuits dedicated to detecting grid impedance add to the cost.

3.3. Anti-island detection method on the power grid side

(1) Impedance insertion detection method

Impedance insertion is done by installing a low-impedance element (usually a capacitor bank) within the area of the grid where an island effect can occur. In Figure 2-8, for example, a capacitor bank is connected at point b on the grid side by switching K, which usually jumps away. When grid side switch K1 jumps off, after a short delay, switch K closes and accesses the capacitor bank. If the local load matches the output power of the inverter before grid tripping, the additional large capacitance will break the state of energy balance, resulting in a sudden change in current-voltage phase and a sudden drop in frequency, triggering the underfrequency protection. The short delay between the switch K1 on the grid side and the capacitor bank switch K on is necessary, because the additional large capacitor may also compensate the inductive load, resulting in the power matching state and the failure of islanding effect detection. In this case, the inductive load is very large, and if the grid trips, a large frequency shift will occur before the capacitor bank is connected. The short delay will allow ample time for frequency changes to be detected. Another type of impedance such as a large resistance could theoretically be used, which would cause a sudden change in the voltage amplitude at node A. However, the use of capacitors has the function of reactive power compensation to the power grid [10].

(2) This scheme is very effective for the detection of island effect as long as an appropriate time delay is allowed between grid trip and capacitor bank insertion to ensure that capacitor bank insertion does not result in power balance between grid-connected inverter and load. In addition, the required capacitor banks are readily available and can be compensated for reactive power.

However, impedance insertion also has four serious disadvantages:

(1) The capacitor bank increases the cost, making the grid-connected inverter using this scheme economically unfeasible. Meanwhile, if the installation time of multiple grid-connected inverters in the system is different, it is impossible to determine who is responsible for the cost of the capacitor bank;

(2) There are multiple series switches in the power grid, all of which may lead to the occurrence of island effect, that is to say, island systems of different structures and forms may be formed, so each switch has to be equipped with a capacitor bank when adopting this scheme;

(3) Because the input of capacitor banks needs to be delayed, the response speed is slower than other schemes, which may not meet the requirements of the grid connection standard on the detection time;

(4) This scheme requires the capacitor bank to be installed on the grid side, which complicates the installation process, and this arrangement also has adverse effects on the grid.

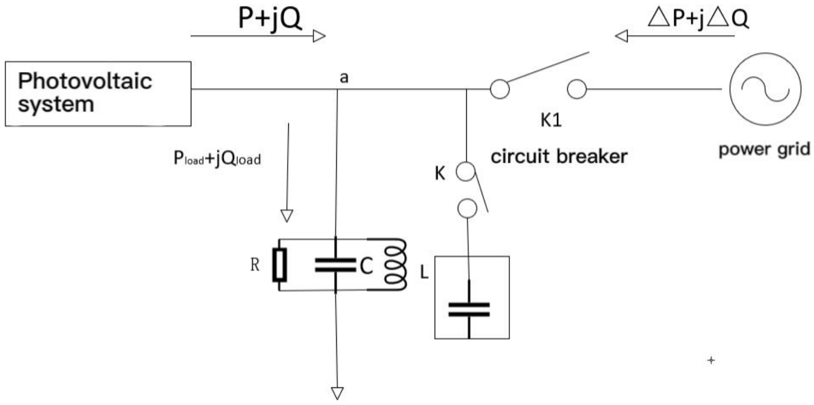

Figure 5. Impedance insertion scheme

4. Conclusion.

This paper mainly introduces the concept and harm of islanding effect, analyzes and discusses the mechanism, cause and harm of islanding effect, and puts forward three anti-islanding schemes, namely over/under voltage (over/under frequency) detection scheme, reactive power compensation detection method and grid side anti-islanding detection method. And to each kind of anti-islanding effect detection scheme is discussed and technical analysis, has certain reference significance for Everbright researchers.

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The research content of this project focuses on the characteristics of electric vehicles, multi-energy power integrated management and vehicle network interactive integration, integration and complementarity, establishing the system integration, integration and complementarity model of electric vehicles, smart grid and distributed power generation, and studying the interactive integration strategy of charging facilities and multi-energy smart grid. The energy scheduling integration mechanism of electric vehicles and multi-energy smart grid will be formulated;

3). Key Science and Technology Projects of Henan Province: Vehicle high-beam violation detection and Capturing system, Project No. 182102310784; The main research is the detection of high beam violation, computer recognition and the research and development of software and hardware system for capturing the relevant information of illegal vehicles;

4).Key science and technology projects of Henan Province: 222102240117, Research on fusion technology of electric vehicles, smart grid and distributed power generation: Research content around the electric car, distributed generation, energy storage, power grid interactive integration features, research targets in the safety management and economic operation of energy management and control strategy, set up the electric car with smart grid, a distributed power generation system integration security integration model, study the charging infrastructure and the safety of power grid and distributed generation fusion strategy; Formulate a security integration mechanism for electric vehicles, smart grid and distributed power generation in multiple scenarios.

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