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A Review of Islanding Detection Methods for Photovoltaic Generation System

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Abstract

Islanding phenomenon may be caused by power system fault. Therefore, islanding detection is the priority among priorities. Islanding detection is a prerequisite of two operating mode switching for Micro-Grid. Characteristics of methods of islanding detection are introduced in the paper. The advantages and disadvantages of these methods are analyzed and summarized in detail. In this way, the best detection result can be achieved by exploiting the advantage of each method. A reference for the choice of what kinds of detection methods in the practical application is provided, which has certain guiding significance. The future research will focus on the transition from interconnected to islanding and application of islanding operation in microgrid.

Keywords: *Micro-Grid, islanding detection, active detection, passive detection*

1. Introduction

Micro-Grid is a relatively new type of network structure and a simple system. It is composed of a set of micro power sources, load, energy storage system and the control unit. Micro-grid is a system that is able to achieve a self-protection, control, management and can run in isolation. It is grid-connected operation when the micro-grid-connected with external distribution network [1-2]. Micro-grid is a new concept relative to the traditional large power grid, which is refers to the number of distributed generation (DG) and its related load according to the topological structure of the network structure, then through the non-dynamic switch associated to the ordinary grid [3]. The development and expansion of micro grid can fully promote the distributed generation and renewable energy large-scale connected to the grid. It can realize various forms of energy and high reliability of supply to a load [2-6]. This is a kind of effective method for realizing active distribution network, and a form of traditional forms of power transition to the smart grid. They can support each other and improve the stability and reliability of power supply when the power grid and micro-grid in parallel [6-7].

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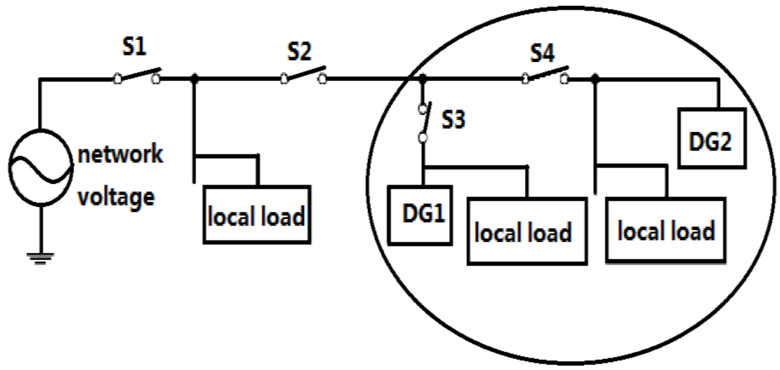

Figure 1. The Structure of Grid-Connected Distributed Generation Systems

For large power grid, if the scale of micro grid reaches to a certain extent, which can improve the economy of large power grid operation. Moreover, when the stability of large power grid is threatened by disturbance, distributed generation in micro grid can provides electric energy, frequency and voltage support for important load. Therefore, the reliability of power supply is improved. If the power quality cannot satisfy the needs of users or the power grid fault, micro-grid by grid-connected operation mode switching into islanded operation mode that ensure the reliability, stability and flexibility of regional power supply[5-6]. However, in the two mode of operation, control strategy of distributed power supply in the micro-grid used is different. Therefore, the transition of micro-grid by grid-connected operation mode to islanded operation mode must is stable. The key problem of micro-grid switching operation state is the islanding detection.

Islanding detection standards are not unified for all countries, and that brings a lot of troubles. IEEE specified standards are used in this paper. Table.1 is the IEEE on the islanding detection maximum time limit standard [7-8].

Table 1. IEEE std.929-2000/UL1741 on the Islanding Detection Time Limit [7-8]

state	Voltage Amplitude	Voltage Frequency	Allow maximum detection time
A	$0.5V_N$	f_N	6 cycles
B	$0.5V_N < V < 0.88V_N$	f_N	2 seconds
C	$0.88\ V_N \le V \le 1.10V_N$	f_N	proper functioning

D	$1.10V_N < V < 1.37\ V_N$	f_N	2 seconds
E	$1.37V_N \leq$ V	f_N	2 cycles
F	V_N	$f < f_N$ -0.7HZ	6 cycles
G	V_N	$f > f_N$ +0.5HZ	6 cycles

①Where V_N is a network voltage ratings, the amplitude of voltage ratings of power grid in China are AC 220V (effective value).

②Where f_N is the voltage frequency rating, voltage frequency of international rating is 60Hz, while it is 50Hz in China.

This paper focusing on islanding detection technology, analysis and summarizes the commonly used methods in detail, such as passive and active test methods in power quality and the advantages and disadvantages of detecting blind area, *etc.*

2. Micro-Grid Islanding and Its Harm

Micro-grid islanding phenomenon refers to the power grid stop power supply due to equipment failure, misoperation or natural factors. Distributed generation system failed to detect the state of power failure quickly and do not out of the grid, which is still supplying power to the load. Therefore, an island of self-power supply is formed and electric power company is unable to manage and control [9]. [10-12] proposed islanding operation mode must achieve the balance of power and load capacity. If (active power and reactive power) power is imbalance, the stability of voltage and frequency within the island will not be able to guarantee. Therefore, it also cannot be sustained and stable operation. From the mode of operation, the island is divided into planning and unscheduled island [13-18].

In order to maintain the stability of the isolated system, reasonable island area should be defined according to the total capacity of distributed power supply and the local load [14]. When the micro-grid and the main grid system is isolation, which does not require a large adjustment would be able to maintain a balanced and stable voltage and frequency within the power of the islands [15]. Such a pre-designated islands area is known as Intentional Island. In general, intentional islanding is supplement in Distributed Generation (DG) supply for large power grid. This can be used as an emergency means supply for the important user. The following is schematic diagram of the grid-connected inverter system [17].

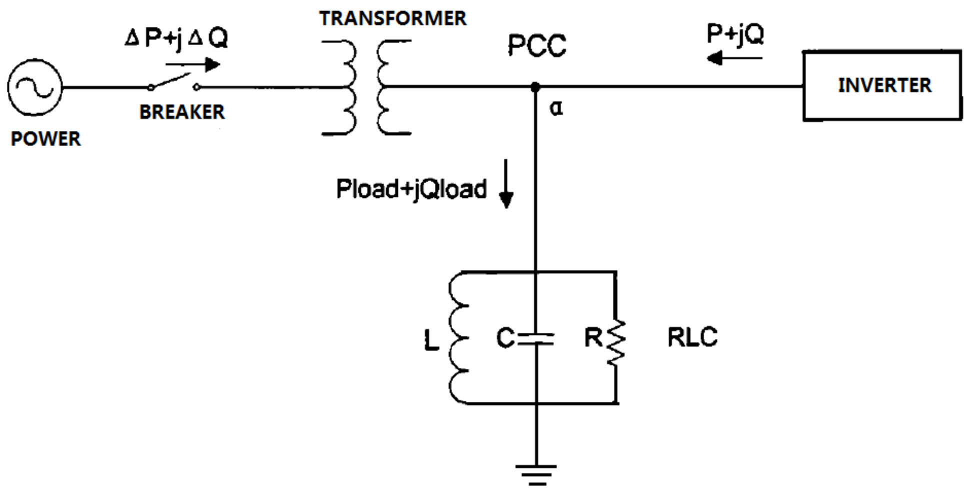

Figure 2. Schematic Diagram of the Grid-Connected Inverter System [7]

When grid-connected operation, power grid and inverter power supply at the point of common coupling (PCC) connection to provide load power. Therefore,

$$P_{Load} = P + \Delta P, Q_{Load} = Q + \Delta Q \quad (1)$$

$$P_{Load} = V_{PCC}{}^{2} / R \quad (2)$$

$$Q_{Load} = V_{PCC}\left(\frac{1}{\omega L} - \omega C\right) \quad (3)$$

Where, V_{PCC} is the Voltage at the point of common coupling, P、Q is active power, reactive power respective output by the inverter, P_{Load} , Q_{Load} is active power, reactive power respective consumed by the load, ΔP , ΔQ is active power, reactive power respective of power grid supply.

Further can be obtained:

$$\omega = \frac{1}{2\sqrt{LC}}\left(\sqrt{\left(\frac{Q_{load}}{Q_f P_{load}}\right)^2 + 4} - \frac{Q_{load}}{Q_f P_{load}}\right) \quad (4)$$

Where, $Q_f = R\sqrt{\frac{C}{L}}$ or $Q_f = \frac{1}{P}\sqrt{Q_L \times Q_C}$ is the quality factor of load [7-23].

After the generation of non-intentional islanding, the main system no longer provides energy to the island. The output power of inverter power supply will not immediately change, therefore, at the moment of the formation of isolated island, island inside will have a power shortage in generally. *i.e.* $\Delta P \neq 0$, $\Delta Q \neq 0$, and this leads to voltage and frequency change at the point of common coupling. According to formula

Non intentional islanding refers to the main distribution power system fault tripping or other reasons and Distributed Generation (DG) with operation load does not match. In general, after the DG and the main grid system separately, the power in the non-intentional islanding is unbalanced. If it continues to run for a long time, will inevitably leads to the imbalance of system voltage and frequency of the islands, DG and the load of electrical equipment around serious damage, eventually lead to a system crash. It causes serious damage to DG and its surrounding load and electrical equipment, eventually led to the collapse [23-24].

In addition, when the failure of the primary side of the main distribution power system, distribution power system side protection device tripping, DG in Non-intentional islanding system continues to provide short-circuit current to the point of failure. Therefore, the fault and insulation has been unable to return to normal. It will leads to the system focused on closing failure or distribution power network reconstruction cannot run correctly. Therefore, islanding protection devices need to be installed, and the non-intentional islanding control DG to exit from running [25].

When the distributed generation system in the micro grid in islanding operation state, it will produce a series of adverse effect. For example: Electricity equipment's of users is damaged; Personal safety of maintenance staff is menaced; A serious threat to security of the grid.

Islanding detection method is generally divided into two categories: Passive detection method and active detection method [14].

Article mainly analyzed and introduced the passive detection method and the active detection method. Active detection method is to control the inverter and makes its output power (p), frequency (f) or phase (ψ) exist certain disturbance. *i.e.* exist $p \pm \Delta p$, $f \pm \Delta f$, $\psi \pm \Delta \psi$ .When the normal work of power grid, due to the effect of balance of the power grid, which cannot detect the change of p 、 f 、and ψ . Once the power grid failure, the inverter output disturbance will be quickly accumulated and beyond the scope allowed so that triggering islanding detection circuit. High detection accuracy of the method and the non-detection area is small, but the control is more complex, moreover the quality of the output power of the inverter is reduced. The current anti islanding strategy of grid-connected inverter is generally used method of passive detection and active detection combined.

3. Several Methods Included in Active Detection Method and Its Advantages and Disadvantages

3.1. Active Frequency Drift (AFD)

AFD is a more common active disturbance detection method. The active frequency shift method has been used so that the frequency of the inverter output current slightly distortion. It can form a trend of continuous frequency change, which final result in the output voltage and current values exceed the limit of frequency protection value, so as to achieve the purpose of anti-islanding effect.

The advantages of this method: It can be quickly detected islanding within the stipulated time, higher output power quality, and meets the grid-connected standards.

The disadvantages of this method: AFD may affect the power factor of the output power, and brings harmonic pollution to power grid. It is only suitable for power waveform quality requirements are not high, has certain limitations.

3.2. Slip-Mode Frequency shift (SMS)

Reference [15] introduces a method of Slip-Mode Frequency Shift (SMS) that is a kind of active islanding detection method. It controls the output current of the inverter so that exist a phase difference between the voltage and the common point voltage.

When the network voltage loss, common point frequency deviation from the normal range, so as to detect islanding. In general, the inverter phase response curve in the vicinity of system frequency within the range of design. Unit power factor inverter phase changes faster than the RLC load increases. When the distribution network and the inverter parallel operation, distribution network enables the inverter to work stably under power frequency through the provision of fixed frequency and the reference phase angle. When the islanding was formed that if the inverter outputs voltage and frequency with small fluctuations, and the inverter phase responses curve with small changes in the inverter output voltage and frequency that make the phase error increasing obvious. It reached a new steady state. The frequency of the new state points will be beyond OFR/UFR action thresholds, inverter will shut down because of frequency error.

The advantages of this method: Only need little change in the basis of PLL of the original inverter and easier to achieve the following aspects: Its detection efficiency is high and small Non Detection Zone (NDZ); The detection efficiency without interference and effect of multi inverter parallel, simple and easy to implement, does not need additional hardware facilities, and high islanding detection reliability *etc.*

The disadvantages of this method: Due to the phase of the inverter output current needs to be revised, therefore, it will affect the output power quality. In the design to fully consider the output power quality and efficiency of detection; That method is based on the premise of external disturbance, and cannot predict the time required for DG system off the island after the occurrence; For resistive loads and the majority of the loads are most effective, but, if the tilt range of SMS curve is less than the load curve, and there may be a stable operating point in the OFRNFR action zone. It leads to an island missing detection, that is, as the quality factor of the load increases, which the possibility of islanding detection failure becomes large.

3.3. Alternate Current Disturbances (ACD)

References [16-17] put forward a method of ACD that is a kind of active islanding detection method. For the current source type inverter, every certain period decreases photovoltaic grid-connected inverter output current, then change the active power output [15-16]. When the inverter parallel operation, the output voltage is constant that is called the voltage of power grid. When the power supply is cut off, the output voltage of the inverter is determined by the load. When arriving at the moment of current disturbance, output current amplitude change and the load voltage change. When the voltage reaches the range of under-voltage can detect islanding occurs [15-19].

The advantages of this method: When the grid power failure, the inverter output voltage depending on the load, which is not affected by other factors and anti-interference ability. Detection is more accurate.

The disadvantages of this method: When the grid power failure, because the inverter output voltage is determined by the load, and the periodic current interference test detection range is limited, can only detect under-voltage, and has certain limitations.

3.4. Reactance Insertion (RI) Method

Reactance Insertion method [16] is relay with automatic switching capacitance or inductance, and the relay in the DG and local load near capacity matching. Change the system load impedance. When the electric power system fault, get the capacitance or inductance into relay, and damages the system balance with reactive power. By detect abnormal changes of voltage and frequency to determine whether the islanding.

The advantages of this method: If it insert the shunt impedance capacity is small and inserted into the short time, has little impact on the system; Capacitors or inductors were cheap and easy to obtain, and also can be achieved reactive compensation.

The disadvantages of this method: Capacitor or inductor group inputs increases the implementation and installation costs; Capacitor or inductor group takes time to input, delay, slow response times; The insertion of the load impedance may have a great impact on system and miscarriage of Justice; This point with anti-Islanding in contrary to the trend of development within the inverter.

3.5. Sandia Voltage Shift (SVS)

Reference [17] puts forward a method of Sandia Voltage Shift (SVS) that applying positive feedback for the inverter output current effective value or the active regulation. After losing power, public point voltage quickly deviation from the normal range, therefore, an island state can be detected. The inverter output current $I(k) = I(k-1) + A(U_a \cdot (k-1) - U_0)$, where, A is the gain of output current for testing point voltage error; U_0 is the rated power frequency voltage. When power grid normal operation, the voltage is conditioned by the grid will not change, and the current amplitude will not change. However, when Power off, due to the effect of positive feedback, the inverter output power and load power does not match, which causes the voltage changes can cause I upheaval, and causes the change of the U_a. However, the change of U_a causes I change, therefore, the loop until U_a beyond the threshold value, then UVR/OVR can detect islanding occurs [16-17].

The advantages of this method: This approach has little effect on normal operation of micro-grid power quality. When under the condition of many Distributed Electric Resource, the detection efficiency remains high; For the inverter power supply with micro controller, this method is easy to implement; By reasonable set the parameters of positive feedback control system, detection efficiency is very high: SVS, AFD, SFS, and SMS using frequency detection method is very efficient and has a very small NDZ.

The disadvantages of this method: For a weak system, Sandia method of voltage deviation of inverters cannot be used too much, which will impact negatively on the transient response and power quality; The normal operation of the power grid and the network voltage is not constant that may makes the inverter power departure from the rated working point. If the transmission power is too large and long-term operation will damage the inverter in the condition and reduce the service life.

3.6. Output Power Perturbation (OPP) Method

Output Power Perturbation is by periodically added perturbation in the active power P or reactive power Q of inverter output. When the power off and the disturbance is large enough, which will makes the frequency or common coupling point voltage changed obviously, then detect islanding [16].

3.6.1. Active Disturbance Detection (ADD) Method

References [17-18] introduce the method of Active Disturbance Detection that exists of intermittent disturbances to current amplitude of the inverter output so that the active power output change. When the normal operation of the distribution network, the inverter output voltage constant is the network voltage and load required power will be obtained from the grid; When the micro grid power off, inverter output voltage is determined by the load. Once, at the moment of disturbance, output current amplitude and the load voltage changes, the islanding can be detected.

The advantages of this method: It is simple controls, easy to operate and achieve; Requirements of sensor accuracy is not high; Do not need to add additional hardware costs; NDZ is very small to the single inverter of load impedance is greater than the grid impedance,

The disadvantages of this method: when many grid-connected inverters, the detection precision will be affected by the disturbance is not synchronous. Output power variation is very large, and this may causes voltage flicker and grid unstable.

4. Several Methods Included in Passive Detection Method and the Advantages or Disadvantages

Passive detection method detects of inverter output voltage amplitude, frequency, phase and harmonic is abnormal or normal to judge whether the islanding at the power grid power off [18-19].

The advantages of this method: The control strategy of grid-connected inverter needs to detect the terminal voltage so that this method does not need to add additional hardware circuit or independent protection relay; It will not produces interference to grid and the power quality will not be lowered; Under the condition of more than one inverter did not reduce the detection efficiency.

The disadvantages of this method: There is a big Non Detection Zone (NDZ); it is difficult to set the threshold value, which not only higher than that of normal run-time values but also less than the value of the island. In order to reduce NDZ, improved the sensitivity of the device is one way, but it will causes trouble free trip and affect the normal operation of the system; In some special cases, there is great range of NDZ: This method cannot be directly measured some parameters, which requires complex calculations to get results, moreover, the calculation time and calculation error will have a certain impact on the detection results. Passive detection methods are usually combined with active detection methods, and applicable occasions including the output power of inverter does not matching, and the load frequency does not change significantly.

4.1. Over / Under Voltage and Over / Under Frequency Detection Methods

Over / under voltage and over / under frequency detection methods are some detection ways of stop grid-connected inverter operation when the amplitude of voltage and frequency at the point of common coupling exceed the normal range [18-19]. A reasonable range of voltage and frequency should be determined when the inverter working. The normal fluctuation of network voltage and frequency are allowed. In general, the network voltage is 220V, and the frequency is 50Hz. The range of voltage and frequency is $194V \leqslant V \leqslant 242V$、$49.5Hz \leqslant f \leqslant 50.5Hz$. If the deviant of voltage or frequency reaches to the threshold of islanding detection set, which can detects the islanding occurs. However, when the local load of inverter and its output power close to matching, the deviant of voltage and frequency will be very small or even zero, therefore, the method exists of NDZ. The economy of this method is better. However, because of the larger NDZ, therefore, it is not up to the purpose only to use the OVR/UVR and OFR/UFR islanding detections [18-22].

The advantages of this method: The principle of the method is simple and easy to realize, the economy is best, and does not influence the quality of electric energy. It can be achieved only by existing detection parameters without any additional hardware circuit to judge the islanding.

The disadvantages of this method: When the active power and reactive power are small from power grid or power grid off, the change of voltage and frequency are not obvious at PCC. These changes could not start the OVR/UVR and OFR/UFR therefore, islanding detection failed; In order to prevent misoperation from normal voltage and frequency fluctuations, four kinds of protective threshold value cannot be set too low, which leads to the existence of large NDZ; This method is generally not used alone. It is necessary to combine with other detection methods.

4.2. Harmonics Detection (HD) Method

Harmonics detection method [19] through monitoring the Total Harmonic Distortion (THD) of testing point voltage to determining whether an islanding states. When normal parallel operation, impedance of power grid is small, the inverter output current harmonic is mainly flow into the grid. The voltage of point of common coupling is decided by the voltage of power grid. Usually voltage harmonic content is small. When the power supply is cut off, due to the non-linear characteristics of transformer hysteresis output current produces distortion voltage in transformer; Non-linear load harmonic current flowing into the inverter will also have a large harmonic. Whether an island is occurred can be judged by detection the harmonic distortion of the output voltage.

The advantages of this method: This method is simple, feasible and high detection accuracy. Detection range is wide and does not affect the power quality; the change of detection effect is not obvious under the condition of more than one inverter together; when the power match with the load, detect islanding effect is still very good.

The disadvantages of this method: There is a NDZ; Due to the factors of non-linear load and the existence of large power network voltage harmonics, which is difficult to determine the action threshold of harmonic detection and has significant limitations and difficulties in practice.

4.3. Phase Jump Detection (PJD) Method

Reference [20] puts forward the method of Phase Jump Detection that through the detect phase of grid-connected inverter output current and voltage of Point of Common Coupling (PCC) difference to judging the islanding. When the power grid proper functioning, due to the existence of PLL in grid-connected inverter, the system must run in unity-power-factor mode, and grid-connected inverter output current is always synchronized with the network voltage. When power off, the point of common coupling voltage is determined by the load impedance and the inverter output current [20-23]. Because the DG system is equivalent to a current source, the output current is a sine wave of frequency and phase is constant. Therefore, for the non-resistive load, if the voltage phase mutation of public connection point can determine whether the island by detect phase difference between the output current and voltage [24-26].

The advantages of this method: The algorithm of this method is simple and easy to realize; Inverter power supply with PLL synchronous with the power grid [25]. It is only needs to increase the phase difference between the voltage and the inverter output current. If it exceeds the threshold, the inverter can be closed; Phase jump does not affect the power quality and system transient response; Islanding detection will not produce the dilution effect and take the edge off to the system of many inverters [24-27].

The disadvantages of this method: When the impedance angle is smaller or local load is resistance, phase difference is constant, and island state cannot be detected, NDZ is larger.

4.4. Change Detection of Key Power (CRDKP)

After the islanding, due to the instability of the system, frequency, power and other power fluctuations, and their rate of change will increase. Fist, frequency rate, power, unbalance, harmonic distortion and the partial derivative of the frequency power are detected by the method. Second, compared the variable value with the limit value, and then determine whether the islanding [28-30].

These methods all belong to the passive detection methods and their characteristics are identical. These methods are commonly measured other physical quantity to improve the detection accuracy, however, it is need to measure quantities which lead to the cost of measurement rising [32-33].

In view of the above methods have both advantages and disadvantages. In the practical application and the future work, the detection time, the requirements of load for power supply, the balance of power supply and load demand and a series of circumstances need to be considered after the islanding. One method or several methods for detecting can be used to reach the purposes of anti-islanding protection [34]. Islanding detection methods are grouped together even though they use different principles. It is easy to obtain better performance by the method above. This is the direction of future islanding detection development [35].

5. Conclusion

Islanding detection technology is one necessary function for grid-connected distributed generation system. Several methods of islanding detection for distributed generation system are summarized in this paper. According to the mechanism of islanding and installation sites, these methods are classified into categories. In this paper, the basic principle of active detection method and passive detection method are analyzed in detail. The advantages and disadvantages of various methods for the detection are summarized conscientious. There is a certain reference and guidance value for select the islanding detection methods.

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