TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol.12, No.1, January 2014, pp. 433 ~ 441
DOI: http://dx.doi.org/10.11591/telkomnika.v12i1.4147

Review on Islanding Detection Methods for Photovoltaic Inverter

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Abstract

Solar power generation, which is regarded as an ideal environment-friendly manner for power generation, is getting more and more attention. When photovoltaic inverter is connected to the grid, the island effect is a special problem to confront. This paper briefly analyzes the island effects and makes a summary of both domestic and external research progress concerning islanding detection methods; the islanding detection methods can be divided into two classes: one is grid-side detection; the other is local detection. The local detection is generally divided into passive methods and active methods. The theory of advantages and disadvantages of those methods are briefly introduced in this paper. At the end of the paper, to deal with the disadvantages of those methods that are mentioned, it proposes the research direction for deeper study of islanding detection methods.

***Keywords**: photovoltaic inverter, islanding detection, non-detection zone, grid-side detection*

1. Introduction

Energy sources all over the world are becoming less and less, and environmental pollution is becoming worse and worse. Especially, our country is facing severe shortage of power energy. Under such circumstances, solar power generation can be used as an ideal and environmental protection method, which has great advantages and wide development future. Electric energy generated from solar power generation must be converted by photovoltaic inverter, and then it can be connected to power grid. The island effect is one of the most serious problems. Photovoltaic inverter needs to convert DC current to AC current and makes them be transferred into power grid. We must take island effect into consideration besides some necessary protection such as current protection, voltage protection and frequency detection protection. This paper mainly introduces the island effect and makes a method survey about related detection methods of island effect.

2. Method Survey of Island Effect

Island effect means one state. When power grid stops serving electric power, and photovoltaic system cannot timely detect the non-electric state of power gird and stop the connection with power grid, photovoltaic system and its load will form an island, which cannot be controlled by power energy companies. The most serious result is that it will threat the safety of electric line serviceman and facilities.

2.1. The Principle of Island Effect

Sketch map of photovoltaic grid connection is displayed in Diagram 1. When system is working in normal state, with inverter closed, power grid and photovoltaic system serve electric power to load at the same time. When power grid stops serving electric power to load because of failure or disoperation, breaker closes, and photovoltaic system continues to provide load with electric power, then photovoltaic system and load will form island effect and serve by it.

Received June 27, 2013; Revised August 28, 2013; Accepted September 20, 2013

In figure 1 PV grid-connected inverter takes use of current feedback control. Its power factor equals to 1, its output wave form is sine wave and its load spot is expressed in RLC parallel circuit. When power grid works in a normal state, active and reactive power for load provided by inverter respectively are P, Q. Active and reactive power for load provided by power grid are *ΔP*、*ΔQ*. The load needs $\boldsymbol{P_{load}}$、$\boldsymbol{Q_{load}}$. So there will be horse-power formula in the following passage.

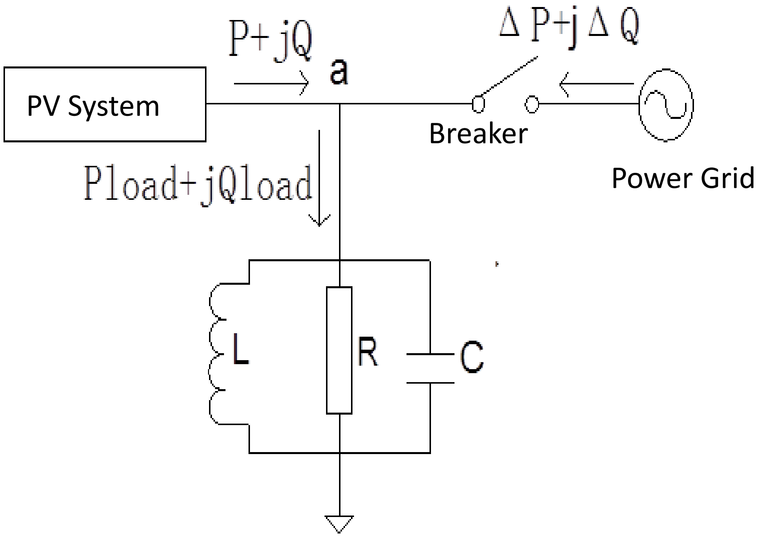

Figure 1. Photovoltaic (pv) grid work and power diagram

$$P_{load} = P + \Delta P \quad (1)$$

$$Q_{load} = Q + \Delta Q \quad (2)$$

If the power of load equals to the one outputted by inverter, then $P_{load} = P$ 、 $Q_{load} = Q$. When power grid is off connection, PV system will continue to supply power to load. At this time, the output voltage of inverter depends on parallel RLC load. Inverter can control it to make the output current frequency equal to that of terminal voltage and control current frequency equal to resonant frequency of load.

2.2. Generating Condition of Island Effect

In Figure1, there are three cases of island effect [3]

(1) Power grid stops operating and leads to the power cut of all power grid, but cast brake switch is still connected to power grid, so PV system has the possibility to continue to work for some time.

(2) Power distribution network breaks at a place or switch trips, which will cause PV system and its load to form an integrated system supplying power by itself.

(3) Switch trip of PV system breaks autonomously or in accident, but grid-connected system and its load operate in island form.

2.3. Damages of Island Effect

Island effect will take a series of serious damages.

(1) It will make serviceman have an accident hurt and lower the safety of power grid.

(2) If load capacity is larger than that of PV system, it will make system operate in an over load state.

(3)When system is in island state, it will do harm to electric equipment, because capacity is unstable, which makes output frequency and voltage of inverter unstable.

3. Detecting Methods of Island Effect

We use the Non-Detection Zone, NDZ [2] to measure the effect of detective methods of island effect. NDC defines proper area. In this area island effect cannot be detected. Commonly, we want the NDZ as small as possible. But too small NDC will cause disoperation of island protection because of complicated conditions of power grid.

Detective methods of island effect can be divided into two parts: [7] one part is local detection by checking frequency and amplitude to judge island effect; the other part is power grid detection by the communication between PV system and power grid or some mixed mode to judge island effect.

Key to local detection of island effect is the outage of power grid. The less the detection time is the better the result will be. Commonly, this detection can be divided into two kinds, passive one and active one.

3.1. Island Detection in Power Grid Side

3.1.1. Supervisory Control and Data Acquisition (SCADA) [2]

We can supervise system operating state by detecting each secondary contact. The island area will be quickly detected by Supervisory Control and Data Acquisition (SCADA) system. However, this method will increase cost of investment and complexity of PV system. And it also asks close connection between power grid and PV system.

3.1.2. Power Line Carrier Communications（PLCC）

This island detection method does not need to set up communication channel but uses electric transmission line as channel. It uses Power Line Carrier Communications (PLCC) to transmit signals. PV system judges whether island effect happens by judging whether acceptor has normal power grid operation communication signals. PLCC can be used in several inverters' parallel operation and it will not decrease grid connection quality. Its disadvantage is that it is hard to choose communication signals because of the limitation of PLCC and it is hard to use by electric power company.

3.1.3. Detection of Insert Impedance

Add a low impedance element in the areas which are easy to have island effect. Commonly, we can use capacitor bank. Because adding capacity bank will not lead to balance between load power and inverter and trigger under-frequency protection. In addition, this method can provide regular working power system with reactive compensation, to keep voltage in the area of nominal voltage. But adding capacity bank in power grid side will increase process complexity and cost and it will have some delay when adding capacity bank in this method, so responding speed will be low.

3.1.4. Automatic Isolation Equipment

Automatic isolation equipment concludes two independent and parallel main monitoring units. Each unit monitors power grid by continuously monitoring impedance, voltage and frequency. But automatic isolation equipment needs to add current to make certain impedance, so electric power quality will decrease. At the same time, it will disturb each other when adding several automatic isolation equipments and its dedicated hardware circuit and redundancy design will increase cost.

3.2 Passive Detection Method

3.2.1. Over/Under Voltage, High/Low Frequency Test

Common passive detection methods are overvoltage, under-voltage, high frequency, low frequency detection. These detection methods can prevent PV system output voltage or frequency from exceeding normal working range. Just as Fig.1 shown, we use the most common resistance R, inductance L and capacity C paralleled as the system load. Point a is the connection of inverter and power grid. When breaker closes, there will be following formula:

$$\Delta P = P_{load} - P \tag{3}$$

$$\Delta Q = Q_{load} - Q \tag{4}$$

When PV system operates in grid-connected state, it will work with its unit power factor. Then Q equals 0 and $\Delta Q = Q_{load}$. In Fig.1, this is the active and reactive calculating formula of RLC load.

$$P_{load} = \frac{U_a^2}{R} \quad (5)$$

$$Q_{load} = \frac{U_a^2}{\frac{1}{\omega L} - \omega C} \quad (6)$$

U_a is the voltage of panel point a. When inverter works in grid-connected state, voltage amplitude and frequency are kept mostly unchanged under the control of power grid. When island effect occurs, power grid breaks, if ΔP or ΔQ is large, it means load power and PV system output power cannot match, which makes PV system output frequency or voltage have great change. When the change is out of normal range, overvoltage, under-voltage, over-frequency, under-frequency circuits can realize that island effect occurred. But when ΔP or ΔQ is small, protection circuit cannot detect island effect because voltage and frequency are in normal range.

3.2.2. Phase Hit Detection

Phase hit detection [7]: During the PV system works with grid connected, output current of PV system has the same phase and frequency with power grid, which means power factor is 1. After power grid breaks, it comes out the result that PV system supply electric power to load, island effect. At this time, voltage of a, us, is decided by load impedance Z and output current. Current frequency and phase are locked in system inside by phase-locked loop, which makes current have the same phase with voltage at the zero crossing point. Current pulls ahead or falls behind voltage out of zero crossing point, making voltage phase hit. So to judge whether island effect occurs we can use this phase hit detection method to make it realize.

Advantages of phase hit detection method are easy arithmetic, easy to realize. But when load is approximate to resistive load, and phase hit is too small to detect, this method will be out of work.

3.2.3. Voltage Harmonic Detection

Voltage harmonic detection [7] , this method is based on the fact that when PV system breaks away from power grid, current injected into load will make some heavier harmonic at point a, because load impedance is much larger than power grid impedance. When we find that voltage harmonic content of point an increases suddenly, we can judge that island effect occurs. But there are some nonlinear load factors, and power grid voltage has heavy harmonic content, so it is really hard to make certain about threshold value of harmonic content. So this method has serious limitation.

3.2.4. Passive Island Detection Method Based on $\Delta f / \Delta P$ Detection Indicative

The three passive island detection methods above to judge whether island occurs based on electric quantity change. But when island effect occurs, yet load power and PV system output power matches, changes of inverter frequency or voltage are little, protection circuit cannot detect the occurrence of island because frequency and voltage are in the normal range.

When island occurs, and power supply or load changes, power, frequency and other electric quantity are all sensitive, then system will be unstable and these electric quantities' rate of change will be great. So we come up with a new island detection method, which judges whether island happens by detecting $\Delta f / \Delta P$ change. It can quickly detect island effect even voltage or frequency just changes a little, with its detection time less than 2s. It has no influence on electric quality. So this method has advantages of validity, rapidity and effectiveness.

To sum up, advantages of passive detection methods are easy to realize, with easy principle, and having no harmonic effect on power system. But power of partial power grid load is balanced with that of PV power supply, leading to the tiny changes in output frequency and voltage of inverter. So when we take passive detection, it is easy to have some large detection dead zone.

3.3. Common Active Detection Methods

Here are some common active detection methods, such as slip mode frequency shift (SMS), output frequency disturbance, current disturbance, active frequency drift(AFD). AFD is one method detecting island effect by adding frequency, currency or phase disturbing signals in inverter's output side. When PV system is running in island state and adding disturbing signals to make influence on line voltage, the disturbing signals will be shown in line voltage and accumulate. At last related facilities will detect the occurrence of island effect.
3.3.1 Active Frequency Drift (AFD) detection and improving methods.

AFD [9] detection method is widely used in island detection. Because this method is based on SCM control system, with easy operation and no more extra hardware, its performance is better than the passive detection methods. The first part from front half period of I that the current is outputted from photovoltaic system still maintains sinusoidal. When the current reaches zero, grid-connect inverter makes the current maintain zero for T2. In the second half period, when the current reaches zero again, it will maintain zero until the voltage reaches zero.

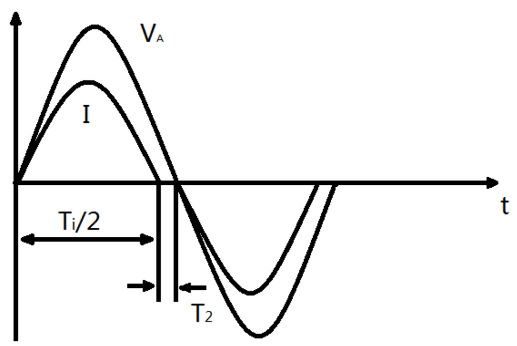

Figure 2. AFD method detection principle diagram

Make the mentioned current waveform through Fourier decomposition, because there are both sinusoidal component and cosine component, so the fundamental component of current outputted from inverter system has a shift relative to this current. When island comes up, the fundamental component will lead I with the phase that corresponds to T2/2. Repeatedly so, frequency will increase and the disturbance of frequency will realize.

AFD detection has the disadvantages as follows:

(1) It has NDZ. In photovoltaic system, when local load has high quality factor, load resonant frequency and the frequency of the grid voltage are the same, or phase difference aroused by active frequency shift is equal to the load circuit phase, the NDZ will occur.

(2) When the *cf* is larger, the grid will be more obviously influenced by inverter system and will have more harmonic components, shorter testing time and smaller NDZ. It can be observed that it is difficult to choose a *cf* which will make\test time, THD and NDZ all be the best.

(3) When direction of disturbances and c*f* are opposite, testing time will be longer.

(4) When more than one inverter run in parallel, the detection method may be invalidated.

AFD is the most commonly used detection methods now, but AFD method itself has the flaws mentioned above, therefore people put forward many improved detection methods. To some extent, these methods can eliminate or reduce the defects of ordinary AFD method and achieve better detection result.

Among those methods, the most simple and practical one is Active Frequency Drift with Positive Feedback (AFDPF). The *cf* of this method fits the formula as follow:

$$cf_k = cf_{k-1} + F(\Delta W_k) \quad (7)$$

Compared with the traditional AFD method, this method improves the islanding detection speed, but the NDZ problems still exist.

In order not to increase the grid current THD and to accurately and quickly detect the island area, a new AFD method with the variable feedback coefficient is put forward. In this method, there is a feedback coefficient k and if Δf changes, k will change. The AFD method with a variable coefficient has short detection time, small grid current total harmonic content and a good application prospect.

Considering that the quality of load will cause the loss of AFD detection methods' effect and aiming at this defect, the periodic disturbance AFDPF detection method is raised based on the original methods. The method throws continuously periodic disturbance in both positive and negative directions into inverter output voltage, so it eliminates the condition that when disturbance direction is single, load balance will influence detection result. This method further narrows NDZ and improves the effect of the islanding detection.

Since the classic AFD has the phenomenon that current frequency shifts upward and downward, it puts forward the coupling disturbance AFD test point voltage frequency current, and proposes AFD method which exerts disturbance into the coupling voltage point.
In practice, there are many defects in this method. But this method can effectively solve the NDZ problem of local island effect. Therefore, the method can be combined with the classic active AFD method, which may obtain more reliable and faster island detection effect.

AFD method has two important flaws: one is that there is NDZ under the particular conditions; the other is that there is loss of quality of photovoltaic grid. 2N periodic perturbation method is proposed as an improved AFD method. Principle is shown in figure 3.

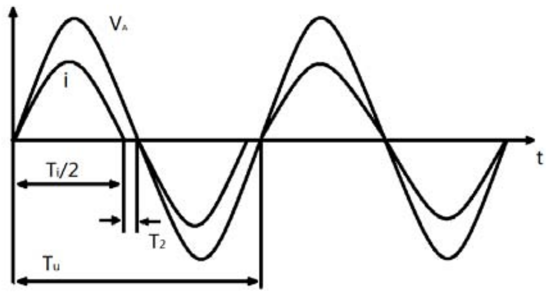

Figure 3. The principle diagram of the 2N periodic perturbation method

The method still has serious NDZ problem. But it can be combined with other methods, for eliminating the NDZ and improve its practicability of engineering.

In addition to the above method, there are also methods based on the condition that AFD may fail in a distributed power generator, so it proposes the improved principle that aims at distributed generator. In the method, every inverter is made to support each other, so it is suitable for distributed generator. Another method based on fuzzy control is variable step AFD. When this kind of method is under the normal operation of power grid, harmonic content is low. At the same time, when power grid breaks away, it can detect the island quickly and accurately.

3.3.2. Slip Mode Frequency Shift (SMS) Detection Method

After the occurrence of island, the SMS method introduces θ_{SMS} into detection. For impedance load, under positive feedback of the system, it makes load voltage frequency f of point a increase and increase gradually. When the f increases to the preset threshold, system will detect the island. SMS method [9] and AFD method are similar. The main difference between them is that the SMS method introduces the phase angle shift SMS while AFD method introduces error Δf.

Relative to passive solutions, SMS method reduces the quality of the output power, and when grid inverter outputs huge power and the gain of feedback loop is very large, it may lead to decline of power quality, longer detection time, transient response problem and other issues.

3.3.3. The Output Power Disturbance Detection

For the current controlled grid-connected inverter, the output power disturbance detection is to control the PV system periodically output the active power and reactive power disturbance, when the grid inverter is under the island state, this disturbance will make the system frequency or voltage obviously exceed the preset threshold, so as to detect the island. If the detection method is used on the single photovoltaic inverter, the good experiment effect will be produced. But if there are multiple photovoltaic grid-connected inverters, because the synchronization of power interference is hard to realize, this method would be affected.

3.3.4. Current Interference Method

Current interference method puts fixed cycle disturbance into grid current amplitude. By detecting whether voltage amplitude changes, when the disturbance is in operation, it can detect if the island occurs. When the grid is in normal operation, this method does not change inverter output current frequency and initial phase Angle, so compared with other active method, the effect to quality of grid is smaller.

3.3.5. Islanding Detection Method Based on Wavelet Analysis

Islanding detection method based on wavelet analysis adopts a step in the scale and discretization of location area, namely uses the discrete wavelet transform analysis. This set of base wavelet coefficients of the same points can be used to observe the exact characteristics of signal of same point.

Using island detection method based on wavelet analysis, the grid cannot be polluted by harmonic wave. It reduces NDZ and islanding can be accurately detected. The island detection speed will be improved. In addition, wavelet algorithm in high number, large scale distributed grid for small and medium wave test has good reliability and wide prospect of application.

In addition to the above methods, some researchers using the fuzzy system propose distributed generator island detection method based on neural fuzzy inference system, mixed time-frequency island detection method based on fuzzy logic system and so on. These methods have good accuracy, even under the condition that there is harmonic wave, it can accurately detect whether island occurs. Compared with conventional methods, their testing time is short and has faster response speed.

3.4 Some Composite Detection Method

3.4.1. O/U Voltage Method Combined with Leading Phase Detection Method and its Expanded Method

O/U Voltage method combined the O/U Voltage method and leading phase detection method together. As islanding occurs, at first, we adopt the Over/Under Voltage detection method to detect the voltage effective value. When grid voltage is beyond the preset threshold, the detection signal will be sent. Or it will use the leading phase detection send signal of island, and then make the PV system off the grid.

The method adopts the combination of two kinds of passive detection method, effectively reduces the blind spots, compared with the single method. The detection method is easy for the construction of the hardware circuit. It is convenient and suitable for engineering implementation, and has no effect on power quality.

After the above method reaches the NDZ, the AFD method can be used to make up, in order to realize no blind spot detection. It can be used as a reference for engineering applications

For further narrow the reduce NDZ, we can add phase angle shift θ_{SMS} after adding positive or negative frequency interference. Under the function in two kinds of interference, it can quickly detect island [25]. Island detection effect is good after this improvement. The combination of the two active methods narrows the NDZ. But there is testing time problem and problem of damaging the power quality. The composite test ideas can also be used on other active methods.

3.4.2. AFD Combined with Current Interference Method for Island Detection

From the above analysis of AFD method, it can be seen that both the NDZ and THD of AFD contradict each other. At the same time, the pure electric current perturbation method has a great influence on power quality of the power grid in the normal operation.

The advantage of AFD combined with Current interference method for island detection is that the two methods can complement each other and solve the problem that load properties and *cf* influence island detection time. It has little harmonic influence to power quality of grid and can accurately and quickly detect island. But more than one inverter is in parallel operation or load resonant frequency is same with the network voltage frequency, so the method may be invalidated.

4. Conclusion

To sum up, the islanding detection methods can be divided into two parts: One is grid-side detection, the other is local detection. The local detection is generally divided into passive methods and active methods. The theory of advantages and disadvantages of those methods are briefly introduced in this paper. It can be seen from the summary of new detection methods. In the study of island detection in recent years, the methods based on the traditional active and passive methods which form composite detection method and methods that are improvements on traditional AFD occupy a certain component. Meanwhile there are methods that use some novel intelligent detection method for the island detection. But all sorts of methods still have some shortcomings, especially DNZ problem, problems of affecting the power quality or not applying to distributed generator. There are some methods lacking of practical engineering inspection and only stay in the simulation phase. All these problems mentioned above can be used for further research.

Acknowledgements

This work is supported by Foundation of Shandong Education Department (J12LN01)

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