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Islanding Detection Algorithm Based on Adaptive Voltage Positive Feedback

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Abstract

Islanding detection is an essential function of the grid-connected inverter of distributed power generation system. The deficiency of traditional islanding detection methods should be given due importance, especially the phenomena such as islanding detection failure when the output power of the inverter balances with the load power, and the use of active frequency and phase shifting method affecting the quality of power. In this regard, an improved islanding detection method based on adaptive voltage positive feedback was proposed. A mathematical model was established, and the hardware circuit was tested. The constraint conditions on the success of islanding detection and the pattern of voltage variation at the point of common coupling before and after incorporation to the grid were studied. The simulation result shows that this method has the advantages of high detection speed, small blind area and high reliability. The index requirements specified in IEEE Std.2000-929 are met. The reasonability of the proposed scheme is verified.

Keywords: *distributed generation, inverter, positive feedback, islanding detection, power qualit*

1. Introduction

The grim situation of "energy-saving and emission reduction" boosts the large-scale and rapid development and application of distributed generation (DG). Therefore, a considerable amount of renewable energy is converted by inverter before being incorporated to the grid. Because the DG connection to grid can give full play to its energy efficiency and improve the operation economy of the power system, the ways of power generation and inversion in this field have become the core and focus of research workers in recent years [1, 2]. One of the most key technologies is islanding detection [3-5]. Islanding refers to the condition in which the inverter still supplies energy to the power grid even when the grid breaks down. It forms a self-supported power supply system with the local load, which is independent of the control of public power grid [6]. Islanding may threat the sequence of the protective action of the power distribution system or the restart of automatic reclosure. The phenomenon of non-simultaneous grid connection may also appear. In this case, the power supply control device may be damaged, and even personal injury may be caused [7, 8]. Therefore, the research of islanding detection has very important practical significance for eliminating the harm of islanding and for maximizing the energy efficiency of renewable power generation system.

Many islanding detection methods are mentioned in the existing researches. They are mainly divided into two types, remote and local. The former has only found limited applications because of the high cost of operation; the latter can be further divided into active and passive mode. Passive islanding detection method is mainly based on the variation of electricity quantity of point of common coupling (PCC). The problems such as blind area and setting difficulties exist [9, 10]. The active islanding detection method has higher reliability. But the relevant detection strategy or algorithm theory is not reasonable. The adverse effects are highly probable. Negative sequence current perturbation method mentioned in literature [11] realizes the islanding detection by periodically injecting negative sequence current to the grid and detecting the voltage component of PCC. But due to the existence of unbalanced current in the DG system itself, the probability of erroneous judgment is obviously increased. Islanding detection method using the given P-U and Q-f power curves is simple, with small blind area. In

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the meantime, no harmonic pollution is caused to the power grid. But its objects of application need to include the power control link, and the detection time is affected by the [12] power enormously. Thus, the practical application is narrow. Literature [12] indicates that when the Sandia frequency shift anti-islanding method was used in the three-phase constant-power system, the detection performance was attenuated. Literature [13] presented an islanding detection method using Q-f sag curve, which was tested according to IEEE 1547 and UL 1741 standards. But the effects of outer loop power on the detection algorithm were not considered.

The gain coefficient of the traditional islanding detection with voltage positive feedback is a fixed value. Whether the power of distributed power supply matches with the power required by load has a large impact on islanding detection [14-17]. When the voltage injected into PCC by the inverter is large, the detection effect is satisfactory, with high reliability. But the quality of power may be affected. On the contrary, the islanding state may not be easily discriminated. When the output power of the grid-connected inverter is equal to the local load, the voltage of PCC will no longer change, and this method will fail. The islanding detection method designed in this study can dynamically give the current value of the inverter. The output voltage amplitude of the port varies according to direction of voltage variation, thereby increasing the deviation of the voltage of PCC after losing voltage, which is favorable for islanding detection. The voltage variation of PCC after islanding develop in the same direction as positive feedback, thus increasing the deviation of the voltage of PCC and improving the success probability of islanding detection.

Islanding detection employing voltage positive feedback is featured by high reliability and small blind area. But the specific algorithm is not yet fully studied in relevant literature, and there is a lack of theoretical support. This study analyzed the specific algorithm model for islanding detection in detail, tested the hardware circuit and verified the effectiveness of the proposed scheme by simulation. It provides a theoretical basis for the relevant study on the islanding detection of distributed power generation system.

2. Principle of Islanding Detection Employing Voltage Positive Feedback

2.1. Passive Islanding Detection

The method for passive islanding detection is shown in Figure 1. The principle is to acquire the power output of the distributed power supply, or the voltage U^P, and frequency, ω of PCC to detect islanding. For the convenience of analysis, the local load is replaced by the RLC parallel model. The judgment process is shown as follows.

1) The distributed power supply operates in connection to grid and the active power of the distributed power supply does not balance with the power required by local load. Then according to the principle of conservation of energy, the power balance equation could be obtained:

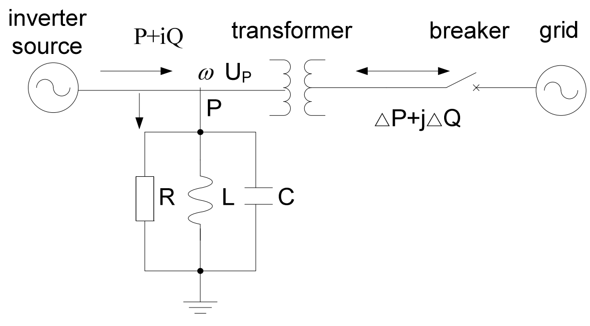

Figure 1. Equivalent Model of Islanding Detection

$$P = P_L + \Delta P \tag{1}$$

$$Q = Q_L + \Delta Q \tag{2}$$

$$P_L = 3U_P^2 / R \tag{3}$$

$$Q_L = 3U_P^2 / \left(\omega C - 1/\omega L\right) \tag{4}$$

In the equation: P and Q are active and inactive power output of inverter power supply, respectively; P_L and Q_L are the active power and reactive power required by local load, respectively; △P and △Q, are the differences of active power and reactive power, respectively.

2) When islanding occurs, the output power of the inverter remains unchanged. When the power required by load balances with the inverter power, then the following relationship could be obtained:

$$P = P_L' = 3U_P'^2 / R \tag{5}$$

$$Q = Q_L' = 3Q_P'^2 / (\omega C - 1/\omega L) \tag{6}$$

Where $\omega' = \omega + \Delta\omega$ is the angular frequency of PCC after islanding occurs; $U_P' = U_P + \Delta U_P$ is the phase voltage of PCC. When the above 6 equations are combined, the following can be obtained:

$$\Delta U_P = \sqrt{U_P^2 + \Delta PR/3} - U_P \tag{7}$$

It is obvious that the mismatch between the inverter power and the local load power causes the fluctuation of the voltage of PCC. In this case, the passive detection is more effective. The methods for passive islanding detection are widely reported in the literature. There is no need for discussion here. On the contrary, if the powers of the two equal, then there is no voltage fluctuation of PCC. However, the passive detection is more likely to fail. Therefore, this article presents an active islanding detection method.

2.2. Active Islanding Detection Algorithm

The core of islanding detection algorithm employing adaptive voltage positive feedback is expressed as follows: the voltage of PCC incorporated to the distributed power supply is compared with the voltage of the system, and the perturbation value is introduced as the given component of the current output of inverter. Then according to the preset algorithm and positive feedback compensation principle, the model established is expressed as.

The model of the preset algorithm:

$$I_d = kU_r + U_d \tag{8}$$

$$\begin{cases} U_r = \dfrac{U_p}{U_m}, U_d = \left|K_d\right|, k = +1; U_p > U_m \\ U_r = \dfrac{U_m}{U_p}, U_d = -\left|K_d\right|, k = -1; U_p \le U_m \end{cases} \tag{9}$$

Where I_d is the current perturbation of inverter; U_r is the feedback of intensity coefficient; U_p and U_m are the peaks of voltage PCC and the system, respectively; k is the adaptive coefficient; U_d is the periodic perturbation. In the islanding detection algorithm employing voltage positive feedback, the formula for output current of the inverter in the distributed power generation system is expressed as follows:

$$I_o = (\mathrm{I_m} + kU_r + U_d)\sin(\omega_0 t) \tag{10}$$

Where Im is the preset value when the inverter is in the normal operation. In order to speed up the islanding detection, the improved algorithm is used. Then the output current of the inverter is written as follows:

$$I_o = (\mathrm{I_m} + kU_r^3 + U_d)\sin(\omega_0 t) \tag{11}$$

In the ideal system, the value of U_m is constant. But the actual voltage of the power grid has fluctuation. The theory suggests that the voltage peak of the grid is kept constant within a relatively short period. At the same time, when the inverter is connected to the grid, then $U_p = U_m$. It can be assumed that $U_m(r) = U_p(r-n)$. That is to say, in a relatively short period of time, the peak voltage of the power grid of the rth cycle is equal to the peak voltage of point p of the r-nth cycle. It is assumed that power grid fails in the r cycle. In the subsequent n cycles, Um can be represented by the normal outputs, *Up(r-n+1), Up(r-n+2), ……Up(r)*, of the inverter.

i.e. $$\begin{cases} U_m(r+1) = U_p(r-n+1) \\ U_m(r+2) = U_p(r-n+2) \\ \cdots \\ U_m(r+n) = U_p(r) \end{cases}$$

Based on this assumption, the output current of inverter is given by:

$$I_o(r) = (\mathrm{I_m} + k\left(\frac{U_p(r)}{U_p(r-n)}\right)^3 + U_d)\sin(\omega_0 t)\ ,\ U_p > U_m \tag{12}$$

$$I_o(r) = (\mathrm{I_m} + k\left(\frac{U_p(r-n)}{U_p(r)}\right)^3 + U_d)\sin(\omega_0 t)\ ,\ U_p \le U_m \tag{13}$$

To verify the effectiveness of the abovementioned algorithm, several possible situations of system voltage fluctuation are discussed:

(1) When $U_p > U_m$ and the islanding occurs in the r cycle, then $U_p(r) > U_m(r) = U_p(r-n)$. It can be seen from Equation (8) and (9) that the perturbation current of the inverter in the r+1th cycle will increase. Therefore, the given current of the inverter increases. According to the positive feedback principle of Figure 2(a), it can be inferred by analogy that the voltage of PCC has a rising trend. When the current increases to a certain value, the voltage of PCC rises to a preset threshold, then the system detects the islanding state. At this time, U_d plays the regulatory function by employing the voltage positive feedback, which contributes to the islanding detection.

(2) When $U_p < U_m$ and the islanding occurs in the rth cycle, then $U_p(r) < U_m(r) = U_p(r-n)$. It can be seen from Equation (8) and (9) that the perturbation current of the inverter in the r+1th cycle will be reduced. Thus, the given current of the inverter decreases. As inferred by analogy from the positive feedback principle of Figure 2(b), the voltage of PCC also has a decreasing trend. When the current decreases to a certain value, the voltage of PCC drops to a predetermined threshold, then the system detects the islanding state. At the same time, U_d plays the regulatory function by employing the voltage positive feedback, thus accelerating the islanding detection.

(3) When islanding occurs at $U_p = U_m$ and the output power of the inverter is equal to the load power, it is most difficult to detect the islanding. Equation (8) and (9) indicate that the auxiliary control effect of $U_d = -K_d$ is obvious. The introduction of U_d reduces the output current of the inverter. Then the voltage of PCC decreases. When $U_p < U_m$ is satisfied, the working process is similar to that in the second situation. The response time under voltage variation of the distributed power supply is shown in Table 1.

$$\left.\begin{matrix} \frac{U_p}{U_m}\uparrow \\ U_d\uparrow \end{matrix}\right\} \rightarrow I_d\uparrow \rightarrow (\mathrm{I_m}+I_d)\uparrow \rightarrow I_o\uparrow \rightarrow U_p\uparrow$$

(a) $U_p > U_m$

$$\left.\begin{matrix} \frac{U_p}{U_m}\downarrow \\ U_d\downarrow \end{matrix}\right\} \rightarrow I_d\downarrow \rightarrow (\mathrm{I_m}+I_d)\downarrow \rightarrow I_o\downarrow \rightarrow U_p\downarrow$$

(b) $U_p < U_m$

Figure 2. Working Principle of Positive Feedback

Table 1. Voltage Response Schedule of Distributed Power Supply

Voltage of power of interconnection	Requirements
$U<50\%U_N$	The maximum opening time not exceeding 0.2s
$50\% U_N <U<85\%U_N$	The maximum opening time not exceeding 2.0s
$85\% U_N <U<110\%U_N$	Continuous operation
$110\%U_N <U<135\%U_N$	The maximum opening time not exceeding 2.0s
$U>135\%U_N$	The maximum opening time not exceeding 0.2s

3. Hardware Circuit of the Detection System

The detection circuit is designed to cause the periodic perturbation to the amplitude of output current of the inverter to increase the deviation of voltage at PCC after islanding occurs. The preset value of the output current of the inverter consists of two parts: Im is the preset value of power in the normal operation, with the additional current perturbation quantity as I_d. The hardware circuit for the detection is shown in Figure 3. The phase lock loop (PLL) ensures that the voltage of PCC and output current of inverter are in the same frequency and phase. According to the principle of positive feedback control, the higher the voltage of PCC, the larger the current of inverter, thus causing the voltage of PCC to further increase. On the contrary, the voltage of PCC reduces. Thus, the reliability of islanding detection is guaranteed.

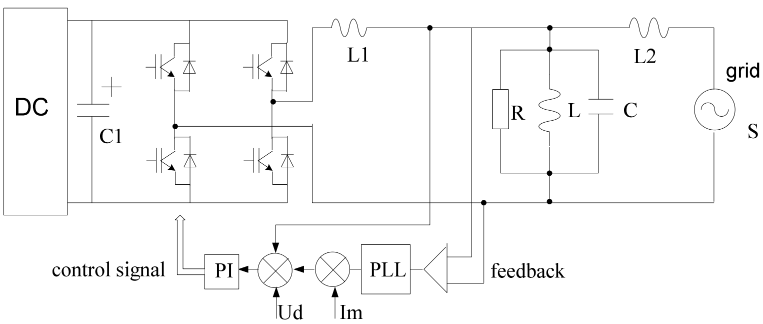

Figure 3. Diagram of Hardware for Islanding Detection Employing Positive Feedback

4. Simulation Study

The simulation parameters: voltage of system 220V, frequency 50Hz, output power of inverter 3kW, output current 15.2A. It is supposed that when the output power of the grid-connected inverter is equal to the load power, the island occurs. At this time, the frequency of the grid is consistent with the resonant frequency of load; the quality factor Qf is 2.5. Combining with the constraint conditions in Table 1, the design parameters are as follows: R=16, L=20.3mH, C=500 μF. The following three situations are simulated: when $U_p>U_m$, the grid failure occurs at 0.3S, then islanding ensues. Under the action of the perturbation signals and according to the positive feedback principle, when the output current of inverter is increased and the voltage of PCC exceeds a preset value at the moment of 1.2S, the system detects the islanding and the output is stopped. Figure 4(a) is the output voltage waveform of inverter. Figure 4(b) is the voltage waveform of power grid. When $U_p<U_m$, the working principle is similar to that in the first case. The difference is that the voltage variation is gradually decreased. Figure 4(e) is the voltage waveform of power grid, and the fault occurs at 0.2 s. Figure 4(d) is the output waveform of inverter. The islanding is detected at 1.2S and the output is stopped. When $U_p=U_m$, the output power of grid-connected inverter and the power required by load are consistent. The voltage peak of PCC remains constant, which is most detrimental to the rapid detection of islanding. But due to the effect of Ud as Figure 4(c) indicates, the Ud perturbation can still disrupt the voltage balance of the original PCC. As a result, the voltage of PCC decreases. Due to the positive feedback, the load voltage of PCC is reduced continuously. After 1.3S, the voltage of PCC exceeds the preset value, and the system detects the islanding and acts accordingly. The analysis of the simulated waveforms shows that in the worst case, the islanding can be detected less than 2 S after the action of Ud. This response time is far less than the maximum tripping time (120 cycles) specified by the IEEE 2000-929 standard after islanding occurs. But according to the waveforms, the time of islanding detection is significantly prolonged. IEEE 2000-929 standard is shown in Table 1. In the table, UN is the rated value of the voltage of power grid.

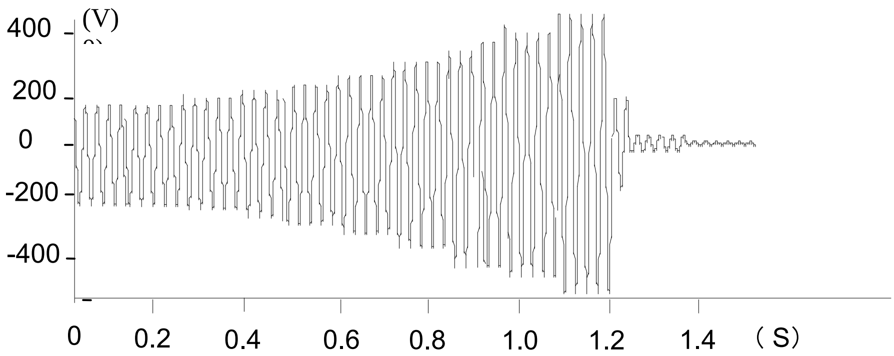

Figure 4 (a). Output Voltage Waveform of Inverter when $U_p > U_m$

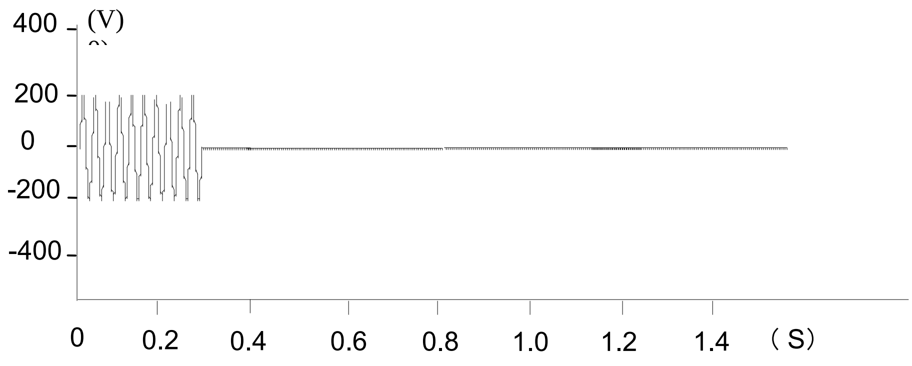

Figure 4(b). Output Voltage Waveform of PCC

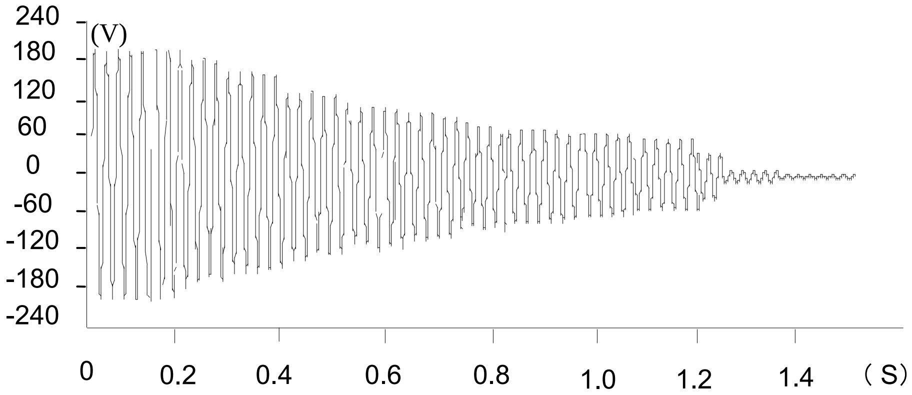

Figure 4(c). Output Voltage Waveform of Inverter when $U_p = U_m$

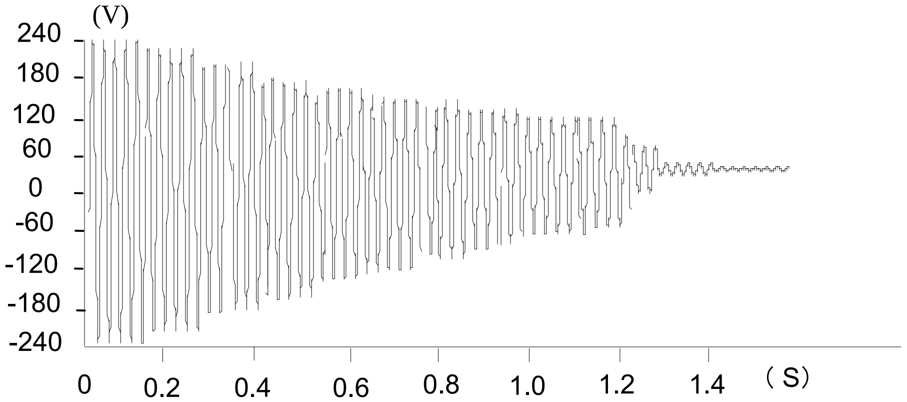

Figure 4(d). Output Voltage Waveform of Inverter when $U_p < U_m$

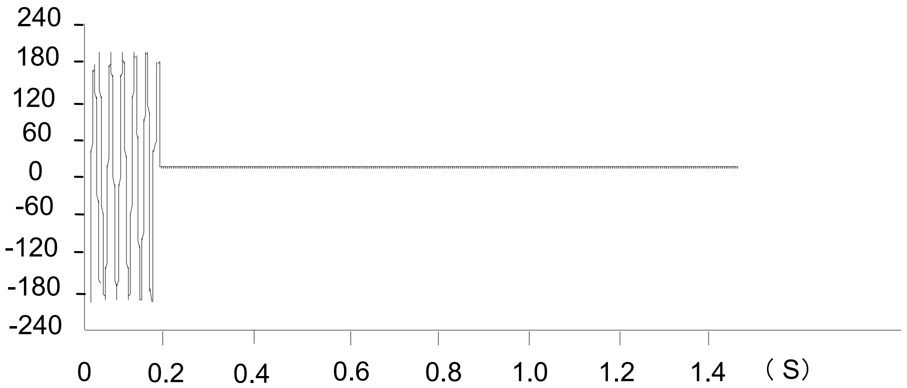

Figure 4(e). Output Voltage Waveform of PCC

5. Conclusion

This article presents a islanding detection strategy employing voltage positive feedback based on fast adaptive prediction algorithm. Then the theoretical analysis and numerical simulation are carried out. The results show that this method can increase the perturbation of positive feedback, make the voltage of PCC less stable and improve the traditional passive islanding detection algorithm. The algorithm increases the speed of islanding detection and overcomes the blind area existing in the traditional islanding detection method. The principle of this method is simple, and the effect is satisfactory. This method does not affect the quality of power, and at the same time, provides theoretical guidance for the islanding detection in the power grid with grid-connected inverter. Its application is expected to be of high value.

Acknowledgements

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References

[1] Rai, Anil K, Kaushika ND, Singh, Bhupal, Agarwal Niti. Simulation model of ANN based maximum power point tracking controller for solar PV system. *Telkomnika.* 2011; 95(2): 773-778.
[2] Atia, Doaa M, Fahmy Faten H, Ahmed Ninet M, Dorrah Hassen T. A new control and design of PEM fuel cell powered air diffused aeration system. *Telkomnika.* 2012; 10(6): 291-302.
[3] IEEE Std 929-2000. IEEE recommended practice for utility interface of photovoltaic (PV) system.
[4] Liu Furong, Kang Yong, Duan Shanxu, Tang Aihong. Boundary Conditions of Voltage Shift Techniques for Islanding Detection. *Transactions of China Electro technical Society*. 2012; (27)3: 247-251.
[5] Liu Fangrui, Duan Shanxu, Kang Yong, Zhang Yu. Islanding Detection Methods for Multiple PV Converters System. *Transactions of China Electro technical Society*. 2010; (25)1: 167-171.
[6] Smith GA, Oninons PA, Infield DG. *Predicting islanding operation of grid connected PV inverters.* IEE Proceedings Electric Power Applications. 2000; 147(1): 1-6.
[7] Yuan Chao, Wu Gang, Zeng Xiang-jun, et al. Protection technology for distributed generation systems. *Power System Protection and Control.* 2009; 37(2): 99-105.
[8] Guo Xiao-Qiang, Wu Wei-yang. Islanding Detection Method for Photovoltaic Grid-Connected Power System. *Transactions of China Electro technical Society*. 2007; (22)4: 157-162.
[9] Zeineldin HH, Kirtley JL. Performance of the OVP/UVP and OFP/UFP method with voltage and frequency dependent loads. *IEEE Transactions on PowerDelivery*. 2009; 24(2): 772-778.
[10] Samantaray SR, El-Arroudi K, Joos G, et al. A fuzzy rule-based approach for islanding detection in distributed generation. *IEEE Transactions on Power Delivery*. 2010; 25(3): 1427-1433.
[11] Wang Yidi. Research on the islanding detection of three grid-connected inverter with active negative-sequence current disturbing. Qinhuangdao. Yanshan University. 2011.
[12] Wang XY, Freitas W, Xu W, et al. Impact of DG interface controls on the Sandia frequency shift antiislanding method. *IEEE Transactions on Power Conversion*. 2007; 22(3): 792-794.
[13] Zeineldin HH. A Q-f droop curve for facilitating islanding detection of inverter-based distributed generation. *IEEE Transactions on Power Electronics*. 2009; 24(3): 665-673.
[14] Guo Xiaoqiangm, Zhao Qinglinm, Wu Weiyang. Islanding Detection Method for Photovoltaic Grid-Connected Power System. *Transactions of China Electro technical Society*. 2007; (22)4: 157-162.
[15] Ropp M. Design issues for grid-connected photovoltaic systems. Georgia Institute of Technology. 1998.
[16] EZH Kolwalkar A, Zhang Y, et al. Evaluation of anti-islanding schemes based on nonelection zone concept. *IEEE Transactions Power Electronics.* 2004; 19(5): 1171-1176.
[17] Ye Z, Walling R, Garces L. Study and development of anti-islanding control for grid-connected inverters. Subcontractor Report: NREL/SR-560-36243, GeneralElectric Global Research Center, Niskayuna.NewYork, 2004.