Islanding Detection Based on High Frequency Injection for Multi Inverter Microgrid

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Abstract: Islanding detection is one of the indispensable protection detections for grid-connected inverters. The detection of islanding is the key factor that should be considered in the analysis of grid-connection security. The non-detection zone is the performance index of anti-islanding plan. According to the phase feature, quantitative analyses of the non-detection zone of several frequency disturbance schemes are conducted under several different coordinate systems by increasing disturbance, namely injecting third harmonic to the modulating wave that produces inverter drive signal and detects the voltage value and the total harmonic distortion of the power grid. The active current all-disturbance islanding detection scheme has been chosen as the initiative scheme of anti-islanding detection to complete the parameter design and simulation. According to the experimental result, this method is feasible to detect the island of microgrid. In this paper, the simulation model of islanding detection of microgrid is established through MATLAB/SIMULINK, and the simulation analysis of islanding phenomenon after the injection of third harmonic wave is conducted. The simulation result verifies the validity and availability of the islanding detection method.

Keywords: İslanding detection, multi-inverter, microgrid, active detection, experimental analysis.

1. INTRODUCTION

Microgrid, compared with the traditional large grid, is characterized with less investment, no pollution, higher reliability, no need of long-distance power transmission. It can both operate with grid connected, and supply power separately [1]. Grid-connected operation which can provide supplement for the large grid system is the main tendency of electric power development nowadays. Even though the microgrid has many advantages, there are still irresolvable problems. For example, the islanding detection in grid connection. At present, the islanding detection of microgrid mainly includes two kinds of methods: passive islanding detection and active islanding detection. The two kinds of islanding detection methods have their own features: the passive islanding detection is simple, exerts no influence to the power quality of the grid, and needs no extra equipment. However, the passive islanding detection method has non-detection zone, which will cause detection failure easily. The active islanding detection method has such advantages as short testing time, small non-detection zone, and high detection precision [2-4]. But due to the injection of disturbance, the power quality of the grid is influenced. Therefore, it is very necessary to seek a safe and reliable islanding detection method, which has little influence on the power quality of the grid and small or even no non-detection zone.

This paper firstly introduces the basic knowledge of microgrid and islanding detection method, including definition, structure, developing history, the present situation and significance of the research, etc. It also introduces the relevant standard, islanding detection methods, advantages and disadvantages of these methods, and analyzes the reason of islanding detection failure and the non-detection zone. Then, according to the research on the existing detection methods, a valid islanding detection method with third harmonic injected is proposed [5-7]. This method is to detect the voltage value and the total harmonic distortion of the power grid by increasing disturbance, namely injecting third harmonic, to the modulating wave that produces inverter drive signal. In this part, the principle of the new method is introduced in detail. After that, this paper presents the simulation realization of ISE software based on FPGA.

2. MULTI-INVERTER MICRO-GRID ISLANDING DETECTION METHOD

Active current disturbance method is an active islanding detection method. For current source controlled inverter, as shown in Fig. (**1**), L_f and C_c are respectively the output filter inductance and capacitor of the inverter. RLC is load, S_1 is the switch of the connected grid, i_g is current reference, i_{gd} is the periodical disturbance signal.

To decrease the influence of disturbance to input power, and also to the parallel operation of multi-distributed power generator, an active current all-disturbance islanding detection method is analyzed as follows.

All-disturbance control algorithm is: to add two disturbance signals to the primary current standard i_g, one periodic disturbance signal I_{gd} (functions after a fixed time), another one I_d functions in every grid period. Analyze the variation

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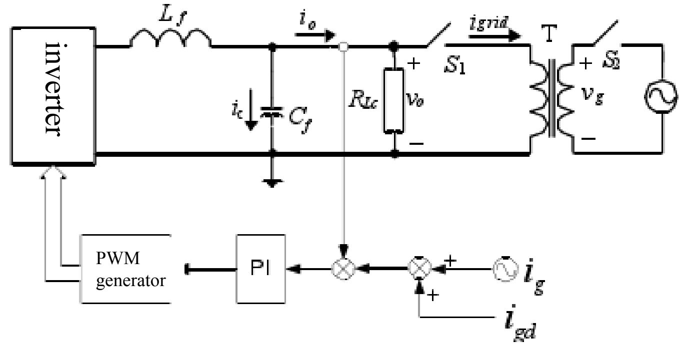


Fig. (1). Active Islanding Detection Method Block Diagram.

of the output voltage before exerting disturbance, and then exert relevant disturbance respectively. Detect the island through the combined function of these two disturbance signals [8].

For current-control inverter, if the output follows the standard completely, then the output current amplitude Io is:

$$I_0 = I_g + I_{gd} + I_g \tag{1}$$

Where: Ig is the given current amplitude, Igd is periodic disturbance signal amplitude, Id is the amplitude of disturbance that functions in every period. Their values are decided by the following equations:

$$I_{gd} = \begin{cases} I_D & U_0(k)>U_0(k-1) \\ -I_D & U_0(k)\le U_0(k-1) \end{cases}$$
$$I_d = \begin{cases} I_d+\Delta x & U_0(k)>U_0(k-1) \\ I_d-\Delta x & U_0(k)\le U_0(k-1) \end{cases} \tag{2}$$

In the above equation, id is the periodic disturbance signal strength, id is the disturbance superposition of each period, Δx is the disturbance quantity, U_0 (k) is the maximal output voltage amplitude of inverter in current period, U_0(k-1) is the maximal output voltage amplitude of inverter in last period [9]. The strength of these two disturbance signals are both related to the variation of output voltage.

As is shown in Fig. (**1**), without disturbance exerted, output current follows given current ig(sinusoidal signal with same frequency and inphase to grid), then output current of inverter i0=ig, the actual output current with disturbance signal igd and id is:

$$I_0 = \left(I_g + I_{gd} + I_d\right)\sin wt \tag{3}$$

Where, ω is the angular frequency of power grid.

When the grid connects: influenced by the network voltage, the output end node voltage is same for the network voltage, and keeps almost invariant. The disturbance signal id is always zero without accumulation. When there is no periodic disturbance, inverter input current is fixed, when the periodic disturbance is coming, the input current amplitude decreases by igd, and after the periodic disturbance, input current regains its original value. Therefore, in the process of grid connection, disturbance signal hardly brings influence to the grid and system control, and the periodic disturbance signals just change the input power [10, 11].

Grid unconnected: voltage of the inverter output end is decided by both output current and load Z:

$$u_0 = Z_{i_0} = Z\left(I_{gd} + I_d + I_g\right)\sin wt \tag{4}$$

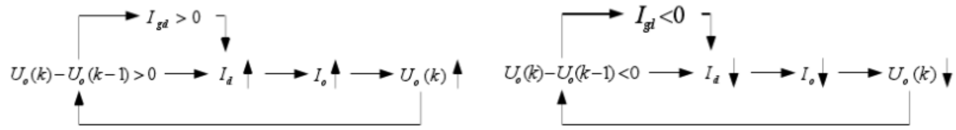
The detection of islanding can be realized by observing the variation of the voltage in the inverter output end.

3. ANALYSIS OF THREE KINDS OF DETECTION METHODS

(1) When the output power of inverter is greater than what load needs, the output voltage of the inverter will increase, namely $U_0\left(k\right) > U_0\left(k-1\right)$. According to equation(2), I_d=I_d+ Δ x, then the whole current standard increases, the output current increases. According to equation (4), the output voltage increases. Due to the continuous accumulation of id in each grid period, the output voltage increases continuously until to the prescribed value so that the island can be detected. If the periodic disturbance signal igd also comes, then igd is also a positive value. Two disturbance signals functioning at the same time will further increase the output voltage, then accelerate the detection of the island [12]. Its variation tendency is as shown in Fig. (**2a**).

(2) When the output power of inverter is less than what load needs, the output voltage of the inverter will decrease, namely $U_0\left(k\right) < U_0\left(k-1\right)$. According to equation (2), I_d=I_d- Δ x, then the whole current standard decreases, the output current decreases. According to equation (4), the output voltage decreases. Due to the continuous accumulation of id in each grid period, the output voltage decreases continuously until to the prescribed value so that the island can be detected. If the periodic disturbance signal igd also comes, then igd is also a negative value. Two disturbance signals functioning at the same time will further decrease the output voltage, then accelerate the detection of the island. Its variation tendency is as shown in Fig. (**2b**).

(3) When the output power of inverter is equal to what load needs, the output voltage of the inverter keeps invariant, then id=0. Neither of the two disturbances functions and the



a) output voltage increases b)output voltage decreases

Fig. (2). Disturbance of Grid Unconnected.

output voltage keeps invariant all the time before the arrival of periodic disturbance, thus the islanding cannot be detected. But when the periodic disturbance arrives, based on $U_0(k) = U_0(k-1)$ and equation (1), we can get $I_{gd} = -I_d$. It will decrease the current standard, then the output voltage decreases, and the following situation is similar to that when the output power of inverter is less than what load needs. The islanding can also be detected in this situation.

From the above analysis it can be concluded: when the output voltage of the inverter is unmatched with what load needs, the disturbance signal id that functions in every period will cause the output voltage to increase or decrease continuously. In such case, the islanding can be detected completely. While the function of the periodic disturbance signal I_{gd} that functions in fixed time is to exert a negative disturbance when the inverter power matches completely and the output voltage keeps invariant. This negative disturbance decreases the output voltage, and breaks the power balance and thus makes the disturbance signal I_d function. On the occasion of the unmatched power, the periodic disturbance signal igd will accelerate the change of output voltage, and thus the occurrence of islanding can be detected immediately [13]. With this control method, invalid islanding detection will not happen. In addition, the influence of the average impact is much less for the case of multiple distributed generator system connected in parallel. Provided that the variation of the output voltage can be detected, the variation of output voltage in the same direction can be realized and thus the islanding can be detected immediately.

4. PARAMETER DESIGN

Consider the following two questions in the design of periodic disturbance signal igd:

(1) the period of the disturbance signal igd cannot be too long, for that might influence the speed of islanding detection; and too short period will cause frequent input power variation and influence the stability of the system.

(2) the actuating quantity of igb cannot be too big, which might cause the inverter output voltage to be less than what load needs and lead to the power transmission to load when the periodic disturbance functions in the grid connected pattern with critical load.

Set disturbance signal igb proportion is x_1, the disturbance period is t1. The proportion of disturbance signal id is x2, detection periodicity is n, grid period is T, set detection threshold value is (0.88Un~1.1Un), Un is the specified voltage amplitude of the grid. When the grid is unconnected with unmatched power, the output voltage increases, as long as it satisfies:

$$nx_2 > 0.1 \quad (5)$$

When the output voltage decreases, as long as it satisfies:

$$nx_2 > 0.12 \quad (6)$$

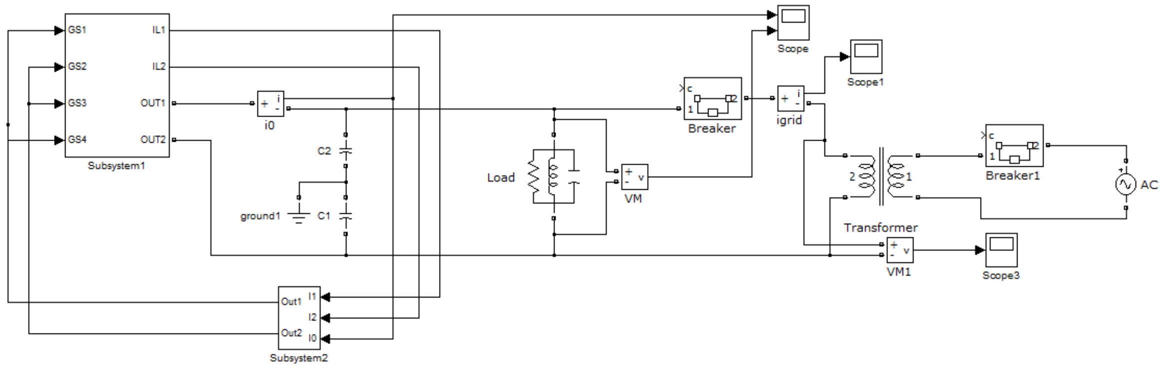
Set its maximum $nx_2 > 0.12$, then the detection time is nT. During this period, if igd functions, then the detection time is much shorter. On the occasion of unmatched power, the longest detection time is t1+nt. When the output voltage amplitude is less than 0.5 Un or more than 1.37 Un, the islanding can be completely detected through passive detection method [14-16]. To guarantee the detection time is in accordance with the detection standard as shown in Table **1**, where Ua and Un are respectively the amplitudes of terminal voltage and electric supply, the period is the electric supply period. As long as it satisfies t_1+nT<120T, then t_1<2.0.02n. According to nx_2 >0.12, the relevant parameter can be chosen reasonably.

Table 1. IEEE 929-2000 Islanding Protection Time Standard.

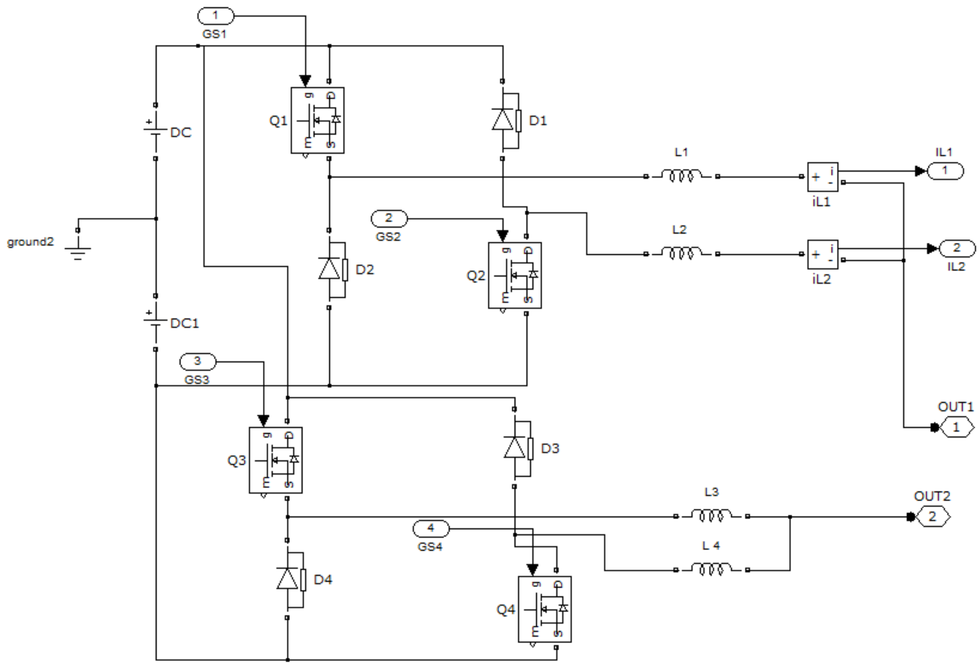
Voltage Range of Common Coupling Point	Max Trip Time
Ua/Un<50%	6 Cycle
50%<Ua/Un<88%	120 Cycle
88%<Ua/Un<110%	Normal operation
110%<Ua/Un<137%	120 Cycle
137%<Ua/Un	6 Cycle

5. SIMULATION DESIGN

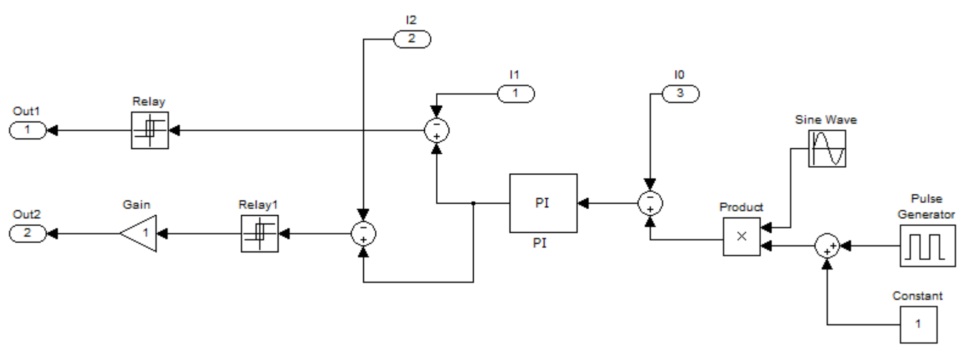
Fig. (**3**) shows the principle simulation model of the current disturbance. Where, (a) is the general simulation model, which includes the main electricity route model, control model, load and power grid. On-off controls are on the inverter output side and power grid side. Where, main electricity route model is double depressurization inverter, as (b) shows. The control model includes the occurrence of the disturbance signal, PI regulation and hysteresis control, as is



(**a**) Integrated system simulation model



(**b**) Main circuit model

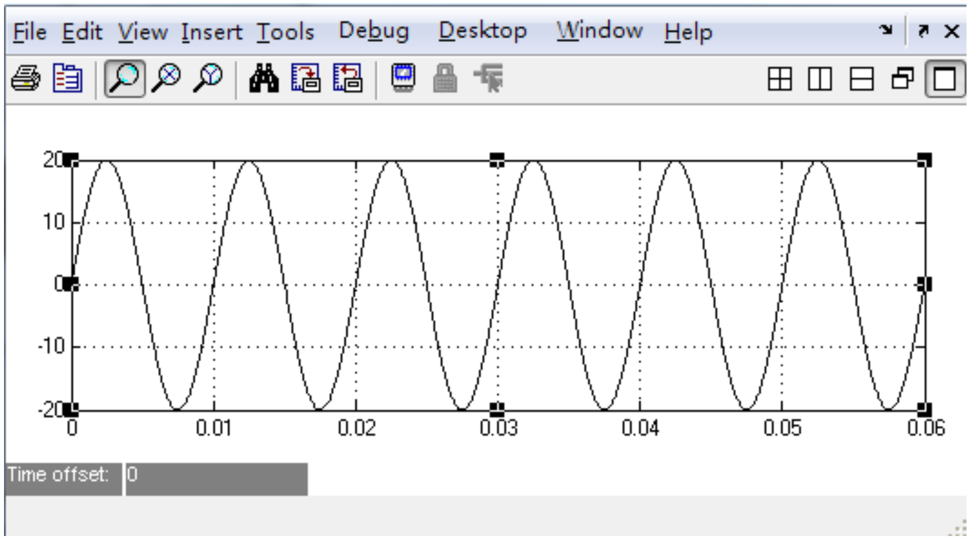


(**c**) Control simulation model

Fig. (3). Simulation Circuit Diagram.

shown in Fig. (c). The control model sends relevant driving signals to main electricity route, thereby driving the switching tube to realize the control of output voltage.

In the simulation study, the double pressurization bridge type inverter is the main circuit, network voltage is 220V/50Hz, specified power is 1kVA, filter inductance



(**a**) Output current waveform

Fig. (4). Current Disturbance Simulation Waveform.

Lf=520μH, Cf=9.4μF, disturbance signal Igd period is 0.8s, namely functioning every 0.8s and lasting for two grid periods, 0.04s, the disturbance proportion is 0.1, namely the current standard changes for 1/10. The disturbance proportion of Id is 0.03. To make the variation trend of the output end voltage obvious, set the overvoltage- undervoltage as 0.8Un~1.2Un, Un as the specified electricity supply amplitude. Fig. (**4**) shows the simulation waveform of the active current.

The blackout time under the three conditions is all at 1.5s. According to the output voltage waveform, because the output voltage is same as that of the network voltage before the blackout, the output voltage keeps invariant even though the output current disturbance happens at 0.8s.

The simulation result is as shown in Fig. (**4**): it is grid-connected in 0-1.5s, after which it is blackout time. According to the simulation waveform, the output current disturbance occurs every two seconds, but during the grid-connected period, the output voltage is equal to the network voltage. When the grid goes blackout and the disturbance occurs, the output voltage changes with the current variation. The voltage amplitude decreases to 248V.

According to the simulation waveform

(1) If there is only periodic disturbance signal added, without the judgment of voltage direction, the disturbance signal must be set very large. Especially when the disturbance direction is opposite to the direction in which the output end voltage changes, the disturbance must offset the mismatching quantity, namely the disturbance proportion should be greater than 0.4 at least.

(2) If periodic disturbance signal is added after judging the voltage variation, then the disturbance quantity can be increased, and with a disturbance proportion of 0.2, a complete detection can be realized.

(3) According to the complete disturbance control method introduced in this paper, judging the direction of voltage variation and adding two disturbance signals with different functions, then the periodic disturbance proportion can be 0.1 or even less, namely causing the output end voltage to change.

According to the above analysis [17], the islanding detection method of active current complete disturbance control can detect the occurrence of islanding without blind zone. Increasing the disturbance proportion of the disturbance signal Id can accelerate the detection. The detection time can completely satisfy IEEE2000-929 standard.

6. SUMMARY

Islanding detection is one of the indispensable protection detections for grid-connected inverters. The detection of islanding is the key factor that should be considered in the analysis of grid-connection security. The non-detection zone is the performance index of anti-islanding plan. According to the phase feature, to make quantitative analyses to the non-detection zone of several frequency disturbance schemes under several different coordinate systems. To choose the active current all-disturbance islanding detection scheme is the initiative scheme of anti-islanding detection and complete the parameter design and simulation.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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