Novel Islanding Detection for PV Generation implemented by d-q Voltage Harmonic Component

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Abstract. In this paper, islanding problem of grid-connected PV generation system is discussed. Based on the technology of passive island detection, a novel principle of islanding detection is proposed which is implemented by using the d-q voltage harmonic components. According to the principle that the inverter-side power quality is different from the grid-side power quality at PCC, the characteristic harmonic frequency d-q voltage components of islanding can be extracted by FFT algorithm. Theoretically, the method can eliminate the non-detection zone resulted from the extraction and identification of microscopic variables. Solar grid-connected PV generation model is set up with PSCAD/EMTDC and the proposed islanding detection algorithm is carried out with Matlab. The simulation results show that islanding state can be detected rapidly and effectively. The proposed method has high response speed and no influence on the power quality of the system.

Introduction

With the increasingly serious energy crisis and environmental pollution problems, the development and utilization of renewable energy and green energy more and more be taken seriously, the most realistic and the most promising solar energy, as the cleanest energy, will play an important role in modern power grid [1]. Solar grid-connected PV generation is the main trends of development of solar photovoltaic utilization. However, with the large capacity PV system grid-connected, PV system grid-connected will have a larger influence on power system. At the same time, it brings about a series of technology problems to power system. Besides that, grid-connected PV generation system has a special fault state, called as islanding state, should also be considered [2,3].

A DG system is shown in Fig 1. In Fig 1, when the accident occurs due to a failure of power supply or power outage maintenance cause the tripping, each client DG system failed to detect the off state timely which will cut itself off the mains network, eventually a self-powered isolated power systems is formed by the DG system and its connected loads, which is called as an island state.

![Figure 1. Islanding of distributed generation system scheme.](image)
The generation of islanding can bring power system equipment and related personnel hazards shown as follows:

(1) Island effect can make voltage and frequency out of control. If distributed generation systems has no ability to adjust the voltage and frequency and there is no voltage and frequency protection relay to limit the voltage and the frequency offset, so voltage and frequency in an island state of power system must have larger fluctuations which cause harm to electric network and user equipment.

(2) When power system operation mode changes from the island state into a parallel operation state, the distributed power generation device in re-closing system may be out of sync with the grid. That will lead to circuit breaker device damaged and may also cause high impact current which may endanger device in the island system and even lead to power grid to trip again.

(3) Island effect may cause that the failure cannot be removed, which result in the damage of power equipment, and interfere with the normal power supply system of power grid automatically or manually.

(4) Island effect can cause that some are thought to have broken line charged with all the power, it would bring to power grid maintenance personnel or the user the risk of electric shock.

On islanding problem discussed above, many experts and scholars put forward the corresponding strategies to solve the islanding problem [4-6]. This paper proposes a new method of islanding detecting, which is realized by using d-q voltage harmonic components. The method proposed is simple and easy to be set. Moreover, it has low requirement to the sampling frequency and can be realized easily only using a specific frequency signal (150 Hz and 250 Hz and 350Hz) data.

The Islanding Strategy Based on Voltage Harmonic DQ Component Detection Principle

The method using d-q voltage harmonic components to detect islanding is implemented by monitoring voltage harmonic distortion at PCC.

When DG is connected to grid, grid can be thought of as an infinite power. Grid inverter produces harmonic current, which will flow into the low impedance of grid. The small grid harmonic current and low impedance of grid make the voltage output located in the grid inverter side contain only a small amount of harmonic voltage. That is to say, the voltage distortion rate closes to zero.

After the grid disconnection, harmonic current flows into the load impedance, which is much higher than the grid impedance, the larger voltage distortion will be produced at PCC. The islanding fault quickly and efficiently detected by fast Fourier transform to extract the specific frequency (150Hz and 250Hz and 350Hz) harmonic of d-q voltage components.

Failure Criterion and Setting

From the section 2, the content of voltage harmonic at PCC has changed when island happens. According to the above problem, specific harmonics (third-harmonic, fifth-harmonic, and seventh-harmonic) can be monitored, and every harmonic corresponding threshold values are set. When one or multiplex voltage is more than setting value, we can think the PV system is in the islanding state. Its setting rules are as follows:

\[
|\Delta U_{d3}| > U_{set1} = 0.0025U_1
\]

\[
|\Delta U_{q3}| > U_{set2} = 0.0025U_1
\]

\[
|\Delta U_{d5}| > U_{set3} = 0.0006U_1
\]

\[
|\Delta U_{q5}| > U_{set4} = 0.0006U_1
\]
\textbf{Simulation Verification}

\textbf{Establishment of a Grid-connected PV Generation System Model}

Photovoltaic inverter vector control based on VOC is shown in Fig. 2.

\begin{equation}
\left| \Delta U_{7d} \right| > U_{\text{set}5} = 0.0006U_1
\end{equation}

\begin{equation}
\left| \Delta U_{7q} \right| > U_{\text{set}6} = 0.0006U_1
\end{equation}

In Equ. 1-6, $U_1$ is the RMS value of the fundamental voltage, $\Delta U_{3d}, \Delta U_{3q}$ are the RMS value of the third-harmonic voltage d-axis component, third-harmonic voltage q-axis component, respectively. $\Delta U_{5d}, \Delta U_{5q}$ are the RMS value of the fifth-harmonic voltage d-axis component, fifth-harmonic voltage q-axis component, respectively. $\Delta U_{7d}, \Delta U_{7q}$ are the RMS value of the seventh-harmonic voltage d-axis component, seventh-harmonic voltage q-axis component, respectively. $U_{\text{set}3}, U_{\text{set}2}$ are the third-harmonic voltage d-axis and q-axis component setting value, respectively. $U_{\text{set}5}, U_{\text{set}6}$ are the fifth-harmonic voltage d-axis and q-axis component setting value, respectively. $U_{\text{set}7}, U_{\text{set}6}$ are the seventh-harmonic voltage d-axis and q-axis component setting value, respectively.

In the grid voltage oriented synchronous rotating coordinate, $e_d = |E|$, $e_q = 0$. System of the instantaneous active power $p$ and instantaneous reactive power $q$ are:

\begin{equation}
p = 1.5e_d \cdot i_d
\end{equation}

\begin{equation}
q = 1.5e_d \cdot i_q
\end{equation}

If ignoring the grid voltage fluctuation, namely $E_d$ for a certain value, the photovoltaic inverter instantaneous active power $p$ and reactive power $q$ only with photovoltaic inverter output current is proportional to the d and q axis component. This suggests that, if the grid voltage constant, photovoltaic inverter of active and reactive power can be controlled by d and q axis component.

Photovoltaic inverter control strategy is shown in Fig. 3, inverter control part adopts double closed loop control.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2}
\caption{Photovoltaic inverter vector control based on VOC.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3}
\caption{Photovoltaic inverter control strategy.}
\end{figure}
On the basis of the double closed loop control circuit of a 500kW grid-connected photovoltaic system sketch, which is established with PSCAD/EMTDC[7-9], is shown in Fig. 4.

![Figure 4. A 500kW grid-connected photovoltaic system sketch.](image)

In Fig. 4, inverter module is IGBT three-phase full bridge inverter circuit, the output voltage is 270V (line voltage), the output current is 1000A, the actual output power is 470kW. Local load using the delta connection in parallel RLC circuit simulation (the situation is in the worst island situation), quality factor is 1.2, $R=0.465\ \Omega$, $L=0.00123\ \text{H}$, $C=8214\ \mu\text{F}$ [10-11]. Through two levels of step-up transformer, the voltage will rise to 110kV, which is connected to the grid. System operation time is 1.2s, islanding failure occurs at $t=1s$ time, the islanding duration time is 0.1s. System operation parameters is shown in Fig. 5.

![Figure 5. A 500kW grid-connected PV generation system operation parameters.](image)
From Fig. 5, it can be seen that there are no changes of running parameters in normal operation and island operation, which shows that the island situation is in the worst situation.

**Simulation Verification**

In this paper, simulation model is established with PACAD, and the method of islanding detection is implemented with Matlab. In simulation, the sampling frequency is 4.8 kHz, the shifting data window length is 20ms [12]. Because the length of the paper is limited, the output voltage data of low side of transformer are given in this paper [13-14].

**Voltage Component Analysis When Three-Phase Circuit Breaker Tripping Occurs**

When the three-phase circuit breaker tripping occurs, called as symmetrical failure, the voltage fault component waveform is shown in Fig.6-8. Fig.6 is the 150Hz voltage d-q fault component waveform, Fig.7 is the 250Hz voltage d-q fault component waveform and Fig.8 is the 350Hz voltage d-q fault component waveform.

From Fig.6-8, we can see that every harmonic voltage d-q fault component close to zero in the normal operation state of grid. When islanding occurs (sampling points for 480), every harmonic d-q fault component has not changed, after two cycle (40ms, sampling points for 672), 150Hz and 250Hz and 350Hz voltage d-q fault component are greater than setting value. According to the setting logic, islanding detecting is success.

![Figure 6. 150Hz voltage d-q fault component waveform.](image)

![Figure 7. 250Hz voltage d-q fault component waveform.](image)
Voltage Component Analysis When Single-Phase Circuit Breaker Tripping Occurs

When single-phase circuit breaker tripping occurs, the voltage fault component waveform is shown in Fig.9-11.

Fig.9 is the 150Hz voltage d-q fault component waveform, Fig.10 is the 250Hz voltage d-q fault component waveform and Fig.11 is the 350Hz voltage d-q fault component waveform.
Figure 11. 350Hz voltage d-q fault component waveform.

From Fig.9-11, we can see that every harmonic voltage d-q fault component close to zero in the normal operation state of grid. When islanding occurs (sampling points for 480), every harmonic d-q fault component has not changed, after two cycle (40ms, sampling points for 672), 150Hz and 250Hz and 350Hz voltage d-q fault component are greater than setting value. According to the setting logic, islanding detecting is success.

Voltage component analysis when two phase circuit breaker tripping occurs

When two phase circuit breaker tripping occurs, the voltage fault component waveform as shown in Fig.12-14. Fig.12 is the 150Hz voltage d-q fault component waveform, Fig.13 is the 250Hz voltage d-q fault component waveform and Fig.14 is the 350Hz voltage d-q fault component waveform.

Figure 12. 150Hz voltage d-q fault component waveform.
From Fig.12-14, we can see that every harmonic voltage d-q fault component close to zero in the normal operation state of grid. When islanding occurs (sampling points for 480), every harmonic d-q fault component has not changed, after two cycle (40ms, sampling points for 672), 150Hz and 250Hz and 350Hz voltage d-q fault component are greater than setting value. According to the setting logic, islanding detecting is success.

**Conclusions**

The method uses the d-q voltage harmonic component to implement the islanding detecting according to the difference of the voltage harmonic component in the normal operation and islanding operation state. It takes 40ms to detect the island mode and activate the protection scheme. A great deal of simulation results show that the method proposed is effective.

In the case of power quality being not affected, the method can effectively detect islanding fast, and no island blind spot detection can be achieved. The method is simple and has a wide application scope, sampling frequency is low, easy to implement with hardware.
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