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A Study of Islanding Detection of Grid-connected Three-phase Photovoltaic Power Conditioning System

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***Abstract*--Islanding phenomenon of a grid-connected photovoltaic (PV) power conditioning system (PCS) is said to occur if the PCS continues to power a section of the utility system after that section has been disconnected from the utility source. Since islanding creates hazards for personnel and equipment, PCSs are required to detect and prevent it. In this paper, several islanding detection methods (IDMs) and reactive power variation method are described. Islanding test results for 9kW PCS are presented for verification.**

Keywords—photovoltaic system, islanding, inverter, power conditioning system, protection, reactive power variation method

1. Introduction

In a grid-connected photovoltaic (PV) system, the PV system is connected to the public low-voltage utility via a power conditioning system (PCS). As every PCS being connected to the public utility, the PCS has to comply with common safety standards. A major safety issue in PCS is to avoid abnormal operation in islanding phenomenon when the grid is being tripped at fault conditions or for maintenance purposes [1].

Islanding phenomenon of grid-connected PCS refers to their independent operation when the utility is disconnected. The local section energized by self-activated PCS becomes an island isolated from the remaining power system. Concern about such phenomenon is raised because it causes danger to uninformed maintenance personnel. Therefore, it is desirable to incorporate detection functions into PCS for protection. Islanding detection methods (IDMs), which have been proposed, are generally classified into passive and active IDMs.

In this paper, several IDMs and reactive power variation method are described. The islanding test results for 9kW PCS are presented for verification

2. Islanding detection methods (IDMs)

2.1 Passive IDM

A PCS equipped with an over-voltage relay (OVR), an under-voltage relay (UVR), an over-frequency relay (OFR), and an under-frequency relay (UFR) has the basic islanding detection capability [1]. Once the voltage level or frequency at the terminal exceeds the preset normal range, the situation is regarded as utility malfunction. The PCS is shut down to prevent lasting islanding operation. However, such relays fail under source-load balanced conditions because the terminal voltage does not change in magnitude or in frequency. Other methods should be applied to enhance the detection ability. One of them is the voltage harmonics monitoring method. The method is mainly based on the nonlinear characteristics of power transformers in the distribution systems. Without the strong utility voltage source, the current injected from PCS into power transformers would cause large voltage harmonics. Continuous monitoring terminal voltages can effectively detect islanding operation when the harmonics level increases. Even though the test results from Rokko Island, Japan revealed that this is a rather effective detection method [2].

Another method called phase jump detection method [3] monitors terminal voltages in a different way. PV PCS usually output currents in phase with the utility voltage for unity power factor. When the utility is disconnected, the phase angle between the output current and the terminal voltage of PCS is determined by the load condition. An instant phase change of the voltage may occur and triggers protection circuits. The detection methods mentioned before all depend on some kind of monitoring of PCS terminal voltages. They are classified as passive IDMs. Their ability of islanding detection is not guaranteed for all load conditions, especially for source-load balanced conditions. As a result, active IDMs are invented for enhancement.

2.2 Active Frequency Shift IDM

One simple active IDM is the active frequency shift method (AFD) [4]. It is based on the frequency shift of PCS output current without synchronization needed for islanding detection. When the utility is disconnected, phase difference between the terminal voltage and the output current of a PCS depends on the load. It is detected by the internal phase-locked-loop (PLL) circuitry. To eliminate the phase difference, the frequency of the PCS output current is forced to drift up or down. The intension is to make the frequency of the terminal voltage deviate from its nominal value until OFR or UFR is triggered. Nevertheless, it has been demonstrated that nondetection zone (NDZ) still exists [5]. That is, the previously mentioned AFD become ineffective under certain load conditions, especially paralleled RLC resonant loads.

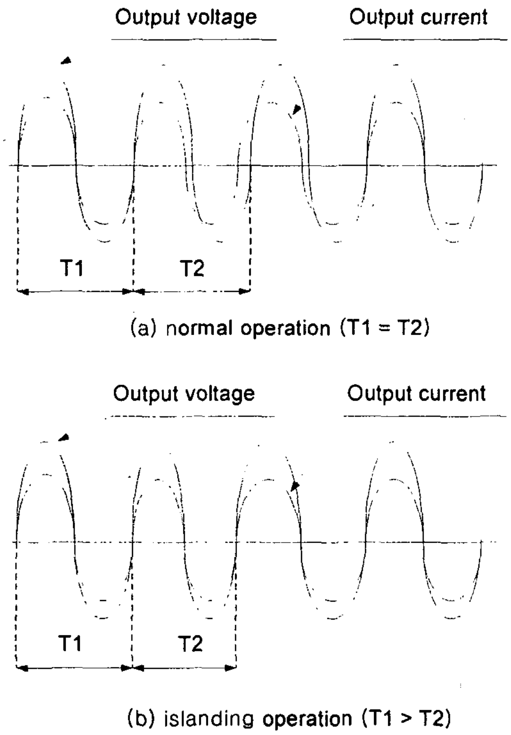

Fig. 1. Output voltage and current waveform of a PCS applying RPV.

3.3 Reactive Power Variation IDM

To avoid this problem, the reactive power variation (RPV) method is proposed. RPV is to change output power of PCS periodically. This is effective to break source-load balanced conditions. When the utility is connected, the frequency of PCS voltage is equal to the frequency of utility and the effects of reactive power fluctuation are not manifest (Fig. 1(a)). But when the utility is disconnected, the frequency of PCS terminal voltage will be change corresponding to the fluctuation of reactive power (Fig. 1(b)). Therefore it is possible to detect islanding operation by monitoring the range of frequency fluctuation. The flow diagram of the RPV algorithm is shown in Fig. 2. The reactive power reference Q* varies in 10Hz and its amplitude is 5% of active power reference P*. Frequency f_S is calculated by zero-crossing of terminal voltage. The limit value of frequency change $df_{S,LIMIT}$ is about 0.75Hz.

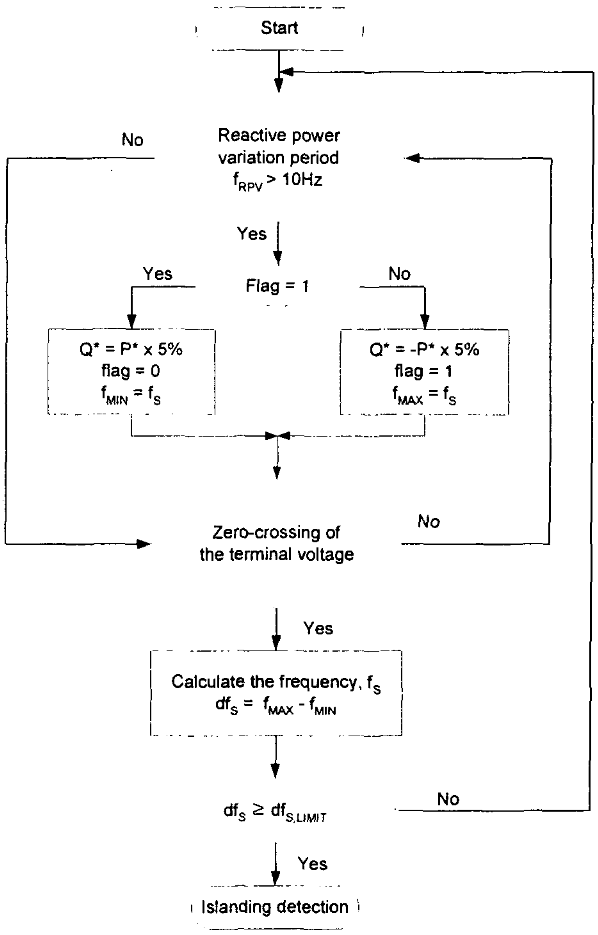

Fig. 2. Flow diagram of RPV.

3. Experimental results

A 9kW PV PCS is constructed for experiment. The power stage consists of a boost converter, and voltage source inverter (VSI). A Texas Instruments TMS320VC33 is used as the main controller. The boost converter provides a static dc voltage source from an unregulated output voltage of PV array. The VSI acts as a sinusoidal current source. The

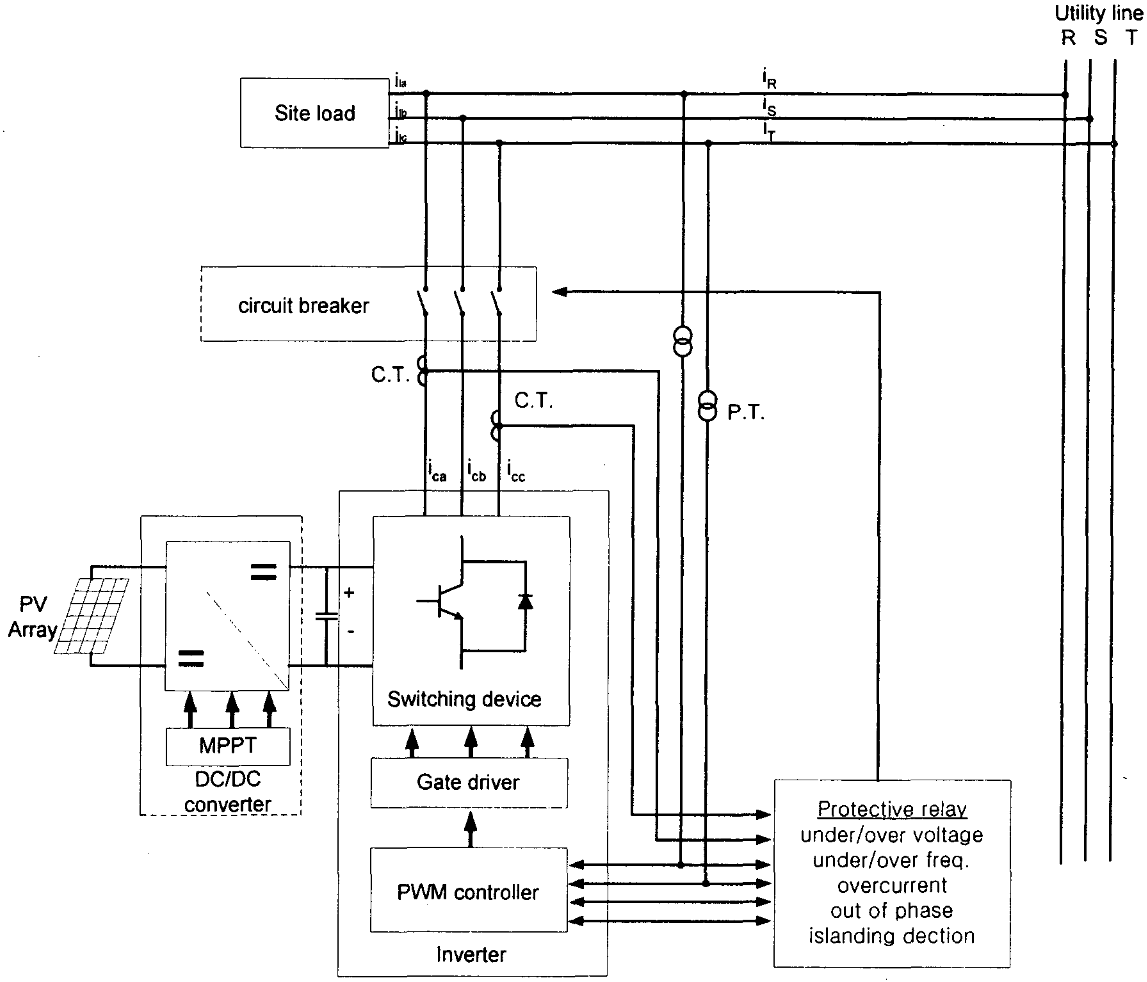

Fig. 3. Experimental circuit diagram.

maximum power point tracking (MPPT) algorithm of the controller determines the output current amplitude. The site load consists of RLC circuit, and its value is adjusted to be source-load condition.

Experimental result of PCS operation without RPV is shown in Fig. 4. There is no power fluctuation, and minimum value of power factor (pf) is 0.99.

Experimental result of PCS operation with RPV is shown in Fig. 5. There is power fluctuation in a 10Hz period, and minimum value of power factor (pf) is 0.98.

Figure 6 shows the results of the islanding test for RPV method. This test procedure involved running the PCS at rated output power, and adjusting the site load so that active and reactive power flow while connected to the utility are under 1% of rated value, thereby islanding operation. Figure 6 indicates that PCS shut down time is 0.44 second after utility disconnection, showing that the proposed RPV method works well.

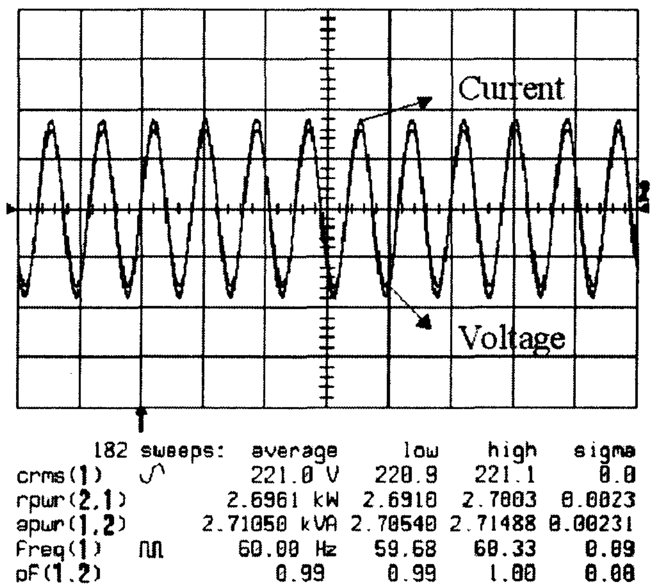

Fig.4. Experimental result without RPV. (CH1: phase voltage, 100V/div; CH2: PCS output current, 10A/div, TIME: 20ms)

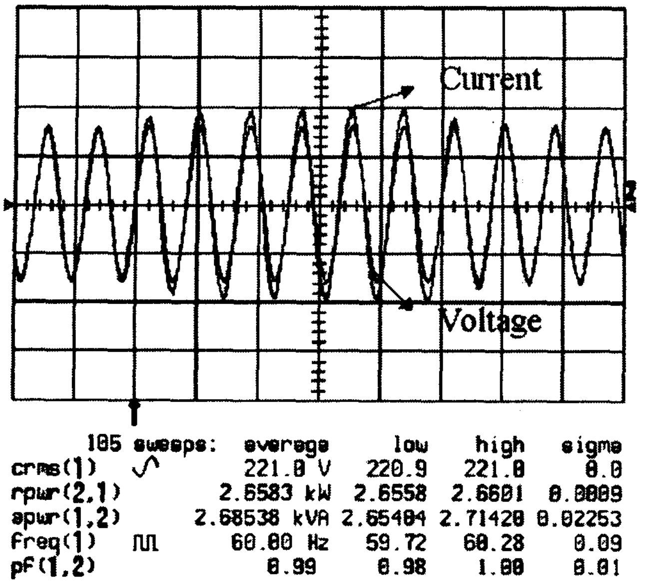

Fig.5. Experimental result with RPV. (CH1: phase voltage, 100V/div; CH2: PCS output current, 10A/div, TIME: 20ms)

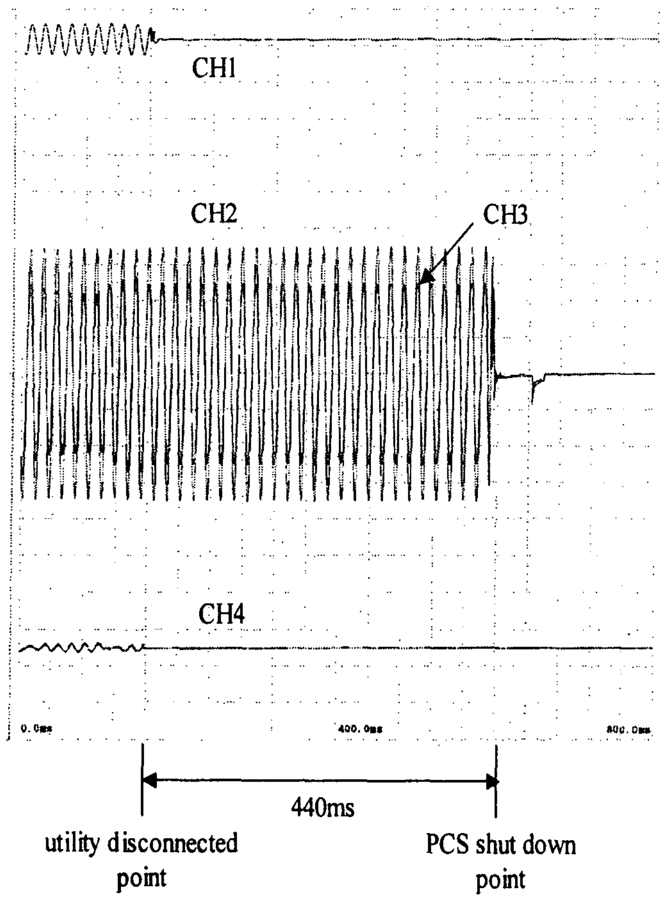

Fig.6. Islanding detection result with RPV. (CH1: utility phase voltage, 745V/div; CH2: PCS output voltage, 90V/div, CH3: PCS output current, 7A/div, CH4: current at point of common coupling, 20A/div, TIME: 40ms)

4. Conclusions

Several islanding detection methods are described and reactive power variation method was proposed. The islanding test results for 9kW PCS are presented for verification. Test results show that RPV method has good performance even in worst situation; no power flow in point of common coupling.

Acknowledgments

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