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Active islanding detection method for the grid-connected photovoltaic generation system

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ABSTRACT

This paper proposes an active islanding detection method incorporated into the control of the grid-connected inverter to protect the photovoltaic generation system from the islanding operation. The proposed active islanding detection method performs the grid-connected inverter as a virtual resistor with the operation frequency slightly higher or lower than the fundamental frequency of the utility voltage. The function of virtual resistor will not be actuated when the utility is nominal, and the grid-connected inverter can convert the DC power from the solar array to an AC power. When the strong utility is lost, the grid-connected inverter acts as a virtual resistor with the operation frequency slightly higher or lower than the fundamental frequency of the utility voltage. Thus, the frequency and the amplitude of the local load voltage will be away from their normal values under the islanding operation. Hence, the proposed active islanding detection method can immediately detect the islanding operation. A prototype is developed and tested to demonstrate the performance of the proposed active detection method. Both computer simulation and experimental results verify that the performance of the proposed active islanding detection method is expected.

1. Introduction

The interest in renewable energy has been increased due to Kyoto agreement on the global reduction of greenhouse emissions. Small-capacity distributed power generation systems, including solar power, wind power, are directly incorporated into the utility for supplying electric power to local load or injecting into the utility [1,2]. The photovoltaic generation system is an important small-capacity distributed power generation system. Fig. 1 shows the system configuration of a grid-connected photovoltaic generation system. The utility is adapted to supply AC power with an almost fixed frequency. The grid-connected photovoltaic generation system includes a solar cell array, a DC/DC converter and a DC/AC inverter. The DC/DC converter is used to trace the maximum power point of the solar cell array and regulate the voltage generated by the solar cell array to match the required DC voltage of the DC/AC inverter. The DC/AC inverter is adapted to convert a DC power into an AC power for supplying to the local load or injecting into the utility. The utility and the grid-connected photovoltaic generation system are connected in parallel via circuit breakers. The circuit breaker CB1 is for connecting or disconnecting the local load to the utility, while the circuit breaker CB2 is for connecting or disconnecting the grid-connected inverter to the local load.

When the utility power interruption occurs, the grid-connected photovoltaic generation system still supplies power to the local load. This phenomenon is known as the “islanding operation” [3–5]. There are many reasons for being the islanding operation undesirable.

First, it creates a safety hazard to maintenance workers. Second, islanding operation may cause unregulated voltage and frequency of the electric power, which may damage the electrical equipment. Third, the standard protection relays installed at the grid-connected point may function incorrectly. Finally, once the utility is recovered, islanding operation may cause asynchronous problem between the grid-connected photovoltaic generation system and the utility. Hence, many islanding control standards, such as UL 1741 [6], IEEE Std. 1547.1-2005 [7], IEEE Std. 929-2000 [8] and VDE 0126-1-1 [9], have been established for the grid-connected system. IEEE Std. 929-2000 and UL 1741-2000 address the issue of islanding operation and suggest a procedure for testing and qualifying the distributed power generation system. The IEEE 1547.1-2005 has been developed to address the interconnection issues for all types of the distributed power generation systems.

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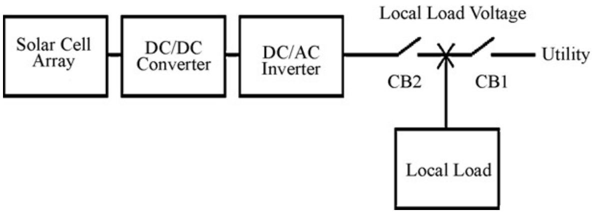

Fig. 1. System configuration of a grid-connected photovoltaic generation system.

Many islanding detection methods have been developed, which can be divided into passive, active and grid-level types. Passive islanding detection methods detect the changes in electrical parameters for determining whether the islanding operation occurs or not. Examples of passive islanding detection methods include the system-frequency detection method, voltage-amplitude detection method, and harmonic-contained detection method [3,10–13]. When the output power of the grid-connected inverter is almost equal to the power demanded by the local load, a power balance is established. As a result, the change in the amplitude or frequency of local load voltage is not significant when the islanding operation occurs. In this condition, these passive detection methods cannot detect the islanding operation, and it is named as the “non-detection zone”. Therefore, the passive islanding detection methods cannot meet the requirements of islanding control standards.

As to the active detection methods [3,13–18], the islanding detection is incorporated into the control of grid-connected inverter. Generally, a small fluctuation is added to the output current of the distributed power generation system. Since the utility is relatively strong in comparison with the distributed power generation system, the additional small fluctuation cannot significantly affect the local load voltage when the utility is in the nominal condition. Conversely, the small fluctuation can cause a significant change in frequency, amplitude or waveform of the local load voltage when the utility is interrupted. Hence, the islanding operation can be detected and judged immediately by such a change. Instantly, the distributed power generation system must be disconnected from the utility so as to avoid the islanding operation. Nevertheless, active detection methods must comply with all international islanding control standards, such that the total harmonic distortion (THD) of a current supplied from the distributed power generation system must be less than 5% [8]. Hence, the fluctuation resulted from the active detection methods must be restricted by the islanding control standards, thus increasing the detection time of islanding detection, which affects the operating reliability. Since most active detection methods still have several drawbacks, a non-detection zone still exists in some active detection methods [13,17]. Furthermore, active detection methods may be complicated and pose difficulty to their implementation.

As to the grid-level methods, they measure the electrical parameters in the utility side. Examples of grid-level detection methods include the impedance insertion methods [19]. This can prevent the islanding operation as long as the small delay is allowed between the time of switch opening and the time of insertion of capacitors or inductors to ensure that the insertion of capacitors or inductors will break the power balance between the distributed power generation system and the local load. However, the grid-level methods have the disadvantages of additional cost for inserting the capacitors or inductors and poor response as compared with other methods.

In this paper, an active islanding detection method is proposed. The proposed active islanding detection method is incorporated into the control of grid-connected inverter for protecting the grid-connected photovoltaic generation system from islanding operation. The proposed active islanding detection method performs the grid-connected inverter as a virtual resistor with the operation frequency slightly higher or lower than the fundamental frequency of the utility voltage. When the strong utility is lost, the grid-connected inverter acts as a virtual resistor with the operation frequency slightly higher or lower than the fundamental frequency of the utility voltage. Thus, the frequency and the amplitude of the local load voltage will be away from their normal values. Hence, the proposed islanding detection method can immediately detect the islanding operation. To verify the performance of the proposed active islanding detection method, a prototype, based on the digital signal processing controller TMS320LF2407A, is developed and tested.

2. Operation theory and function description

The proposed active islanding detection method performs the grid-connected inverter as a virtual resistor with the operation frequency slightly higher or lower than the fundamental frequency of the utility voltage, and it is incorporated in the controller of grid-connected inverter. The function of virtual resistor is not actuated when the utility is nominal, and the grid-connected inverter can convert the DC power from the solar array to an AC real power. For outputting an AC real power, the output current of the grid-connected inverter is desired to be sinusoidal and in phase with the utility voltage under the nominal utility condition. Harmonic components (integer multiples of the fundamental frequency) may generally exist in the utility voltage. The operation frequency of the virtual resistor is selected to be slightly higher or lower than the fundamental frequency of the utility to prevent the virtual resistor from responding to the fundamental and harmonic frequencies of the utility, which would enlarge the THD% of the grid-connected inverter’s output current. When the utility is in nominal condition, the local load voltage is equal to the utility voltage. Since the system capacity of the utility is significantly larger than that of the grid-connected inverter, the effect due to the virtual resistor operation of the grid-connected inverter is very small. Hence, the grid-connected inverter of the photovoltaic generation system is almost used to output a real power, with its output current nearly sinusoidal and in phase with the utility voltage. Consequently, the THD% of the grid-connected inverter’s output current can be maintained at a lower level to satisfy the THD% specified in the islanding control standards. Conversely, the grid-connected photovoltaic generation system is the only power supplying to the local load when the utility power interruption occurs, the virtual resistor operation of the grid-connected inverter will be actuated and resulted in a positive feedback process. Consequently, the effect of virtual resistor on the grid-connected inverter becomes more and more significant, resulting in a change of both frequency and amplitude of the local load voltage. Owing to the above response of the virtual resistor operation, the operating frequency of the local load voltage is rapidly shifted toward the vicinity of the operating frequency of the virtual resistor and the amplitude of the local load voltage is greatly changed. Therefore, the islanding operation of the grid-connected photovoltaic generation system is detected and then disconnected from the utility.

3. Control block diagram

Fig. 2 shows the control block diagram of the proposed islanding detection method for the grid-connected inverter. The grid-connected inverter is controlled by the current-mode control. The reference signal contains two components, a real power control signal S_1 and a virtual resistor control signal S_2.

Preferably, the real power control signal S_1 is a sinusoidal signal and in phase with the utility voltage. If the utility voltage is