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Active islanding detection method for inverter-based distribution generation power system

Wen-Jung Chiang [a,1], Hurng-Liahng Jou [b,*], Jinn-Chang Wu [c]

[a] Ablerex Electronics Co. Ltd., No. 157, Shueiyuan Rd., Sanmin District, Kaohsiung City 80766, Taiwan
[b] Department of Electrical Engineering, National Kaohsiung University of Applied Sciences, 415 Jiangong Road, Kaohsiung 80778, Taiwan
[c] Department of Microelectronics Engineering, National Kaohsiung Marine University, 142 Haijhuan Road, Nanzih District 81143, Taiwan

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ABSTRACT

A novel islanding detection method for an inverter-based distribution generation power system is proposed in this paper. The inverter-based distribution generation power system includes a dc power source and a grid-connected DC/AC inverter. The grid-connected DC/AC inverter acts as a virtual capacitor as the frequency is slightly lower than the fundamental frequency of utility voltage. Since only the inverter-based distribution generation power system supplies power to the load as the utility power interruption occurs, the virtual capacitor operation of the inverter-based distribution generation power system will result in the change of load voltage in amplitude or frequency. Hence, the proposed method can immediately detect the islanding operation.

1. Introduction

Generally, small capacity distributed generation power systems, such as small capacity power stations or renewable power stations, serve in some electric power markets. Currently, renewable energies suitable for generating electric power include solar power, wind power and fuel-cell power. In the future, many small capacity distributed generation power systems will be incorporated into the utility power system.

The small capacity distributed generation power systems are directly incorporated into the utility for supplying electric power to loads. Conventionally, there are some protection methods for the distributed generation power systems, including the detection of electric power quality and islanding operation. An operation so-called "islanding operation" is where a small capacity distributed generation power system still supplies electric power when the utility is cut off due to power failure or maintenance of electrical equipment [1,2]. Accordingly, this may cause the distributed generation power system supplying electric power individually. Many problems caused by the islanding operation are:

(1) islanding operation may jeopardize public security or endanger maintenance workers;
(2) islanding operation may cause unregulated voltage and frequency of electric power of the distributed generation power systems so that the electrical equipment may be damaged;
(3) islanding operation may cause malfunction of protection relays; and
(4) once the utility is recovered, islanding operation may cause asynchronous problems between the distributed generation power systems and the utility.

Hence, many islanding control standards, such as, UL1741–2000 [3], IEEE1547.1–2005 [4] and IEEE929–2000 [5] have been established in Europe, United States of America, Japan and other countries.

The islanding detection methods can be divided into active, passive and communication-based detection methods. The passive detection methods are used to detect the change of parameters in a distributed generation power system for determining whether the islanding operation occurs. For example, the passive detection methods include a system-frequency detection method [6], a voltage-amplitude detection method [6], and a harmonic-contained detection method [7]. However, both amplitude and frequency will not change if the power supplied from the distributed generation power system is the same as the power demanded by the load. In this condition, these passive detection methods cannot detect the islanding operation, and it is named as the "non-detection zone". Accordingly, these passive detection methods cannot meet the requirements of the islanding control standards.

As to the active detection methods, it is used in the distributed generation power system with inverter interface, named as

* Corresponding author. Tel.: +886 7 3814526x5519; fax: +886 7 3921073.
E-mail addresses: peter.chiang@ablerex.com.tw (W.-J. Chiang), hljou@mail.ee.kuas.edu.tw (H.-L. Jou), jinnwu@mail.nkmu.edu.tw (J.-C. Wu).
[1] Tel.: +886 7 3978640x829.

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inverter-based distribution generation power system, and a small fluctuation is incorporated with the output current to inject into the utility [8–15]. When the utility is nominal, the small fluctuation results in a neglected change of load voltage because the utility is very strong. Conversely, when the utility is interrupted, the small fluctuation can cause a great change in frequency or amplitude of load voltage. In this way, a protection relay can immediately detect such a change and judge it as an islanding operation. Instantly, the inverter-based distribution generation power system must be disconnected from the utility so as to avoid islanding operation. Nevertheless, these active detection methods must comply with all international islanding control standards, such that the total harmonic distortion of an output current supplied from the inverter-based distribution generation power system must be less than 5% [5]. Hence, the fluctuation resulting from these active detection methods must be restricted by the islanding control standards so that the detection time of islanding detection is increased. However, there is a non-detection zone still existing in some active detection methods. Furthermore, a control method employed in the inverter-based distribution generation power system with these active detection methods may be sophisticated.

The communication-based methods for detecting the islanding operation are mainly based on monitoring the state of circuit breakers and switches and trip the grid-connected power converter when the utility is disconnected [16,17]. However, these methods are more expensive and complexity than other islanding detection methods because the additional hardware for communication is required.

A novel islanding detection method for an inverter-based distribution generation power system is proposed in this paper. In the proposed method, the grid-connected DC/AC inverter acts as a virtual capacitor as the frequency is slightly lower than the fundamental frequency of the nominal utility. When the power interruption of the utility occurs, the amplitude or frequency of load voltage will be changed evidently. Hence, the islanding operation can be immediately detected. Finally, a prototype is developed and tested to verify the performance of the proposed active islanding detection method.

2. System configuration and function description

Fig. 1 shows the system configuration of an inverter-based distribution generation power system. The utility is adapted to supply a fixed frequency of AC power. The inverter-based distribution generation power system includes a DC power source and a grid-connected DC/AC inverter, wherein the DC power source can be selected from a solar-energy cell, a fuel cell, an output voltage of AC/DC converter for a wind power generator or any other renewable energy sources. The grid-connected DC/AC inverter is adapted to convert the power of DC power source into an AC power for supplying to the load and injecting into the utility. The utility and the inverter-based distribution generation power system are connected in parallel via electromagnetic switches.

In the proposed islanding detection method, the grid-connected DC/AC inverter of inverter-based distribution generation power system is controlled to act as a virtual capacitor at a frequency slightly lower than the fundamental frequency of the utility. When the utility is nominal, the load voltage is equal to the utility voltage. The output current of the grid-connected DC/AC inverter is sinusoidal and in phase with the utility voltage, which supplies real power to the load or injects into the utility. Owing to the utility being strong enough and not containing the operating frequency of the virtual capacitor; the output current of the grid-connected DC/AC inverter is not influenced apparently by the operation of virtual capacitor and maintained below the total harmonic distortion (THD) provided in the islanding control standards. Conversely, when the utility is interrupted, only the inverter-based distribution generation power system supplies power to the load so that the inverter acting as the virtual capacitor is enabled. In response to the influence of the virtual capacitor operation, the frequency of the load voltage is rapidly shifted toward the vicinity of the operating frequency for the virtual capacitor or the amplitude of the load voltage is greatly changed. Accordingly, the islanding operation of the inverter-based distribution generation power system is detected and thus the inverter-based distribution generation power system is disconnected from the utility. Hence, the proposed islanding detection method can detect the islanding operation effectively. However, the influence of the virtual capacitor operation to the output of the inverter is unapparent under the nominal utility; thus the output current of the inverter-based distribution generation power system will be sinusoidal and can meet the harmonic standard.

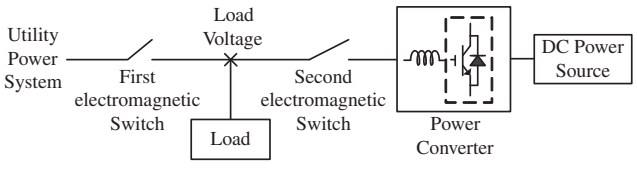

Fig. 1. System configuration of a distribution generation power system.

3. Control block diagram

Fig. 2 shows the control block diagram of the proposed islanding detection method for the grid-connected DC/AC inverter. The grid-connected DC/AC inverter is controlled by the current mode control. The reference signal contains two components including a real power control signal S_1 and a virtual capacitor control signal S_2. The real power control signal S_1 can determine the amount of real power supplied from the inverter-based distribution generation power system. Preferably, the real power control signal S_1 is a sine-wave signal whose frequency and phase are identical with those of the utility voltage. Initially, the load voltage is detected by the voltage detector and sent to a band-pass filter (I), with a center frequency the same as the fundamental frequency of the utility. The output of band-pass filter (I) is the waveform of real power control signal S_1. The output of the band-pass filter (I) is multiplied by an amplitude signal in a multiplier so as to obtain the real power control signal S_1. Since the real power control signal S_1 is sinusoidal and in phase with the utility voltage, the real power supplied from the inverter-based distribution generation power system is proportional to the amplitude of the real power control signal S_1. Accordingly, the amplitude signal is determined by the magnitude of energy generated from the DC power source if the loss of power converter can be neglected.

The virtual capacitor control signal S_2 is used to control the grid-connected DC/AC inverter to act as a virtual capacitor. The operating frequency of the virtual capacitor is slightly lower than the fundamental frequency of the utility for detecting the islanding operation. The detected load voltage and the output of the band-pass filter (I) are sent to a subtractor, and the results of the subtractor are the components of load voltage whose frequency is unequal to the fundamental frequency of the utility. Subsequently, the subtracted result is sent to a band-pass filter (II), which has a center frequency slightly lower than the fundamental frequency of the utility. Subsequently, an output of the band-pass filter (II) is sent to the differential circuit to generate the virtual capacitor control signal S_2.