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Hybrid photovoltaic generation system with novel islanding detection method

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ABSTRACT

This paper proposes an islanding detection method for a hybrid photovoltaic generation system (HPGS). This HPGS is controlled using an improved voltage-mode control method in both the grid-connected and the stand-alone conditions to unify and simplify the control circuit. The inverter of this HPGS is multi-functional, so it can perform the functions of active power filter, charging/discharging a battery set, uninterruptible power supply, and injecting power into the grid of distribution power system. The proposed islanding detection method is incorporated into the controller of the inverter. The advantage of islanding detection method is the time required to add a disturbance for detecting the islanding operation is very short. A prototype is developed and tested to verify the performance of the proposed HPGS. The experimental results verify that the proposed islanding detection method can effectively detect the islanding operation, so this HPGS achieves the expected performance.

1. Introduction

The photovoltaic generation system (PGS) can be divided into three types, namely stand-alone, grid-connection, and hybrid. A stand-alone PGS supplies power to the individual load, and its inverter is generally controlled by a voltage-mode control to supply a sinusoidal voltage for the load. A grid-connected PGS converts the unregulated output power from a solar cell array into regulated power and its inverter is generally controlled by a current-mode control to generate a sinusoidal current that is injected into the utility. If a non-linear load is applied at the output of the inverter, the non-linear load generates a harmonic current that is injected into the utility. Under this condition, the utility current is distorted. Therefore, a conventional grid-connected PGS cannot solve the harmonic current problem in a nonlinear load. A hybrid photovoltaic generation system (HPGS) combines the hybrid sources, a solar cell array and a battery set [1,2], so it can be operated in the grid-connected condition for a nominal utility and in the stand-alone condition for a failed utility. This means that the control of the inverter for a HPGS must switch between the current-mode and the voltage-mode when the operation mode of the HPGS is changed, which complicates the control circuit. Non-trivial transient currents may also occur at the transient when the operation mode changes [2]. If both of the grid-connected and the stand-alone conditions of the HPGS can use the voltage-mode control, the switch between two control modes can be avoided, so the control circuit is unified and simplified, and the problem of non-trivial transient currents is alleviated. However, if the two control loops (amplitude and phase) are incorporated, the transient response of the conventional voltage-mode grid-connected power converter is slower than that of the current-mode grid-connected power converter [3].

For operational safety, the PGS must be disconnected from the utility to avoid unintentional islanding operation [4,5]. Several detection methods for unintentional islanding operation of the renewable power generation system have been developed, and can be divided into passive, active, and grid-level types. Passive islanding detection methods [6–9] have the disadvantage of having a “non-detection zone”. Active detection methods incorporate islanding detection into the control of the inverter [8,10–12]. Generally, they have a disadvantage that a small perturbation is always added to the output current of the inverter for islanding detection. Nevertheless, active detection methods must comply with all international islanding control standards, so the total harmonic distortion (THD) of the output current supplied from a renewable power generation system must be less than 5% [13–15]. This limits the reliability of islanding detection for active detection methods. Compared to other methods, grid-level detection methods [14] have the disadvantages of the additional cost of inserting the capacitors or inductors and poorer response.

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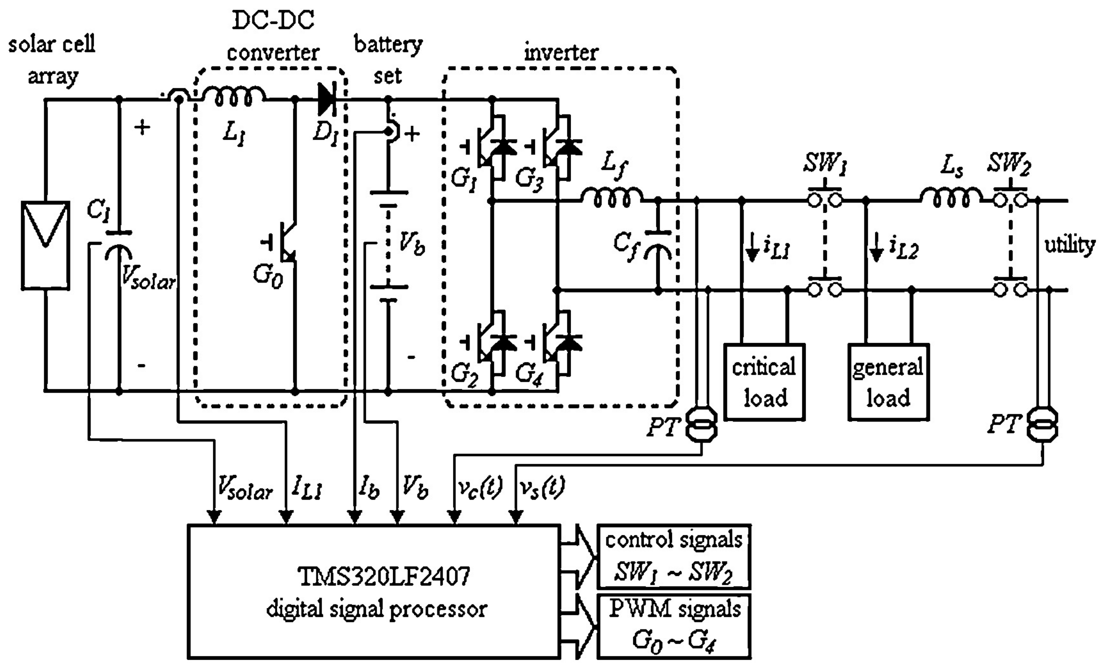

Fig. 1. Proposed configuration of the HPGS.

Conventionally, most active detection methods are designed only for the current-mode PGS where the inverter generates a sinusoidal current to be injected into the grid [9,16,17]. The perturbation of active detection methods must be always applied for islanding detection, and it may be the interference of the distribution power system. Since a battery set is incorporated in the HPGS, it can supply an uninterruptable power to the load. Accordingly, the HPGS can operate in both the grid-connected and the stand-alone conditions. The islanding detection method is important to detect the utility condition and thus to switch the operation modes of HPGS. In this paper, an improved voltage-mode control method [18] is used in both the grid-connected and stand-alone conditions, and the control circuit of HPGS is unified and simplified. An islanding detection method is proposed and integrated into the improved voltage-mode control of a hybrid photovoltaic generation system. The salient feature of the proposed islanding detection method is that the perturbation for detecting the islanding operation is applied only when the amplitude of the utility current approaches zero. Therefore, the proposed islanding detected method has an advantage that the perturbation is not applied continually. Hence, the time required to add a disturbance for detecting the islanding detection is very short. A prototype is developed and tested to verify the performance of the proposed HPGS.

2. System configuration

Fig. 1 shows the proposed configuration of the HPGS. As can be seen, it includes a solar cell array, a DC–DC converter, an inverter, a battery set, a link inductor L_s, two switches (SW_1 and SW_2) and a controller that uses a digital signal processor (DSP). The battery set is placed between the DC–DC converter and the inverter to serve as an energy buffer. The DC–DC converter is a boost converter that boosts the voltage and tracks the maximum output power of the solar cell array when the utility is normal, and it charges the battery set when the utility fails. The output of the inverter is connected to the utility through a link inductor, SW_1 and SW_2. The critical load is connected between the output of the inverter and SW_1, and the general load is connected between SW_1 and the link inductor. The critical load is emergency equipment. A low-pass filter that is composed of L_f and C_f is applied to filter out the switching harmonics of the inverter. When the utility is normal, the inverter processes the bidirectional power conversion between the DC and AC sides and performs the function of an active power filter. An islanding detection control is also incorporated into the control of the inverter. Therefore, the inverter can also detect the islanding operation and trip off the switches SW_1 and SW_2. As a result, the power of the general load is interrupted, and the inverter supplies uninterrupted power to the critical load. Switches, SW_1 and SW_2, are closed again when the utility recovers.

3. Control principle

The inverter is controlled using an improved voltage-mode control algorithm [18]. Fig. 2 shows the simplified equivalent circuit for the inverter controlled by the voltage-mode control. Both the amplitude and phase of the output voltage of the inverter are used to regulate the reactive and real power flows. Since the HPGS performs the function of an active power filter, the utility current must be sinusoidal and the unity power factor independent of the loads. As seen in Fig. 3, the output voltage of the inverter is derived as [18]:

$$V_c = V_s \mp jX_sI_{s1} \quad (1)$$

where X_s is the impedance of the link inductor. As seen in (1), the only parameter that can be controlled in the improved

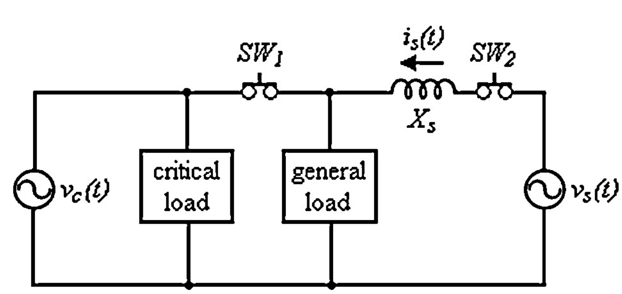

Fig. 2. Simplified model of the inverter controlled by the voltage-mode control.