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Uninterruptible smart house equipped with the phase synchronization control system

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ABSTRACT

Recently, the exhaustion of energy resources has become an important issue. Hence, renewable energy has attracted considerable attention. In particular, the development of a smart house equipped with a photovoltaic (PV) system and storage battery is proceeding rapidly. A smart house must avoid interruptions of power supply because the power supply is very important for an all-electric house. Therefore, the smart house needs uninterruptible power features. The proposed uninterruptible smart house has seamless features for transitioning between stand-alone mode and grid-connected mode by phase synchronization control. Also, this smart house achieves a reduction of transient current at transition from stand-alone mode to grid-connected mode. The effectiveness of the proposed method is verified by simulation results in MATLAB®/SimPowerSystems.

Introduction

Reduction of carbon dioxide emissions for the prevention of global warming is a big challenge for every nation. Residential energy conservation is also an important issue. Methods to reduce wasteful energy consumption without the conscious efforts of residents are required because energy conservation can lower costs of power use, and it is difficult to get residents to consciously reduce consumption. HEMS (Home Energy Management System) is mentioned as a solution that can be used to reduce energy consumption and help achieve energy conservation [1–6]. After the Tohoku Earthquake in Japan, saving power at home has become a recommended goal and shortage of power supply has become a concern for the nation. Hence, building a society which minimizes energy consumption is necessary. The smart grid and micro-grid are likely be solutions to achieve this society by the effective use of energy for houses and buildings, and transport systems that are connected the IT network in the region [7–10]. In particular, the expected interest in a smart house equipped with a photovoltaic (PV) system and HEMS has been increasing and the smart house will perform a central role on building a smart grid and micro-grid. Housing manufacturers have begun to develop houses equipped with HEMS, hence the spread of smart houses has been rising. Currently, PV systems are widely used in houses, and a stand-alone operation feature is installed, so that power can be used even when an extended outage has occurred due to natural disasters such as typhoons and earthquakes. However, switching to stand-alone mode must be done manually, after which the power is supplied only to emergency outlets. The transition from stand-alone mode to grid-connected mode must also be done manually.

In addition to the PV system, the installation of a storage battery in the house has also gained a lot of attention. For a long lasting power outage, a storage battery on the degree of 8–10 kW h is required to ensure the capacity of a full night. If an inhabitant wishes to install a larger capacity storage battery, they will be required to spend a lot of money for storage battery installation, because the price of batteries is directly related to size. If it becomes possible to supply power to a house using a small capacity storage battery, then the rapidly widespread use of storage batteries can be considered. There are some problems in transitioning from stand-alone mode to grid-connected mode. If a fault occurs in the distribution system and the house loses the phase information of the distribution system, compensating the power with a frequency of 60 Hz in house will be necessary. Also, if a phase difference between the distribution voltage and receiving voltage is generated while in stand-alone mode, the power system in the house must perform a phase synchronization with the distribution system to connect again after the recovery of the distribution system.

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The proposed smart house in this paper is disconnected automatically from the system during a distribution system fault. Stand-alone mode compensates the power with a frequency of 60 Hz at house. When the power is restored, the house is connected automatically to the distribution system. In addition, the smart house is equipped with a small capacity storage battery and a PV system. The proposed energy management which is assumed to be HEMS is capable of supplying power from the PV system and a storage battery while in stand-alone mode. In order to achieve high-efficiency operation, maximum power point tracking (MPPT) control, which considers partial shadowing, has been applied to the PV system [11–13]. Validation of this study are verified by MATLAB®/SimPowerSystems.

System configuration

The smart house introduced in this paper is assumed to have HEMS and smart appliances which can be operated by the HEMS. In addition, it is also assumed that a wireless communication unit is used in the house and that the device is capable of sending signals to each smart appliance from the HEMS using Wi-Fi (wireless fidelity). By using wireless communication techniques, it becomes possible for the inhabitants to control smart appliances and to retrieve data, such as the state of the system and power consumption in the house. Fig. 1 shows the configuration of the smart house. If an accidental power outage or voltage sag occurs in the distribution system, then the in-house power system will supply power. After the restoration of a fault, the in-house power system performs an automatic phase synchronization and reconnects to the distribution system.

The house is equipped with a small capacity storage battery (2 kW h) and PV system (3 kW). By using the small capacity battery, a significant reduction of installation costs can be expected when compared to the installation of a large capacity storage battery. In the past, a battery on the degree of 10 kW h was required to ensure overnight power. In this paper, demand balance control using the storage battery of 2 kW h is achieved by adjusting the power consumption of the smart appliances with load controlling. Fig. 2 shows the simulation circuit configuration. The PV system is connected to a DC–DC buck-boost converter in order to perform MPPT control of the PV. The storage battery is connected to the DC–DC boost converter for maintaining a DC-link voltage of 350 V. The PV and storage battery are also connected to the DC-link. Accordingly, a reduction of the number of converters used, along with a reduction of power loss becomes possible. Also, reduction of PV output power fluctuation is made possible by the storage battery. The DC system comprising the PV and storage battery is connected to the single phase distribution system of 200 V.

Photovoltaic system

The model of the PV array used in this study has been simulated as a current source with the basic equations of a PV [14]. Table 1 shows the values of constants for the standard state of each PV panel used in the present study. The SEPIC (Single-Ended Primary Inductance Converter) is shown in Fig. 3. It is a buck-boost converter which has been adopted as DC-DC converter and is connected to the PV panel [15,16]. SEPIC has many advantages such as a protection function during a short-circuit, the polarity of the input and output voltages are the same, and in principle the input voltage ripple is suppressed to zero.

Storage battery system

The storage battery has been boosted from 200 V to 350 V by connecting to a DC–DC boost converter as shown in Fig. 4. Droop control has been applied to suppress fluctuations of the DC-link voltage, V_{DC}, and to control charging and discharging of the storage battery [17]. Fig. 5 shows the control configuration of the storage battery. The current command value, I_b^*, is determined by the PI control using the state of charge for storage battery, ξ_b, and the droop coefficient, R_b. Allowable DC-link voltage variation is ±30 V ($V_{DC} = 320 \sim 380$ V).

Control method

Phase detection

The detection accuracy of the distribution voltage phase and the receiving voltage has a significant impact on control performance. Because this paper assumes a fault in the distribution system, a PLL (Phase-locked loop) circuit is required to estimate the phase with good accuracy at times of voltage fluctuations and frequency variations. Therefore, the phase of the system is estimated using a single-phase ALOF-PLL circuit that maintains a good accuracy during voltage fluctuations and frequency variations [18].

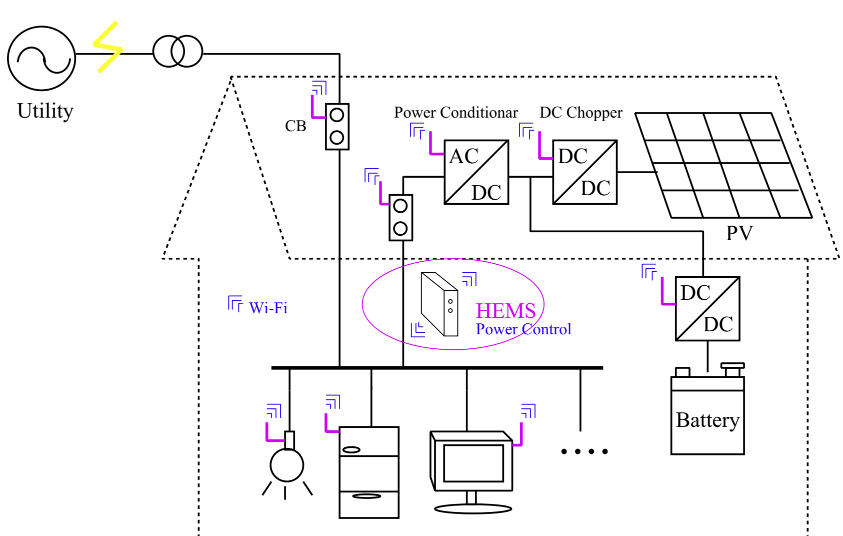

Fig. 1. Configuration of smart House.