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Modeling and coordinate control of photovoltaic DC building module based BIPV system

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Abstract

This paper presents the modeling method and coordinate control strategy for photovoltaic dc building module (PV-DCBM) based building integrated photovoltaic (BIPV) system. The PV-DCBM based BIPV system consists of plenty of PV-DCBMs and a centralized inverter which are coupled to the common dc bus in parallel. Each PV-DCBM is integrated with a PV building material to extract maximum power from it and then a centralized inverter is used to transfer the power to the grid. The PV-DCBM based BIPV system has some significant advantages for building integrated applications, such as individual MPPT, inherent data monitor, low cost and excellent expandability. A coordinate control strategy based on energy balance of the PV-DCBM based BIPV system is proposed to realize the individual control for each PV-DCBM and the centralized inverter. The accurate small-signal model of the PV-DCBM based BIPV system is built based on the proposed operation principle and a detailed design approach of the coordinate controller is proposed. Experimental results on the laboratory prototype verify the validity of the proposed modeling and coordinate control method.

Keywords: Building integrated photovoltaic; Centralized inverter; Coordinate control; Photovoltaic dc building module; Small signal modeling

1. Introduction

Building integrated photovoltaic (BIPV) system not only produces electricity, it also serves as part of the building envelope, such as roof tiles, facade elements and shading devices. The BIPV system operates as a multifunctional construction material and has some advantages such as reduced installation costs, shortened energy payback time and pleasant architectural appearance. Therefore, BIPV systems are attracting more and more concerns all around the world in recent years.

A number of BIPV systems have been installed and operated well in many countries (Castro et al., 2005; Jansen et al., 2008; Yang et al., 2004). The power configurations usually adopted in these BIPV systems include centralized system, string/multi-string system and ac module based system (Kjaer et al., 2005). In centralized system (Kim et al., 2009; Liu et al., 2009), the PV modules are usually series connected as a string to avoid further amplification of the voltage, and then plenty of strings may be parallel connected by string diodes to achieve expected power levels. However, the energy efficiency of the centralized system is poor due to a centralized maximum power point tracking (MPPT), mismatch losses between the PV modules, and losses in the string diodes. Each PV module string in the string/multi-string system is connected to a dc–dc converter to perform MPPT, and then a common inverter is used to interface with grid (Meinhardt et al., 2000). The string/multi-string system is especially suitable for the BIPV system, in which the PV modules have several different installation orientations and angles, because it has individual MPPT tracker for each PV module string and cancels the

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string diodes. However the mismatch losses in the PV module strings are still existent. The ac module integrates a dc–ac converter and a PV module into one plug and play ac generator device with individual MPPT (Choi and Lai, 2010; Islam et al., 2006; Kjaer, 2004). The ac module based system, which consists of plenty of ac modules coupled to the grid in parallel, is almost a perfect choice for BIPV application, because it is easy to enlarge system capacity and has good anti-mismatch performance. However the ac module integrated inverter needs more complex circuit topologies to achieve high voltage gain, hence the overall converter efficiency may be reduced. Moreover, the ac module based system is hard to operate both in the grid-connected and stand-alone mode.

The photovoltaic dc building module (PV-DCBM) based BIPV system is an efficient and cost-effective power configuration for building integrated application due to some significant advantages over conventional power configurations, such as individual MPPT for every PV module, inherent and low cost data monitor and excellent expandability (Liu et al., 2011). The PV-DCBM based BIPV system, as shown in Fig. 1a, is composed of plenty of PV-DCBMs and a centralized inverter which are coupled to the common dc bus in parallel. The PV-DCBM boosts the lower output voltage of the PV module to a high enough voltage, such as 200 V and 400 V, and thus a simple and high-efficiency single stage inverter can be used to power the grid. The main function of the controller in PV-DCBM is tracking maximum power point of the corresponding PV module. According to the specific demand of PV module, several design criterions of PV-DCBM are proposed and some suitable converter topologies are compared and evaluated, and the active clamping current-fed half-bridge converter (ACCFHBC) (Han et al., 2005) is selected as the more potential candidate for designing PV-DCBM. The ACCFHBC has some significant advantages: (1) lower input ripple can be achieved with minimum electrolyte capacitor size, which increases MPPT efficiency and lifetime; (2) the zero voltage switching (ZVS) of all active switches can be achieved, and the voltage surges across the turn-off switch are low; (3) all magnetic components can be integrated into one magnetic assembly to reduce number of components. Suitable converter topologies for PV-DCBM based BIPV system are shown in Fig. 1b, where the conventional full-bridge converter is adopted as the centralized inverter. However, the detailed modeling and controller design method of the system have not been discussed.

The illumination and temperature of PV modules depend on many factors, such as solar radiation, circumstance temperature, and partial shadow condition. The output power of PV modules varies with illumination and temperature, and is complex to accurately forecast. Therefore the system control strategy must be powerful enough to extract more energy from each PV module and transfer them to the grid steadily and rapidly. The objective of this paper is to present the detailed modeling and coordinate control strategy of the PV-DCBM based BIPV system in which the topologies shown in Fig. 1b are adopted. Some experimental results on the laboratory prototype are provided to verify the proposed modeling method and coordinate control strategy.

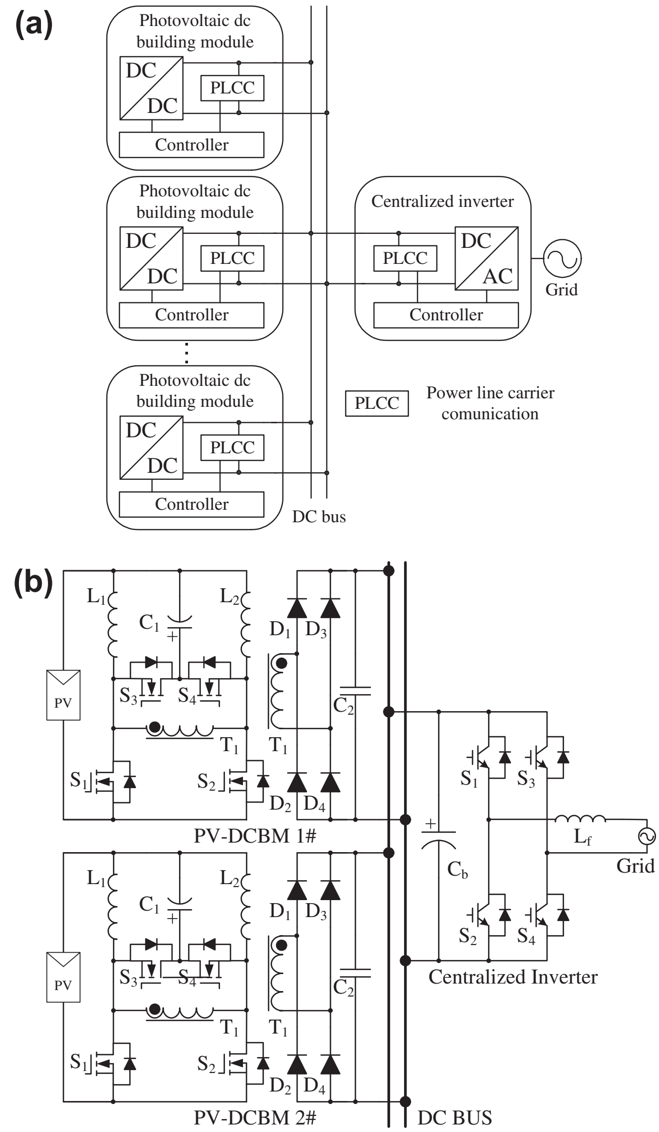

Fig. 1. PV-DCBM based BIPV system: (a) power configuration and (b) suitable converter topologies.

2. Principle of coordinate control

In the PV-DCBM based BIPV system, each of the PV-DCBMs extracts the maximum power from the integrated PV module, and all the energy is gathered together and fed into the grid via the centralized inverter. Fig. 2 shows the energy flow in the PV-DCBM based BIPV system, which consists of the N PV-DCBMs and a centralized inverter. P_{pvi} is the output power of the ith PV module, P_m is the total input power of the centralized inverter, and P_g is the output power to the grid. The necessary condition for