Photovoltaic Micro Converter Operated in Boundary Conduction Mode Interfaced with DC Distribution System

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Abstract

Research on photovoltaic (PV) generation is taking a lot of attention due to its infinity and environment-friendliness with decrease of price per PV cell. While central inverters connect group of PV modules to utility grid in which maximum power point tracking (MPPT) for each module is difficult, micro inverter is attached on each module so that MPPT for individual modules can be easily achieved. Moreover, energy generation and consumption efficiency can be much improved by employing direct current (DC) distribution system. In this paper, a digitally controlled PV micro converter interfacing PV to DC distribution system is proposed. Boundary conduction mode (BCM) is utilized to achieve zero voltage switching (ZVS) of active switch and eliminate reverse recovery problem of passive switch. A 120W prototype boost PV micro converter is implemented to verify the feasibility and experimental results show higher than 98% efficiency at peak power and 97.29% of European efficiency.

1. Introduction

DC distribution system is considered as an effective solution to the system such as residential and commercial buildings, in which a majority of power consumption devices prefers DC-type power supply. Moreover, renewable energy sources and storage devices can be fully utilized due to their excellent compatibility with DC distribution system. In alternative current (AC) system, renewable sources such as photovoltaic require DC-AC inverter interface because they generate DC power or they need DC link (wind farm). However, they can be directly connected to DC system with reduced power conversion stages which allows achieving higher system efficiency [1, 2].

Photovoltaic is a representative renewable source due to its infinity and ease of utilization. Furthermore, recent light-to-electric conversion efficiency improvement and cost reduction of PV cell also increase its feasibility. And also, building integrated PV (BIPV) modules are widely applied in buildings due to its merits. In application of PV to residential and commercial buildings, mismatch issue caused by radiation differences,

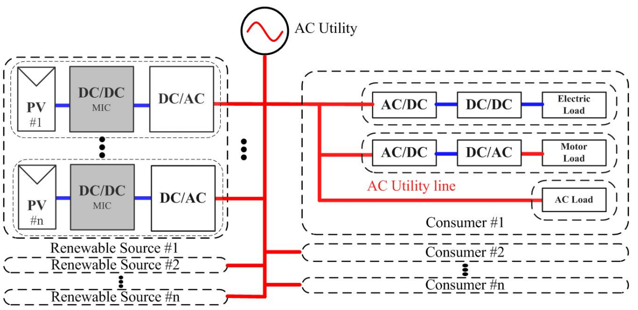

Fig. 1. Conventional AC distribution system with PV generation.

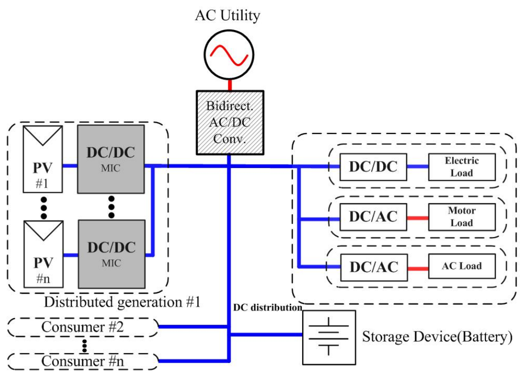

Fig. 2. DC distribution system with PV generation and storage device.

reflection, obstacles and PV cell tolerance which cause difficulties in maximum power point tracking (MPPT) of each PV module become a major concern. Module integrated converters (MIC), which are attached on the back of each module and play as a maximum power tracker from the individual PV panels, are known as a general solution and a lot of researches have been done [3]-[5]. In this paper, a PV micro converter for a BIPV module interfaced with DC distribution system is proposed. The converter is operated in BCM to obtain ZVS of MOSFET and eliminate reverse recovery loss of diode. A 120W boost type micro converter module is designed considering operating conditions. Experimental results show maximum efficiency of 98.1% at maximum power point achieving zero voltage turn-on of MOSFET and zero current turn-off of diode.

2. Micro Converter Interfaced with DC Distribution

Fig. 1 shows the conventional system diagram of AC distribution system with PV micro inverters. As shown in dotted boxes in Fig. 1, micro inverters are attached in each module to fully harvest the solar energy. In view of system energy flow, the generated power should be converted to AC although PV modules generate DC power. Moreover, it should be converted again to DC by internal AC/DC rectifier in electric equipment in AC interface

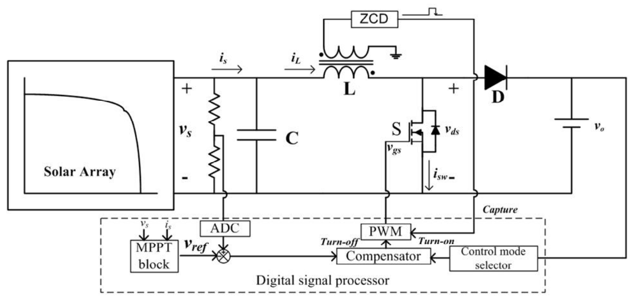

Fig. 3. Boost PV micro converter operated in BCM with a DSP.

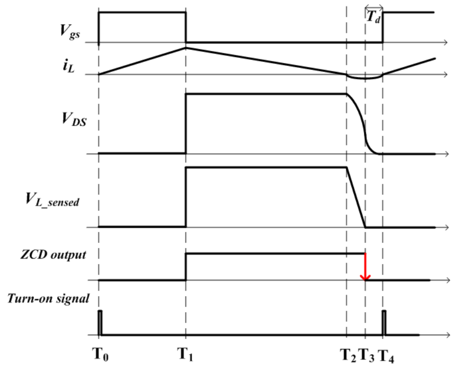

Fig. 4. Operational waveforms of BCM boost converter.

system. Due to its inefficacy, substantial energy dissipates in conversion stages.

Fig. 2 shows the DC distribution system equipped with DC PV micro converters. The system is much simpler than the conventional one as the redundant AC-DC and DC-AC power conversion stages are eliminated. Integrated bidirectional AC-DC converter at the front of a building interfaces to the AC grid. With storage devices such as Li-ion battery which can back up the energy generated by renewable sources minimizing unnecessary energy exchange, the energy efficiency can be maximized.

In this paper, boost converter for a 120W BIPV module is considered to obtain high efficiency with simple structure and ease of control. The converter is operated in boundary condition to achieve ZVS of switch and zero current turn-off of diode, which are effective to reduce switching losses.

Fig. 3 shows schematic of the boost micro converter operated in BCM. A digital signal processor is employed and it controls the operating condition of PV module. PV voltage and current are sensed to achieve MPPT and a zero current detector is used to implement BCM operation. As shown in fig. 4. the voltage across the inductor is sensed through the auxiliary winding, and ZVS can be achieved with proper time delay T_d. Output voltage of MIC is also monitored to change operation mode in special cases such as utility disconnection and for system protection (anti-islanding).

3. Converter Design and Experimental Result

120W prototype PV micro converter was designed considering a BIPV module whose MPPT voltage is about 130V. DC distribution voltage, output voltage of PV converter is tightly regulated at 380V by an AC-DC power supply. 65kHz minimum operating frequency f_s and 710uH of inductance are determined based on (1). Switching frequency range is about 65 kHz to 200kHz according to radiation. To suppress switching loss at light load condition and achieve high efficiency, maximum frequency limitation is implemented in the software.

$$L = \frac{V_s(V_o - V_s)}{2 I_s f_s V_o} \qquad (1)$$

TMS320F28335, a digital signal processor manufactured by Texas Instrument Incorporated is employed utilizing its ADC, E-PWM, E-CAP modules as shown in block diagrams in fig. 3.

Fig. 5 shows the experimental results of the prototype PV converter at maximum radiation condition. ZVS operation is achieved using zero current detection circuit and 98.1% efficiency is observed. And also, switching frequency increase at light load condition is suppressed by control algorithm. By utilizing ZCD circuit together with the algorithm, ZVS is achieved in the entire load condition. Fig. 6 shows the experimental waveforms which confirm the algorithm at 20% radiation condition and 97% efficiency is achieved. European efficiency as below, weighted summation of efficiency considering daily radiation is 97.29%.

$$\eta_{Euro} = 0.03\eta_{5\%} + 0.06\eta_{10\%} + 0.13\eta_{20\%} + 0.1\eta_{30\%} + 0.48\eta_{50\%} + 0.2\eta_{100\%}$$

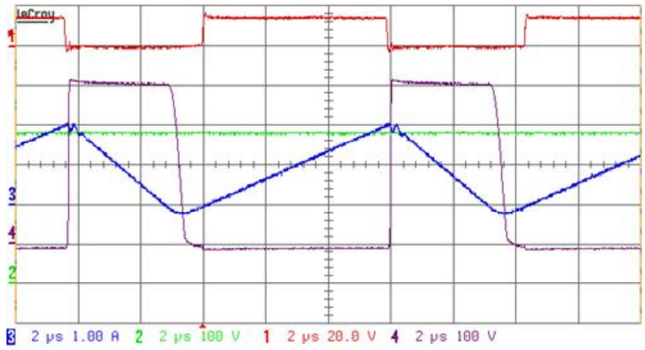

Fig. 5. Experimental waveforms of designed boost converter at 120W. CH1: V_{gs}, CH2: V_o, CH3: i_L, CH4: V_{DS}

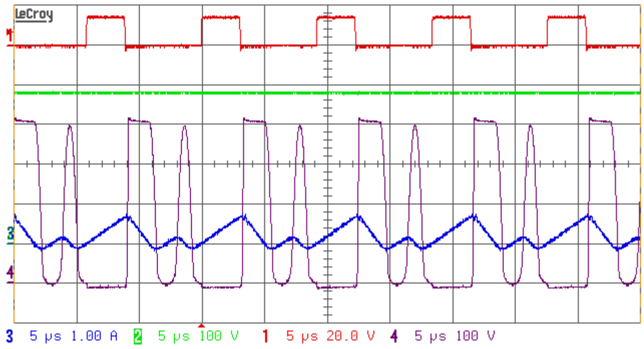

Fig. 6. Experimental waveforms of designed boost converter at 24W. CH1: V_{gs}, CH2: V_o, CH3: i_L, CH4: V_{DS}

4. Conclusion

In this paper, a digitally controlled PV micro converter interfaced with DC distribution system is proposed. With this approach, the advantages of renewable energy sources can be maximized with very high energy generation and consumption efficiency. In addition, simple structure and intelligent algorithm increase its feasibility. High efficiency of maximum 98.1% and 97.29% of European weighted efficiency confirms its applicability to DC distribution system in residential and commercial buildings.

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