Digitally Controlled Interleaving Tapped-Inductor Boost Converter for Photovoltaic Module Integrated Converters (PV MIC)

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Abstract

As global warming due to burning fossil fuels and natural resource depletion issues have emerged, the development of renewable energy sources such as photovoltaics (PV) has been brought to recent interest. Amongst the vast efforts to harvest and convert solar energy into electricity, the module integrated converters (MIC) has become a worthy topic of research for grid-connected photovoltaic systems. Due to the required high-boosting qualities, only a restricted amount of DC/DC converter topologies can be applied to MICs. This paper investigates the possibility of a tapped-inductor boost converter as a candidate for PV MICs. A dual-inductor interleaving scheme operating slightly above the boundary of the two conduction modes (BCM) is suggested for reduction of input current ripple and minimization of component stress. A digital controller is used for implementation, assuring maximum power tracking and transfer while providing sufficient computational space for other grid connectivity applications, etc. For verification, a 200W converter is designed and simulated via computer software including component losses. High efficiency over a wide power range proves the feasibility of the proposed PV MIC system.

1. Introduction

The increasing interest towards clean and sustainable energy generation has brought attention to renewable energy sources such as solar energy, wind energy, etc. Among these energy sources solar power generation is extremely prominent because it uses the almost infinite radiation of sunlight and it creates almost zero pollution during the generation process. Many scientists have been studying vast fields related to photovoltaics where the recent development of monocrystalline and polycrystalline silicon photovoltaic cells has yielded prototype energy conversion efficiencies of up to 50%; the PV output voltage ranges from 18 to 40V and output power ranges from 100 to 250W under standard test conditions. Although the average output power of the PV cells has roughly doubled during the past decade, the PV output voltage range has remained nearly constant [1]. To entirely utilize the generated solar power from the PV panel, a converting stage is required to match the demanded voltage for effective grid connection. Since the conventional 220V AC grid requires a minimum DC link voltage of 350V, a DC-DC converting topology with a boosting ability of more than 10 times its input is inevitable.

Recent development of household solar generation systems has brought the downsizing of PV modules to as low as several hundred watts. As households differ in size and power demand, conventional multi-kilowatt stereotype-capacity solar power models cannot cover the optimal design for smaller applications. Conventional solar power models usually stack up or connect PV panels in series to obtain a relatively higher overall output voltage, relieving the DC-DC converter stage from a high boosting requirement. But as a side effect the PV output power consequently increases together, eliminating the possibility of smaller sized applications. Therefore by implementing a high boosting converter to each of the smaller PV panels, the diversity of solar power applications can be achieved. This is typically called a module integrated converter (MIC). Fig. 1 shows two types of single phase PV MICs where (a) includes micro-inverters for direct AC grid connection and (b) utilizes a larger external inverter.

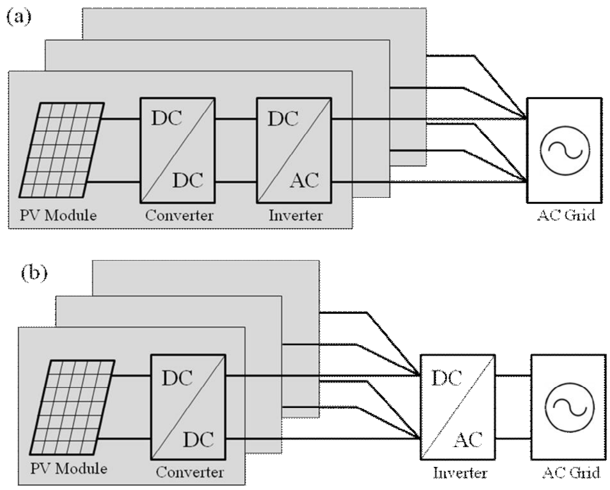

Fig. 1 Single-phase grid-connected PV MIC system block diagrams :
(a) MIC with integrated inverter,
(b) Inverter-less MIC

In this paper, a digitally controlled interleaving boost converter deploying a tapped-inductor is presented. The tapped-inductor allows voltage step-up of tens of times its input while maintaining a moderate duty ratio. Interleaving of two inductors creates a reduced overall input current ripple which leads to enhanced efficiency [2].

Digital control of the converter allows the flexibility of control scheme selection and enables the excess processing capabilities to be used in other digital computations such as MPPT (Maximum Power Point Tracking) and user-interface information processing.

Computer-aided simulation results are shown of a 200W converter to explore the possibilities of the proposed converter and to verify the feasibility of the topology.

2. Proposed PV MIC System

2.1 Interleaving Tapped-Inductor Boost Converter

Since MICs require a high boosting rate, the tapped-inductor boost converter is an excellent topology considering its simple structure and high efficiency. But due to the high boosting effect, a relatively high ripple occurs in the input current of the converter.

This increases the PV current variation which decreases the MPPT efficiency. Therefore, to minimize the current variation, an interleaving scheme of two parallel converter modules is deployed. The parallel connection not only reduces the current variation but also increases the overall system reliability due to the reduced stress of the components. Since lower component stress devices can be used, a cost effective design with reduction in system size and weight can be achieved [3].

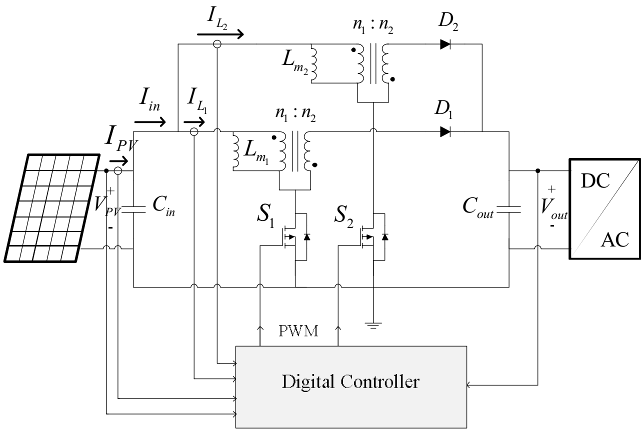

Fig. 2 Basic circuit diagram of the interleaving tapped-inductor boost converter

A basic circuit diagram of the interleaving tapped-inductor boost converter is shown in Fig. 2. The tapped-inductor is theoretically a transformer with the one of the primary ends and the complementary other secondary end tied together. An equivalent circuit model of a tapped-inductor can be comprised of an ideal transformer with a significant magnetizing inductance on the primary side as depicted in Fig. 2. Following the notations in the diagram, the magnetizing inductance can be expressed as,

$$L_m = \left(\frac{n_1}{n_1 + n_2}\right)^2 \cdot L$$

Applying the volt-second balance to the magnetizing inductance, the analytical expression for the voltage gain in continuous conduction mode (CCM) can be obtained as,

$$M(D) = \left(\frac{1}{D'}\right)\left(1 + \frac{n_2}{n_1} D\right)$$

The CCM analysis can be directly used for BCM analysis. Operation in BCM plays a critical part in the efficiency enhancement of the converter, since the conduction losses of the switches and the diode reverse recovery losses are eliminated due to the zero current/voltage transitions in each of the respective components [4].

2.2 Digital Controller

The main idea in the control part of the converter is to maintain a steady output voltage of 350V while operating in an interleaved manner. The inductor current is kept low assimilating boundary conduction mode operation. By using a turn-on time synchronized voltage-mode master-slave interleaving method, stable operation of the desired goals can be achieved [5].

2.3 Experimental Results

A computer aided simulation of the proposed model including component losses has been conducted. The simulated waveforms of the consisting components is given in Fig. 4. The tapped-inductor has a turns ratio of 1:8 and the switching frequency was 100kHz. The simulation focus was to affirm the theoretical results and to explore the possibilities of future improvement.

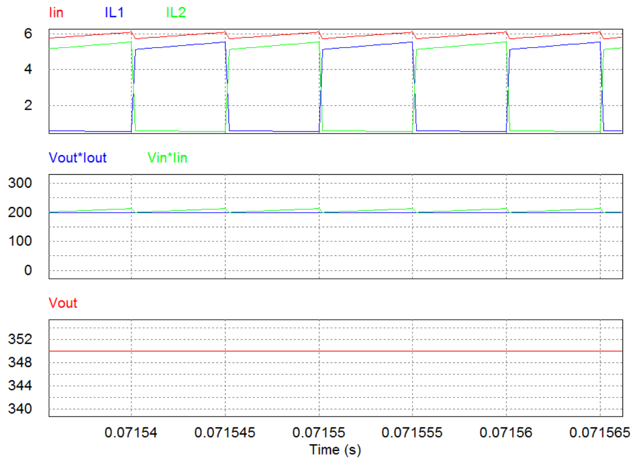

Fig. 4 Simulation results of the proposed converter : Vin=35V, Vout=350V, Pout=200W

An overall efficiency of 97% was obtained at maximum power output of 200W and 95% at 100W output. Even though BCM is not completely achieved, the conduction losses of the switches and the diode reverse recovery losses are minimized. If the converter should operate in BCM, the efficiency is sure to increase, which verifies the feasibility of the proposed converter.

3. Conclusion

A digitally controlled interleaving tapped-inductor boost converter operating in BCM has been proposed as a candidate for PV MICs. Theoretical analysis and verification by computer simulation of a 200W converter has been conducted. A high efficiency of 97% was obtained, verifying the possibility of addition improvement.

Further study for complete soft-switching and input current variation reduction is needed. Also, active efficiency enhancing techniques such as maintaining complete boundary conduction mode and phase shedding should be followed up [6,7].

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