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A novel hybrid boost converter with extended duty cycles range for tracking the maximum power point in photovoltaic system applications

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ABSTRACT

Nowadays, a large number of power conversion applications is commonly based on DC/DC converters with high voltage boost capability. Different voltage-boosting techniques have been reported in the literature. Each technique has its own merits and demerits depending on the application, cost, complexity, power density, reliability and efficiency. To meet the growing demand for such applications, new power converter topologies are continuously being proposed. This paper focuses on a novel hybrid boost converter, which combines the conventional boost (CB) and the quadratic boost (QB). This new topology allows the extension of the output voltage gain and the duty cycle range regarding to the original topologies. Thus, it ensures high conversion voltage ratio for almost duty cycle values. Consequently, it has two working modes, one as QB mode and the other one as CB mode. In order to verify the performance of the proposed topology, several simulations have been carried out under Matlab/Simulink environment for both QB and CB modes. The well-known P&O algorithm was implemented into a FPGA (Field Programmable Gate Array) board in order to verify experimentally the designed hybrid boost. Experimental results confirm the convenience of the proposed topology for tracking the maximum power point in photovoltaic systems.

Introduction

Industrial development around the world increased global energy demand in recent decades, along with the problem of energy shortage; this also caused environmental problems, especially from the overuse of fossil energy. This situation has led to the exploitation of renewable energy sources. Among these renewable energy sources, photovoltaic (PV) energy is a very promising and has been gaining popularity. PV has many advantages: clean, quiet, and maintenance-free [1]. However, it also has some shortcomings related to the efficiency of PV cells, the sun intermittence and the dependence on the atmospheric conditions mainly solar irradiance and air temperature. Usually, PV modules provide large output voltage and current; however its maximum power is delivered for

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only one particular value of current and voltage. The I–V and P–V characteristics of PV modules depend mainly on three parameters: solar irradiance, temperature and the cells aging [2].

To track the maximum power point (MPP) at any time, a DC/DC converter is often set between the PV modules and the load, as shown in Fig. 1, in order to ensure an impedance matching between the load impedance and the output DC/DC converter impedance at the MPP [3]. Global efficiency improvement of PV systems is possible by adding Maximum Power Point Tracking (MPPT) controllers in association with DC/DC or DC/AC converters [4].

In the last decades, power electronics knew such development which has contributed to the improvements of DC/DC and DC/AC converters. It has played an essential role in the improvement of PV systems. The main purpose of using DC/DC converters is to increase or reduce the input DC voltage from the PV arrays and to track the MPP. Besides, there are two categories of DC/DC converters: isolated and non-isolated. It depends on the usage of a galvanic isolation between the input and the output by transformers. For the majority investigations, the non-isolated DC/DC converters have been mostly used presenting a suitable solution because of their capabilities to achieve a high level of efficiency and lower cost when compared with isolated ones. Each converter topology has its own modes of operation and its relevant advantages and disadvantages [5].

Usually in conventional PWM converters, the power switching devices should operate ideally at maximum switching frequencies to ensure wider conversion range. This operation consists to provide the lowest or the highest possible duty ratios of the converter; however it is limited by the finite commutation time of the power switching devices. Another approach to increase the conversion range is the use of a step-down or step-up transformer with the corresponding difficulties in switching surges and operating frequencies [6]. A solution to this problem is proposed in Ref. [7], it consists to use n-stages connected in cascade and use only one active switch, thus reducing the huge switching losses at each stage and avoiding complex control circuitry [8–10].

In this paper, considering the low cost implementation and the relatively high performance of boost converters which are suitable for many PV applications [11], a new boost topology, combining two n-stages connected in cascade using one active switch ($n \in \{1,2\}$), is performed. This topology has two working modes: one mode as 1-stage which is known by the conventional boost (CB), and the second one as 2-stages which is known by quadratic boost (QB). It benefits from both their advantages and will extend the duty cycle range for higher output voltage gain, because each mode ensures high output voltage for specific interval of duty cycle values: The quadratic boost works better for small duty cycles, which is opposite for the conventional boost. So, the extension of duty ratio range given by the hybrid boost and its ability to provide two different output voltages for the same duty cycle value make this hybrid topology advantageous and very interesting.

By the way, this new topology is attractive especially when it is applied for tracking the MPP in PV systems. This hybrid boost DC/DC converter is powered directly by the PV module; it is controlled by a command block, including current/voltage sensors and a Field Programmable Gate Array (FPGA) board where the MPPT algorithm is implemented. The use of FPGA for designing the MPPT controller increases the robustness, provides high performance and makes the hardware implementation more flexible [12–14].

So, after reading the instantaneous PV voltage and current, the corresponding instantaneous power is computed and compared to its previous value. Then according to the result of this comparison, the duty cycle ratio is increased or decreased that means the perturbation and observation (P&O) of the system. By repeating this operation, the command system will track the MPP of the PV array. The P&O MPPT algorithm is used herein for its relatively high performance and accuracy in uniform environmental conditions and mainly for its ease of implementation [13,15–18]. Based on the value of the duty cycle ratio, the FPGA controller generates a PWM command signal which manages directly the on/off states of the main switch of the hybrid boost DC/DC converter. The proposed MPPT hybrid boost has been simulated using Matlab/Simulink, and then verified experimentally.

A comparable research was established in Ref. [19], where a quadratic boost converter with MPPT ability for high step-up ratio application was proposed, but with a more advanced MPPT algorithm based on fuzzy logic. The authors have also used Matlab/Simulink to simulate their proposed converter but they have not performed their tests in a real PV system. However, their experimental verifications were conducted using a PV system emulator. Our proposed MPPT hybrid boost has been experimentally tested using a real PV system and the important parameters have been measured in real time and visualized by oscilloscope. Consequently, the hybrid boost presents very good performance in term of reaching the MPP for both working modes (QB and CB).

This paper is structured as follows: a brief overview on the MPPT algorithms is highlighted in Section MPPT algorithms. Section The proposed hybrid boost presents a detailed description of the proposed DC/DC converter topology. Simulation procedure followed by a discussion and interpretation of results are given in Section Simulation results. Experimental verification is of the proposed hybrid boost is provided in Section Experimental verification.

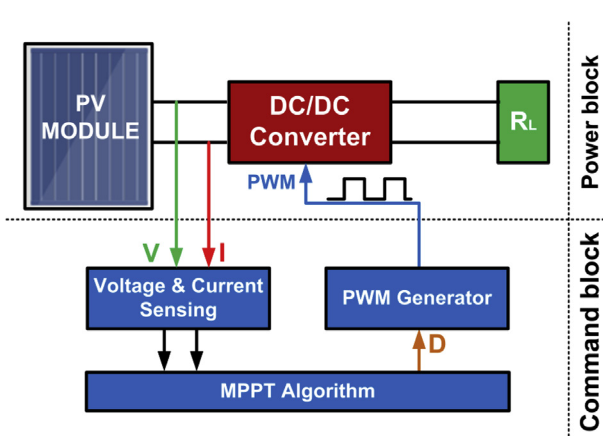

Fig. 1 – MPPT Control system.

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