Incorporation of a Step-Up Boost Converter in Photovoltaic Power Systems for DC Applications

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***Abstract*—The dependency of relying on switching power supplies is increasing and in more demand these days to present superior efficiency as it's compared to conventional linear power supplies. The main target in any type of photovoltaic power system is to increase the efficiency rate of the PV arrays; and as a result power systems that depend on a set of PV arrays have a priority to track the maximum power point MPP to extract the ultimate maximum power from the set of arrays. One of their important characteristics is the ability to provide step-up in the form of Boost converters, step-down in the form of buck converters, and utilized in the sense of inverting. In this research paper we will delineate a sector of the various sort of switching regulators used in dc-dc conversion especially the boost converter. In addition a review of the control techniques for these converters were touched based.**

***Index Terms*— Photovoltaic, maximum power point tracking, MPPT.**

I. Introduction

Restricted fossil energy and expanded air contamination have impelled scientific analysts to move into a clean energy source. One of these sources is the photovoltaic (PV) power generation modules that have been studied heavily over the past two decades, due to its ability to produce a clean and non-polluted energy source. The PV is evident to be one of the productive techniques utilized for generating electricity.

There are many and several practical applications, where a PV arrays can be utilized as an integral part mainly in battery charging, solar vehicles, grid-connected power systems, and other standalone power systems.

Based on many researchers observations due to PV arrays low conversion efficiency there was a need to minimize the overall expenditure of the system and the ultimate solution in this case was to adapt a high efficiency power processors [1]. Such a power processor will normally implement dc-dc converter as its energy processing system.

As a rule of thumb it is a definite must to use dc-dc converters with PV modules due to the nonlinear characteristics of the system and due to the changes that take place in regards to the irradiance and temperature parameters.

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Thus to generate the maximum power, P_{max}, we need to make the system operates at the maximum power point (MPP) of the PV arrays in order to fully extract the maximum allowable power for raising the usage rate of the PV arrays. As a matter of fact, in this case the output voltage will fluctuate and won't stay at the preferred constant DC voltage which will be stressed out in the next sections.

II. Analysis of Photovoltaic power generation

As mentioned earlier and since the output voltage does not stay as a constant DC voltage, this situation will necessitates, implementing a dc-dc converter with a proper voltage regulation to be used in order to connect in parallel with Photovoltaic power systems to maintain and preserve the output voltage in the desired preset constant DC voltage range. This technique can be demonstrated in the following, block diagram, as shown in Fig. 1.

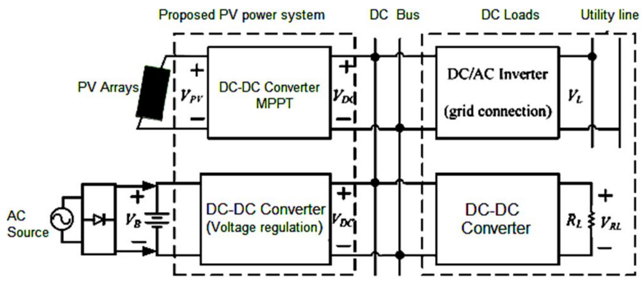


Fig. 1: Block diagram of PV system for DC load.

To further discuss the methodology of the intended design we may refer to Fig.1, and make further discussions in regards to the block diagram components. In Fig. 1, the DC bus voltage plays an integral role in this area of study where it provides a DC/DC converter for DC load and it could supply a DC/AC inverter for a grid-connected power system, and so forth as it carries on. As per the DC/DC converter and the DC/AC inverter those are looked upon as DC loads.

In this research the suggested power supply will consist of a regular DC/DC converter that will correspond to the intended maximum power point tracking (MPPT) point of the PV arrays as well as a DC/DC converter to compensate for the load voltage regulator. The main target in any sort of photovoltaic power system is to boost the efficiency rate of the PV arrays; consequently any power systems that may utilize a set of PV arrays have a priority to track the maximum power point MPP to extract the ultimate maximum power from the set of arrays. The literature is well enriched with various recommended MPPT algorithms [2-3]. As a matter of fact we may list some of them that were renowned for an excellent reputation in this field of study and as a result the most popular of those ones are the Perturb and Observe (P&O), Incremental Conductance, Hill Climbing MPPT, and Constant Voltage Algorithm.

In general, many researchers were adopting the perturb and observe method as it proved to be a simple and yet an easy algorithm as it comes to its implementation and ease of configuration and thus being recommended for MPPT implementation in an ordinary power system. Maximizing the conversion efficiency of Photovoltaic power system is very crucial, and can be adapted to the utilization of switching power converters that are well known as DC/DC converters. The suggested PV power system requires a set of components namely, a high step-up DC/DC converter, a transformer or coupled inductor is usually presented into switching power converters [4-5]. Contrasted with the converter utilizing an isolation transformer, one with a coupled inductor has a simple winding structure and a higher coupling coefficient. It can diminish inductor currents to guarantee bring down conduction losses and decline leaking inductance to achieve a lower switching loss. Accordingly, we can utilize a lower value of the input filter capacitor to get a decent regulation of the output voltage. In this manner, any system utilizing a coupled inductor is moderately attractive. Knowing that the energy is held in the leaking inductor of the coupled inductor, it won't increase voltage stresses, yet incite huge switching losses of the switches in the converter. With a specific end goal to tackle these problematic issues, a few techniques have been proposed as listed in [6-7].

In [6], a resistor-capacitor-diode (R-C-D) snubber is utilized to mitigate switch voltage stresses, yet the energy caught in the leaking inductor is disseminated by the resistor, bringing about a lower conversion efficiency of the converter. A passive loss circuit [8] is adopted to recuperate the energy and lessen voltage spikes across switches; yet active switches are still functioning in hard switching mode. An active clamp circuit is brought into the converter for recouping the energy of the leaking inductor and limit voltage spike across switches. As specified over, a boost converter associated with a coupled inductor is discussed in this exploration as a DC/DC converter, and shown in Fig. 2.

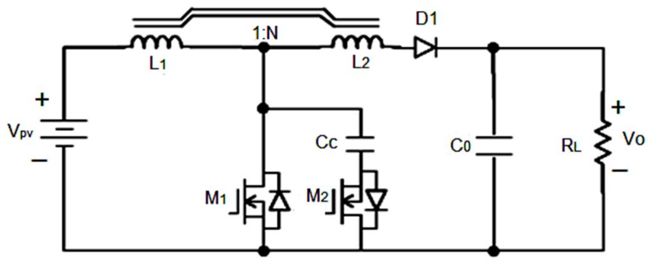


Fig. 2. Boost converter with coupled inductor.

The evaluated dc/dc converter can be simplified in Fig. 3 where the interleaved active clamp boost converter can use less component counts to achieve a high step-up voltage ratio and similar conversion efficiency for reducing the costs. Figure 3 is displaying a two dc/dc converters form an interleaved active clamp boost converter with coupled inductor.

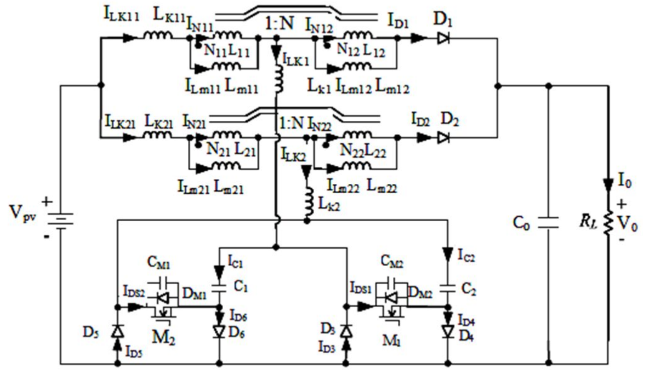


Fig. 3. Interleaved active clamp boost converter with coupled inductor.

The section that holds the MPPT control algorithm is used to extract the P_{max} from the PV arrays. Whereas the other section is equipped with a voltage regulation control method, which is needed to regulate the power between the PV arrays and loads and to produce a constant output voltage for supplying power to the dc loads. It is evident that MPPT control algorithm uses PV arrays as the power source, knowing that its microcontroller (the controller), is divided into two control units: MPPT and power management units. The MPPT can obviously track the maximum power point (MPP) of the PV arrays. This is applied through the utilization of perturb and observe method, whereas the power management block can regulate the output voltage of dc/dc converters with MPPT control algorithm and with the voltage regulation control method, according to the relationships between the maximum power $P_{PV(max)}$ of the PV arrays and the load power P_L by signals M_1 and S_p.

Pulse Width Modulation (PWM) IC unit is used to control the dc/dc converter by the voltage regulation control method to maintain a constant output voltage. Regulation of the output power by control signal S_p is also required. Thus the target is to propose PV power system that can achieve the optimal utility rate of PV arrays.

III. Control Algorithm of the Proposed PV Power System

In order to achieve a proper power management of the PV power system, the topology of the PV power system and power management are described in the following sections.

A. Circuit Topology of the Proposed PV Power System

The PV power system consists of a dc/dc converter along an MPPT, and a dc/dc converter with voltage regulation and controller, as shown in Fig. 4. Figure 3 displays the interleaved active clamp boost converter with coupled inductor. The MPPT block MPPT control algorithm is used to extract the P_{max} from the PV arrays. The other block is equipped with a voltage regulation control mechanism; that function to regulate the power between the PV arrays and loads and to generate a constant output voltage for supplying power to the dc loads. MPPT control algorithm uses PV arrays to supply the power source. Its microcontroller was split to two control sections: MPPT and power management units.

First, MPPT unit's role is to track the maximum power point (MPP) of the PV arrays. This can be achieved using perturb and observe method for example, which was explained in many researchers articles and specifically in [9].

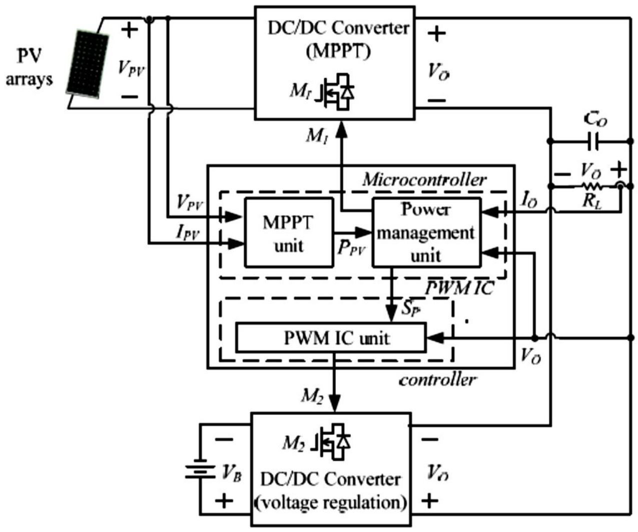


Fig. 4. Interleaved boost converter with coupled inductor.

The power management unit can separately regulate the output voltage of dc/dc converters with MPPT control algorithm and with the voltage regulation control method, according to the relationships between the maximum power $P_{PV(max)}$ of the PV arrays and the load power P_L by signals M_1 and S_p. PWM integrated circuit (IC) unit is in-line to control the dc/dc converter by the voltage regulation control method to obtain a constant output voltage. Thus the proposed PV power system can achieve the optimal utility rate of PV arrays.

B. Power Management

The PV power system consists of two dc/dc converters in the form of parallel connection to supply power to the load. Its functional and operational modes can be divided into multi modes which will be analyzed shortly.

Let us define some of the terms as follows:

P_{PV}: output power of the PV arrays,

P_{VB}: output of the battery

P_L : denoted as load power

A value of "1" corresponds to the power which is generated by P_V arrays or dissipated by load, whereas a value of "0" is a numerical notation of neither the power which is generated nor being dissipated.

C. Operational Mode 1

During the operational mode 1, the dc/dc converter that has a battery will be considered to supply power to the load. When the load power $P_L > P_{VB(max)}$, the proposed PV power system is shut down. When the load power $P_L < P_{VB(max)}$, the power curve of the PV arrays follows the load power, as shown in Fig. 5 , until energy stored in battery is completely discharged. The PV power system is then shut down.

D. Operational Mode 2

During operational mode 2, the dc/dc converter that consists of a PV arrays has its power source used to supply power to the load, as shown in Fig. 6. Referring to Fig. 9; when the maximum power $P_{PV(max)} \geq P_L$, power curve of the PV arrays follows that of load power. If $P_{PV(max)} < P_L$, then the proposed PV power system is shut down.

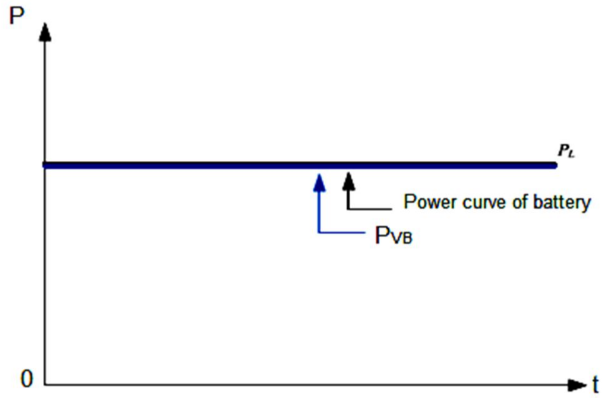


Fig. 5. Power curve of the proposed PV power system under operational mode I.

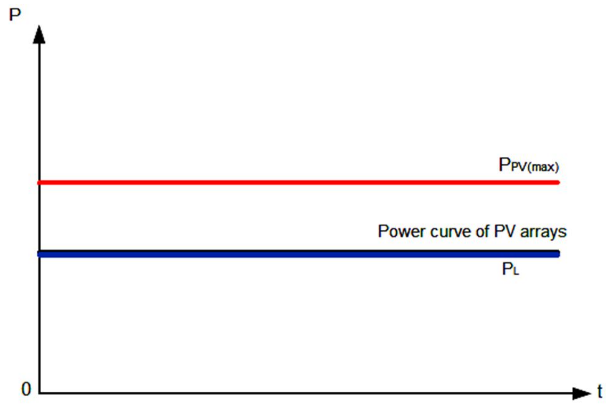
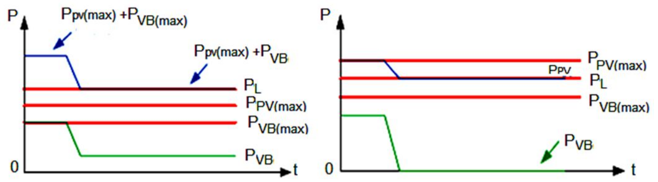


Fig. 6. Power curve of the proposed PV power system under operational mode II

E. Operational Mode 3

In operational mode 3, two dc/dc converters will be depending on using both PV arrays and battery as their power sources. This scheme will be considered to supply power to the load as illustrated in Fig. 7. When the total maximum output power of the two dc/dc converters is equal to or greater than P_L, the PV power system can be working. On the opposite direction the operational conditions within this operational mode, is shut down. When the total maximum output power ($P_{PV\ (max)} + P_{VB\ (max)}$) > P_L, dc/dc converter with PV arrays acts as its power source. It functions at MPP of the PV arrays and the one with battery as its power source is operated under the output power of ($P_L - P_{PV\ (max)}$), as shown in Fig. 7(a). In addition, when $P_{PV(max)} > P_L$, the one with battery as its power source is shut down and the output power P_{PV} of the PV arrays is equal to P_L, as shown in Fig. 7(b).

Here we considered P_{L} as the sum of P_{PV} and P_{VB} and P_{L} extracts as much power as possible from the PV arrays to increase utilization rate of the PV array. Below is a sketch diagram of the power curves P_{PV}, P_{VB} and P_{L}



(a) (b)

Fig. 7.
(a) $P_{PV(max)} + P_{VB(max)} \geq P_{L}$ (b) $P_{PV(max)} + P_{VB(max)} \geq P_{L}$ and $P_{PV(max)} \geq P_{L}$

IV. Conclusion

An interleaved active clamp boost converters with coupled inductor was explored to form and to structure a PV power system for dc load applications. The interleaved active boost converter utilized a PV arrays and batteries as their power source, to implement a maximum power point tracking system MPPT and power management. The operational modes were analyzed in this paper at a concise technical level. The main focus in this analysis was to introduce the vital role of efficiency on any applicable system.

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