

Design and Simulation of Interleaved DC-DC Boost Converter for Stand-alone Systems Using Solar Panel

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ABSTRACT: This paper describes the development of photovoltaic applications with highly reliable and efficient converter and inverter equipped with advanced control strategies, which made the photovoltaic system compatible for higher power ratings. In this paper a number of solar PV modules are interconnected to generate abundant electrical energy which is connected to an interleaved boost converter and single phase voltage source inverter through which the energy is evacuated to the load. The interleaved boost converter is controlled by maximum power point tracking (MPPT) and the inverter is controlled by sinusoidal pulse width modulation technique (SPWM). The proposed system eliminates the use of low frequency transformers at the AC side which reduces a major part of the power losses. The proposed system is simulated using PSIM 9.3.

KEYWORDS: Interleaved boost converter, MPPT algorithm, single phase voltage source inverter, SPWM technique.

I. INTRODUCTION

With the increase in the power demand and limited fossil fuels the renewable energy source plays a vital role to overcome these challenges. The fossil fuels based energy source causes environmental pollution. This led to the need for renewable energy sources (solar, wind, biomass) which is abundant and pollution free [1]-[3]. DC-DC converters play a vital role in photovoltaic (PV) systems as power interface. For stand-alone PV systems such as water pumps, LED, and signals, the MPPT technique is implemented [4]-[5]. Interleaved DC-DC converter is a technique where it can be implemented by paralleling the converters such that it reduces the switching stress and peak inductor current compared to conventional boost converter [6]. The block diagram of proposed system is as shown in fig.1.

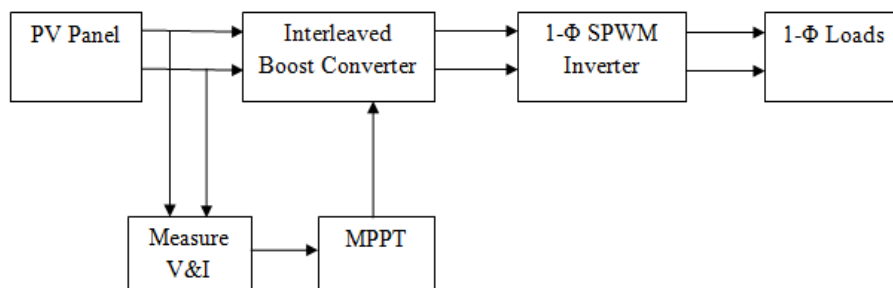


Figure 1: Block diagram of proposed system

In this fig.1 the PV panel is used as input to the interleaved boost converter. The output of an interleaved boost converter is fed to 1-Φ SPWM inverter. In order to increase the efficiency of solar panel the MPPT technique is used. In this work the perturb and observe (P&O) MPPT technique is employed.

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II. INTERLEAVED BOOST CONVERTER

This paper proposes an interleaved boost converter. Interleaving is a technique which is implemented by paralleling the converters as shown in fig.2. By using this technique, the input current divides in the inductors which improves the reliability and makes the system to be efficient.

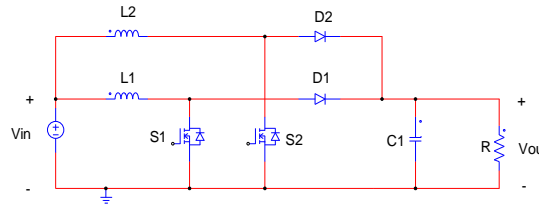


Figure 2: Circuit configuration of Interleaved Boost converter

The interleaved boost converter consists of two stage parallel connected switches S_1, S_2 ; diodes D_1, D_2 ; inductors L_1, L_2 ; capacitor C and load resistor R with common input source (V_{in}). The gating pulses to the interleaved boost converter is given by $\left[\frac{260^\circ}{n}\right]$, where n is the number of parallel stages. Here the two-phase interleaved boost converter is used hence the phase difference is $\left[\frac{360^\circ}{2} = 180^\circ\right]$. [7]

The analysis of proposed converter is as follows:

V_{in} – Input voltage; V_0 – Output voltage; L_1, L_2 – Inductors; C_1 – Capacitor; R – Load resistance;

T_s - Switching period; $F_s = \left(\frac{1}{T_s}\right)$ – Switching frequency; D- Duty cycle;

V_{L1} – Voltage across inductor L_1 ; V_{L2} – Voltage across inductor L_2 ;

Δi_{L1} – Change in the inductor current L_1 ; Δi_{L2} – Change in the inductor current L_2 .

There are two modes of operation:

Mode 1: (S_1 – Closed, S_2 – Opened)

In this mode the switch S_1 is closed and switch S_2 is opened, the equivalent circuit is as shown in fig 3.

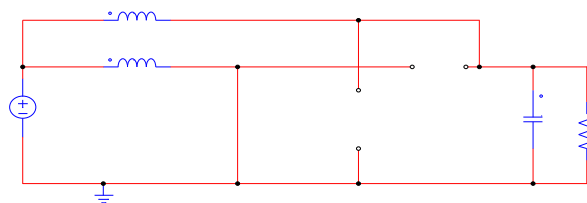


Figure 3: Circuit configuration when switch S_1 is closed

In mode 1, diode D_1 is reverse biased while diode D_2 is forward biased. The input supply energy to the inductor L_1 and the voltage across inductor L_1 is given by:

$$V_{L1} = V_{in} = (L_1) * \left(\frac{di_{L1}}{dt}\right) = (L_1) * \left(\frac{\Delta i_{L1}}{DT_s}\right) \quad (1)$$

$$(\Delta i_{L1})_{S1-closed} = \left(\frac{V_{in}}{L_1}\right) * DT_s \quad (2)$$

From the above equation, it can be concluded that the current in the inductor L_1 increases linearly.

The voltage across inductor L_2 is given by:

$$V_{L2} = V_{in} - V_0 = (L_2) * \left(\frac{di_{L2}}{dt}\right) = (L_2) * \left(\frac{\Delta i_{L2}}{DT_s}\right) \quad (3)$$

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$$(\Delta i_{L2})_{S1-closed} = \left(\frac{V_{in}-V_o}{L_2}\right) * DT_s \tag{4}$$

Since V_o is greater than V_{in} . From the above equation it can be concluded that current in the inductor L_2 decreases linearly.

Mode 2: (S_1 – Opened, S_2 – Closed)

In this mode the switch S_2 is closed and switch S_1 is opened, the equivalent circuit is as shown in fig 4.

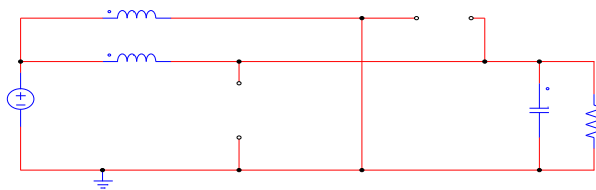


Figure 4: Circuit configuration when switch S_2 is closed

In mode 2, diode D_1 is forward biased while diode D_2 is reversed biased. Inductor L_1 discharging and supplying energy to the load resulting in fall of the inductor current i_{L1} .

The voltage across inductor L_1 is given by:

$$v_{L1} = (V_{in} - V_o) = (L_1) * \left(\frac{di_{L1}}{dt}\right) = (L_1) * \left(\frac{\Delta i_{L1}}{(1-D)T_s}\right) \tag{5}$$

$$(\Delta i_{L1})_{S2-closed} = \left(\frac{V_{in}-V_o}{L_1}\right) * (1 - D)T_s \tag{6}$$

Since V_o is greater than V_{in} . From the above equation it can be concluded that current in the inductor L_1 decreases linearly.

The voltage across inductor L_2 is given by:

$$v_{L2} = V_{in} = (L_2) * \left(\frac{di_{L2}}{dt}\right) = (L_2) * \left(\frac{\Delta i_{L2}}{(1-D)T_s}\right) \tag{7}$$

$$(\Delta i_{L2})_{S2-closed} = \left(\frac{V_{in}}{L_2}\right) * (1 - D)T_s \tag{8}$$

From the above equation, it can be concluded that the current in the inductor L_2 increases linearly.

The net change in the inductor current is zero

$$(\Delta i_{L1})_{S1-closed} + (\Delta i_{L1})_{S2-closed} = 0 \tag{9}$$

Substituting equation (2) and (6) in equation (9)

$$\left(\frac{V_{in}}{L_1}\right) * DT_s + \left(\frac{V_{in}-V_o}{L_1}\right) * (1 - D)T_s = 0 \tag{10}$$

By solving the above equation, we get

$$V_o = \left[\frac{V_{in}}{1-D}\right] \tag{11}$$

The minimum inductor values L_1 and L_2 to operate converter in continuous conduction mode (CCM) are given by:

$$L_{1min} = L_{2min} = V_{in} * \left(\frac{D}{\Delta i_{L1} * F_s}\right) \tag{12}$$

The capacitor C is given by:

$$C_1 = \frac{D}{\left(R * F_s * \left(\frac{\Delta V_o}{V_o}\right)\right)} \tag{13}$$

III. MAXIMUM POWER POINT TRACKING

In view of enhancing the efficiency of solar panel, it is necessary to increase the radiation falling on it. Thus it is necessary to implement solar tracking system because the sun changes its position throughout a day. There are mainly two types of solar tracking system i.e. single-axis tracking and dual-axis tracking. But the sun tracking system requires electric motors, gear box, and light sensors for the accurate tracking. This tracking system increases the cost and complexity of the system and hence it is not suitable for house-hold and small scale applications. The maximum power

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point tracking (MPPT) technique requires only some electronic circuits like voltage measurement and current measurement circuits to transfer the maximum power to the load. This technique overcomes the drawbacks of sun tracking system that is the usage of electric motors, gear box, and light sensors. The basic principle of MPPT technique involves that it uses an algorithm. The algorithm includes measurement of voltage and current then the calculation of power. Based on the different conditions of algorithm the duty cycle of power electronic switch of the DC-DC converter is adjusted to maintain the requirement of load. The P&O technique is used for MPPT.

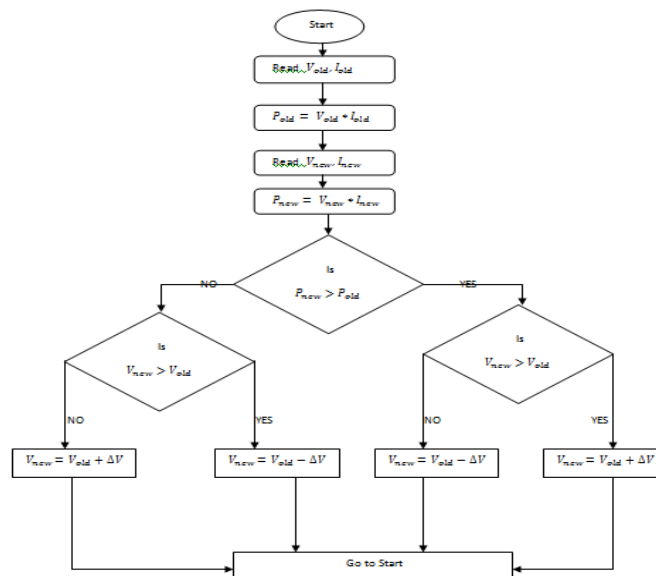


Figure 5: Flow chart of perturb and observe method

The P&O algorithm is based on the calculation of the PV power and voltage by sampling the PV current and voltage. The flow chart is as shown in fig 5. In this approach, the module voltage is periodically given a perturbation and the corresponding output power is compared with that at the previous perturbing cycle. [8].

IV. SIMULATION RESULTS

The interleaved boost converter and single phase inverter is designed and simulated for solar applications.

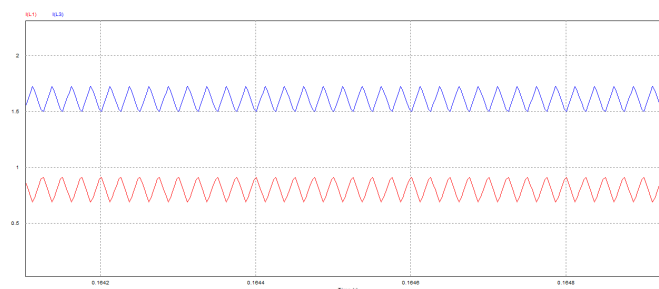


Figure 6: Waveforms of Inductor currents of conventional (in blue) and Interleaved Boost converter (in red)

Fig.6 shows the simulation results of inductor current for the conventional and interleaved boost converter. The inductor peak current and switch current is less in interleaved boost converter comparatively.

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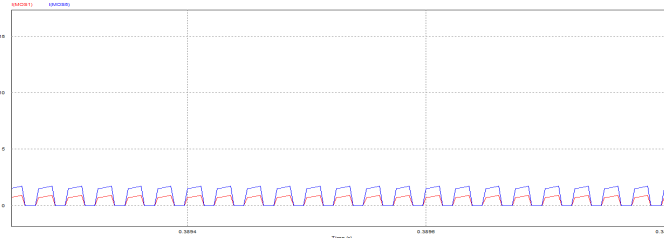


Figure 7: Waveforms of currents through switch for conventional and Interleaved Boost converter

Fig.7 shows the current through switches for conventional and interleaved boost converter. Fig 8 shows switching states and change in the inductor currents of interleaved boost converter. Fig.9 shows the waveforms of open loop simulation with photovoltaic source, DC link voltage, and AC output. Fig.10 shows the waveforms of photovoltaic source, DC link voltage, and AC output with MPPT technique.

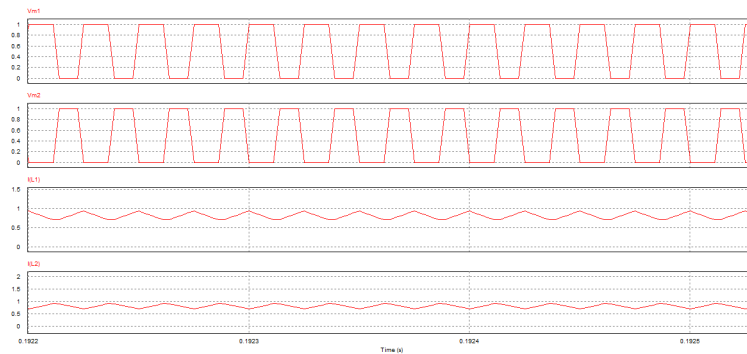


Figure 8: Switching states and Inductor currents of interleaved boost converter

The above fig.8 shows the switching states which are obtained from the P&O MPPT algorithm and it is given to MOSFET switches of interleaved boost converter and current through inductors. The total input current is divided into two phases, resulting in reduction of the current rating of the switching devices.

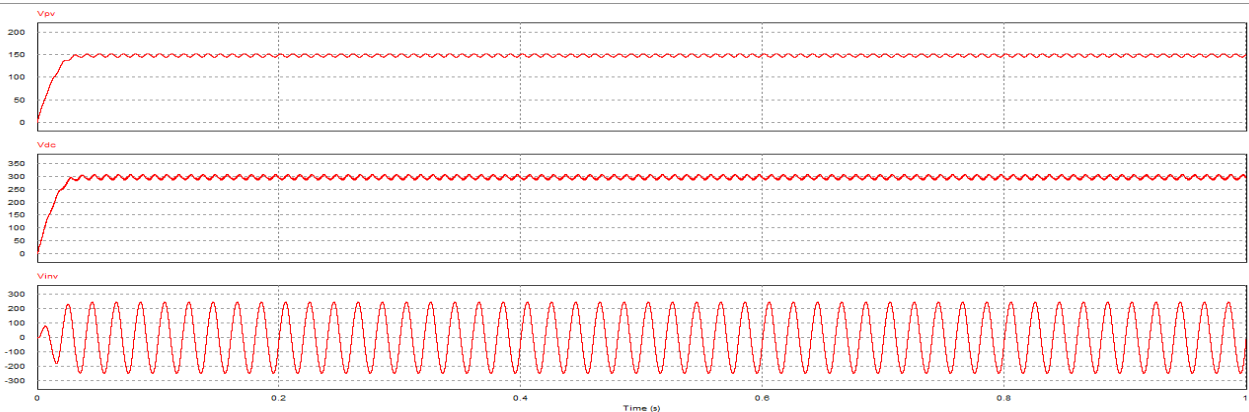


Figure 9: Waveforms of PV array voltage, DC link voltage, Load voltage. (Open loop)

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For simulation circuit, solar panels are connected in series and an output of 150VDC is obtained. This voltage is given to interleaved DC-DC boost converter as an input, it boost up the voltage from 150VDC to 300VDC by using interleaving technique. The output terminal of interleaved boost converter is connected to a single phase inverter therefore the DC output from the interleaved boost converter is inverted by single phase inverter. The Sinusoidal Pulse Width Modulation (SPWM) technique is used for pulse generation to MOSFET switches of the single-phase inverter. Finally at load side 240VAC, 50Hz supply is available.

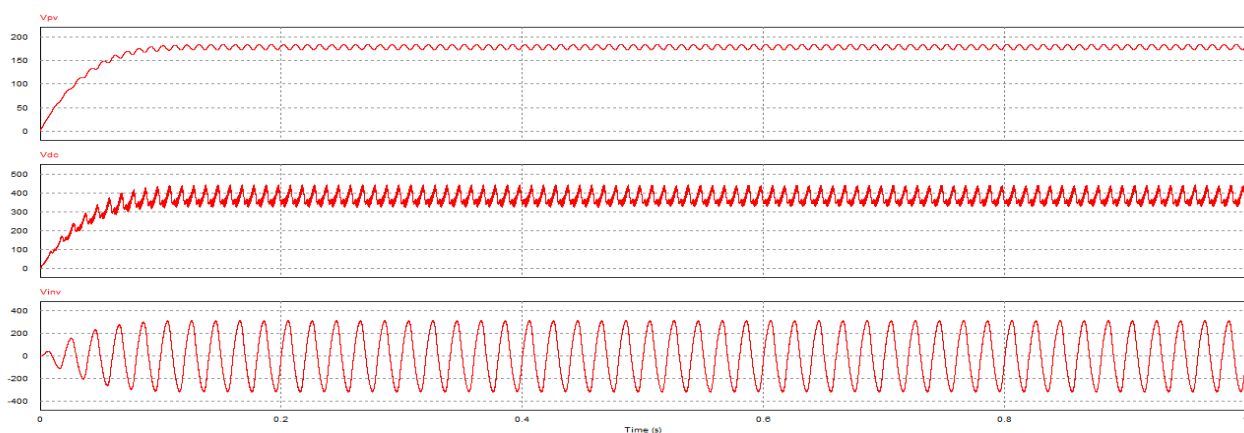


Figure 10: Waveforms of PV array voltage, DC link voltage, Load voltage. (Closed loop)

V. CONCLUSION

In this paper the interleaved boost converter is designed and simulated for photovoltaic applications. The interleaved boost converter has advantages over traditional boost converters such as

- 1) It has less switching stress
- 2) Less peak inductor current

The proposed converter can also be used for fuel cell, ultra capacitors, and hybrid electric vehicle systems.

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