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Design and Analysis of an Efficient Boost Converter for Renewable Energy Sources

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ABSTRACT: An appropriate dc-dc converter is suggested for very effective solar energy systems. This paper brings out design, simulation and implementation of a two phase interleaved DC-DC boost converter. An interleaved boost dc-dc converter is proposed for current sharing on high power application. Moreover, this converter also reduces the output ripple current. The advantages of interleaved boost converter compared to the conventional boost converter are low output ripple voltage, high efficiency, faster transient response, reduced electromagnetic emission and improved reliability. The performance parameters of the proposed interleaved boost converter are analyzed by MATLAB simulation.

KEYWORDS: interleaved boost converter (IBC), ripple voltage and current, duty ratio, solar electric vehicle.

I. INTRODUCTION

Climate change and the need to manage diminishing fossil fuel reserves are, today, two of the biggest challenges facing the planet. In order to secure the future for ourselves and generations to follow, it is widely accepted that we must act now to reduce energy consumption and substantially cut greenhouse gases, such as carbon dioxide. World leaders have resolved to tackle global warming by signing the Kyoto Protocol, an international treaty committing signatory countries to reduce their emissions of carbon dioxide. For many years, fossil fuel has been the primary source of energy. However, there is a limited supply of these fuels on Earth and they are being used much more rapidly than they are being created. Eventually, they will run out. In addition, because of safety concerns and waste disposal problems, renewable energy is definitely the solution since such technology is “clean” or “green” because they produce few if any, pollutants. The world trend nowadays is to find a clean source of energy. The most effective and harmless energy source is probably solar energy, which for many applications is so technically straightforward to use. For many years, fossil fuel has been the primary source of energy. However, there is a limited supply of these fuels on Earth and they are being used much more rapidly than they are being created. Eventually, they will run out. In addition, because of safety concerns and waste disposal problems, renewable energy is definitely the solution since such technology is “clean” or “green” because they produce few if any, pollutants. The world trend nowadays is to find a clean source of energy. The most effective and harmless energy source is probably solar energy, which for many applications is so technically straightforward to use.The power generated from the PV system exhibits a nonlinear I-V characteristic. Its maximum power (MP) point varies with the solar insolation and temperature. As a result the efficiency becomes low [1]. In order to overcome these limitations, it’s crucial to have a power conditioning system, which is capable of transmitting the power to the load with high efficiency. Simple converters such as buck and boost converters enter into discontinuous current mode at lower intensity insolations, resulting in improper utilization of power devices and increased conduction losses due to increased current ripple. To reduce the input current ripple and Lo alleviate the problem of discontinuous input current, we propose to use two cell interleaved boost converter for PV applications. Although this converter increases the number of components compared to conventional boost converter, the actual increase in cost may not be significant. Further, interleaved operation has many desirable features such as a lower value of ripple amplitude, high ripple frequency in the resulting input and output waveforms, it reduces maintenance and increases reliability and fault tolerance. several problems are identified with conventional boost converter circuit as:

- High reverse recovery current across the diode.
- Turn on and turn off losses.

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- Leakage inductance energy
- Current stress in switching device

II. BLOCK DIAGRAM

The block diagram representation of proposed system is shown in figure1.

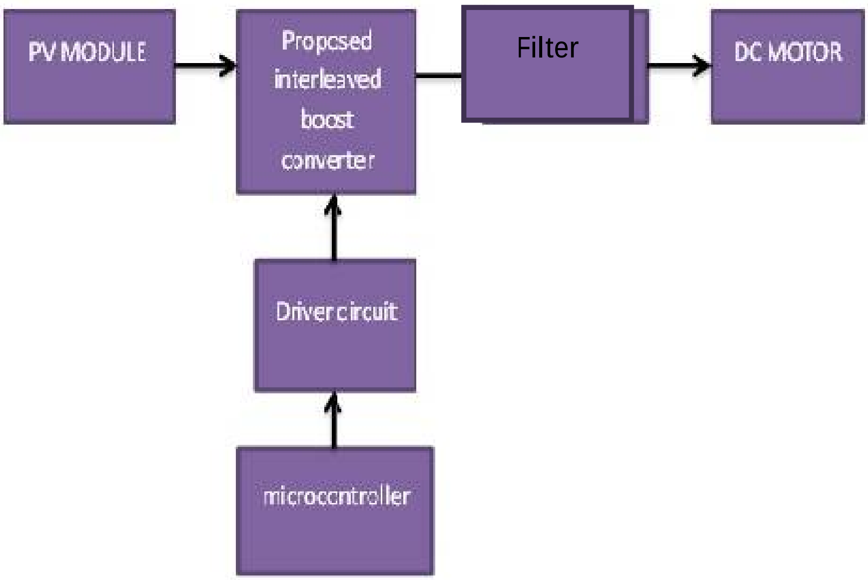

Fig.1. Block diagram of the proposed system.

Solar cells have relatively low conversion efficiency and the improvement of overall system efficiency is an important design factor: in the area of PV systems. This can be partly achieved by using high-efficiency intermediate converters with maximum power point controllers (MPPT). The main requirements of these converters are: (1) the converter input current has small ripple and (2) the converter efficiency should be high, even at lower intensity insolations. The intermediate converter produces a chopped output dc voltage and controls the average dc voltage applied to the load. In this proposed system, the sunlight is incident on the solar panel or module, and then the dc voltage is produced. This voltage is fed into the interleaved boost converter for step up the dc voltage. The Controller is used for generating the control signals to turn on/off of the power switches present in the converter circuit to get the desired output voltage. The output voltage of the DC-DC converter is given to the filter circuit for regulating the dc voltage. This regulated dc output is given to the dc load. This proposed system consists of following components. They are Photovoltaic module, Interleaved Boost Converter, Controller, DC filter, DC load.

III. ANALYSIS OF TWO CELL INTERLEAVED BOOST CONVERTER

Interleaving is the process wherein the pulse frequency of any periodic power source is increased. Several smaller sources are synchronized and operated under multiple phase shifts, is the concept of interleaving.

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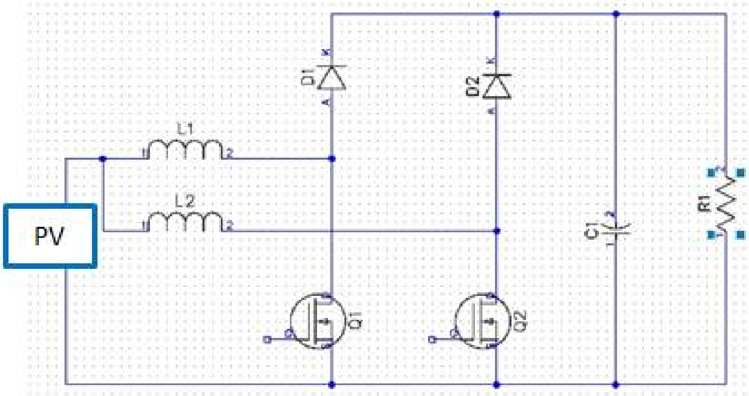

Fig.2. circuit diagram of proposed interleaved boost converter

The circuit diagram of a two phase interleaved topology is shown in fig.2. The added benefit of interleaving is that the frequency of the ripple components (undesired harmonics) at the waveforms are increased in proportion to the number of interleaved cells. This feature facilitates easy filtering of the ripple components or using smaller sized filtering elements. The ability to reduce the size of passive elements is beneficial for reducing the cost and obtaining a compact converter. The benefits of interleaving include high power capability, modularity, and improved reliability. Interleaving add benefits such as reduced ripple current in both input and output circuits. Higher efficiency is realized by splitting the output current into 'n' paths, substantially reducing I2R losses and inductor losses. The main advantage of interleaving is that the total current are divided in to two phase, resulting in reduction of the current rating of the switching devices.
The operation of the converter is as follows, here similar inductors are considered i.e.; L1=L2=L.
D1 and D2 are the duty cycles of Q1 and Q2. There are three mode of operation.

MODE 1:

At t =0, the gate pulse is given to the switch'Q1' of the first phase. Then the switch 'Q1' is turned on, the current across the inductor L1 rises linearly. At the same time, the switch 'Q2' in the second phase is turned off and the energy stored in the inductor L2 is transferred to the load through the output diode D2. In this time interval, the diode D1 in the first phase is in reverse bias condition .the rate of change of il2 is given by

$$\frac{dil1}{dt} = \frac{Vi}{L}$$

Whereas rate of change of il1 is;

$$\frac{dil1}{dt} = \frac{Vi}{L}$$

MODE 2:

At time t1, Q1 and Q2 are opened. The inductors L1 and L2 discharge through the load. The rate of change of iLl and iL2 are

$$\frac{dil1}{dt} = \frac{dil2}{dt} = \frac{Vi-Vo}{L}$$

MODE 3:

At t = t2, the gate pulse is given to the switch 'Q2' of the first phase. Then the switch 'Q2' is turned on, the current across the inductor L2 rises linearly. At the same time, the switch 'Q1' in the first phase is turned off and the energy stored in the inductor L1 is transferred to the load through the output diode D1. In this time interval, the diode D2 in the second phase is in reverse bias condition. At time t1, Q2 is closed. The current in the inductor L2 starts to rise while L1 continues to discharge. The rate of change of iL1 is approximately given by,

$$\frac{dil1}{dt} = \frac{Vi - vo}{L}$$

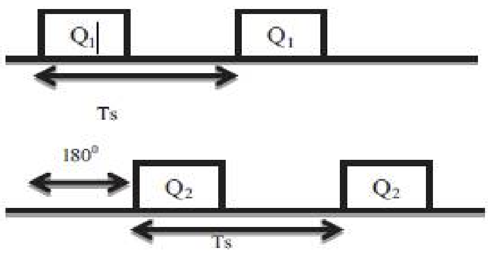

Fig.3. switching pattern of interleaved boost converter

IV.DESIGN OF INTERLEVED BOOST CONVERTER

In high-power boost converters, the major design aspect is the selection of the boost inductor and the output capacitor. The major concern is the size, cost, and weight of such a high-power inductor that is the single heaviest component in the entire dc/dc converter. To reduce the inductor size and weight, a small inductance value is required. In addition, the dc-dc converter performance directly influences the characteristics of the PV. Indeed, the ripple and harmonic content of the current is one of the various phenomena influencing pv efficiency as well as battery lifetime .So the main objective of this research is to minimize inductor size, capacitor, current/voltage ripples and harmonic content.

For reduced switching losses, proper choice of semiconductor devices, and design of inductor and capacitor, No. of phases and decision on duty ratio are of importance. The methodology follows as:

- Selection of no. of phases and duty ratio
- Design of inductance
- Determination of power semiconductor switches
- Designing an output filter

A. SELECTION OF NUMBER OF PHASES AND DUTY RATIO

It has been observed that that the ripple current in the input current decreases with increase in the number of phases. On the other hand, the cost and complexity of the circuit increases. So a compromise has made between them. In in this paper, the number of phases was chosen to be two to reduce the ripple content without increasing the cost drastically. The input current I_{in} is divided among each phases. Assuming that all phases are symmetric, the current will be equally shared in each inductor L to Ln, and their respective switches. Hence, current rating of power modules can be reduced with the increase in number of phases.

Duty ratio also aids in ripple reduction and hence it has to be selected carefully. From the plot of the input current ripple versus the duty ratio, it can be found that for an N-phase IBC, the ripple can be zero at particular values of duty ratio. The duty cycle ratio (D) is defined as,

$$D = 1 - \frac{V_{in}}{V_o} \text{………….(1)}$$

Where V_{out} is the output voltage, and V_{in} is the input voltage. Assuming appropriate switching frequency (f_{sw} = 20 kHz).

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B.SELECTION OF INDUCTORS& OUTPUT CAPACITOR

Design of inductance is very important in boost topologies so that the inductor is sized correctly. The inductor value is selected using the following equation,

$$L = \frac{V_{in} * D * T_S}{\Delta I_{in}} \ldots\ldots\ldots\ldots\ldots\ (2)$$

By assuming appropriate peak to peak capacitor ripple, the output capacitor value can be obtained from the following equation,

$$C_{out} = \frac{V_O * D * T_S}{R_L * \Delta V_O} \ldots\ldots\ldots\ldots (3)$$

Where, R_L is the load resistor, D is the duty ratio and T_S is the Total time.

V.SIMULATIONOF PROPOSED IBC

As per the design equation, a two phase interleaved converter is simulated in MATLAB/SIMULINK. The values of the components are L_1=L_2 =90µH, C_{out}=48.8µF,R_L=7.68Ω.The MATLAB SIMULINK model of the proposed converter is shown in fig. 4.Figure 6 shows the simulated output of the proposed converter. The switching frequency is 20KHZ and the switches Q1 and Q2 are fired with a phase shift of 180^0.

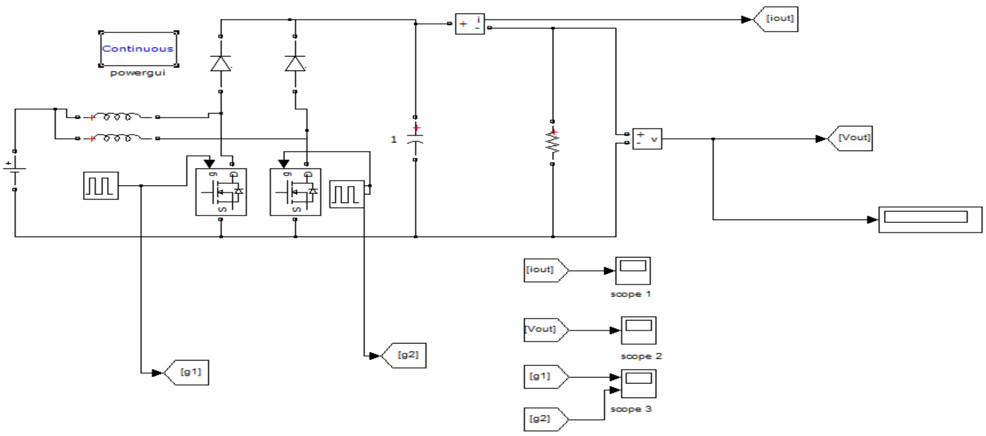

Fig.4.MATLAB SIMULINK model of two phase interleaved DC-DC converter

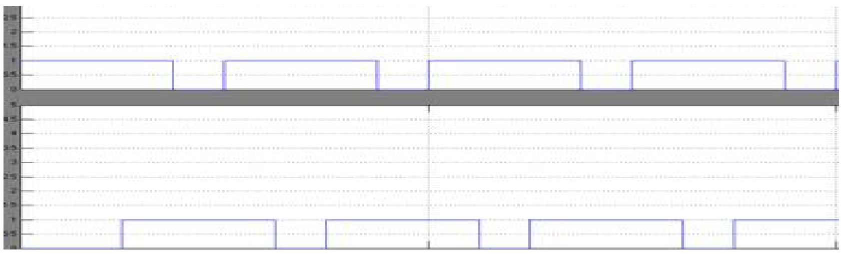

Fig.5 Gate pulses for the switches

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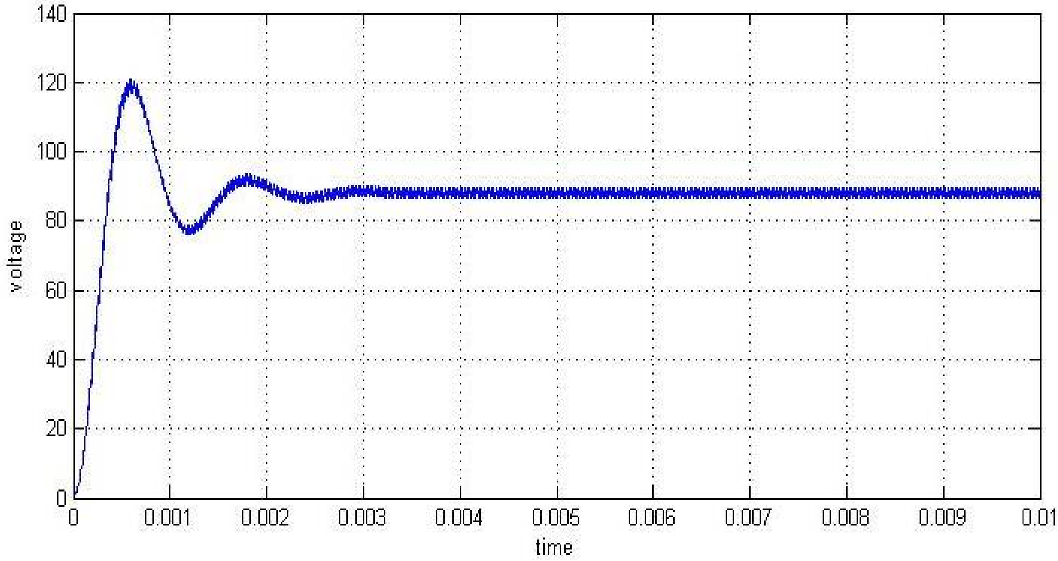

Fig.6. Simulated output voltage of the proposed converter

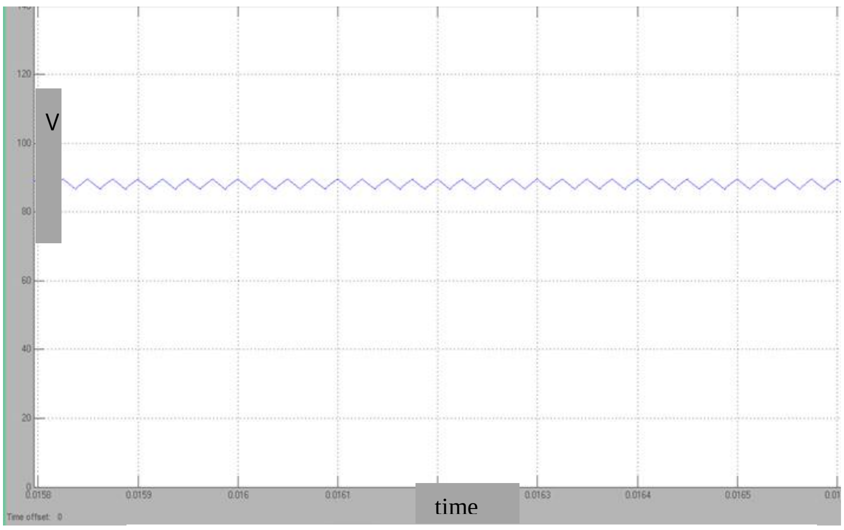

Fig.6. output voltage ripple of the proposed converter

VI. HARDWARE PROTOTYPE AND EXPERIMENTAL RESULTS

In order to validate the actual performance of the presented interleaved boost dc-dc converter, a hardware prototype was designed and built. Fig. 7 shows the hardware prototype of the interleaved boost dc-dc converter.

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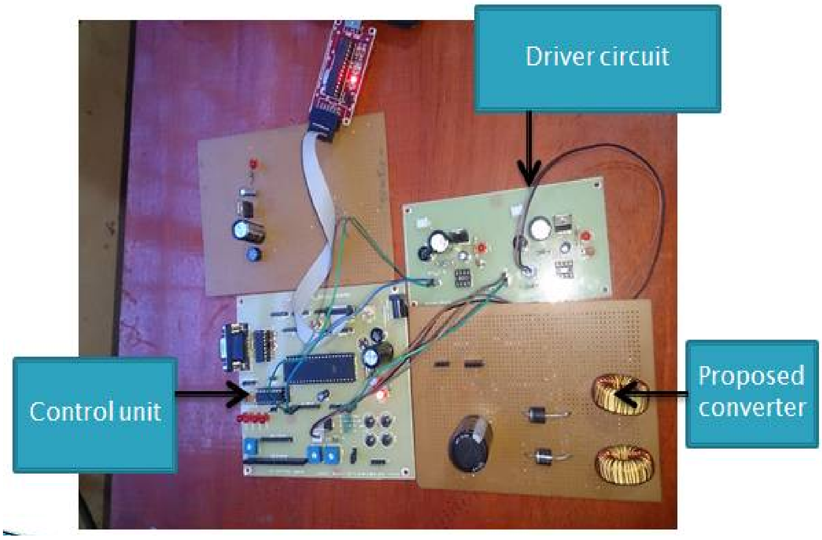

Fig.7. Hardware prototype of the interleaved dc-dc boost converter

Each switch in this interleaved boost dc-dc converter is running at 20khz switching frequency. The experiment results of the implemented inteleaved boost dc-dc converter gate pulses and output voltage is shown in figure 8-9.

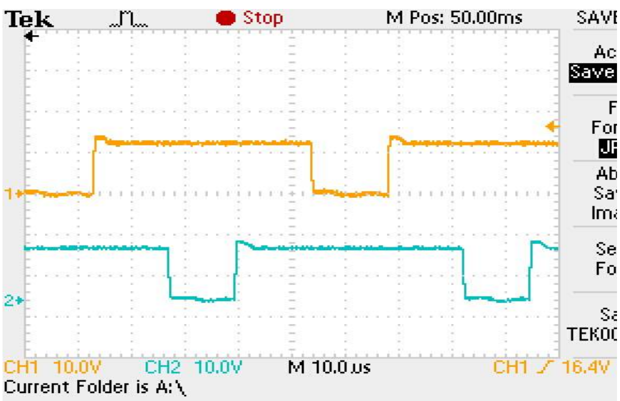

Fig.8.Gate pulses for the switches

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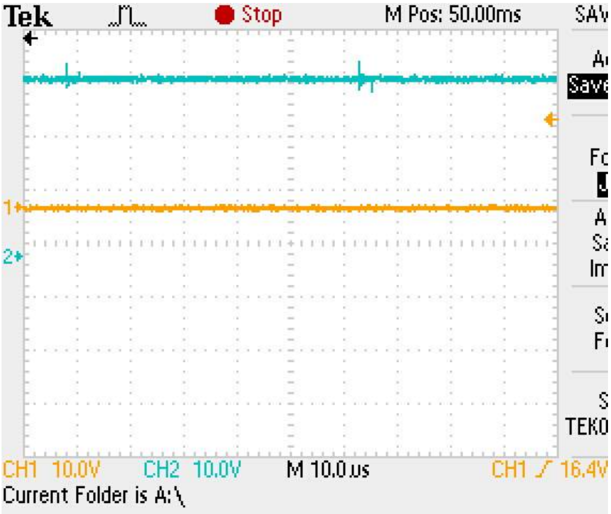

Fig.9. input and output voltage waveform of the proposed IBC

VII.CONCLUSION

Interleaved boost converter has so many merits and is a proper converter for renewable energy applications. The two phase interleaved dc-dc boost converter has been designed, simulated and implemented. With this converter the input current is shared and the stress on switch reduces allowing lower current rating devices to be used for high power density converters and consequently reduces the size and cost of the system.Simulation and experimental results shown that the interleaved boost converter have the ability for input current sharing as well as reducing the ripple input current. The performance of conventional and proposed converter were compared.

Parameters	Conventional boost converter	Proposed IBC
Input current ripple	1.78%	0.06%
Inductor current ripple	13.8%	5.35%
Output voltage ripple	0.87%	0.03%

Table .1.comparison of conventional and proposed IBC converter

A. FUTURE WORK

The proposed converter can be used for electric traction, photovoltaic generation system, UPS and so on.

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