A Comparative Study of DC-DC Boost Converter & Interleaved Boost Converter Using Solar Energy (PV) System

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Abstract - **In recent years, a DC-DC converter with high output voltage is mainly used for transferring the energy from any renewable sources to conventional AC systems. The Photovoltaic (PV) energy system is a very new concept in use, which is gaining popularity due to increasing importance to research on alternative sources of energy over depletion of the conventional fossil fuels world-wide. Among various converter topologies the Interleaved Boost Converter has low ripples in both input current and output voltages. Reductions in size and electromagnetic emission along with an increase in efficiency, transient response, and reliability are among the many advantages to using such interleaved boost converters. In this paper, a comparison of boost converter & interleaved boost converter has taken for Solar Energy (PV) System using MATLAB/Simulink software.**

Keywords- **Boost converter, Interleaved Boost Converter, Closed loop control, Solar Energy (PV) System, Ripples, MATLAB, Efficiency.**

I. INTRODUCTION

In general, this paper presents a design of IBC for renewable energy application. The converter is used in various range of application such as renewable energy, communication and electric drives. Insulated Gate Bipolar Transistor (IGBT) is used as a switch power in the IBC circuit because it has several advantages such as high switching frequency and high current handling capability. It also combines in it all the advantages of the bipolar and MOS field effect transistor (MOSFET). In addition, interleaving provides high power capability, modularity and improved reliability [1]. With simple and handy design, the IBC is very suitable for EV application due to its increase in efficiency, improving electric performance, reduction in size, and has greater reliability [2]. It has high voltage step up, reducing voltage ripple at the output, low switching loss, reduces electromagnetic interference and also faster transient response [3, 4].

The IGBT is a three-terminal power semiconductor device primarily used as an electronic switch. In newer devices, it is noted for combining high efficiency and fast switching. It switches electric power in many modern appliances: electric cars, trains, variable speed refrigerators, air-conditioners and even stereo systems with switching amplifiers. In this paper, the IGBTs are chosen as the switching device. This is because the IGBT has several advantages such as low duty cycle, low frequency which is less than 20 kHz, narrow or small line or load variations as well as has high-voltage applications which is greater than 1000Volt compared to other switching devices [2]. Presently, some of the newest IGBTs can offer competitive performance which can operate at 100 kHz and above.

Renewable energy sources with low output voltage, such as the fuel cell stacks and photo-voltaic (PV) generation system, have received a great attention in research fields because they appear to be the possible solutions to the environmental problems[5]-[7]. The voltages produced by renewable energy sources such as photovoltaic (PV) arrays and fuel cell stacks are generally low. These voltages need to be increased to high voltages for certain applications such as 380 V for full-bridge inverter and 760 V for half-bridge inverter of a 220 V AC grid-connected system. One of the challenges in the development of renewable energy systems, which are based on photovoltaic modules and fuel cell stacks, is the conversion of relatively low DC voltage to high DC voltage [8].

DC-DC converters are an important component as power electronics interfaces for photovoltaic generators and other renewable energy sources. Most renewable power sources, such as photovoltaic power systems and fuel cells, have quite low-voltage output and require series connection or a voltage booster to provide enough voltage output [9]-[12].

Figure 1 shows a typical block diagram of a standalone PV system.

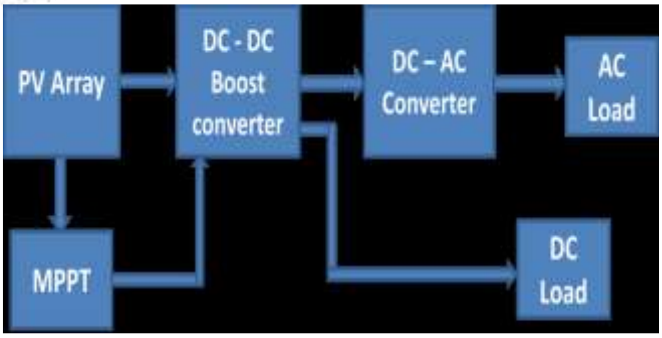

Figure 1: Typical block diagram of a standalone PV system.

In stand-alone PV system applications, it is of much importance that maximum power is extracted from the solar panel and delivered to the load whenever possible. For this reason, a dc-dc power electronic converter is incorporated into the system such that the load is connected to the solar panel through it, controlled by a Maximum Power Point Tracking (MPPT) algorithm. Unfortunately, in practice, the efficiency of the power electronic converter stage is heavily dependent on the operating point of the solar panel which is mainly determined by solar irradiation and temperature [13]. Nature decides whenever irradiation and temperature changes, hence the output power of the solar panel might change at any time.

Due to the non-linear nature of the PV output power, it is of essential that its maximum power which can be obtained from it is tracked at all times and fed to the load. An MPPT is used for tracking the PV maximum power under any operating condition and the dc-dc boost converter is used to step up the voltage and fed to the load. The two main types of dc-dc converter topologies that are predominantly employed in stand-alone PV system are the conventional dc-dc boost converter and interleaved dc-dc boost converter.

One of the two dc-dc boost converters aforementioned offer better efficiency under weak operating point of the solar panel, whilst the other offer improved efficiency under strong operating point of the solar panel [13]. The standalone PV system developed can be used to power TVs, Compact Disc (CD) players, Laptops, etc.

II. DESIGN OF A DC-DC BOOST CONVERTER

In a boost converter, the output voltage is greater than the input voltage – hence the name "boost". A boost converter is shown below:

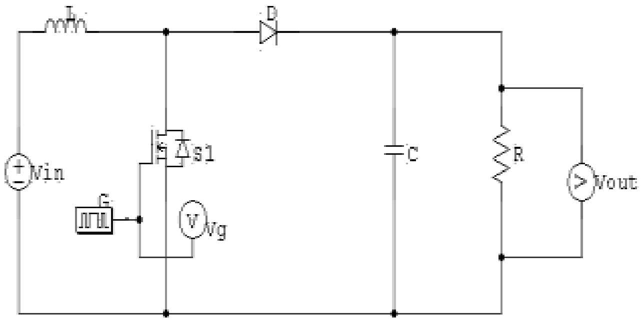

Figure 3: Circuit diagram of Conventional Boost Converter

Power for the boost converter can taken from any suitable DC sources, such as DC generators, batteries, solar panels and rectifiers. The method that changes one DC voltage to a different DC voltage is called DC to DC conversion. Generally, a boost converter is a DC to DC converter with an output voltage greater than the source voltage. It is sometimes called a step-up converter since it "steps up" the source voltage. Since power (P = V I) must be conserved, the output current is lower than the source current. [14]

For high efficiency, the SMPS switch must turn on and off quickly and have low losses. The advent of a commercial semiconductor switch in the 1950s represented a major milestone that made SMPSs such as the boost converter possible. The major DC to DC converters were developed in the early 1960s when semiconductor switches had become available. The aerospace industry's need for small, lightweight, and efficient power converters led to the converter's rapid development.

Switched systems such as SMPS are a challenge to design since their models depend on whether a switch is opened or closed. R. D. Middle brook from Caltech in 1977 published the models for DC to DC converters used today. Middle brook averaged the circuit configurations for each switch state in a technique called state-space averaging. This simplification reduced two systems into one. The new model led to insightful design equations which helped the growth of SMPS. [14]

The function of boost converter can be divided into two modes, Mode 1 and Mode 2. Mode 1 begins when switch 1 is switched on at time t=0. The input current rises and flows through inductor L and switch 1.

Mode 2 begins when switch 1 is switched off at time t = t1. The input current now flows through L, C, load, and diode D. The inductor current falls until the next cycle. The energy stored in inductor L flows through the load.

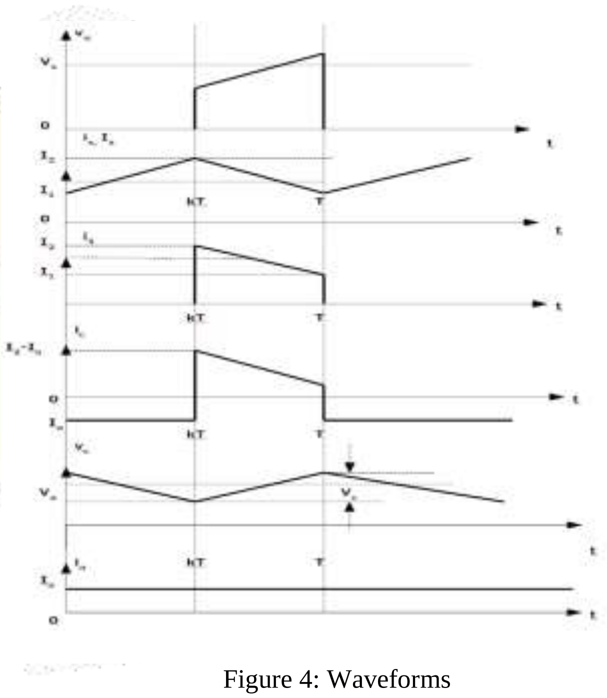

Figure 4: Waveforms

The voltage-current relation for the inductor L is:

$$i = \frac{1}{L}\int_0^t V\,dt + i_0$$

Or

$$V = L\frac{di}{dt}$$

For a constant rectangular pulse:

$$i = \frac{Vt}{L} + i_0$$

When the switch 1 is switched:

$$i_{pk} = \frac{(V_{in} - V_{Trans})T_{on}}{L} + i_0$$

Or

$$\Delta i = \frac{(V_{in} - V_{Trans})T_{on}}{L}$$

And when the switch 1 is switched off the current is:

$$i_0 = i_{pk} - \frac{(V_{out} - V_{in} + V_D)T_{off}}{L}$$

Or

$$\Delta i = \frac{(V_{out} - V_{in} + V_D)T_{off}}{L}$$

Here V_D is the voltage drop across the diode D, and V_{Trans} is the voltage drop across the switch 1.

By equating through delta i, we can solve for Vout:

$$\frac{(V_{in} - V_{Trans})T_{on}}{L} = \frac{(V_{out} - V_{in} + V_D)T_{off}}{L}$$

$$V_{in} - V_{Trans}D = (V_{out} + V_D)(1 - D)$$

$$V_{out} = \frac{V_{in} - V_{Trans}D}{(1 - D)} - V_D$$

Neglecting the voltage drops across the diode and the transistor:

$$V_{out} = \frac{V_{in}}{1 - D}$$

So, it is clear that the output voltage is related directly to the duty cycle. The main challenge when designing a converter is the sort of inductor to be used. From above equations, it can be seen that the inductance is inversely proportional to the ripple current. So, to reduce the ripple, a larger inductor should be used [16] [17].

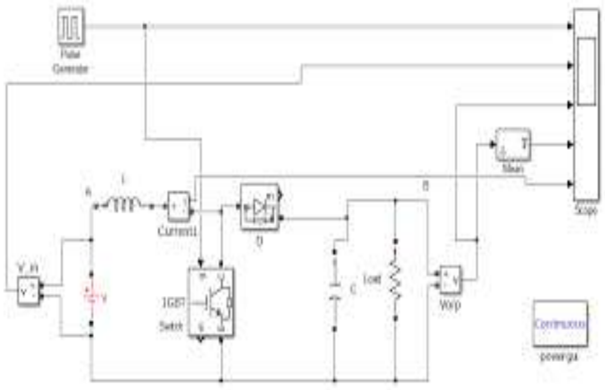

Figure 5: Boost Converter Simulation Model using IGBT

III. DESIGN OF A DC-DC INTERLEAVED BOOST CONVERTER

A two phase interleaved boost converter is mainly used in high input to high output voltage conversion applications and also the interleaved boost converter is used to reduce the current ripple in both input and output. In interleaved boost converter the number of phases is increased with the ripple content in input the complexity of the circuit is increased thereby the cost of implementation also increasing [18].

Therefore to minimize the ripples, size and cost of input filter a two phase Interleaved boost converter fed photovoltaic generation system is simulated using MATLAB/Simulink software in this paper.

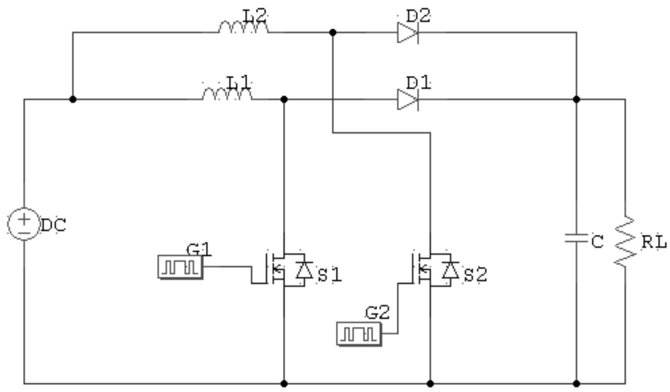

Figure 6: Circuit diagram of Proposed Interleaved Boost Converter

The advantages of interleaved boost converters are reducing input current ripple, increasing efficiency, improving reliability etc. The number of switching devices, number of inductors and diodes are same as the number of phases used in the circuit [19]. The circuit diagram of proposed two phase interleaved boost converter is shown in figure 6. The input voltage is 100-300V [20]. Each leg of the converter has the switching frequency of 20 KHz. The gating pulses of the power electronic switches are shifted by,

$$360^\circ/n$$

Where 'n' is the number of phases. Which is,

$$360^\circ/2 = 180^\circ$$

A. SELECTION OF SWITCHES:

The MOSFET, is a device that is voltage controlled device and not current-controlled. MOSFETs have a positive temperature coefficient, stopping thermal runaway. The on-state-resistance has no theoretical limit; hence on-state losses can be far lower. The MOSFET also has a body-drain diode, which is particularly useful in dealing with limited freewheeling currents. All these advantages and the comparative elimination of the current tail soon meant that the MOSFET became the device of choice for power switch designs.

B. SELECTION OF INDUCTOR:

The inductance value of the IBC is calculated using the following formula,

$$L = V_S \times D / F \times \Delta I_L$$

Where Vs is the source voltage, F is the frequency in Hz and ΔI_L is the inductor current ripple.

C. SELECTION OF OUTPUT FILTER:

The selection of output capacitor is done by the following formula. The capacitance value is depends on output voltage, load resistance, duty ratio and the frequency.

$$C = V_O \times D \times F / R \times \Delta V_O$$

Where Vo is the output voltage in volts, R indicates resistance in Ω, D is the duty ratio and ΔVo is the change in output voltage in volts.

D. OPERATION OF IBC

The two MOSFET switches are used for the controlling the converter by the gate pulses.

MODE 1:
When the switch S1 is turned ON, the current in the inductor is increasing linearly from zero. During this time interval the energy is stored in the inductor L1.

MODE 2:
When the switch S2 is turned OFF, the diode D1 starts to conduct and the energy in inductor ramps down. In this time interval inductor starts to discharge and the current flowing through the diode and to the load. After half switching cycle of S1, the switch S2 also turned ON completing the same cycle.

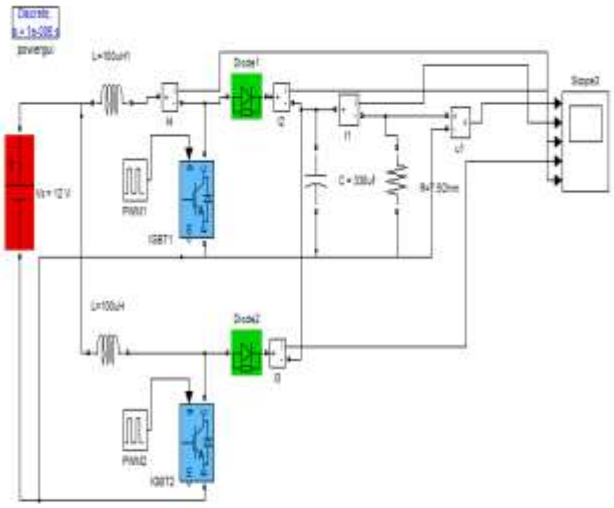

Figure 7: Simulation of IBC circuit using Matlab/Simulink using IGBT

IV. SIMULATION RESULT & ANALYSIS

Table 1: <u>Simulation Model Parameter of IBC using IGBT</u>

S. No	Parameters for an IBC	Value
1.	Input (Vin)	12V
2.	Output Voltage (Vo)	24V
3.	Switching Frequency	40kHz
4.	Inductance (L1 & L2)	100µH
5.	Capacitor (C)	330µF
6.	Resistance (R)	16Ω
7.	Duty ratio (D)	0.5
8.	Switching devices	IGBT

A two-phase IBC simulation model is developed using Matlab/Simulink. Ideal IGBTs and diodes are used in the model using PWM technique of interleaved to switching. Figure 8. shows the simulation result of the output voltage for 0.5 duty cycle.

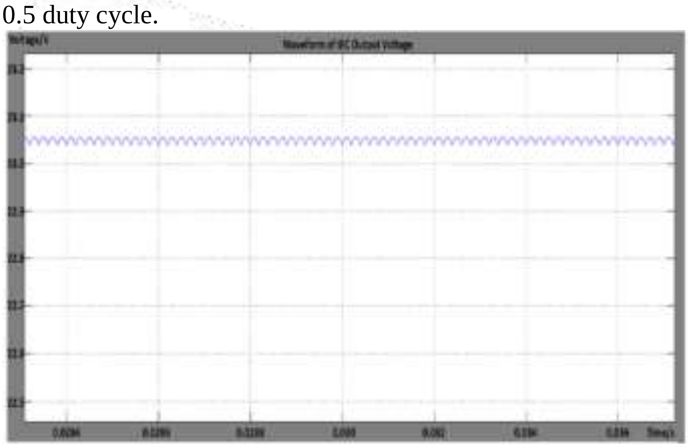

Figure 8. Waveform of output voltage, Vout.

The output voltage ripple calculated is equal to 0.03% which is settled at 23.07 Volt for 0.5 duty cycle. The output voltage is slightly less than the calculated value equal to 24 Volt. The voltage can be regulated from the changing of duty cycle.

Table 2 shows the simulation results of output voltage with different duty cycle.

Table 2: Simulation Result

Interleaved Duty Cycle

Duty Cycle 1	Duty Cycle 2	Output Voltage (V)
0.00	0.00	11.31
0.14	0.14	13.13
0.25	0.25	15.14
0.33	0.33	17.01
0.40	0.40	19.04
0.45	0.45	20.80
0.50	0.50	23.07

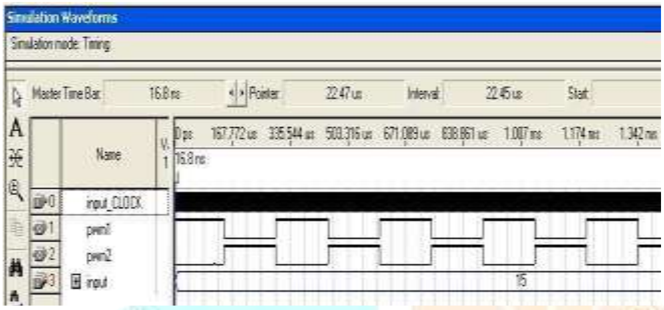

Figure 9: Simulation for PWM generator

Figure 9. shows the generated PWM signal. At this point, the on-off switching times of displayed PWM waveforms are compared with their calculated value and any deviation notes for correction.

Table 3 shows the comparison of output voltage between the calculation; simulation results

TABLE 3. COMPARISON OF OUTPUT VOLTAGE

Output Voltage, Vout (V)

Duty Cycle	Calculation	Simulation
0.00	12	11.14
0.14	14	13.51
0.25	16	15.82
0.33	18	17.59
0.40	20	19.73
0.45	22	21.32
0.50	24	21.90

It shows a slight difference in the value of the output voltage produced by calculation and simulations. It can be proved that the development of IBC has met all the desired objectives because it has been able to produce an output voltage that is close to the desired voltage of 24. After all results are taken, the difference between IBC and Conventional Boost converter has been made to find out the advantages of IBC compared to Conventional Boost converter.

Table 4. shows the comparison between the IBC and Conventional Boost converter.

TABLE 4. COMPARISON BETWEEN IBC AND CONVENTIONAL BOOST CONVERTER

Parameters	**IBC**	**Conventional Boost**
Input Voltage	12 Volt	12 Volt
Output Voltage	23.9 Volt	21.9 Volt
Switching Frequency	40kHz	40kHz
Output Ripple Current	1.65%	18.7%
Output Ripple Voltage	3.32%	5%
Efficiency	99.58%	91.25%

The results of the difference between the IBC and conventional boost converter indicates that the IBC has several advantages compared to the Conventional Boost converter because it has higher efficiency, lower voltage ripple, lower ripple current and high reliability.

V. CONCLUSION

In this paper, a simulation and calculation implementation of IBC is presented. By using this IBC, the output voltage can be adjusted by varying the duty cycle of the PWM switching. The performance of the IBC system under various duty cycles has been investigated. Comparison between the IBC and conventional boost converters shows that the IBC produces higher efficiency and reduced ripple. It is also found that interleaved boost has the ability in input current sharing as well as reducing the ripple current.

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