

Performance Analysis Of High Step-Up DC-DC Converters For Photo-Voltaic Module Application

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Abstract: *In recent years, interest in natural energy has been increased due to increased concern for the environment. Many kinds of circuits and their control schemes for photovoltaic (PV) power generation systems have been studied. A conventional system employs a PV array in which many PV modules are connected in series and parallel. Using this arrangement we can obtain sufficient dc input voltage for generating ac utility line voltage. Sometimes the total power generated from the PV array is reduced due to partial shading. This decreases inherent current generation, and prevents the generation current from attaining its maximum value. To overcome this drawback, an ac module system has been developed. In this system, DC-DC converters are employed for standalone solar powered panel for single-phase supply. Thus the demand of photovoltaic panel and its accessories is increased and this demand needs to be met efficiently and economically. In a standalone system, the photovoltaic panel is preceded by DC-DC converter and then in series with DC-AC converter. In this paper DC-DC converters such as Traditional Boost Converter (TBC), Switched Inductor Boost Converter (SIBC) and Coupled Inductor Boost Converter (CIBC) are discussed along with the modeling and simulation of each with rated power supply for single-phase inverter. Here TBC, SIBC, and CIBC are discussed mathematically and graphically and then simulated in MATLAB.*

Keywords: DC-DC converter, Traditional Boost Converter, Switched Inductor Boost Converter, Coupled Inductor Boost converter, solar Standalone system.

1. INTRODUCTION

In the present scenario solar power energy and wind energy have become the solution to reduce global warming. Photovoltaics is contributing to our energy demands increasingly; a study [1], [2], shows that by 2020, this contribution will reach to 2% of the total world electricity generation and by 2030, it will reach upto 5% with the current growth rate. A good amount of research has been done to improve the techniques to extract solar power energy from the sun. Presently many researchers are developing the control algorithm as well as topologies of DC-DC converters. A conventional system has a PV array in which a number of PV modules are connected in series and parallel. This arrangement obtains sufficient dc input voltage for boost converter. The primary function of DC-DC converter is to convert unregulated DC supply into regulated dc supply at a certain desired voltage level. In a standalone system generally DC input is fluctuating whereas the output requires a constant value. Due to partial shading, it becomes very challenging to make installation in urban area as compared to any open space due to shadows caused by buildings, trees, poles shadows, bird droppings, dust, leaves, passersby etc. When a cell is shaded, it generates less optical current. When these cells are connected in series with other cells, all share the same current. This phenomenon, thereby downgrades the overall system energy yield.

The panel-manufacturing industries follow the standards for the development of panels. For a single module rating varies from 100W to 400W and its open circuit voltage ranges from 12V to 40V. If DC-DC converters are absent, then this rated voltage is directly supplied to DC-AC converter. Due to this lower output voltage the inverter module will not perform efficiently. However, this problem is solved by using high step up DC-DC converters. Basic feature of boost converter is its high stepup voltage gain and high efficiency with no isolation [4]. For any DC-DC converter design parameters are the function of ripple content, power level, peak inductor current, ripple free output voltage and peak output current [5]. Problem associated with the low level PV module can also be solved by cascading a number of ac-module inverters. Although, there is one basic problem with ac-module, i.e., its poor reliability at high temperature.

This paper presents and discusses the comparative analysis of Traditional Boost converter (TBC)[5], Switched Inductor Boost Converter (SIBC) [7, 8] and Coupled Inductor Boost Converter (CIBC)[9] using MATLAB simulation. TBC has an advantage over SIBC and CIBC that it has simple circuiting and design approach. However, CIBC has high voltage gain, very low elemental value and less power and conduction losses. The design parameters are function of the ripple content whereas the switching and conduction losses are function of duty ratio. If the duty ratio of the converter is less, it means that it is ON for lesser time period, therefore the conduction loss per cycle is also less.

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$$I_{ph} = I_0 \left\{ \exp \left(\frac{q(V + IR_s)}{NKT} \right) - 1 \right\} - \frac{(V + IR_s)}{R_{sh}} \quad (1)$$

Assumptions

1. All the parasitic elements, switch drop and inductor resistances are negligible.
2. Ideal conditions are presumed for the converter operation.
3. PWM switching is common to all modules and
4. Photovoltaic as well as ac-inverter module have common rating.

A detailed discussion of the converters is presented in the following sections. First, the power electronics topology and design of the TBC, SIBC, and CIBC is discussed. A pulsewidth modulation (PWM) is a signal generator. It is used to generate duty cycle which in turn generates pulses and these pulses are fed to the gate of IGBT of the boost converter. This allows simple control of the converter. After that the designed parameters for a rated voltage level of solar output level are connected. A current to voltage conversion is used for the solar PV panel output. As voltage is pulsating, a high value of condenser C_{PV} is used. While at DC link a high value of Aluminium electrolytic capacitor C_{LINK} is used. This C_{LINK} is used to reduce the ripple content in the regulated output voltage. DC-DC converters also improve the power transfer stability for ac-module inverter.

Figure-1 shows how the system is connected, where PV represents Photovoltaic panel followed by DC-DC converter and then DC-AC inverter module.

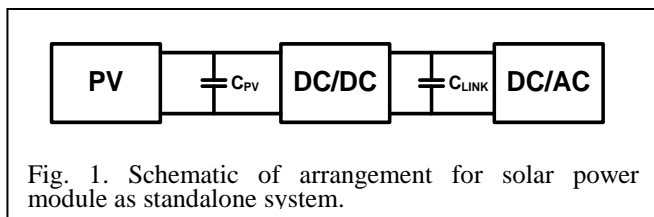


Fig. 1. Schematic of arrangement for solar power module as standalone system.

2. ANALYSIS AND DESIGN OF TBC, SIBC AND CIBC

2.1 SOLAR PANEL

Solar panel is a combination of arrays, which is composed of Series and parallel combination of modules and cells as in Figure.2. Each cell provides a rated open circuit voltage and shortcircuit current.

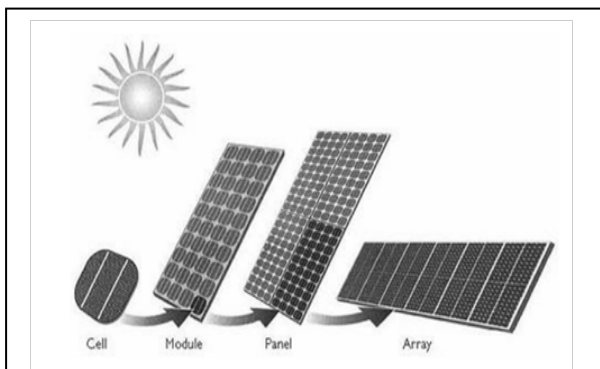


Fig. 2. Component of a typical PV array.[6]

behavior of the solar panel for a specific irradiance. In above equation the various symbols are:

- I= Current to the load
- I_{ph}= Photo current

$$I_{ph} = \frac{\beta}{1000} \times \{ I_{sc} - K_i (T - 298) \} \quad (2)$$

$$I_0(T) = I_0 \left[\frac{T^3}{T_{nom}^3} \right] \exp \left\{ \left(\frac{T}{T_{nom}} - 1 \right) \cdot \frac{E_g}{NV_t} \right\} \quad (3)$$

I₀=Reverse saturation current of the diode

q= Electron charge

V= Voltage across the diode

K=Boltzmann constant

T=Junction Temperature

N=Ideality factor of the diode

R_s=Series resistors

R_{sh}=Shunt resistor

I_{sc}= Short circuit current of the cell

K_i= Temperature co-efficient

β = Solar radiation

Here,

CPV is designed for a specific amount of ripple reduction from the solar panel output.

2.2 Traditional Boost Converter (TBC)

Traditional boost converter is shown in Figure. 3 where V_g is voltage seen across the C_{PV}.

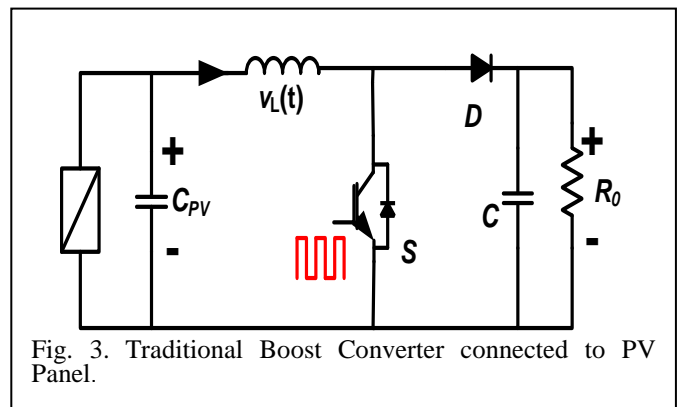


Fig. 3. Traditional Boost Converter connected to PV Panel.

the gain of the system. Gain of the system tells how the output voltage can be controlled by variation of duty ratio. Whereas, equation (5) tells the calculation for inductor and

$$V_0 = \frac{1}{1 - D} V_g \quad (4)$$

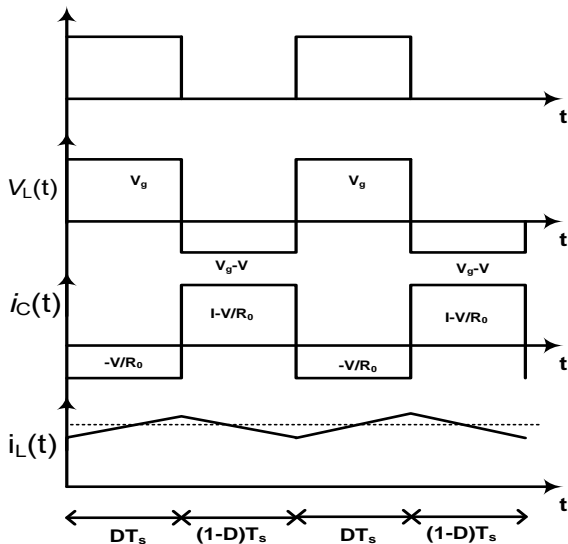
$$L = \frac{V_g}{2\Delta i_L} DT_s \quad (5)$$

$$C = \frac{V_0}{R\Delta v_C} DT_s \quad (6)$$

capacitor with allowable ripple of 5% of the total output voltage and 8%-10% of inductor current. Higher is the inductor current lower is the reliability of the power switch and higher the rating and costing.

Here Δi_L and Δv_C are the allowable ripple contents in inductor current and capacitor voltage respectively. While, T_S is switching period in seconds which is reciprocal of switching frequency. R is load resistance connected across the capacitor. Nevertheless, in the following section table-1

shows the parameter list how it affects the cost and operation. The main advantage of TBC is that it is simple in design and easy in operation. However, this advantage of ease helps in fast switching and low level boost converter. As it can be seen from equation (5) that for higher voltage input, inductor current will be higher, and so will be the value of inductor [5]. However, TBC has several disadvantages also such as, the unregulated DC supply reduces the gain of conversion as well as increases the switching and conduction losses.



2.3 Switched Inductor Boost Converter (SIBC)

During sunny days solar panel provides a high efficiency but partial shadowing, bird droppings etc. impact the operation of the solar power conversion. This causes a great reduction in output voltage and sometimes the controller disconnects the entire string. Researchers [7] discussed the switched inductor and switched capacitor structures for the DC-DC converters. The author introduced a step-up and step down structures for switched inductor and switched capacitor. One of the structures for boost converter is used as switched inductor with higher conversion gain, it also helps in recovering the voltage during partial shading [8]. It can be seen from the figure that SIBC consists of two parts of inductors and three diodes. This arrangement of two inductors and three diodes is known as Switched inductor. It(SIBC) can be obtained from TBC by replacing the inductor of the TBC by switched inductor.

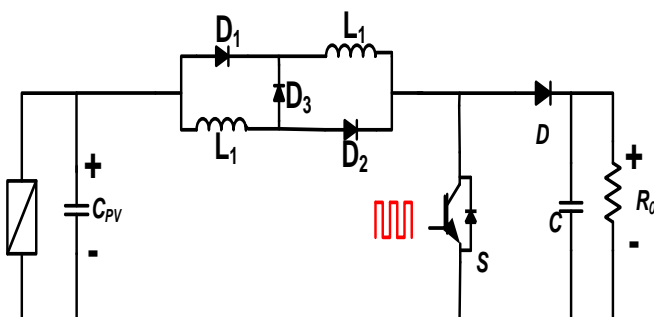


Fig. 5. Switched Inductor Boost Converter connected to PV cell.

The constant duty ratio can be obtained by the following equation:

$$\frac{V_0}{V_g} = \frac{1+D}{1-D} \quad (7)$$

2.4 Coupled Inductor Boost Converter (CIBC)

In any DC-DC converter, inductive circuit is the main part of the operation because it stores and discharges energy in a very efficient manner. But due to leakage of flux coil wound inductor has a lot of loss of energy. In CIBC leakage flux is transferred or linked by the operation of mutual induction. A coupled inductor for photovoltaic[9] has discussed the simulation of CIBC for photovoltaic grid connected system. It is very much obvious from figure that CIBC recovers the loss of leakage flux by means of coupling of inductor. This can be explained in the following manner.

- (1) At $t_0=0$ switch S is on. Diode D_2 is forward biased. Magnetizing inductor L_m transfers its energy through coupled inductor T_1 to charge switched capacitor C_2 . Thus T_1 is energized by V_{in} through switch S. Inductors N_1 and N_2 are mutually energizing each other through leakage inductances. N_1 is charging C_1 and D_1 is reverse biased.
- (2) Switch S is about to turn off. D_2 is now reverse biased, D_1 is already reverse biased. C_2 is charged such that D_3 gets forward biased. Hence C_1 and C_2 release energy to load R. Thus diode D_3 is now acting as free wheeling diode.
- (3) Now switch S is turned off. The magnetizing current supplies energy to C_s (Capacitance of switch S). C_s is charged to voltage V_s such that $V_s > V_c$. Hence diode $D1$ is forward biased again.
- (4) Now D_2 also becomes forward biased. D_3 is reverse biased. Hence C_1 and C_2 are again charging through i_{d1} and i_{d2} . C_1 and C_2 behave as open circuit. C_3 is supplying energy to load R.
- (5) Once C_1 and C_2 are charged as above, $D2$ is forward biased and $D1$ is reverse biased. Switch S is on and the cycle repeats.

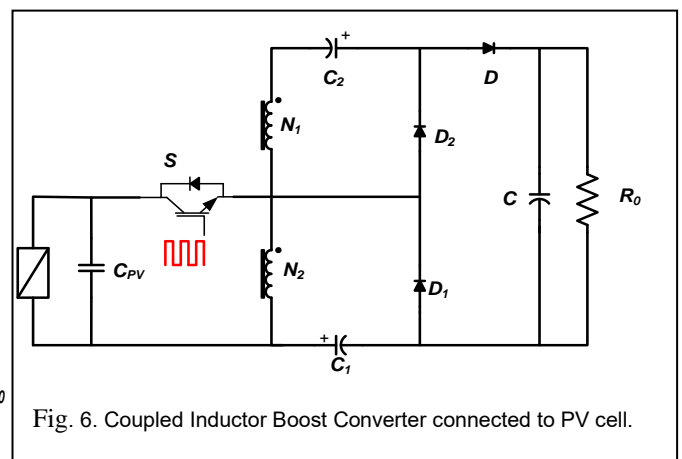


Fig. 6. Coupled Inductor Boost Converter connected to PV cell.

Various studies show that non-isolated DC-DC converters for PV system connected to grid, are more advantageous as

compared to isolated ones, due to the cost of high frequency transformer involved in the latter.

In figure 6, D_1 and D_2 are normal diodes whereas D is high frequency diode similar to that in TBC and SIBC. Diode D works as freewheeling diode. However, N_1 and N_2 are number of turns of coupled inductor with dot convention.

$$\frac{V_o}{V_g} = \frac{1+n}{1-D} \quad (10)$$

In the above equation (10) n is the turns ratio which is given by N_2/N_1 , in many practical applications it is taken greater than 2 and lesser than 20. Higher the turn ratio higher will be the magnetic interference. To minimize the interference of the circuit and to remove the effect of imbalance of voltage distribution it is required that the turns ratio should be taken within range.

3. COMPARATIVE ANALYSIS OF CONVERTERS

In above sections TBC, SIBC and CIBC are discussed with their advantages and limitations individually. If the turns ratio is chosen carefully and properly then application and principle of CIBC is more significant as compared to the remaining two.

Here a comparative table is prepared which shows the detailed design parameters of the TBC, SIBC and CIBC. We have considered the photovoltaic and inverter modules common to all the three type of converters. Also the ambient conditions of operation such as temperature, pressure and irradiance capability of the panel also kept same.

Table 1

COMPARATIVE ANALYSIS FOR THE CONVERTER			
Parameter	TBC	SIBC	CIBC
V_o/V_g	$\frac{1}{1-D}$	$\frac{1+D}{1-D}$	$\frac{1+n}{1-D}$
D	$\frac{M-1}{M}$	$\frac{M-1}{M+1}$	$\frac{M-(1+n)}{M}$
I_L	$\frac{I_o}{(1-D)}$	$\frac{I_o}{(1-D)}$	$\frac{I_o}{2(1+n)(1-D)}$
L	$\frac{V_g}{2\Delta i_L} DT_s$	$\frac{V_g}{2\Delta i_L} DT_s$	$\frac{V_g}{2\Delta i_L} DT_s$
C	$\frac{V_o}{R\Delta v_c} DT_s$	$\frac{V_o}{R\Delta v_c} DT_s$	$\frac{V_o}{R\Delta v_c} DT_s$

In above table all the basic design parameters are given by the symbols having their usual meanings as discussed in previous sections. Here, M is gain ratio of the converter i.e. it is the ratio of output voltage to the input voltage.

Table 2

COMPARATIVE ANALYSIS FOR THE CONVERTER (NUMERICALLY)

Parameter	TBC	SIBC	CIBC
V_o/V_g	5	5	5
D	0.8	0.6667	0.4
I_L [A]	30	18	1.667
L [mH] <small>(for same Ripple current)</small>	0.16	0.1333	0.08
C [μF]	80	66.667	40

Following Figure 7. shows the variation of voltage gain versus duty ratio. It can be seen that for the same duty ratio CIBC provides better conversion of voltage from input to output voltage. Higher the duty cycle, higher will be the conduction loss, and higher the power loss. In Table 2 numerical comparison is shown where $V_o=60V$, $V_g=12V$, $R_o=10\ \Omega$, $I_o=6A$, $f_s=10kHz$, and $n=2$ (turns ratio).

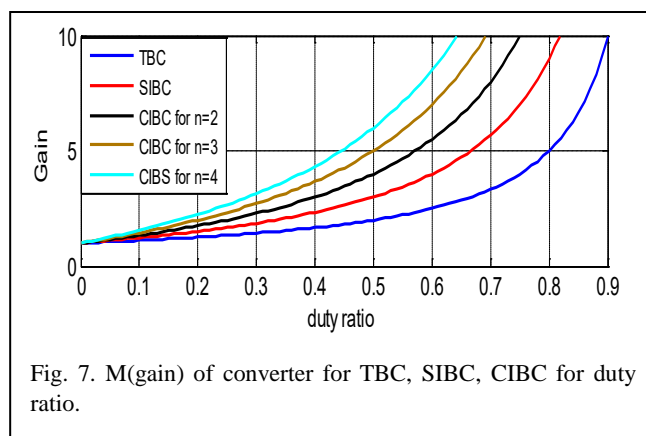
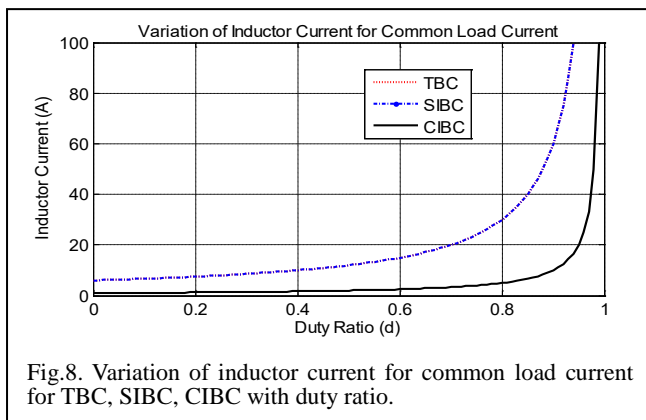


Fig. 7. M (gain) of converter for TBC, SIBC, CIBC for duty ratio.



All the more, Inductor current too is a function of duty cycle if the load current is kept constant. In figure.8, for a fixed duty ratio say 0.5 CIBC will have the least amount of inductor current as compared to the other two. High inductor current causes heating as well as the failure of devices. While considering the effect of switching loss, conduction loss, the average heat loss in inductor, heat loss in capacitor and imbalance voltage transfer (As in case of CIBC) efficiency drops in considerable amount.

4 CONCLUSION

Conclusively, in this paper CIBC shows its advantages over other two converters, i.e. TBC and SIBC. In table 2 design parameters have a low value of elements. Moreover, duty cycle is considerably low for CIBC for the rated conditions, this feature makes the system having lower conduction loss as compared to others.

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