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Comparative Study Of High Step-Up DC-DC Converters For Photo-Voltaic Module Application

Preeti Nema[1], Prof. B. Anjanee Kumar[2]

[1]*Student, Dept Of Electronics And Telecommunication Engg, RITEE, Raipur*
[2] *Asst Professor, Dept Of Electronics And Telecommunication Engg, RITEE, Raipur*

Abstract—In this paper a comparative study of the DC DC converters is done for the standalone solar powered panel for single-phase supply. For present scenario of the electrical energy demand we require a pollution-free eco-friendly solution. Now a days Governament of India has made it compulsory that carbon footprint should be reduced at every stage while generating electricity by incorporating the photovoltaic panel. The photovoltaic panel and its accessories are required to be efficient and economical. A standalone system consists of a photovoltaic panel followed by a DC-DC converter and then a DC-AC inverter connected in series with it. This paper gives a description and comparison of various DC-DC converters such as Traditional Boost Converter (TBC), Swithced Inductor Boost Converter (SIBC) and Coupled Inductor Boost Converter (CIBC) with modeling and simulation for rated power supply along with a single-phase inverter. Though, roof top supply system has become very popular for domestic supply yet partial shading, design elements, rating of components according to the need of electric power is a big issue. Here TBC, SIBC, and CIBC are discussed mathematically and graphically then simulated in MATLAB.

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

I. INTRODUCTION

In the present scenario solar power and wind energy have become the solution for reducing global warming. Photovoltaic is increasingly contributing to our energy demands; a study [1], [2], shows that by 2025, this contribution is expected to reach to 2% of the total world electricity generation and by 2030, it may reach upto 5% with the current growth rate. Many research have been done to improve the techniques to extract solar power from the sun. Presently many studies force the researchers to develop 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 to obtain 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 desired voltage level. In a standalone system usually DC input is often fluctuating whereas the output requires a constant value.

Due to partial shading, it is very challenging to make installation in urban areas compared to that in open space [3]. Lack of maintenance, trees, poles shadow, bird droppings, dust, leaves, passersby, shadow of neighbor's residence cause the partial covering of panels. Partial shading of cells results in less current. When these cells are connected in any series or parallel combination, it downgrades the power quality generated by the system. Almost, every panel-manufacturing industry follows the standards put forward for the manufacture of panels. For a single module rating varies from 100-400W and its open circuit voltage ranges from 12-40V. In the absence of DC-DC converter this rated voltage is directly supplied to DC-AC converter. This voltage works as input voltage to DC-AC converter and being small in amount inverter module does not perform efficiently. However this problem is solved by incorporating high step up DC-DC converter. Basic features of boost converter are its high stepup voltage gain, high efficiency and 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 be solved by cascading a number of ac-module inverters. However, there is one fundamental problem with ac-module,i.e. its poor reliability at high temperature.

This paper presents the performance analysis of Traditionial 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 that it has a simple circuit and design as compared to SIBC and CIBC. However, CIBC has the advantage of high voltage gain, very low elemental value and less switching and conduction losses. 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 small, it means that it is ON for lesser time-duration, therefore the conduction loss per cycle is also less.

Assumptions:

1. All the parasitic elements, inductor resistances and switch drops are neglected.
2. Considering ideal conditions for the converter operation.
3. PWM switching is common to all the modules
4. Photovoltaic as well as ac-inverter module is modeled with common rating.

A detailed description of the converters is presented in the following sections. Firstly, the power electronics topology and design of the TBC, SIBC, and CIBC is explained. A pulsewidth modulation (PWM) is used to generate pulses for different duty cycles, which in turn allow simple control of the converters. After that, various designed parameters for a rated voltage level of solar output level are connected. A current to voltage conversion is used for solar PV output. As voltage is pulsating a high value of condenser C_{PV} is required. At DC link a high value of Aluminium electrolytic capacitor C_{LINK} is used, it reduces the ripple content in the regulated output voltage. DC-DC converters not only improve the solar panel output but also improve power transfer stability for ac-module inverter. Figure-1 shows the manner in which the system is connected. Here PV represents Photovoltaic panel preceded by DC/DC converter and then DC/AC inverter module.

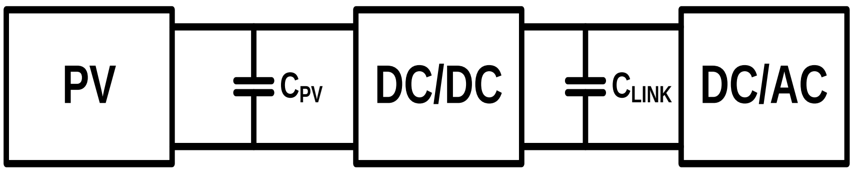

Fig. 1. Schematic of arrangement for solar power module as standalone system.

II. DESIGN AND ANALYSIS OF TBC, SIBC AND CIBC

A. Solar Panel

Solar panel is a combination of many arrays, an array is made-up of a combination of modules and cells in series and parallel as in Figure.2. Each cell provides a rated open-circuit voltage and a short-circuit current.

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

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

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

PV cell acts as a current source. The above equations show the mathematical relationships of the various variables on which the PV cell works. By simulating above equations, we can estimate the behaviour of the solar panel for the specific irradiance. In above equations symbols have the following significance:-

I= Current to the load
I_{ph}= Photo current
I_0=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_{sh}=Shunt resistor
R_s=Series resistors
I_{sc}= Short circuit current of the cell
K_i= Temperature co-efficient
β = Solar radiation , Where

C_{PV} can be designed for the specific amount of ripple reduction from the solar panel output and C_{LINK} is the DC link capacitance.

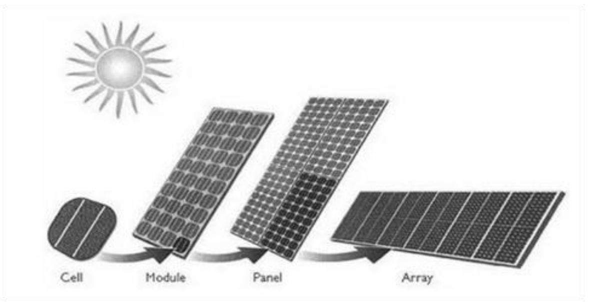

Fig. 2. Component of a typical PV array.[6]

B. Traditional Boost Converter (TBC)

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

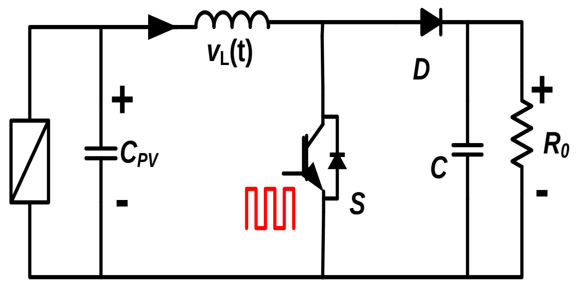

Fig. 3. Traditional Boost Converter connected to a PV Panel.

The DC-DC converter is designed for a specific voltage and load current. The operation of converter can be understood easily from the following waveform . Equation (4) represents the gain of the system, it shows how output voltage can be easily controlled by varying the duty ratio. Equation (5) gives the calculation of inductor and capacitor with allowable ripple of 5% of the total output voltage and 8%-10% of inductor current. If inductor current is higher then the reliability of the power switch is reduced , this increases the rating and costing. Δi_L is the allowable ripple content in inductor current and Δv_C is the allowable ripple content in capacitor voltage.

$$V_0 = \frac{1}{1-D} V_g \tag{4}$$

$$L = \frac{V_g}{2\Delta i_L} DT_S \tag{5}$$

$$C = \frac{V_0}{R\Delta v_C} DT_S \tag{6}$$

T_S is switching period given in seconds which is the reciprocal of switching frequency. Here R is load resistance connected across the capacitor. In the following section table-1 shows the parameter how it affects the cost and operation.

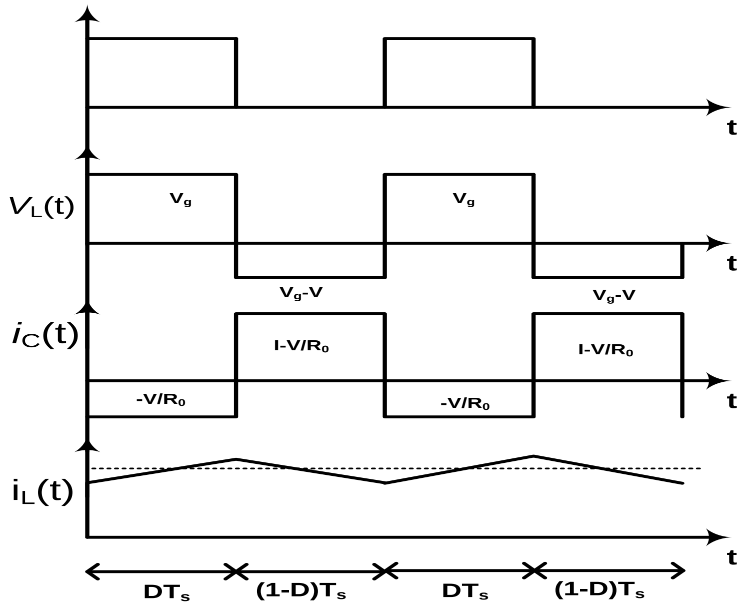

Fig. 4. Waveforms of operation for Traditional Boost Converter connected to PV cell

C. Switched Inductor Boost Converter (SIBC)

Renewable energy sources are the most sought out solution for present scenario of energy crisis. Photovoltaic module is very much used as renewable energy source, whose characteristic in turn depends on environmental conditions such as temperature, solar irradiation, dust accumulation and partial shadowing.These environmental conditions hamper the efficiency of solar panel and impacts the operation of the solar power conversion. Sometimes it causes a great reduction in output voltage and the controller disconnects the whole string. Boris *et. al.* [7] discussed the switched inductor and switched capacitor structures for the DC DC converters. In this discussion, the author has introduced a step-up and step down structure for switched inductor along with the switched capacitor. One of the structures for boost converter is used as switched inductor with higher conversion gain, it also helps to recover the voltage during partial shading [8]. It can be seen from the figure.5 that Switched

Inductor Boost Converter can be obtained from Traditional Boost Converter by replacing the inductor in TBC by a small circuit made of two parts of inductors and three diodes.This arrangement of two inductors and three diodes is known as Switched inductor. SIBC provides high voltage gain and higher efficiency than TBC. The constant duty ratio can be obtained by the following equation:

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

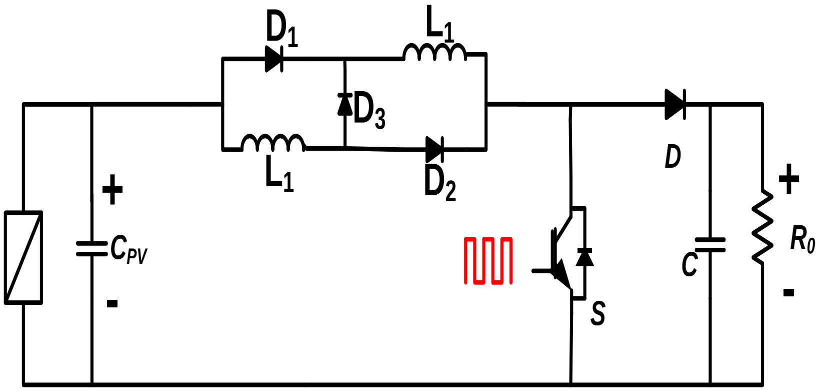

Fig. 5. Switched Inductor Boost Converter connected to PV cell.

D. Coupled Inductor Boost Converter (CIBC)

Inductive circuit is the most important part of DC DC converter as it stores and discharges energy very efficiently. But inductive circuit in the form of coil dissipates energy due to leakage of flux. CIBC uses this leakage flux by transferring it or linking it by mutual induction to coupled inductor. A coupled inductor for PV [9] discusses the simulation of CIBC for photovoltaic grid connected system. Although variation of duty cycle has not been discussed here. It is very much apparent from figure. 6 that according to the working principle of CIBC, it recovers the loss of leakage flux by means of coupling of inductor.

In figure 6, there is a coupled inductor T_1 and a floating active switch S. The primary winding N_1 of T_1 acts as input inductor of TBC. Capacitor C_1 and diode D_1 receive leakage energy from N_1. The secondary winding N_2 of T_1 is connected with another pair of C_2 and D_2 which are in series with N_1.This further enlarges the boost voltage.The rectifier diode D acts as a free wheeling diode and connects to capacitor C. Here, N_1 and N_2 are number of turns of coupled inductor given with the dot convension.

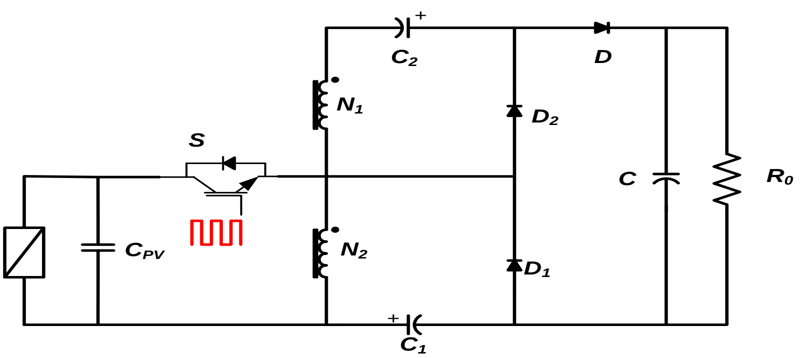

Fig. 6. Coupled Inductor Boost Converter connected to PV cell.

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$$\frac{V_0}{V_g} = \frac{1+n}{1-D} \quad (10)$$

In the above equation (10) n is the turns ratio given as N_2/N_1 and in many practical applications it is taken greater than 2 and less than 20. Higher is the turns ratio higher will be the magnetic interference. Hence, in order to minimize the interference of the circuit and to remove the effect of imbalance of voltage distribution it is required to keep turns ratio well within the range.

III. COMPARATIVE ANALYSIS OF CONVERTERS

We have discussed the advantages and limitations of TBC, SIBC and CIBC in the above sections so far. By choosing proper turns ratio we find that the application and principle of CIBC is more significant as compared to the remaining TBC and SIBC.

In this section, a comparative table has been prepared to show the detailed design parameters of the TBC, SIBC and CIBC. Here we have assumed that the photovoltaic and inverter modules are common to all converters and the same rating of power is transferred from solar photovoltaic panel to inverter module. In addition, the ambient conditions of operation such as temperature, pressure and irradiance capability of the panel kept constant .

Table 1
COMPARATIVE STUDY FOR THE CONVERTER

Parmeter	TBC	SIBC	CIBC
V_0/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	$\frac{I_0}{(1-D)}$	$\frac{I_0}{(1-D)}$	$\frac{I_0}{2(1+n)(1-D)}$
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	$\frac{V_0}{R\Delta v_C} DT_s$	$\frac{V_0}{R\Delta v_C} DT_s$	$\frac{V_0}{R\Delta v_C} DT_s$

In above Table-1 all the basic design parameters are given , the symbols have their usual meanings as discussed in previous sections. Here,M is gain ratio of the converter given by output voltage to the input voltage.

Table 2
COMPARATIVE STUDY FOR THE CONVERTER (NUMERICALY)

Parmeter	TBC	SIBC	CIBC
V_0/V_g	5	5	5
D	0.8	0.6667	0.4
I_L [A]	30	18	1.667

L [mH] (for same Ripple current)	0.16	0.1333	0.08
C [µF]	80	66.667	40

Figure 7. shows the plot of voltage gain with respect to duty ratio.It is clear that for the same duty ratio Coupled Inductor Boost Converter provides better conversion of voltage from input to output voltage. Conduction Losses depend on duty cycle. For higher duty cycle, conduction losses and power losses are also high. Table-2 gives numerical comparison for the V_0=60V, V_g =12V, R_0 =10 Ω, I_0=6A, f_S=*10kHz,* and n=2(turns ratio).

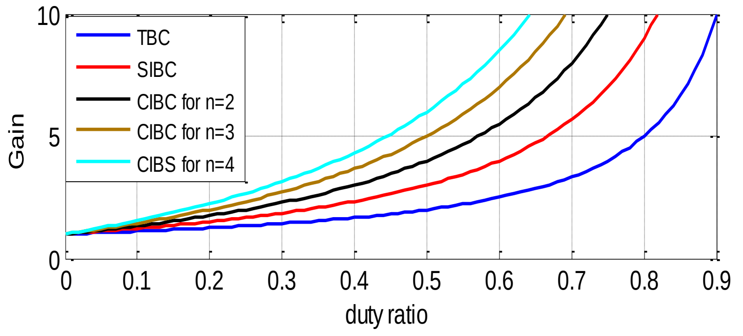

fig. 7. M(gain) of converter for TBC, SIBC, CIBC for duty ratio.

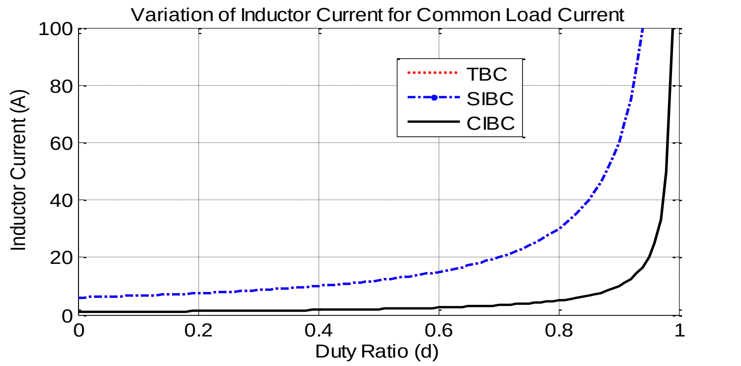

Fig. 8. Variation of inductor current for common load current for TBC, SIBC, CIBC with duty ratio.

Moreover, 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 0.4 CIBC gives least amount of inductor current as compared to the others. Also high inductor current causes heating as well as the failure of devices. In particular,the above mentioned converter is as efficient as 100% ideally with no loss consideration. However, practically the effect of switching loss, conduction loss, the average heat loss in inductor, heat loss in capacitor and imbalance voltage transfer cause drop in efficiency in considerable amount.

IV. CONCLUSION

In this paper CIBC advocates its advantages over the other two converters, i.e.TBC and SIBC. Table-2 gives design parameters with a low value of elements. Moremore, duty cycle is considerably low for CIBC for the rated conditions. Also the transformer function of coupled inductors makes the voltage stress of the switch less as compared to the output voltage. All these facts reduce conduction losses considerably for CIBC as compared to other two boost converters.

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