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

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ABSTRACT : This paper presents the comparative study of DC-DC converters employed for standalone solar powered panel for single-phase supply. Presently, MNRE (Ministry of New and Renewable Energy) India, is compulsorily reducing the carbon footprint generated by production of electricity by incorporating the photovoltaic panel at every level. Increased demand of photovoltaic panel and its accessories needs to be efficient and must be economical. As in standalone system, the photovoltaic panel is preceded by DC-DC converter and then in series with DC-AC converter. In this paper DC-DC converter is discussed with the modeling and simulation of Traditional Boost Converter (TBC), Swithced Inductor Boost Converter (SIBC) and Coupled Inductor Boost Converter (CIBC) with rated power supply for single-phase inverter. In many cases, roof top supply system has become popular for domestic supply but still partial shading, design element, rating of component according to power requirement is a big issue. 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

PRESENTLY 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 2020, 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 studies have been done to improve the techniques to extract solar power from the sun. In the present scenario 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 many PV modules are connected in series to obtain sufficient dc input voltage for boost converter. The main function of DC DC converter is to convert unregulated DC supply into regulated dc supply at a desired voltage level. In standalone system generally DC input is often fluctuating whereas the output requires a constant value. Due to partial shading, it is very much challenging to make installation in urban area compared to any open space [3]. Lack of maintenance, trees, poles shadow, bird droppings, dust, leaves, passersby, cause the partial covering of panels. Partial shading of cells results in less current and when connected in any combination as series or parallel downgrades the power quality generated by the system. Almost, every panel-manufacturing industry follows 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. In the absence of DC-DC converter this rated voltage is directly supplied to DC-AC converter, in case of lower output voltage inverter module will not perform at efficient level. However, this problem is solved by incorporating high step up DC-DC converter. Basic feature of boost converter is its high stepup voltage gain, high efficiency and no isolation [4]. As 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 resolved by cascading a number of ac-module inverters. Although, there is one fundamental problem with ac-module,i.e. the poor reliability with high temperature. This paper presents and discusses the study of the comparative 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 of simple circuiting and design approach as compared to SIBC and CIBC. However, CIBC has the advantages of high voltage gain, very low elemental value and less power and conduction loss. Since, design parameters are function of the ripple content but the switching and conduction loss is function of duty ratio. If the duty ratio of the converter is lesser, 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, switch drop and inductor resistances are neglected.
2. Considering ideal condition for the converter operation.
3. PWM switching is common to all module and
4. Photovoltaic as well as ac-inverter module is modeled in common rating.

A detailed description of the converters is presented in the proceeding sections. First, the power electronics topology and design of the TBC, SIBC, and CIBC is introduced. A pulse-width modulation (PWM) is used to generate pulses for the duty cycle, which allows simple control of the converter. Then, 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 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 to reduce the ripple content in the regulated output voltage. Besides solar panel output 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 preceeded by DC/DC converter and then DC/AC inverter module.

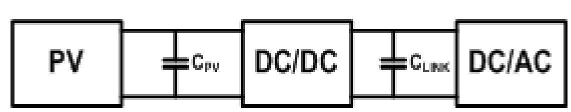

Fig. 1. *Schematic of arrangement for solar power module as standalone system.*

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2 Analysis and design of tbc, sibc and cibc

2.1 Solar Panel

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

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

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

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

Above equations show the mathematical significance of the various variables on which the PV cell acts as a current source. By simulating above equations, one can estimate the behavior of the solar panel for the specific irradiance. In above equation symbols are;

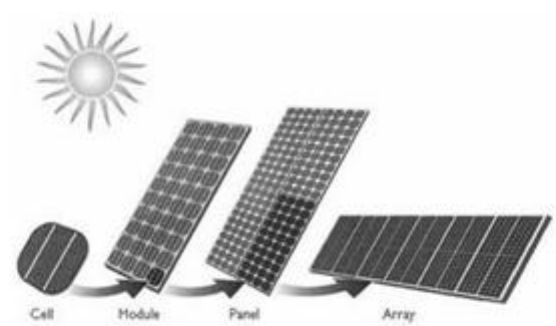

Fig. 2. *Component of a typical PV array.[6]*

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_s=Series resistors
R_{sh}=Shunt resistor
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.

2.2 Traditional Boost Converter (TBC)

Traditional boost converter is given in Figure. 3 with a setup where Vg is voltage seen across the C_{PV}.

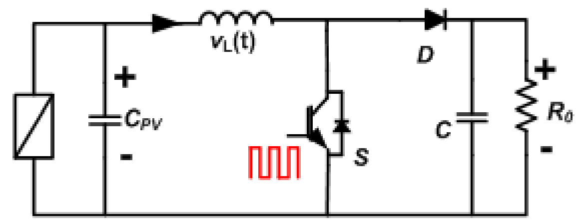

Fig. 3. *Traditional Boost Converter connected to PV Panel.*

For a specific voltage and load current the DC DC converter is designed. According to waveform, operation of converter can be understood easily. Equation (4) represents the gain of the system, how output voltage can be easily controlled by variation of duty ratio. While, equation (5) depicts the calculation for inductor and capacitor with allowable ripple of 5% of the total output voltage and 8%-10% of inductor current. Since, higher

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

$$L = \frac{V_g}{2\Delta i_L}DT_S \qquad (5)$$

$$C = \frac{V_0}{R\Delta v_C}DT_S \qquad (6)$$

the inductor current lower the reliability of the power switch and higher the rating and cost. Δi_L and Δv_C are the allowable ripple contents in inductor current and capacitor voltage respectively. T_S is switching period in seconds which is reciprocal of switching frequency. While R is load resistance connected across the capacitor. Nevertheless, in following section table-1 will show the parameter how it will affect the cost and operation. The main advantage of TBC is that it is simple in design and easy to operate. However, this advantage of ease helps in fast switching and low level boost converter as it is clear from (5) that for higher voltage input, inductor current will be higher,and so the value of inductor [5]. In addition, TBC follows several disadvantages such as, the unregulated DC supply reduces the gain of conversion as well as increases the switching and conduction losses.

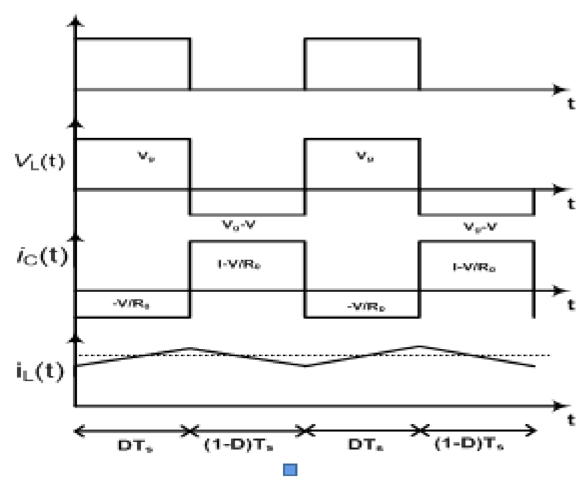

Fig. 4. *Waveforms of operation for Traditional Boost Converter connected to PV cell.*

2.3 Switched Inductor Boost Converter (SIBC)

During sunny days solar panel provides the high efficiency but partial shadowing, bird dropping etc. impacts the operation of the solar power conversion. It causes a great reduction in output voltage and sometimes the controller disconnects the whole string. Boris *et. al.* [7] discussed the switched inductor and switched capacitor structures for the DC-DC converters. In that, author introduced a step-up and step down structures for switched inductor alongwith the switched capacitor. One of the structures for boost converter is used as switched inductor with higher conversion gain and also helps to recover the voltage during partial shading [8]. It can be seen from the figure.5 that SIBC consists of two parts of inductors and three diodes.This arrangement of two inductors and three diodes is known as Switched inductor. SIBC can be obtained from TBC by replacing the inductor of the TBC by switched inductor.
The constant duty ratio can be obtained by the following equation:

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

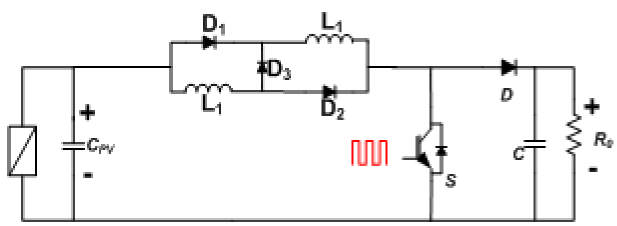

Fig. 5. *Switched Inductor Boost Converter connected to PV cell.*

2.4 Coupled Inductor Boost Converter (CIBC)

In any DC DC converter, inductive circuit is heart of the operation as it stores and discharges energy in a very efficient manner. But coil wound inductor has loss of energy in considerable amount due to leakage of flux. In CIBC leakage flux is transferred or linked with the operation of mutual induction. A coupled inductor for PV [9] has discussed the simulation of CIBC for photovoltaic grid connected system.However variation of duty cycle has not been discussed. As it is very much obvious from figure. 6 that according to the working principle of CIBC, it recovers the loss of leakage flux by means of coupling of inductor. Hereby, in various studies the non-isolated DC-DC converters for photovoltaic system connected to grid, are more advantageous as compared to isolated ones, due to the cost of high frequency transformer involved in the latter [10]. In figure 6, D_1 and D_2 are normal diodes while D is high frequency diode similar to that in TBC and SIBC. However, N_1 and N_2 are number of turns of coupled inductor given with the dot convension.

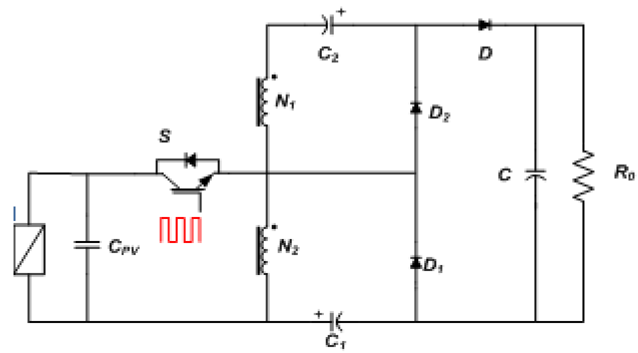

Fig. 6. Coupled Inductor Boost Converter connected to PV cell.

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

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

3 Comparative Analysis of Converters

In above sections TBC, SIBC and CIBC had been discussed and with their advantages and limitations individually. If proper turns ratio is chosen then application and principle of CIBC is more significant as compared to the remaining two. In this section, a comparative table is made to show the detailed design parameters of the TBC, SIBC and CIBC. Here we have considered the photovoltaic and inverter modules common to all converters and common rating of power 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 also kept constant. Table 1

COMPARATIVE ANALYSIS 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 where the symbols have their usual meanings as discussed in previous sections. Only, **M** is gain ratio of the converter given by output voltage to the input voltage.

Table 2
COMPARATIVE ANALYSIS FOR THE CONVERTER (NUMERICALY)

Parmeter	*TBC*	*SIBC*	*CIBC*
V_0/V_g	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 variation of voltage gain with respect to duty ratio.It is clear 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 as also the power loss. In Table 2 numerical comparision is shown for the V_0=60V, V_g =12V, R_0 =10 Ω, I_0=6A, f_S=10kHz, and n=2(turn ratio).*

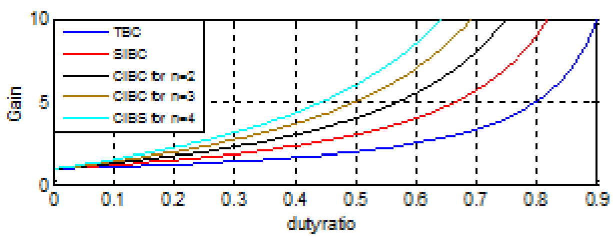

Fig. 7. M(gain) of converter for TBC, SIBC, CIBC for duty ratio.

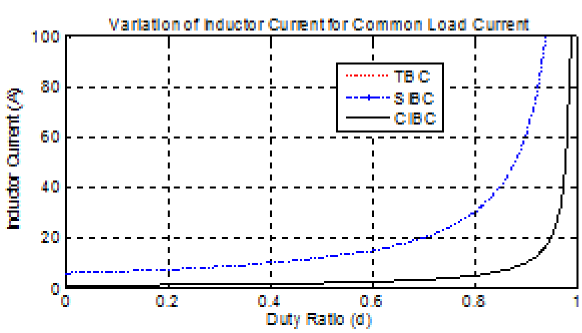

Fig. 8. Variation of inductor current for common load current for TBC, SIBC, CIBC with duty ratio.

Moreover, Inductor current is also a function of duty cycle if the load current is kept constant. In figure.8, for a fixed duty ratio say 0.6 CIBC will bear least amount of inductor current as compared to the others. In particular, high inductor current causes heating as well as the failure of devices. Ideally, the above mentioned converter is as efficient as 100% with no loss consideration. While considering the effect of switching loss, conduction loss, the average heat loss in inductor, heat loss in capacitor and imbalance voltage transfer (CIBC) efficiency may drop in considerable amount.

4 Conclusion

Conclusively, in this paper CIBC advocated its advantages over other converters,i.e.TBC and SIBC. In table-2 design parameters are given with a low value of elements. Furturemore, duty cycle is considerably low for CIBC for the rated conditions which makes the system having lower conduction loss as compared to others.

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