

Design and Simulation of PV Based Two-Phase Interleaved Boost Converter

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Abstract: In this paper, simulation of PV based two phase interleaved boost converter has been discussed. Interleaved Boost Converter (IBC) serves several applications which require boost in output voltage such as fuel cells, photovoltaic cells and batteries etc., because it has several advantages over conventional DC-DC converters. The configuration of IBC comprises parallel combination of a number of boost converters with same phase shift and switching frequency. This paper deals with the design of two-phase IBC for a five level cascaded multilevel inverter (MLI). The source for each bridge of the MLI has been modelled as PV. The simulation has been carried out using MATLAB/SIMULINK.

Keywords: Multilevel Inverter, Interleaved boost converter, Boost converter & Photo-voltaic cells.

I. INTRODUCTION

In recent days, Photovoltaic (PV) applications have become a great hit all over the world because of the abundant availability of the solar energy in almost all parts of the earth. Therefore there is a spurt in the area of photovoltaic research which in turn led to the development of suitability of converters to the photovoltaic systems. One such invention is the Interleaved Boost Converter (IBC) that has the boost and current sharing capability on high power application. It can be configured with many phases that allow the input current sharing and heat dissipation. Even though there are a number of DC boost converters that are available for the PV applications, they have objectionable level of ripples. In addition to the minimization of the ripples, it has higher modularity, reliability and power capability at the cost of additional inductors, diodes and switching devices. In this paper, the two phase IBC can be used with PV so as to get reduced current ripple that comes out of the PV cell. The boosted output voltage of the IBC is used as source of voltage for the five level cascaded (Multi level Inverter) MLI.

II. Two-Phase Interleaved Boost Converter

Application of interleaving technique is remarkable in the field power electronics. The voltage and current stress can go beyond the handling capability in high power applications. Therefore many power devices can be connected in parallel and/or in series. But voltage sharing and/or current sharing will always be a problem. Paralleling of power converters is an alternate solution instead of paralleling power devices which could be more beneficial. Figure 1 shows the two-phase interleaved boost converter topology [1]-[5].

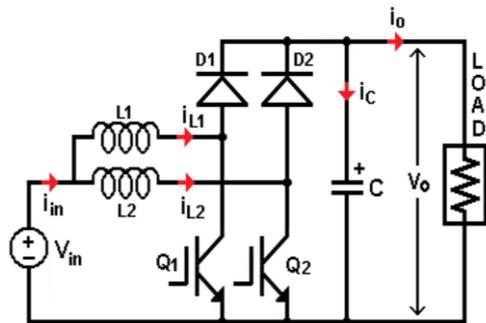


Figure 1. Two-Phase Interleaved Boost Converter

The two-phase IBC consists of two parallel connected boost converter units. Each of the units in the IBC can be controlled by switching the devices with phase shift of $360^\circ/n$, where n is the number of parallel connected units. In this converter, there should be a phase shift implemented between the switching pulses of the both devices. A phase shift of 180° should be provided for each switch as there are two parallel units. The timing signal is shown in figure 2.

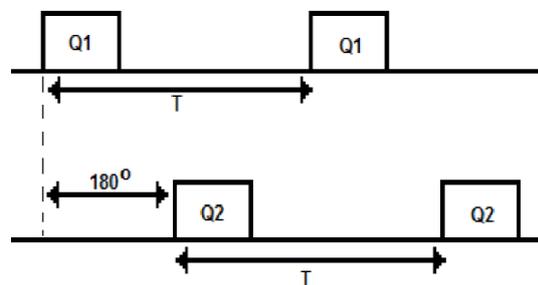


Figure 2. Timing signal of the two-phase IBC

III. Operation Of The Two-Phase IBC

In general, the frequency and phase shift are same for each parallel connected unit in the IBC. Operation of two-phase IBC can be explained based on figure 1. The device Q1 is turned ON first. So, the current in the inductor i_{L1} increases linearly and at the same time energy is stored in inductor L1. When Q1 is turned OFF, diode D1 conducts and the stored energy in the inductor decreases with a slope of the difference in the input and output voltage. When the inductor discharges its energy, the transfer the current to the load takes place via the diode. Once half switching cycle of Q1 is completed, Q2 is also turned ON and completes same cycle of actions. The current ripple produced will be very small as there is a cancellation of ripples due to phase shift of 180° in the switching pulses[7]-[9].

IV. Design Equations Of Two-Phase IBC

The design of magnetic elements in the circuit plays an important role for storing energy and filtering. The two-phase IBC requires two identical inductors for achieving balanced current. The value of the inductor can be calculated as per the following equation.

$$L = \frac{V_{in} M}{f_s \Delta I_L} \tag{1}$$

Where,

M - Modulation Index, V_{in} – Input Voltage, f_s -Switching frequency, ΔI_L - Inductor current ripple.

The value of the capacitor can be calculated by the following equation.

$$C = \frac{I_o M}{f_s \Delta V_C} \tag{2}$$

Where,

M - Modulation Index, f_s -Switching frequency, ΔV_C – Change in output voltage, I_o – Output current.

The number of phases can be chosen based on the amount of ripple to be reduced. Increase in phase number will not result in much reduction in ripple. This poses a restriction to the increase in number of phases. The number of switches, inductors and diodes are equal in number with the phases.

V. PV Modeling

PV cell can be represented by the equivalent electrical circuit shown in figure 3.

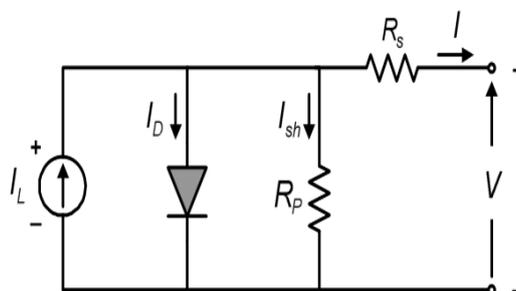


Figure 3. Equivalent circuit of a solar cell

The I-V and P-V characteristics of the solar cells are non linear in nature. The solar cell characteristics mainly depend on the existing atmospheric conditions such as temperature and irradiance. The P-V characteristics of solar cell are shown in figure 4. The I-V curve shown in figure 5 is for the PV module under sunlight and dark conditions.

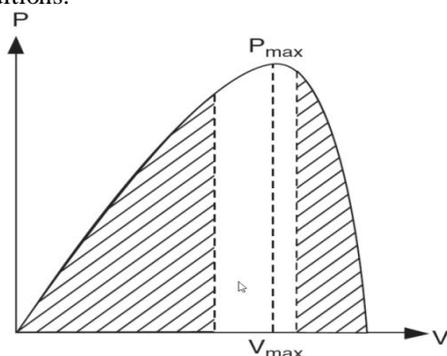


Figure 4. P-V characteristics of a PV cell

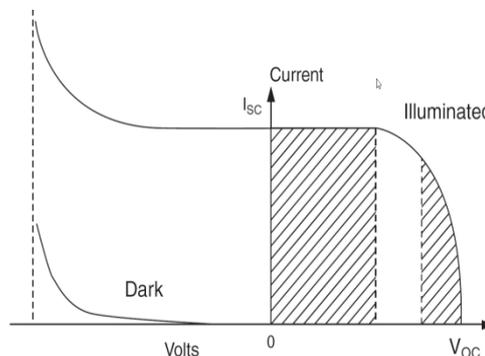


Figure 5. I-V characteristics of a PV cell

The PV cell can be mathematically modelled using the following equations.

The open circuit voltage given by V_{oc} is obtained when load current reaches zero.

$$V_{oc} = V + IR_{sh} \tag{3}$$

The diode current expression is given by

$$I_d = I_D \left[e^{\frac{QV_{oc}}{AKT}} - 1 \right] \tag{4}$$

The load current is given by the following equation

$$I = I_L - I_D \left[e^{\frac{QV_{oc}}{AKT}} - 1 \right] - \frac{V_{oc}}{R_{sh}} \tag{5}$$

Where,

I_D – Diode saturation current

Q – Charge of an electron = 1.6×10^{-19} C

A - Curve fitting constant

k - Boltzmann constant = 1.38×10^{-23} J/K

T – Absolute Temperature in K

VI. Maximum Power Point Tracking

Perturb and Observe algorithm has been implemented for tracking maximum power point in this paper. It is a very simple algorithm which requires the measurement of solar panel’s output voltage and current. The perturbation at each step is used to find out the maximum power. The flow chart of the P & O algorithm is shown in figure 6.

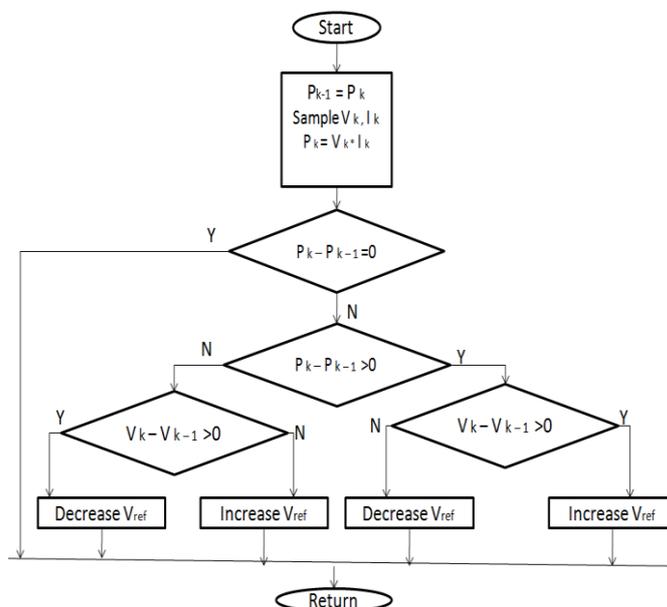


Figure 6. Flow chart of P & O MPPT algorithm

VII. Simulation Results

7.1 Simulation Parameters

The simulation parameters for the PV panel and the IBC are listed in the table 1. The two-phase IBC simulation parameters are listed in the table 2.

Table 1. Simulation parameters of PV array

PV Parameters	Rating
Open circuit voltage V_{oc}	21.24 V
Short circuit current I_{sc}	2.55 A
No of cells N_s	36
Insolation G	1000 W/m ²
Ideality factor A	1.5
Operating temperature T	298 K

Table 2. Simulation parameters of Two-Phase IBC

Two-phase IBC Parameters	Rating
Input voltage	20 V
Inductor	0.015 mH
Capacitor	0.22 mF
Switching frequency	5 kHz

7.2 Mathematical model of PV array in MATLAB/Simulink along with P and O MPPT

The PV array has been modelled using the equations (3),(4) and (5). Single diode model of a solar cell is considered in this paper. Figure 7 shows the mathematical model of the PV array with perturb and observe maximum power point tracking technique (MPPT).For implementing MPPT, the current and the voltage of the PV panel has been taken and used as inputs for the P & O algorithm.

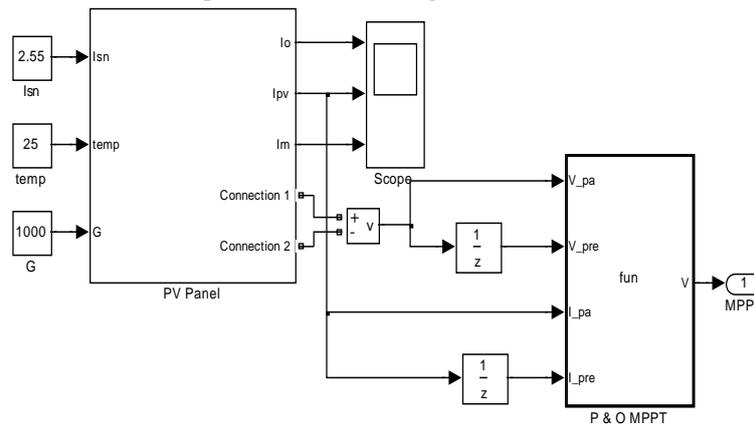


Figure 7. PV model with P & O MPPT

7.3 Simulink model of two-phase IBC

The two-phase IBC has been modelled with PV source implemented with MPPT in Matlab/Simulink. It is shown in the figure 8. The output voltage of the PV array is given to the two-phase IBC.

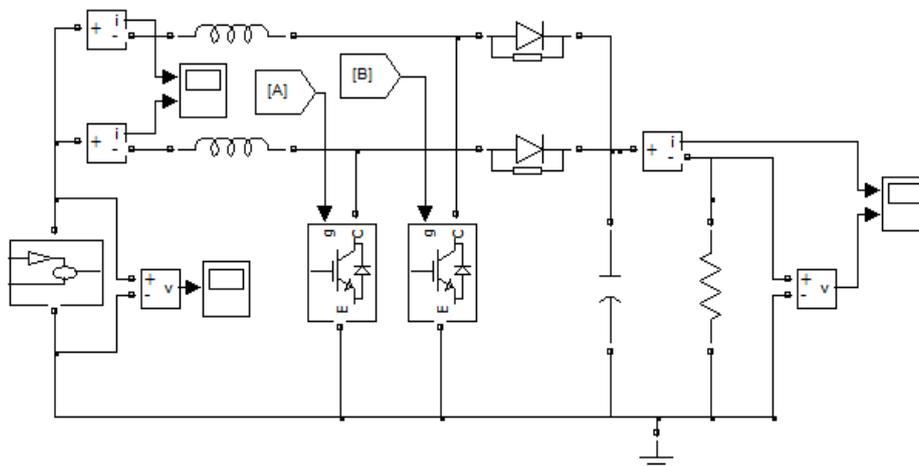


Figure 8. MATLAB/Simulink model of two-phase IBC with PV MPPT

7.4 Pulses for the switches of two-phase IBC

The switches of the two-phase IBC are required to be fired at 180° phase shift. Since there are two phases, the pulses are to be produced at the phase difference of 360°/n, where n=2. The pulse pattern for the two switches are shown in figure 9.

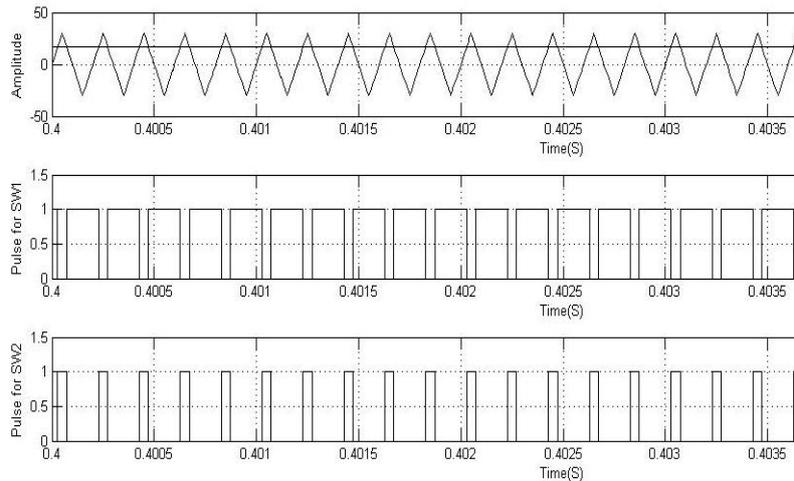


Figure 9. Pulses generated for switches of two-phase IBC

7.5 Inductor current ripple of two-phase IBC

The inductor current ripple of the two phase IBC is shown in figure 10 and it is found to be 6.89%.

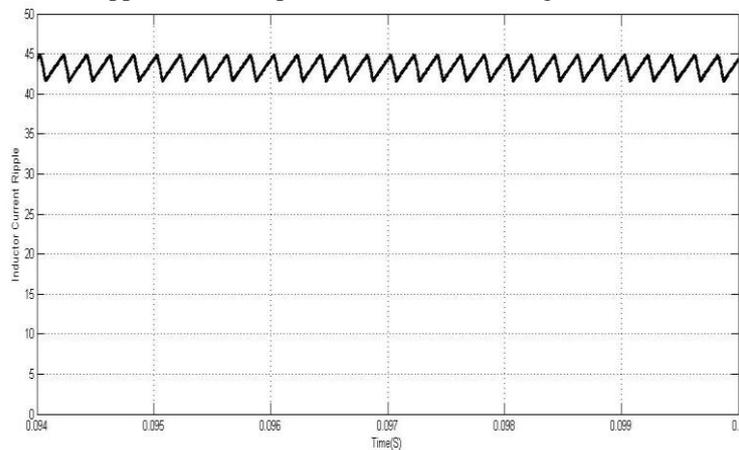


Figure10. Inductor current ripple of two-phase IBC

7.6 Output voltage waveform of two-phase IBC

The output voltage of the two-phase IBC is found to be 90 V for a resistive load of 10 Ω . The waveform is shown in figure 11.

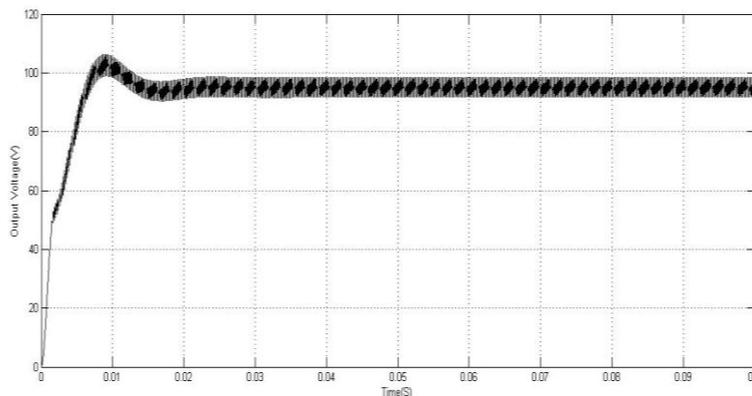


Figure 11. Inductor current ripple of two-phase IBC

7.7 Output voltage ripple of two phase IBC

Figure 12 shows the output voltage ripple of the two -phase IBC. It is found to be 6.31%

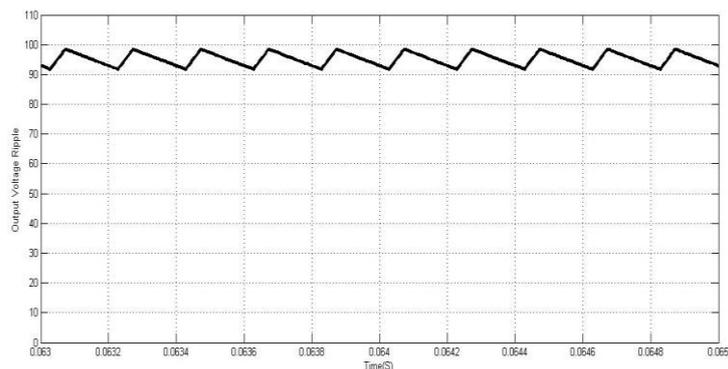


Figure 12. Output voltage ripple of two-phase IBC

7.8 Results of input inductor current ripple and output voltage ripple

Table 3. Calculated ripple values of Two- Phase IBC

Parameter	Ripple in %
Input inductor current	6.89
Output voltage	6.31

The values of input inductor current ripple and output voltage ripple has been calculated from the simulation results and tabulated in Table 3.

7.9 Application of two-phase IBC in a cascaded H-bridge five level inverter

The simulation model is shown in the figure 13.

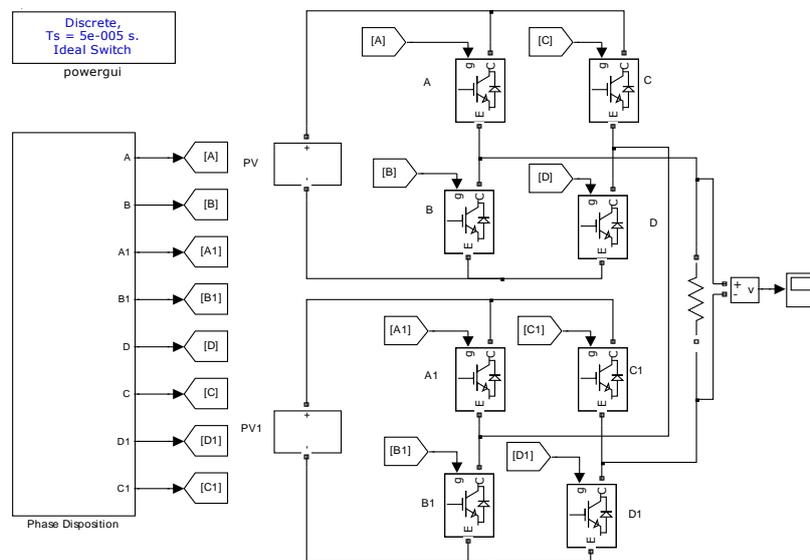


Figure 13. Five-level MLI interfaced to PV sourced two-phase IBC

The two-phase IBC can be used to boost the output voltage of the solar panel which can then be provided as input to the bridges of the multi level inverter. When compared to the conventional DC-DC boost converter, the two-phase IBC has reduced ripple content. It is more suitable for interfacing with the cascaded H-bridge MLI.

7.10 Output voltage of MLI with two-phase IBC

The output voltage of the MLI connected to two-phase IBC is found to be 180 V. An input voltage of 90 V for each bridge is provided by two-phase IBC. The output voltage of five-level MLI with two-phase IBC is shown in figure 14.

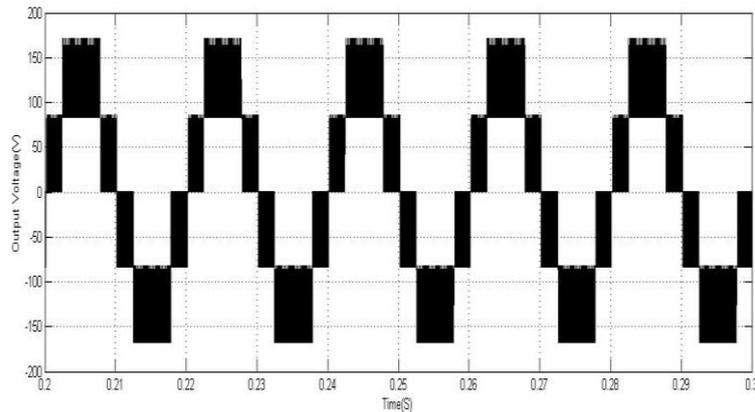


Figure 14. Output voltage of five-level MLI with two-phase IBC

7.11 THD of the output voltage of two-phase IBC

The THD of the output voltage of five-level MLI with two-phase IBC is found to be 22.61%. The frequency spectrum is shown in the figure 15.

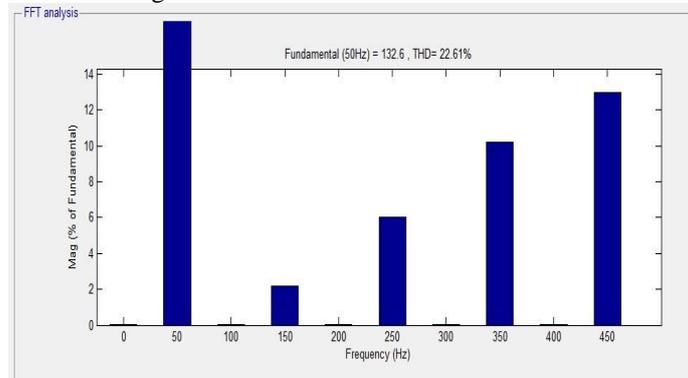


Figure 15. THD of output voltage of five-level MLI with two-phase IBC

VIII. Conclusion

The PV array has been modelled using MATLAB/Simulink and then implemented with perturb and observe MPPT. The reference from the MPPT has been used to generate pulses for the two-phase IBC. The two-phase IBC has been modelled in MATLAB/Simulink and provided with PV source. The output voltage of PV panel is 20 V. It is boosted to 90 V by two-phase IBC. This 90 V is fed to each bridge of the five-level MLI. The output voltage is obtained as 180 V with a THD of 22.61%. The output voltage ripple is found to be 6.31% and the input inductor current ripple is found to be 6.89%. Thus, the two-phase IBC is suitable for interfacing with PV source and it can also act as boost converter for providing voltage for MLI.

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