

INVESTIGATION ON DC-DC CONVERTER TOPOLOGIES FOR PV APPLICATIONS

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Abstract - Photovoltaic power generation systems have gained attention all over the world because of its availability, cleanliness, low maintenance cost and inexhaustible nature. But the output voltage from PV is very low; hence a DC-DC step-up converter is employed. Selection of proper DC-DC converter with reduced output voltage ripple is also an important factor as it has an impact on the overall performance of PV system. This paper analyzes three different converters and a particular topology is chosen for PV applications. Further, ripple reduction topologies are proposed and the performance of DC-DC converter is analyzed in terms of output voltage ripple, input current ripple and inductor current ripple. Simulation studies of the topologies of DC-DC converters are carried out in MATLAB/SIMULINK. Further PV model is carried out and simulated in MATLAB/SIMULINK. In addition to this, maximum power point tracking method is implemented, (i.e.), PSO based MPPT is proposed to extract maximum power from PV and its tracking efficiency is compared with the conventional P&O. Finally, 10W solar panel experimental prototype has been built and tested in the laboratory to validate the theoretical results presented in this paper.

Key Words: Solar PV, DC-DC Converters, Ripple, Maximum Power Point Tracking (MPPT).

1. INTRODUCTION

Growing concerns about climatic change and global warming resulting from carbon emissions have pushed for more use of renewable energy sources such as solar photovoltaic (PV), wind, solar, thermal, etc.[1]. Nowadays, it is necessary to reduce the cost and increase the efficiency to make solar energy to be more useful [2]. As a result, many research works address the development of solar power system in recent years with improved performance. Power electronics converts electrical energy from one form to another, achieving high conversion efficiency of the solar PV-powered system [3] [4]. Since most of the consumer loads and storage elements use DC supply, DC-DC converters have gaining popularity.

In this paper, three different converters i.e., Boost Converter, SEPIC Converter and Non-Inverting Buck Boost Converter have been investigated for PV applications. Boost Converter is a simple step-up whose advantage is that the input current is continuous [5]. Sepic Converter can be operated either in step up or step down mode. It has more number of storage

devices and it is widely used in battery equipment [5]. A Buck Boost Converter operates in step-up or step-down mode operation and it is used for low and medium power application [6]. It also suffers from high switching stress because it is due to inverted output. In order to overcome these drawbacks, Non- Inverting Buck Boost (NIBB) Converter is presented in this paper. Non Inverting Buck Boost Converter produces an inverted output voltage.

The objective of this paper is to propose a suitable DC-DC converter for output voltage ripple reduction in PV applications. Simulation studies of the topologies are carried out in MATLAB/SIMULINK. The topology with reduced output voltage ripple is selected and interfaced with PV and the results are verified.

Section II presents the topologies of DC-DC converters. Section III discusses the ripple reduction topologies and the results are analyzed. Section IV presents the maximum power point tracking methods. The circuit model of the proposed Interleaved Boost Converter Interfaced with PV is presented in Section IV. Finally, Conclusion is discussed in Section V.

2. TOPOLOGIES OF DC-DC CONVERTER

A circuit that converts the DC voltage from one level to another is called DC - DC converter. It involves controlling of the average output voltage to a desired value. The output voltage regulation is achieved by varying the input and output power of the converter. The various applications of DC - DC converter includes regulated switched mode DC power supplies, cellular phones and laptop computers. . The different topologies of DC-DC converter are discussed below and their output voltage ripple is calculated.

2.1 Boost Converter (BC)

A boost converter is a DC-DC converter that has an output voltage greater than the input voltage. Fig. 1 shows the circuit topology of Boost converter. The modes of operation, design equations, specification of the boost converter are listed in the Table 1. The converter operates in two modes of operation. Fig. 2 shows the mode 1 and Fig. 3 shows the mode 2 operation.

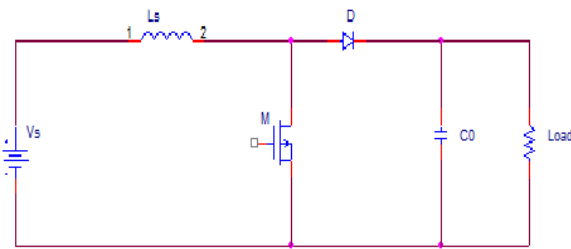


Fig -1: Circuit Diagram of Boost Converter

Mode -1:

The circuit diagram for mode 1 operation is shown in Fig. 2. Mode 1 begins when the switch (\$S_1\$) is turned on at \$t = t_{on}\$. During on-time, the inductor current is greater than zero and it rises linearly. The output current during this interval is supplied from the output capacitor which is large enough to supply load current during on-time [7].

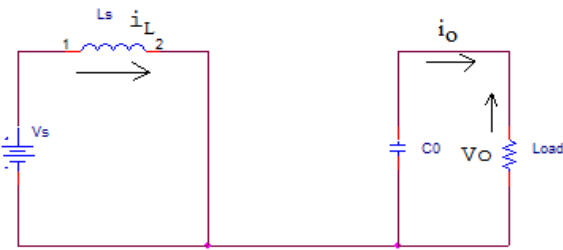


Fig - 2: Mode 1 Operation of Boost Converter

Mode -2:

Mode 2 begins when switch (\$S_1\$) is switched off at \$t = t_{off}\$. The circuit diagram for the mode 2 operation is shown in Fig. 3. The inductor current decreases until the switch is turned on again for the next cycle. In mode 2, operation the current will flow through the \$C\$, \$L\$ and load. The inductor delivers its stored energy to the load [7].

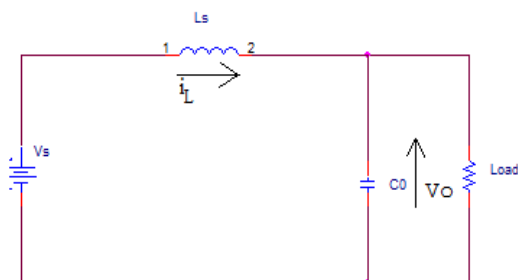


Fig - 3 : Mode 2 Operation of boost converter

Table -1 : Specifications for boost converter.

| Parameters | Values |
|---------------------|---------------|
| Source voltage | 12(volts) |
| Resistive Load | 100(ohm) |
| Inductor | 60(\$\mu\$H) |
| Capacitor | 500(\$\mu\$F) |
| Switching frequency | 100(kHz) |

Design Equations for Boost Converter:

The conversion gain for the boost converter is given in Eq. (1)

$$V_o = \frac{V_s}{1-D} \tag{1}$$

Where \$V_s\$ the source voltage, \$D\$ is the duty cycle for the boost converter, \$V_o\$ is the output voltage.

Boost inductance is selected based on the maximum allowable ripple current [8].

The peak to peak inductor current ripple is given as in Eq. (2)

$$\Delta I = \frac{V_s D}{f_s L} \tag{2}$$

Where, \$L\$ is the inductor.

The peak to peak capacitor voltage ripple is given by Eq. (3)

$$\Delta V_c = \frac{I_a D}{f_s C} \tag{3}$$

Where, \$f_s\$ is the switching frequency, \$C\$ is the Capacitor, \$\Delta V_c\$ is the peak to peak capacitor voltage.

2.2 Single- Ended Primary Inductor Converter (SEPIC)

SEPIC converter is a type of DC-DC converter consisting of single-ended primary inductor. The output of the SEPIC converter is controlled by the duty cycle. It provides the positive regulated output voltage for the given input voltage. Isolation is provided by series coupling capacitor which protects the converter when short circuit occurs. Fig. 4 shows the circuit topology of SEPIC converter.

In steady state operation, the average voltage across capacitor \$C_s\$ is equal to the input voltage. The SEPIC converter operates in two modes of operations. The modes of operation are explained in detail [9], design equations are

explained below and the specifications of the SEPIC converter are listed in Table 2.

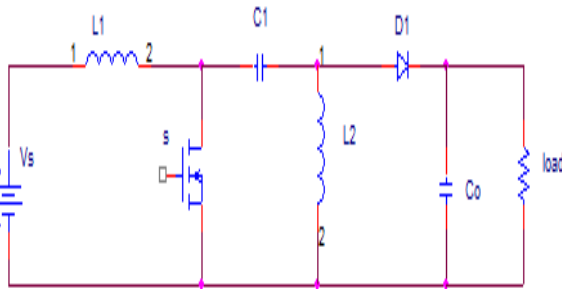


Fig - 4 : Circuit Diagram of SEPIC Converter

Table - 2 : Specifications of Sepic Converter

| Parameters | Values |
|---------------------|---------------|
| Source voltage | 12(volts) |
| Resistive Load | 100(ohm) |
| Inductor | 50(\$\mu\$H) |
| Capacitor | 500(\$\mu\$F) |
| Switching frequency | 100(kHz) |

Design Equations for Sepic Converter:

The conversion gain for the SEPIC converter is given by Eq. (4)

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

Where, D is the Duty Cycle of the SEPIC Converter, \$V_0\$ is the output voltage and \$V_s\$ is the source voltage.

When the switch is turned on the inductor is charging the output current and then it is supplied to the output capacitor [9]. The output capacitor is given by Eq. (5)

$$C_o = \frac{I_0 * D}{V_{ripple} * 0.5 * f_s} \quad (5)$$

Where, \$f_s\$ is the switching frequency, \$C_o\$ is the output capacitor, \$V_{ripple}\$ is the peak to peak capacitor voltage ripple.

The inductor formula is given by Eq. (6)

$$L = \frac{V_s}{\Delta L * f_s} * D \quad (6)$$

Where, L is the Inductor, \$\Delta L\$ is the peak to peak inductor current ripple.

2.3 Non-Inverting Buck Boost (NIBB) Converter

A buck boost converter operates in step-up or step down mode but it suffers from drawbacks such as high switching stress due to inverted output, independent grounding of load and source side. In order to overcome these drawbacks the non-inverting buck boost converter is discussed in this section.

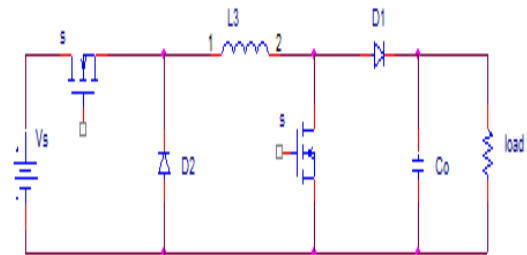


Fig - 5 : Circuit Diagram of NIBB Converter

Fig.5 shows the circuit diagram of non-inverting buck boost converter. The non inverting buck boost converter produces an output voltage that is of the same polarity as the input voltage. In buck mode the output voltage is determined by the operation of MOSFET (\$S_1\$) and diode (\$D_1\$). In boost mode, the output voltage is determined by the operation of MOSFET (\$S_2\$) and diode (\$D_2\$) [10]. The modes of operation, design equations of NIBB converter are discussed in Section A. The specification of the NIBB converter is given in TABLE I and the simulation results of the NIBB converter are shown below.

Simulation and Result Analysis of Different DC-DC Converters:

The different topologies of DC-DC converter operation is studied and analyzed in this section. The DC-DC converter has been simulated. The simulation has been performed in MATLAB/SIMULINK. Fig.6 shows the Simulink Diagram of Boost Converter. Fig.7 shows the simulation waveform of output voltage of boost converter with a source voltage of 12V. Fig.8 shows the simulation waveform of output voltage ripple of boost converter. Fig.9 shows the Simulink Diagram of Sepic Converter. Fig. 10 depicts the simulation waveform of output voltage of sepic converter with a source voltage of 12V. Fig.11 shows the simulation waveform of output voltage ripple of sepic converter. Fig.12 shows the Simulink Diagram of NIBB Converter. Fig. 13 depicts the simulation waveform of output voltage of NIBB converter with a source voltage of 12V. Fig.14 depicts the simulation waveform of output voltage ripple of NIBB converter. Chart 1, shows the output voltage ripple under different duty cycle for different DC-DC converters. The comparisons of different DC-DC converters for output voltage ripple are listed in Table 3.

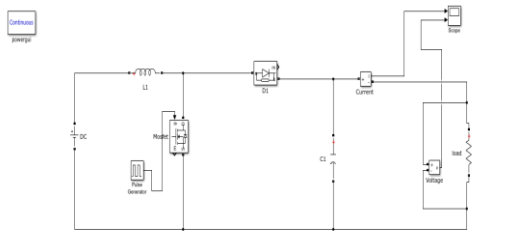


Fig – 6: Simulink Diagram of Boost Converter

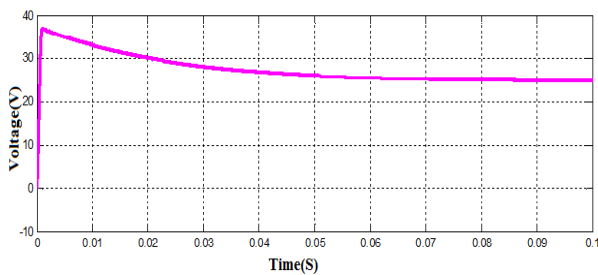


Fig – 7 : Simulation waveform of output voltage of Boost converter

From Fig. 7, it is inferred that the output voltage of Boost Converter is 24V with the given source voltage of 12V.

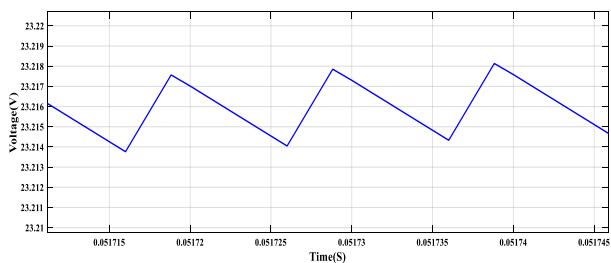


Fig – 8 : Simulation waveform of output voltage ripple of Boost converter.

From Fig. 8, it is inferred that the output voltage ripple of Boost Converter is 0.0025V.

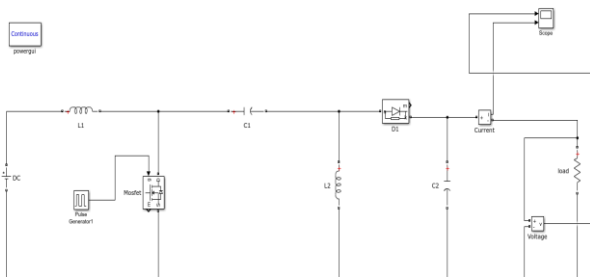


Fig -9: Simulink Diagram of Sepic Converter

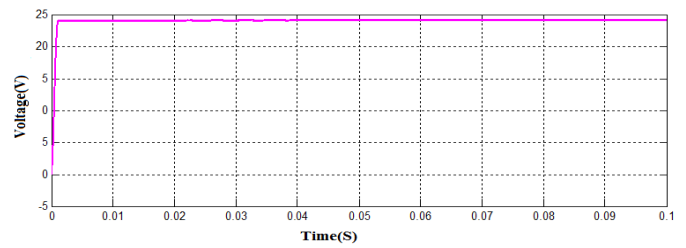


Fig - 10 : Simulation waveform of output voltage of SEPIC Converter

From Fig. 10, it is inferred that the output voltage of Sepic Converter is 24V with the given source voltage of 12V.

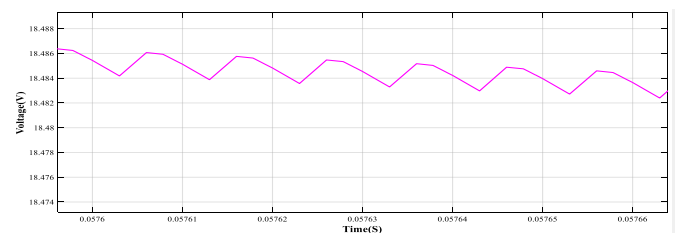


Fig – 11 : Simulation waveform of output voltage ripple of SEPIC Converter

From Fig. 11, it is inferred that the output voltage ripple of Sepic Converter is 0.0029V.

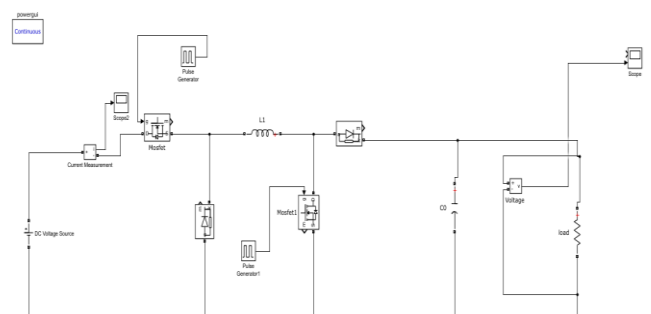


Fig -12: Simulink Diagram of NIBB Converter

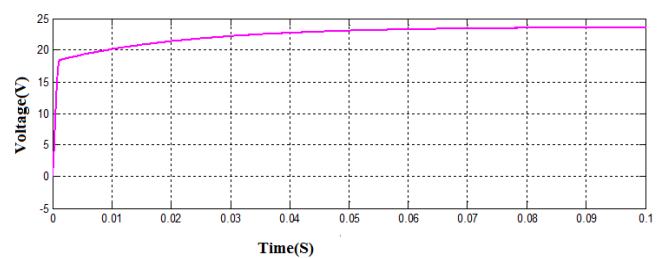


Fig – 13 : Simulation waveform of output voltage of NIBB Converter

From Fig. 13, it is inferred that the output voltage of NIBB Converter is 24V with the source voltage of 12V.

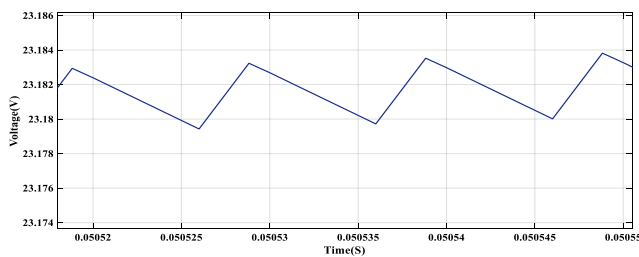


Fig - 14 : Simulation waveform of output voltage ripple of NIBB Converter

From Fig. 14, it is inferred that the output voltage ripple of NIBB Converter is 0.003V.

From Figs. 8, 11, 14, output voltage ripple for different DC-DC converters have been calculated.

Table -3: Comparison of DC-DC Converters for Output Voltage Ripple

| Converter | Output Voltage Ripple(V) |
|-----------------|--------------------------|
| Boost Converter | 0.0025 |
| Sepic Converter | 0.0029 |
| NIBB Converter | 0.003 |

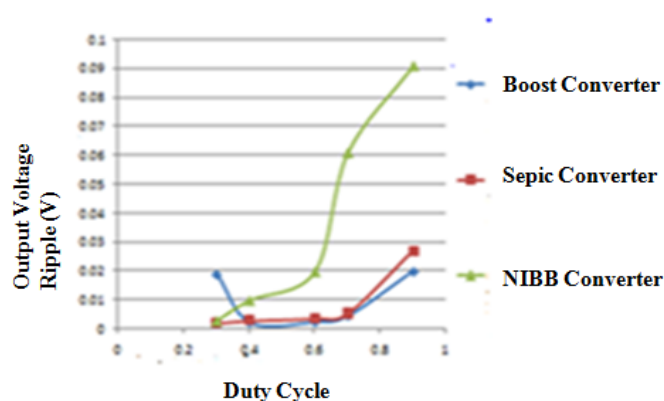


Chart - 1: Output Voltage Ripple Vs Duty Cycle for different DC-DC converters

Chart 1, shows the variation of output voltage ripple with respect to the duty cycle for different DC-DC converters. It is inferred that the boost converter offers less output voltage ripple in comparison with other DC-DC converters. So the boost converter model will be interfaced with PV model.

3. PV MODEL

The design of PV model with different values of irradiation and temperature values was simulated in MATLAB/SIMULINK. The tabulation of the module parameters indicated the characteristics of PV. Fig.15 shows the simulation of PV model and the characteristics of PV are listed in Table 4.

Table 4: Characteristics of PV

| Description | Rating |
|-----------------------------|--------|
| Rated power | 10W |
| Voltage at maximum power(V) | 16.8V |
| Current at maximum power(I) | 1.19A |
| Short circuit current(I) | 0.9A |

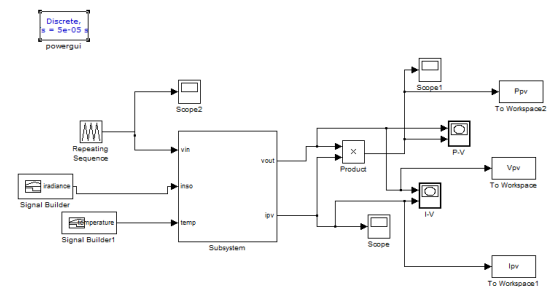


Fig -15: Simulation of PV model

Finally PV model was designed in MATLAB/SIMULINK with the rating of 10W power.

4. BOOST CONVERTER INTERFACED WITH PV

Simulation and Result Analysis for PV Interfaced with Boost Converter:

Due to low output voltage ripple boost converter is chosen for PV model. Now the DC source of boost converter is replaced by the PV model. The boost converter interfaced with PV simulation has been performed in MATLAB/SIMULINK. Fig. 16 shows the simulink diagram of boost converter interfaced with PV. Fig. 17 shows the simulation waveform of output voltage for boost converter interfaced with PV. Fig. 18 shows the simulation waveform of output voltage ripple for boost converter interfaced with PV.

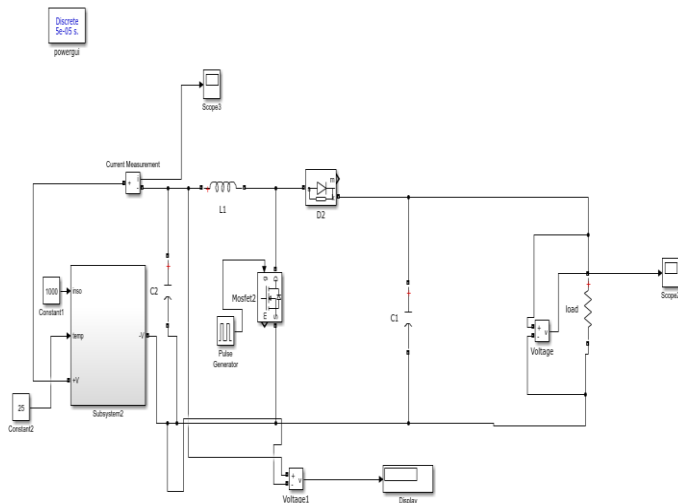


Fig -16 : Simulink Diagram of Boost Converter Interfaced with PV

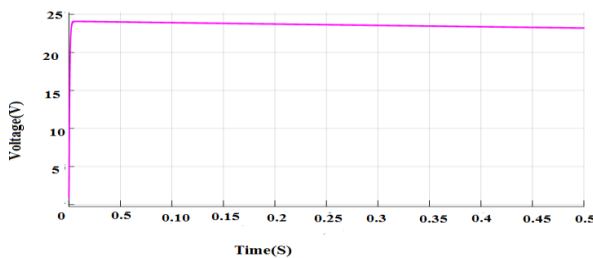


Fig - 17 : Simulation waveform of output voltage of Boost Converter Interfaced with PV

From Fig. 18 it is inferred that the output voltage of Boost Converter interfaced with PV is 24volts.

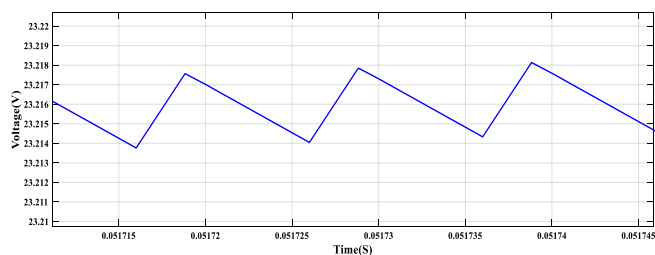


Fig - 18 : Simulation waveform of output voltage ripple of Boost Converter interfaced with PV

From Fig. 19, it is inferred that the output voltage ripple of Boost Converter interfaced with is 0.0025V.

5. RIPPLE REDUCTION TOPOLOGIES

In this section, two topologies are explained briefly: Interleaved Boost Converter (IBC) and bidirectional Converter (BDC).

5.1 Interleaved Boost Converter (IBC)

Boost converter converts DC input voltage to a higher DC output voltage. But interleaving adds additional benefits to reduce the output voltage ripple and input current ripple. Fig. 19 shows the circuit diagram of two-phase Interleaved Boost Converter (IBC). Interleaved Boost Converter interfaced with PV and the simulation is carried out in MATLAB/SIMULINK.

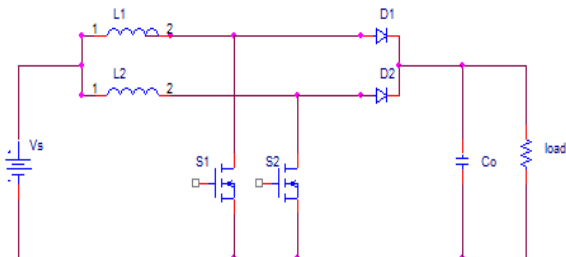


Fig -19 : Circuit Diagram of Interleaved Boost Converter

During t_{on} , when Q_1 is turned on, the current in the inductor L ramps upward. Therefore, the energy will be stored in the inductor L_1 . During t_{off} , when diode D_1 conducts; energy stored in the inductor gets transferred to the capacitor and the load. One half of a switching period, Q_2 also turns on and completes the same cycle similar to Q_1 [11-12]. The modes of operation of interleaved boost converter are explained in detail [13]. The specification parameters are listed in Table 1.

Simulation and Result Analysis of Interleaved Boost Converter:

The Interleaved Boost Converter operation is studied and analyzed in this section. The Interleaved Boost Converter has been simulated. The simulation has been performed in MATLAB/SIMULINK. Fig.20 depicts the simulink diagram of interleaved boost converter. Fig. 21 shows the simulation waveform of output voltage of interleaved boost converter interfaced with PV. Fig.22 shows the simulation waveform of output voltage ripple of interleaved boost converter interfaced with PV. Fig.23 depicts the simulation waveform of input current of interleaved boost converter interfaced with PV. Fig.24 depicts the simulation waveform of input current ripple of interleaved boost converter interfaced with PV.

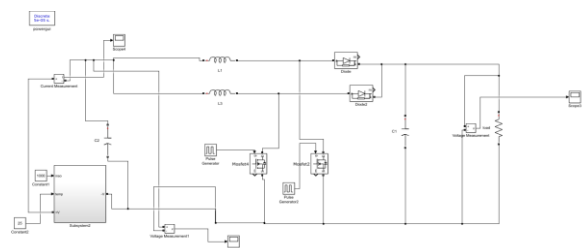


Fig – 20: Simulink Diagram of Interleaved Boost Converter interfaced with PV

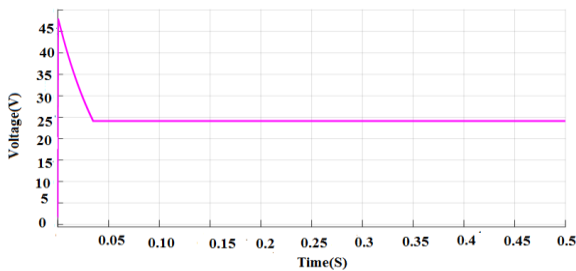


Fig – 21 : Simulation waveform of output voltage of interleaved boost converter interfaced with PV

From Fig.21 it is inferred that the output voltage of interleaved boost converter interfaced with PV is 24V.

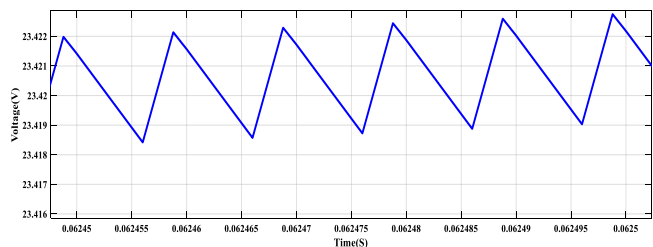


Fig – 22 : Simulation waveform of output voltage ripple of interleaved boost converter interfaced with PV

From Fig.22 it is inferred that the output voltage ripple of interleaved boost converter interfaced with PV is 0.002V.

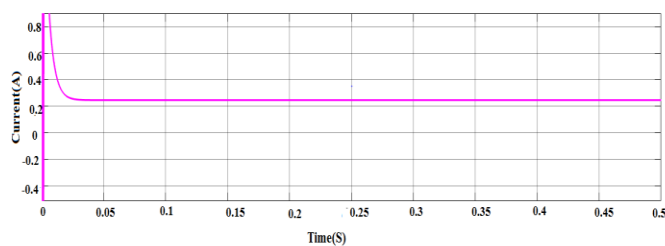


Fig – 23 : Simulation waveform of input current of interleaved boost converter interfaced with PV

From Fig.23 it is inferred that the input current of interleaved boost converter interfaced with PV is 0.24A.

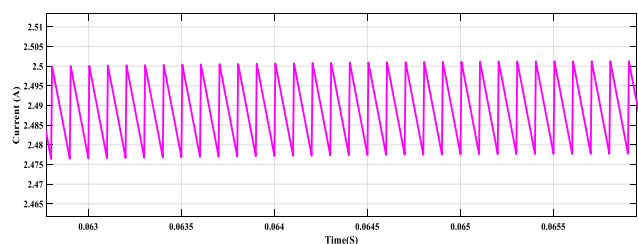


Fig – 24 : Simulation waveform of input current ripple of interleaved boost converter interfaced with PV

From Fig.24 it is inferred that the input current ripple of interleaved boost converter interfaced with PV is 0.01A.

5.2 Bidirectional Converter (BDC)

The bidirectional DC-DC converter along with energy storage is an apt topology for applications such as hybrid vehicle, fuel cell vehicle and renewable energy systems. It not only reduces the cost and improves the efficiency, but also it improves the performance of the system. It also reduces the output voltage ripple and input current ripple. Fig.25 shows the equivalent circuit of bidirectional converter. The bidirectional converter modes of operation, design equation, specification parameters are given in [14].

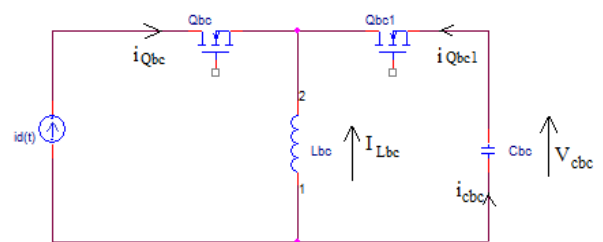


Fig -25 : Equivalent Circuit Diagram of Bidirectional Converter

Simulation and Result Analysis of Bidirectional Converter:

The Bidirectional Converter operation is studied and analyzed in this section. The Bidirectional Converter has been simulated. The simulation has been performed in MATLAB/SIMULINK. Fig.26 shows the simulink diagram of bidirectional converter connected in parallel with boost converter to reduce the output voltage ripple and input current ripple.

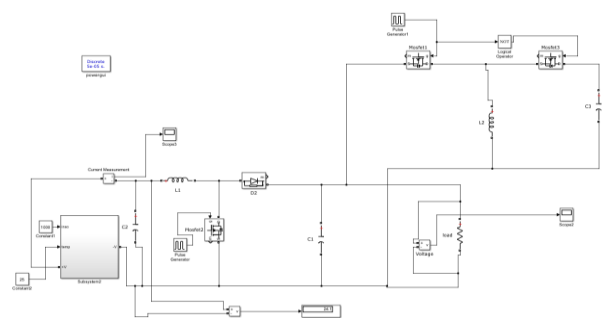


Fig -26 : Simulink Diagram of Boost Converter Integrated with Bidirectional Converter and interfaced with PV

Fig.27 shows the simulation waveform of output voltage of bidirectional converter interfaced with PV. Fig.28 shows the simulation waveform of output voltage ripple of bidirectional converter interfaced with PV. Fig.29 shows the simulation waveform of input current of bidirectional converter interfaced with PV. The comparison parameters of

output voltage ripple for DC-DC converters are listed in Table 5. Chart 2 depicts the comparison of output voltage ripple under different duty cycles for converters interfaced with PV. The comparison parameters of input current ripple for DC-DC converters are listed in Table 6. Chart 3 depicts the comparison of input current ripple under different duty cycles for converters interfaced with PV.

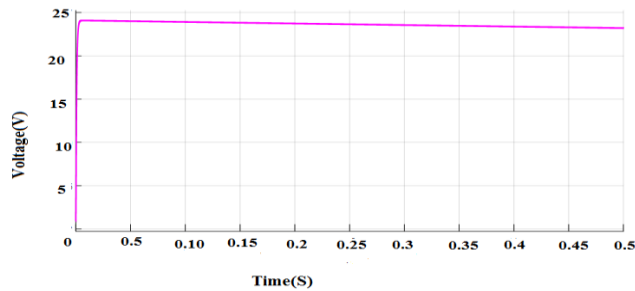


Fig -27: Simulation waveform of output voltage of bidirectional converter interfaced with PV.

From Fig.27, it is inferred that the output voltage of Bidirectional Converter interfaced with PV is 24V.

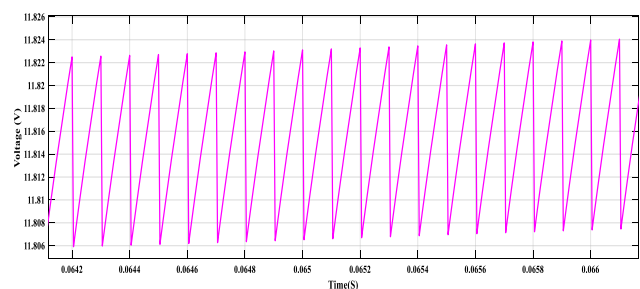


Fig - 28 : Simulation waveform of output voltage ripple of bidirectional converter interfaced with PV

From Fig.28, it is inferred that the output voltage ripple of Bidirectional Converter interfaced with PV is 0.003V.

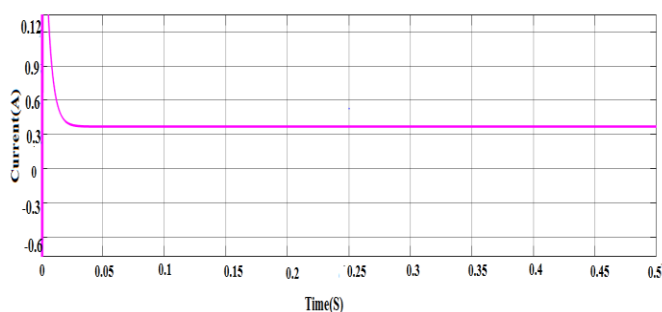


Fig - 29: Simulation waveform of input current of bidirectional converter interfaced with PV

From Fig.29, it is inferred that the input current ripple for bidirectional converter interfaced with PV is 0.34 A.

Table -5: Computation of output voltage ripple Vs duty cycle of DC-DC Converters

| Duty Cycle | Output Voltage Ripple (V) | | |
|------------|---------------------------|-----------------------------|-------------------------|
| | Boost Converter | Interleaved boost converter | Bidirectional Converter |
| 0.3 | 0.001 | 0.001 | 0.002 |
| 0.4 | 0.0016 | 0.0017 | 0.0028 |
| 0.6 | 0.0028 | 0.0027 | 0.0034 |
| 0.7 | 0.0033 | 0.003 | 0.004 |
| 0.9 | 0.0038 | 0.0036 | 0.0046 |

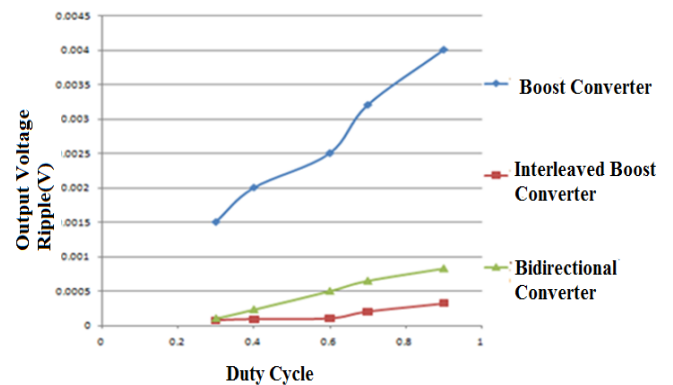


Chart -2 : Output Voltage Ripple Vs Duty Cycle for ripple reduction topologies

From Chart 2, it is inferred that interleaved boost converter offer less output voltage ripple when compared with other converters interfaced with PV.

Table -6: Computation of input current ripple Vs duty cycle of DC-DC Converters

| Duty Cycle | Input Current Ripple (A) | | |
|------------|--------------------------|-----------------------------|-------------------------|
| | Boost Converter | Interleaved boost converter | Bidirectional Converter |
| 0.3 | 0.02 | 0.01 | 0.025 |
| 0.4 | 0.025 | 0.018 | 0.029 |
| 0.6 | 0.032 | 0.030 | 0.036 |
| 0.7 | 0.04 | 0.038 | 0.04 |
| 0.9 | 0.048 | 0.045 | 0.046 |

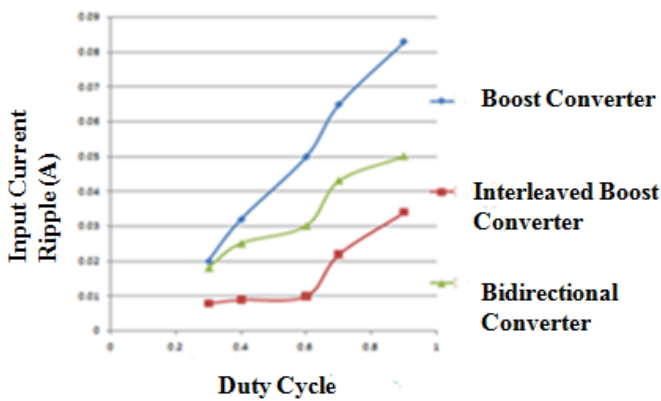


Chart -3: Input Current Ripple Vs Duty Cycle for ripple reduction topologies

From Chart 3, it is inferred that interleaved boost converter offers less input current ripple when compared with other converters interfaced with PV.

Hence from the ripple reduction topologies and the result analysis, it is concluded that the interleaved boost converter offers less output voltage ripple and input current ripple. So interleaved boost converter is interfaced with maximum power point tracking method.

6. MAXIMUM POWER POINT TRACKING

In this section particle swarm optimization and P&O MPPT is implemented to track maximum power from PV [15] [16].The power P_{pv} is calculated by the measured voltage and current. Then the algorithm proceeds to check whether the duty cycle value will result in a better individual fitness value. Fig.30 shows the simulink diagram of interleaved boost converter interfaced with PV and PSO. Fig.31 shows the simulation waveform of output voltage of interleaved boost converter interfaced with PV and PSO. Fig.32 shows the simulation waveform of output voltage ripple of interleaved boost converter interfaced with PV and PSO. Fig.33 shows the simulation waveform of inductor current ripple of interleaved boost converter interfaced with PV and PSO. Fig.34 shows the simulation waveform of actual power Vs track power of interleaved boost converter interfaced with PV and PSO. Fig.35 shows the simulink diagram of interleaved boost converter interfaced with PV and P&O. Fig.36 shows the simulation waveform of actual power Vs track power of interleaved boost converter interfaced with PV and P&O. Fig.37 shows the simulation waveform of output voltage of interleaved boost converter interfaced with PV and P&O. Fig.38 shows the simulation waveform of output voltage ripple of interleaved boost converter interfaced with PV and P&O. Fig.39 shows the simulation waveform of inductor current ripple of interleaved boost converter interfaced with PV and P&O. Fig.40 shows the simulation waveform of actual power Vs track power for interleaved boost converter interfaced with PV and P&O , PSO. The comparison of P&O and PSO are listed in Table 7.

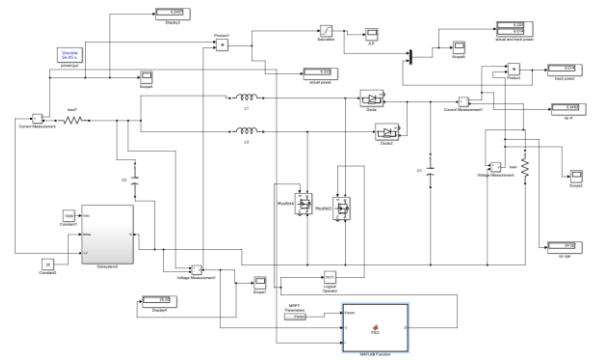


Fig – 30: Simulink diagram of IBC interfaced with PV and PSO

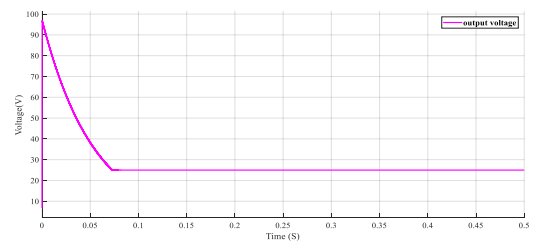


Fig – 31: Simulation waveform of output voltage of IBC with PSO MPPT

From the Fig.31 it is inferred that the output voltage of interleaved boost converter interfaced with PV and PSO is 24V.

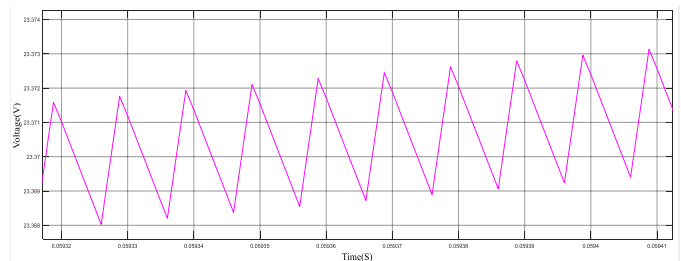


Fig -32: Simulation waveform of output voltage ripple of IBC with PSO MPPT

From the Fig.32 it is inferred that the output voltage ripple of interleaved boost converter interfaced with PV and PSO is 0.0013V.

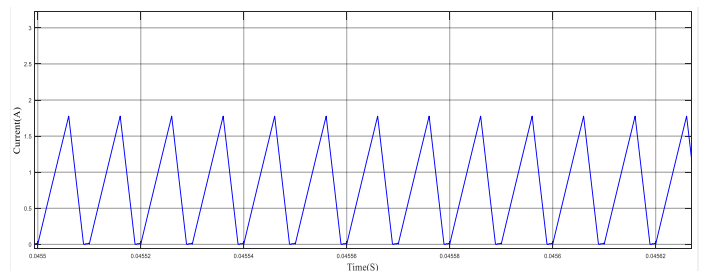


Fig – 33: Simulation waveform of inductor current ripple of IBC with PSO MPPT

From the Fig.33 it is inferred that the inductor current ripple of interleaved boost converter interfaced with PV and PSO is 0.325A.

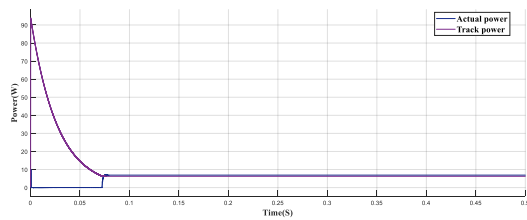


Fig - 34: Simulation waveform of actual power Vs track power for PSO MPPT

From the Fig.34 it is inferred that the actual power is 6.8W and tracked power is 6.214W and the efficiency was calculated as 91.38%.

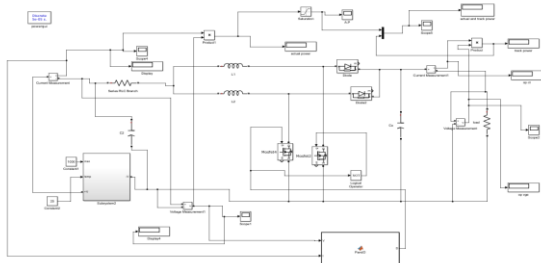


Fig -35: Simulink diagram of IBC interfaced with PV and P&O

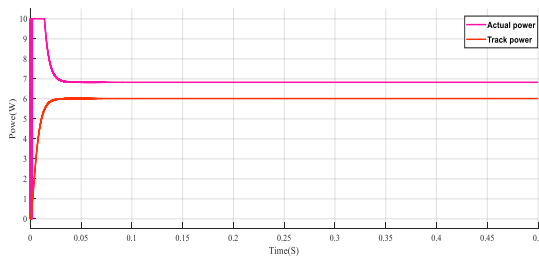


Fig- 36: Simulation waveform of actual power Vs track power for P&O MPPT

From the Fig.36 it is inferred that the actual power is 6.8W and tracked power is 6.014W and the efficiency was calculated as 88.44%

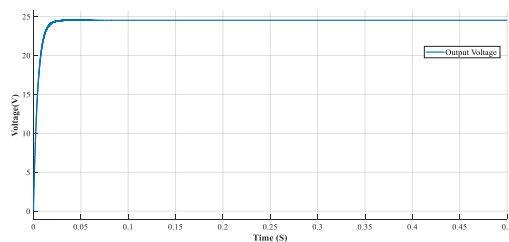


Fig - 37: Simulation waveform of output voltage of IBC with P&O MPPT

From the Fig.37 it is inferred that the output voltage of interleaved boost converter interfaced with PV and P&O is 24V.

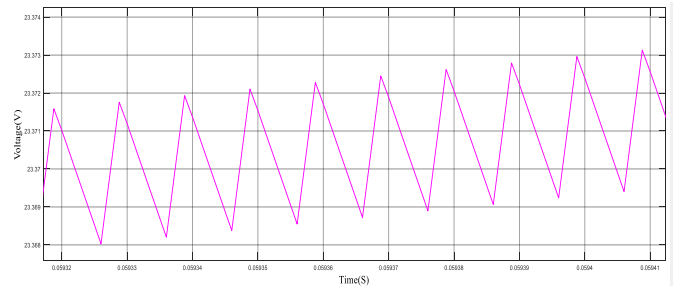


Fig - 38: Simulation waveform of output voltage ripple of IBC with P&O MPPT

From the Fig.38 it is inferred that the output voltage ripple of interleaved boost converter interfaced with PV and P&O is 0.0035V.

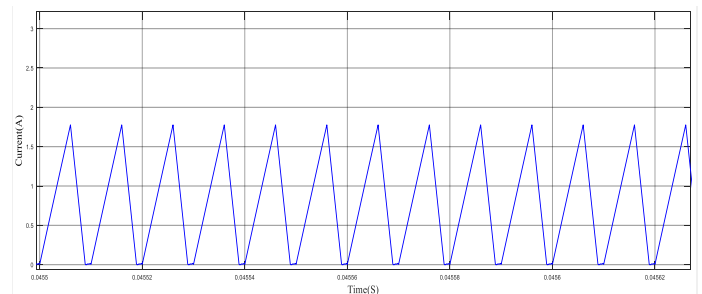


Fig - 39: Simulation waveform of inductor current ripple of IBC with P&O MPPT

From the Fig.39 it is inferred that the inductor current ripple of interleaved boost converter interfaced with PV and P&O is 0.85A.

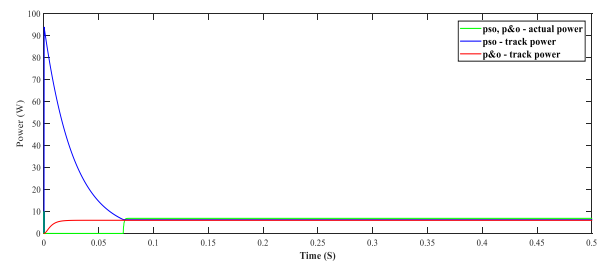


Fig -40: Simulation waveform of actual power Vs track power for PSO and P&O.

From the Fig.40 it is inferred that the actual power is 6.8W and tracked power is 6.214W for PSO and the actual power is 6.8W and tracked power is 6.014W for P&O.

TABLE - 7: Comparison of P&O and PSO MPPT

| Parameters | Perturb and Observe | Particle Swarm Optimization |
|-----------------------------|---------------------|-----------------------------|
| Output voltage ripple (V) | 0.0025 | 0.002 |
| Input current ripple (A) | 0.02 | 0.01 |
| Actual power (W) | 6.8 | 6.8 |
| Track power (W) | 6.014 | 6.214 |
| Efficiency (%) | 88.44 | 91.77 |
| Inductor current ripple (A) | | |

From Table 7, it is inferred that PSO has high track power, high efficiency, low output voltage ripple, low input current ripple and low inductor current ripple when compared with P&O. So IBC interface with PSO is best suited for MPPT.

7. EXPERIMENTAL RESULTS

An experimental prototype of the circuit was built and tested in the laboratory. The circuit components used for hardware implementation are listed in Table 8. The switching pulses are generated using Arduino UNO which is interfaced with the gating circuit. Fig.41 shows the pulse generated for the switches by interfacing with Arduino Board. Fig.42 illustrates the experimental results of the Interleaved Boost Converter using DC supply. Fig.43 shows the experimental waveforms of output voltage ripple of the Interleaved Boost Converter using DC supply. Fig.44 (a) illustrates the experimental results of the Interleaved Boost Converter interface with PV. Fig.44 (b) illustrates the experimental output of the Interleaved Boost Converter interface with PV.

Table -8: Hardware Components for the Interleaved Boost Converter

| Components | Specification |
|------------|---------------|
| PV | 12V, 10W |
| Inductor | 60(μH) |
| Capacitor | 500(μF) |
| Mosfet | IRF450 |
| Diode | FR-107 |
| Load | 100(ohm) |



Fig - 41: Gating pattern for the switches using the Arduino UNO



Fig - 42: Experimental results of the Interleaved Boost Converter using DC supply



Fig - 43: Experimental waveform of output voltage ripple of the Interleaved Boost Converter using DC supply



Fig - 44 (a): Experimental results of the Interleaved Boost Converter interface with PV



Fig -44 (b): Experimental output of the Interleaved Boost Converter interface with PV

Hardware Results Validation

The hardware prototype and different parameter like ripple evaluation are measured and validated with simulation results.

Table – 9: Comparison of output voltage ripple

| Theoretical value | Practical value |
|-------------------|-----------------|
| 0.013V | 2.96V |

From the Table 9, it is inferred that the simulated value of output voltage ripple offers less value when compared to the practical value of output voltage ripple.

8. CONCLUSION

In this paper, DC-DC converter topologies were investigated and analyzed in detail. The different DC-DC converters such as Boost converter, SEPIC and NIBB were simulated in MATLAB and the output voltage ripple was calculated. Further to reduce the ripple in Boost converter, IBC and BDC were investigated. The interleaved boost converter provides less output voltage ripple 0.002V and input current ripple 0.24A when compared with other converters. Then PSO based P&O MPPT is investigated and it is found that the proposed MPPT offers less output voltage ripple 0.013V, less inductor current ripple 0.84A, high tracked power 6.214W and high efficiency 91.77% when compared with classical P & O method. These analyses were carried out in MATLAB/SIMULINK. The hardware prototype of the proposed model of the Interleaved Boost Converter interface with PV was developed and the pulses for the switches are provided using the Arduino UNO. In conclusion, the proposed topology of the Interleaved Boost Converter is very suitable for PV Applications. The parameter such as ripple evaluation was calculated for the hardware prototype and validated with the simulation.

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