

Modified Two-Stage Interleaved Boost Converter (MTSIBC) For Electric Vehicle Application

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Abstract

This paper, to extract maximum power from the source, controllers like Maximum Power Point Tracking (MPPT) are used in circuits. This circuit uses Modified Two-Stage Interleaved Boost Converters (MTSIBCs), which link power from the solar photovoltaic system to the load. An Interleaved Boost Converter is modified and the design of a modified Two-Stage Interleaved Boost Converter (MTSIBC) is discussed. The Converter is an essential part of an e-vehicle. To improve the performance of the converter, an Interleaved Boost Converter is modified. A PWM method is used to generate pulses for the MOSFET in the MTSIBC. To boost the output voltage, the boost converter uses a single switch for ON and OFF. This will increase the stress on the switch thereby affecting the performance of the converter. To reduce the strain on the switches, a two-stage 180° phase shifting technique is implemented in MTSIBC. The stress on the switches is reduced by applying the interleaved technique. Overall losses have been mitigated by using the phase-shifting technique. A PV-based MTSIBC and two-stage interleaved boost converter (TSIBC) with a DC motor load are simulated with 31 kHz switching frequency. The efficiency of the MTSIBC is 4.36% higher than TSIBC efficiency.

Keywords Boost Converter, Electric Vehicle, Interleaved Boost Converter, Maximum Power Point Tracking, Modified two stage interleaved boost converter, Perturb & Observe.

1. INTRODUCTION

Recent years have seen an exponential increase in power demand due to both a rise in household loads and rapid industrial expansion [1-3]. Due to the fast depletion of non-renewable energy supplies, such as fossil fuels, meeting the increasing power demand is imperative. Examples of alternative, renewable energy sources that are currently the focus of much research include wind, solar, hydroelectric power, and biomass energy. Sunlight is converted into electricity by solar cells and used in many power applications, such as electric vehicles [4-6]. Research and development efforts are focused on maximizing the power output of photovoltaic cells as they become increasingly significant in the production of energy [7-9]. Throughout their functioning range, solar photovoltaic systems do not continuously generate electrical power [10]. Maximum power generation is achieved at the MPPT, which is an ideal operating position. Temperature and light intensity have an impact on the MPPT due to the PV's electrical properties. Numerous MPPT algorithms have been proposed and examined in [11-12] including the P&O method employed in this study. Solar PV has a low efficiency and its output power is easily influenced by outside factors like temperature and radiation. Higher efficiency power conditioning systems are required when transferring solar PV electricity to the load [13-14]. The parameters of solar PV module performance are influenced by solar irradiation and cell temperature. Rooftop EVs will soon be equipped with solar panels that will collect all available energy and feed it back into the operating system of EV's [15-16]. In this paper, a review of various interleaved boost converters is presented. The high-gain boost converters are categorized and the performance of these converters is discussed. These converters achieve better voltage gain and reduced current ripple. An exhaustive review of power converters for various applications like transportation, traction, aircraft etc., is presented [17-18]. A converter topology that supports bidirectional energy flow. This feature helps discharge the batteries back to the grid, improving grid stability. This approach improves the efficiency of the extremely fast charging system [19]. In this paper multi device interleaved boost converter is implemented. This results in reduced voltage stress, improved voltage gain and efficiency. A four phase floating interleaved boost converter is used for vehicle applications. The performance of this converter is improved compared to the standard boost converter. This converter can be applied where constant DC voltage is required [20-21]. An analysis of IBC with multiple phases is presented in this paper. In IBC, 'N' parallel converters are connected. Simulation is performed for two, three and four phases [22-23]. This paper discusses the hybrid model of two phase IBC for fuel cell application. This feature improves the power density and system efficiency with minimized ripple current. This converter practically operates in both continuous and discontinuous conduction mode. Transition occurs between these modes in the entire range of duty ratio. This

approach significantly improves the power density and efficiency[24-26]. This paper presents a new design of boost converter which operates in bidirectional mode. By this approach, based on the DC-link voltage the converter can operated in either buck or boost converter. The DC-link voltage is maintained constant in boost mode whereas in buck mode PI control is employed to reduce the voltage ripples. In both mode, current control scheme is employed for equal sharing of battery [27-28]. The article discusses the new IBC techniques for EV application.

2 Solar PV module modelling

The voltage and current levels required are obtained by connecting the solar PV modules in series and shunt configurations. To calculate the generating voltage and power under various loading conditions, numerical displays are needed. The PV equivalent circuit is seen in Fig. 1.

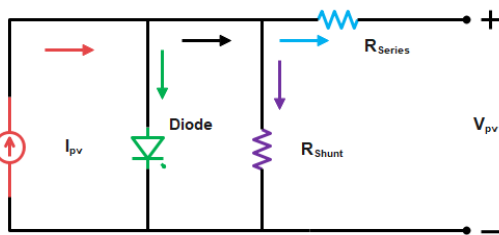


Fig. 1 Equivalent solar PV module circuit

PV technology can directly harvest solar energy for electricity. Mono-crystalline silicon, sometimes called single-crystal silicon, is the material used to create PN junctions and is more resilient and effective than other semiconductors. Unfortunately, monocrystalline silicon costs more because it uses more energy. Conversely, polycrystalline silicon photovoltaic cells are less costly than monocrystalline silicon photovoltaic cells, but they have a lower efficiency. A typical photovoltaic cell has an output voltage of 0.5 V and produces less than 3 W. Several cells are connected in a module to generate a useful voltage and power. About 36 solar cells total, six of which are combined to provide the required power and voltage, are found in each module. The output power of each module may vary from a few watt to over 300 watt. The ratings for nominal open-circuit voltage range from 20 to 30 V. Metal strips and wires are used to link and attach the solar cells, and a translucent coating composed of glass or composite is used to further enclose them. The anticipated lifespan of a module will exceed two decades. For most practical applications, the power needed is far more than one module can supply. This leads to the creation of a series/parallel array through the series/parallel configuration of several modules connected. The performance and dependability are enhanced by series combination in addition to raising the output voltage. However, by maintaining a steady voltage across the array, parallel combinations maximize the output of electricity. To find the operational voltage of the PV array, the DC-DC converter will apply the MPPT approach. PV arrays have unique V-I characteristics because they are designed to perform as a voltage source for much of their working range and as a perfect current source for a portion of it. The temperature and amount of light in the environment in which it is utilized also have an impact on the properties of current and voltage. The electrical parameters of a solar PV module are described in Table 1 and MATLAB/Simulink software is used to simulate it. Here, select 1Soltech I STH-215-P as the PV module's array type in MATLAB. The I-V and P-V characteristics of solar PV modules are also shown in Fig.2 and Fig. 3. The cell is kept at 25°C in temperature.

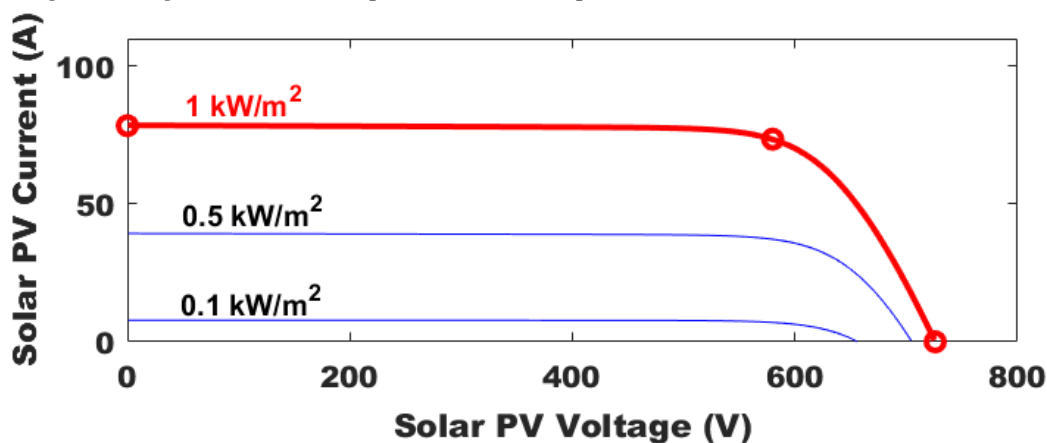


Fig. 2 I-V characteristics Solar PV module (Array type: 1Soltech I STH-215-P)

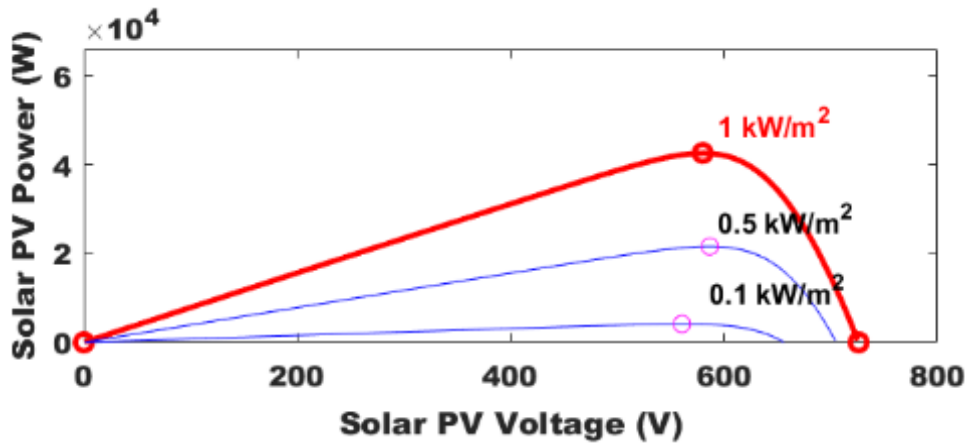


Fig. 3 P-V characteristics Solar PV module (Array type: 1Soltech I STH-215-P)

Table 1 Solar PV module electrical parameter

Module parameter	Value	Unit
V_{Mp}	29	V
V_{oC}	36.3	V
I_{sC}	7.84	A
R_{Sh}	313.39910	Ω
R_{Se}	0.39383	Ω
I_{Mp}	7.35	A
N_{Cell}	60	-

3 P&O MPPT

It is feasible to increase the amount of radiation that strikes a solar panel to boost its efficiency. It is crucial to install a solar tracking system since the sun's position changes throughout the day. Systems for tracking the sun can be separated into two groups. The two types of tracking are single-axis and dual-axis. However, a gearbox, motors, and sensors are needed for precise sun tracking. The system is too sophisticated and expensive for household or small-scale applications with this tracking device included. All that's needed for the MPPT technique to pass the maximum to the load is a minimal number of electronic circuits, like circuits for sensing current and voltage. This method gets around sun tracking devices' drawbacks. The basic principle of the MPPT technique is the use of an algorithm. The voltage and current readings are the first steps of the method, and then power is computed. The power electronic switch of the DC-DC converter balances its duty cycle to maintain the necessary load while accounting for the various demands of the algorithms. MPPT employs the P&O technique. The P&O algorithm samples the PV current and voltage to calculate PV voltage and power. This system regularly modifies the voltage of the solar PV module, and the resulting output power is similar to what was produced during the preceding perturbing cycle. The estimation of the P&O MPPT technique is shown in Fig. 4.

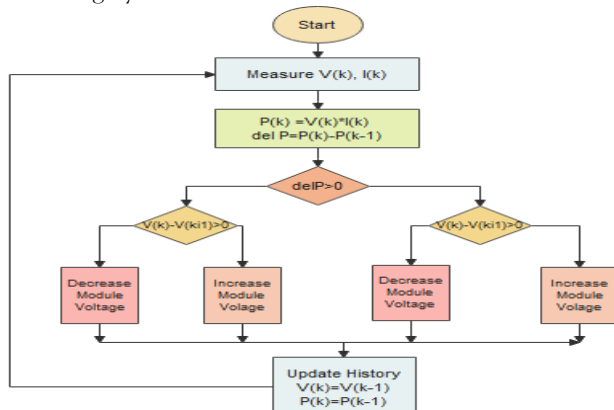


Fig. 4 P&O Algorithm

4Modified Two Stage Interleaved Boost Converter (MTSIBC)

In engineering and research, the DC-DC converter finds wide application. Parallel BC coupled in parallel and maintained in synchronization through the use of the interleaved approach make up the IBC. The phase shift and frequency are identical to those of the IBC. The interleaved technique in converters has a number of benefits, such as a greater ripple frequency, a smaller peak current volume, and the elimination of ripple in both the input-output voltage and current signals. Enhanced dependability and efficiency can also be attained. It is the main responsibility of the DC-DC converter to adjust the output voltage to our requirements. Additionally, there are ripple contents and higher switching stress in buck converter and BC. As a result, it influences the converter's performance instantly. To overcome this problem the techniques for interleaving phase shift concept are introduced. The converter's efficiency can be raised by using the interleaving technique to lower switching stress and ripple content. The two single-stage BCs that make up the MTSIBC are connected in parallel. In the case where interleaving is used to govern each switch, the two PWM signals diverge by 180° . Each boost inductor's current magnitude is reduced when the input current flows through two of them, allowing for a decrease in inductor size and inductance. The entire block diagram for solar PV based on MTSIBC is displayed in Fig. 5. The PV module, MPPT, MTSIBC controller, and load are the four blocks for solar based MISIBC converter. In Fig. 6 shows that the IBC inductor current waveform of two different mode functions.

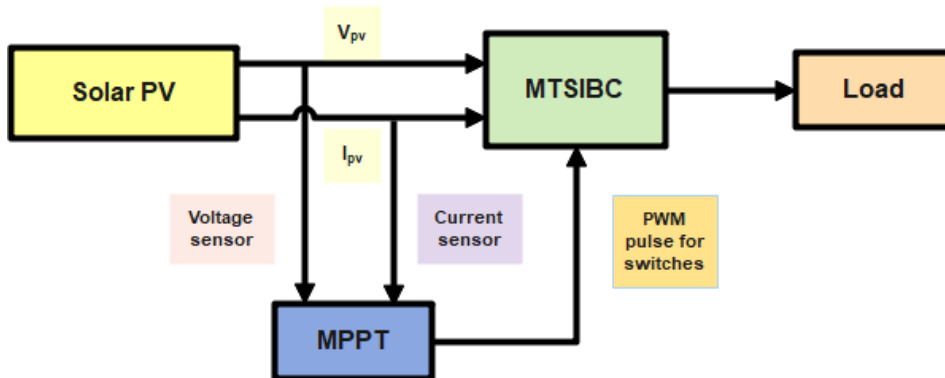


Fig. 5 Block diagram of solar based MTSIBC

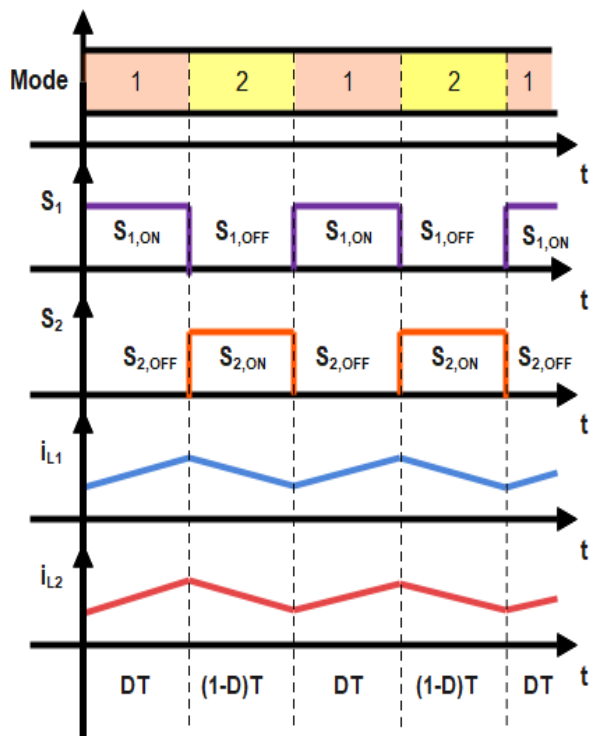


Fig. 6 MTSIBC inductor current waveform

In this case, the switching frequency used by the MTSIBC is 31 kHz. Equation 1 is utilized to calculate the MTSIBC duty cycle. Table 2 contains a list of the simulation parameters.

$$\frac{V_{output}}{V_{input}} = \frac{1}{1 - dutycycle}, \quad (1)$$

The output voltage ripple and the inductor current ripple are reduced as a result of the interleaving techniques, increasing efficiency. Because MOSFETs have superior voltage levels and higher performance, they are the power-switching device of choice for IBC modeling. The entire simulation runs in one second and analyzes the IBC's overall performance. The two PWM gating pulses are shown to be interleaved by an 180° phase shift in Fig. 7.

Table 2MTSIBC and load element data

	Parameter	Unit
MTSIBC	Inductor , (L ₁ and L ₂) in mH	3.225
	Converter Capatior, (C ₁) in μF	1
	Output Capacitor in μF	504
	Resistance of armature (R _a) in Ω	2.581
	Inductance of armature (L _a) in H	0.028
Load	Resistance (field) (R _f) in Ω	281.3
	Inductance field (L _f) in H	
	Mutual inductance of field- armature (L _{af}) in H	0.9843
	Total inertia constant (J) in kg.m ²	0.02215
	Viscous friction coefficient (B _m) in Nms	0.00295
		3

Coulomb friction torque (T_f)	0.5161
in Nm	
Speed initial (rps)	10
Initial field current (A)	1

The PV input voltage, input current, and input power are displayed in Fig. 8, Fig. 9, and Fig. 10. The values are 59.7V, 78.46 A, and 4684 W, respectively. Fig. 11, Fig. 12, and Fig. 13 show the output voltage, output current, and output power, which are, in that order, 105.9 V, 38.99 A, and 4129 W. After a one-second simulation, the input voltage should be 59.7 V and the load current is measured the value of 38.99 A, while 105.9 V is the measured load voltage. Compute the power consumption of the input and output power using Equation (2) and equation (3).
Fig. 7 Gate pulse waveform

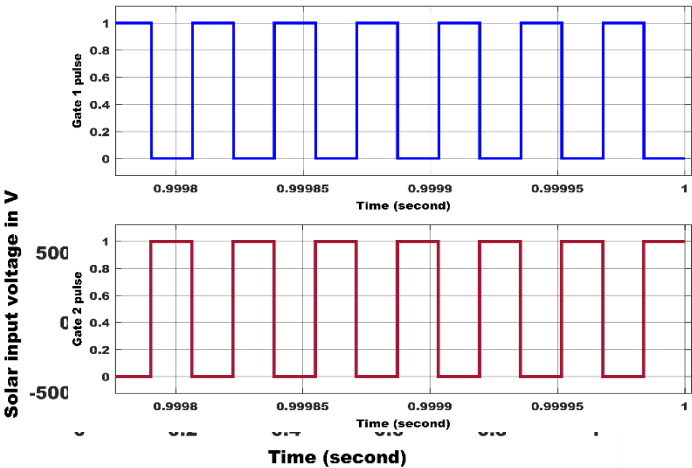


Fig. 8 Solar PV voltage waveform

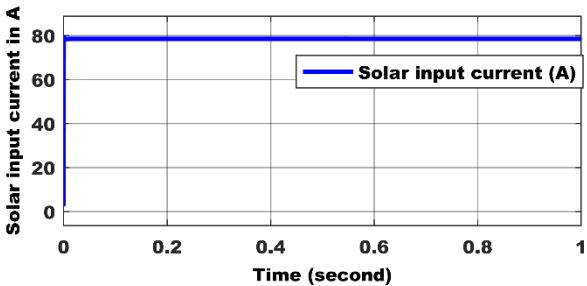


Fig. 9 Solar PV current waveform

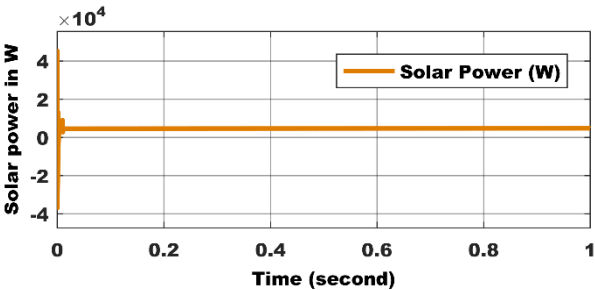


Fig. 10 Solar PV power waveform

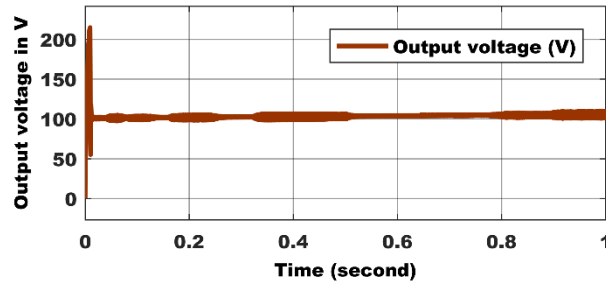


Fig. 11 Output voltage waveform

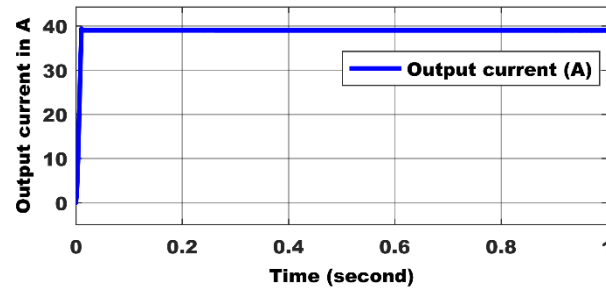


Fig. 12 Output current waveform

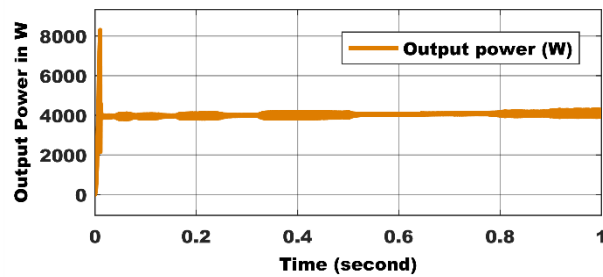


Fig. 13 Output power waveform

$$\begin{aligned} P_{\text{input}} &= V_{\text{input}} * I_{\text{input}} \quad (2) \\ P_{\text{output}} &= V_{\text{output}} * I_{\text{output}} \quad (3) \end{aligned}$$

where, P_{input} is input power(solar PV) in W, P_{output} is output power (load) in W, V_{input} is input voltage (solar PV) in V, I_{input} is input current (solar PV) in A, V_{output} is Output voltage (load) in V, I_{output} is Output current (load) in A, P_{in} is $59.68 * 78.46 = 4682$ W, P_{out} is $109.3 * 39.39 = 4307$ W.

The DC motor angular speed and torque are showed in Fig. 14 and Fig. 15 respectively. The motor speed and torque values are 86.4 rps and 2.366 Nm respectively. Fig. 16 displays the input and output power of the measured values mentioned above. The percentage efficiency was determined to simulate for a maximum of one second. To find the values of the percentage efficiency, use equation 4. The whole simulated systems' percentage of efficiency is displayed in Fig. 17.

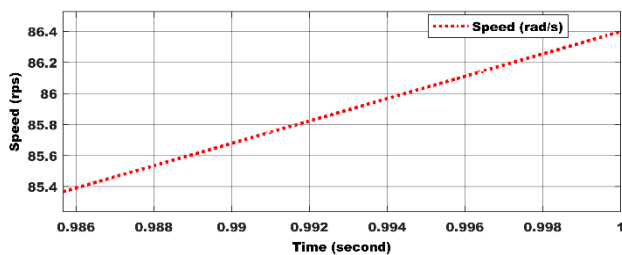


Fig. 14 DC motor speed (rps)

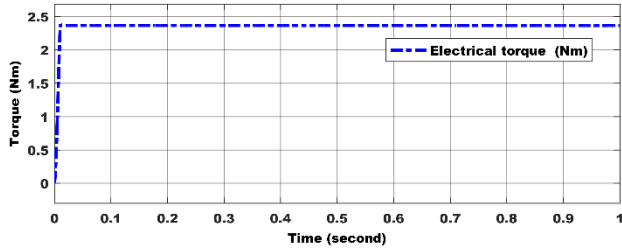


Fig. 15 DC motor torque (Nm)

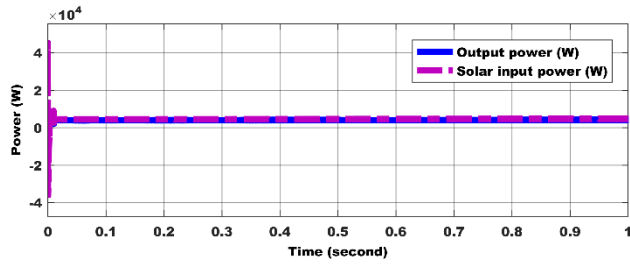


Fig. 16 Input and output power comparison

$$\%Efficiency = \frac{P_{output}}{P_{input}} \times 100\% \quad (4)$$

$$\%Efficiency = (4307/4682) \times 100 = 92\%.$$

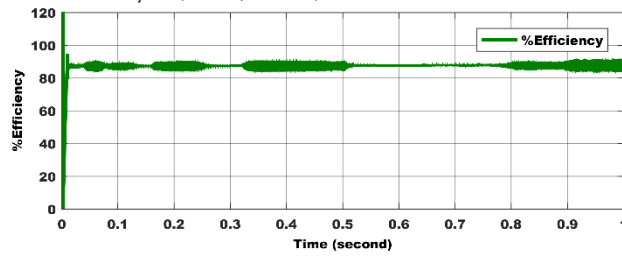


Fig. 17 %Efficiency waveform

The same input parameters used to be simulate the TSIBC. The output performance for the MTSIBC is best compare the result with TSIBC. The output parameters are listed in the Table 3.

Table 3 MTSIBC and TSIBC output parameter comparisons

Converter s	Output parameters			%η
	V _{out} (V)	I _{out} (A)	P _{out} (W)	
MTSIBC	109.3	39.39	4307	92
TSIBC	103	39.57	4076	87.64

The output voltage, power and percentage efficiency of the MTSIBC and TSIBC are showed in Fig. 18, Fig. 19 and Fig. 20 respectively. From the comparison of percentage efficiency of MTSIBC and TSIBC are 92% and 87.64% respectively. This comparison indicate that the better result are shown for the designing a MTSIBC around 4.36% higher than the TSIBC model.

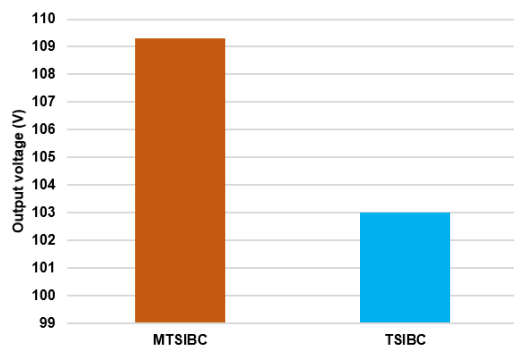


Fig. 18 MTSIBC and TSIBC output voltage comparison

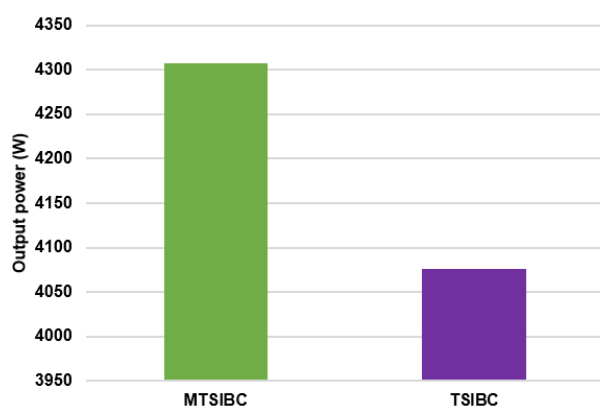


Fig. 19 MTSIBC and TSIBC output power comparison

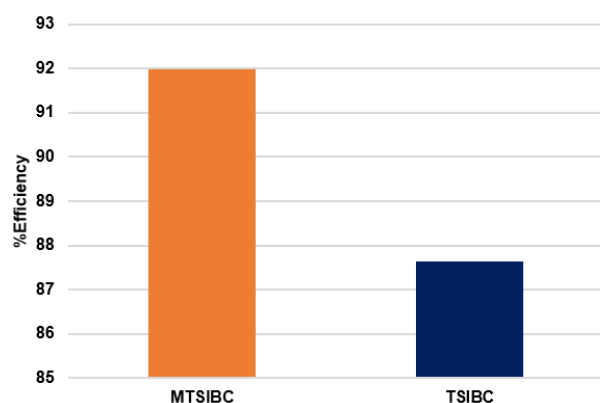


Fig. 20 MTSIBC and TSIBC percentage efficiency comparison

Fig. 21 depicts a MATLAB simulation of an MTSIBC, with 180° phase changes, a switchable pulse with an interleaved action was obtained. The MTSIBC simulation was conducted for a maximum of one second to produce the output voltage of 8.198V with 5V DC input.

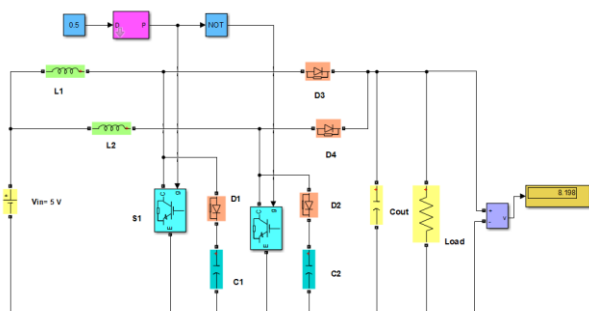


Fig. 21 MTSIBC simulation

5.HARDWARE IMPLEMENTATION

Hardware for an MTSIBC is developed of two MOSFET switches, two capacitors, four diodes, and two identical inductors. Harmonic content is reduced by the filter circuits. A 5 V input source was used to operate this hardware prototype. Since MTSIBC requires an 180° phase shift for the two-phase interleaved approach, transistors are employed to invert signals. The MTSIBC hardware prototype was implemented and validates its output voltage with the help of MTSIBC simulation. The hardware of MTSIBC is shown in Fig. 22. The output voltage waveform of MTSIBC is shown in Fig. 23. In the simulation, the MTSIBC has an output voltage of 8.12 V and an input voltage of 5. The hardware prototype output voltage of 7.52 V is obtained for the same input voltage,

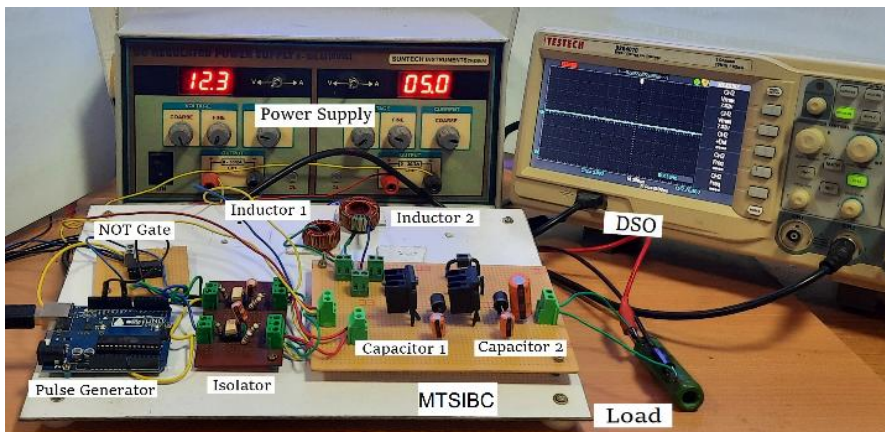


Fig. 22 Hardware prototype of MTSIBC

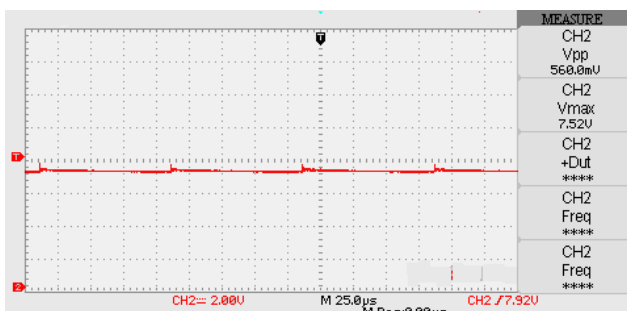


Fig. 23 MTSIBC output voltage waveform

6 CONCLUSION

This paper discusses, a P&O MPPT-based MTSIBC with solar PV. The MATLAB simulation of PV-based MTSIBC and TSIBC, with a solar PV module to the DC motor load, are simulated with an input voltage of 59.68 V for one second. The MTSIBC input voltage of 59.68 V is boosted up to 109.3 V. The input and output power of the MTSIBC are 4682 W and 4307 W respectively. The MTSIBC's output voltage, power, and efficiency are compared with TSIBC. An efficiency percentage of 92% was obtained in this simulation. The efficiency of the MTSIBC is 4.36% higher than the TSIBC efficiency. The MTSIBC model was implemented hardware prototype of MTSIBC that was implemented and its simulation result. The Phase-shifting interleaved approaches eliminate ripples in both voltage and inductor current. To simulate a solar PV module, the PV array has two parallel and two series strings connected. To maximize electricity extracted from solar PV, future electric vehicles will have their roofs equipped with PV and MTSIBC. The vehicle will be powered by a MTSIBC for better performance.

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