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Article Title: Energy-Efficient Photovoltaic-Based Motor Drive with Interleaved Boost Converter for Electric Vehicle

Energy-Efficient Photovoltaic-Based Motor Drive with Interleaved Boost Converter for Electric Vehicle

S. Priyadharsini[1], P. Subha Karuvelam[2]

[1]Faculty of Electrical and Electronics Engineering, Department of Electrical and Electronics, Engineering, Sankar polytechnic college, Sankar Nagar, Tirunelveli 627357, India. dharsini9011@gmail.com

[2]Professor, Department of Electrical and Electronics Engineering, Government College of Engineering, Tirunelveli 627007, India. subha@gcetly.ac.in

ABSTRACT

The Electric Vehicles (EVs) are revolutionary in the transport sector and leads to the phasing out of conventional fuel vehicles. The Renewable Energy Sources (Res) is used for EV. The EV vehicles are cost-effective, environmental friendly. For the proportion of EV, Permanent Magnet Brush Less Direct Current (PMBLDC) motor is used in the Photovoltaic (PV) system. The energy from the PV system is always low due to the environmental conditions, inorder to boost the voltage, this paper proposes Interleaved Boost Converter (IBC) to hybridize energy alternatives in EVs. The energy obtained from the PV system is DC. To step up the DC voltage from the PV array it is required level an interleaved boost converter is integrated. It ensure continous power flow, reduces ripple current and improves the overall power quality of the system.. The drive system's performance for various operating modes, such as stable and varying load conditions are examined from the simulations. The PMBLDC motor helps in effectively managing speed with accordance with the PI controller. The developed system's is evaluated by MATLAB simulations to verify its effectiveness. The presented converter achieves the highest efficiency of (93%) compared to other conventional methods.

Keywords: Electric Vehicle, PV system, Interleaved Boost converter, PI controller, PMBLDC motor, MATLAB/Simulink.

1 Introduction

The rising of EVs in current transporation area is moderately growing to the extinguishing of fuel-driven automobiles. As, crude oils are getting exhausted, the gasoline fueled vehicles are slowly diminishing thus leading to usage of EV s. It reduces the dependence on fossil fuels and diminish green house gas emissions. Reliance on charging stations are reduced in sunny areas and further reduces the environmental impact of EVs .It is noiseless, fuel-saving, and also emission-free [1]. Lately, the eco-friendly energy source is impacting the world to select a possibility to persuade the immense energy needs. The demand of sustainable energy is increasing thus, the exhaustible energy sources are being depleted. Solar energy is adaptable as due to its proximity, cost-efficiency and non-polluting the environment [2].

The emission of CO_2 and fossil fuels are decreased by the use of sustainable energy source due to the drastic growth of PV systems. It is widely used due to cost optimization and improved efficiency of the PV conversion. The PV systems made seamless shift from small stand alone sites to large grid connected systems. The grid connection makes different perspective to the clean energy source market by consolidating the excees time or inadequate of sustainable power with the connected grids that produces base-load power using exhaustible fuel. Various factors leads to the progression of extreme PV systems. The most important element are the global imapct on the energy need and the depletion of conventional sources . the next important factor is the impact of PV technology growth. The PV system needed effective DC-DC converter to boost up the low output of PV into higher level [3-7].

DC-DC converters plays a significant role in stepping up or regulating the input voltage from the battery to meet the motor's operational requirements. Among the popular DC-DC converters, the Conventional Boost Converter, Improved Boost Converter, and Cuk Converter are commonly employed. The Conventional Boost Converter is a simple and widely used topology for stepping up the battery voltage to the desired level. It offers advantages such as ease of implementation, low cost, and high efficiency under steady-state conditions. However, it suffers from drawbacks like high input current ripple, limited gain for high boost requirements, and increased stress on components at higher duty cycles. The Improved Boost Converter addresses few drawbacks of the conventional boost by incorporating additional components or control techniques. This leads to better voltage gain, reduced stress on components, and improved efficiency. Despite these enhancements, it can be more complex and costlier due to the added circuitry and control requirements [8-12].

The Cuk Converter is another efficient topology used to provide both step-up and step-down capabilities with continuous input and output current, which reduces current ripple. The main advantages of the Cuk converter include its ability to maintain a smooth and stable output voltage and improved input current quality. However, it is more complex in design, requires additional components like inductors and capacitors, and may have higher losses compared to simpler converters [13-15]. Therefore, Interleaved boost converter is used to overcome the difficulties faced by the conventional topologies. Moreover, PI controller is commonly applied approach due to its straightforwardness and productivity. It eliminates steady state error while determining systems transient response. The dynamic response and current regulation is ensured by inner currect loop and stability is maintained by outer voltage loop.

2 Related works

Md Rezanul Haque *et al* [2022] [16] have proposed DC-DC converter with a modified PI controller for EV charging applications. This method helps to attain desired output voltage and high current density. The developed converter works in ideal and non-ideal conditions. It provides higher reliability in both open and short circuit failure, compared to the reference DC-DC converter. The components junction temperature is much smaller compared to the worst-

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case scenario. After the integration of the damping resistor, the system provides more stability. The inductor is a crucial element. In case of any mismanipulation, the inductor increases the temperature and power loss that leads to saturation.

Lijin Kunjuramakurup *et al* [2023] [17] have developed PV-fed Two Input Single Output (TISO) for EV applications. This technique accurately monitor and control the signals for tracking Maximum Power Point Tracking (MPPT) by maintaining the DC output source constant regardless of any variations in the PV system. This method achieves high efficiency and low fluctuations by reducing the ripple produced by the output voltage. For the purpose of minimizing the fluctuations and to enhance the tracking speed, multi-step sizes are used. Even though, it affects the parasitic components such as semiconductors, parasitic inductances and capacitances.

Mudadla Dhananjaya *et al* [2022] [18] have introduced multi-output DC-DC converter for EV applications. The multiport converter (MPC) plays a crucial role in EV applications. As single-input-single-output (SIMO) produces the output based on the duty cycle and charging of inductors there is an issue in cross-regulation. But in MPC, cross-regulation problems and load voltage doesn't get influenced by output current deviations. The system is configuration is not complex and can produce three significant outputs without the help of duty ratio or inductor currents. Although, the converter efficiency gets affected as it contains lot of device count and active switches.

P. Anitha *et al* [2022] [19] have implemented Z-source DC-DC converter for EV battery. It provides minimal switching loss, when low input DC voltage is transformed to high output DC voltage with low duty cycle. This technique attains higher conversion efficiency by manipulating ideal design values. The desired output is achieved by triggering the closed loop system switch. It also used to enhance the system steady-state and dynamic performance. Even though it provide wide range of application's including high voltage gain and inherent protection against short circuits, these converters uses sophisticated algorithms which may increase the system cost and complexity.

P. Ramesh *et al* [2022] [20] have offered multiport bidirectional DC-DC converter for EV based applications. This technique proposes three input DC-DC converter, two PV cells and one battery. As the input are independent from one another, the converter liability is increased even an input unit gets failure. For continuous operations, the output port charges the energy storage system. To obtain high power from the battery, this converter manages the PV panels simultaneously. It can manage multiple Res at once by using less number of switches. But still, as the number of port gets increased, the control and hardware requirements also gets complicated.

3 Proposed sytem description and modelling

The proposed block diagram shows a solar PV system integrated with PMBLDC motor drive. The PV system is the primary energy source for converting the sunlight into electrical energy

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and produces output DC voltage and current. An interleaved boost converter is integrated to boost the DC voltage from the PV array to the needed higher level, enhancing the efficiency and reducing the ripple current. The function of the converter is regulated by the PI controller and PWM generator produces switching signal for the converter operation.

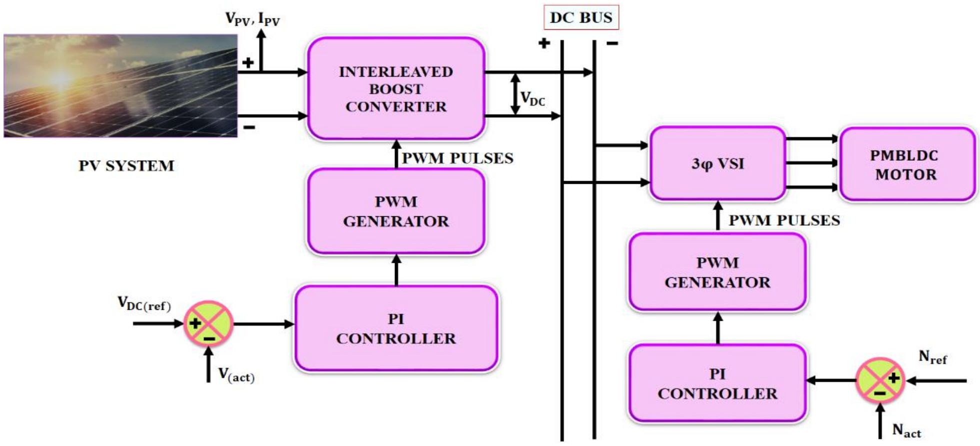

Figure 1: *Block diagram of proposed technique*

The step-up DC voltage is fed into a three-phase VSI that converts DC into AC supply to run the PMBLDC motor. The EV motor gets regulated PI controller The entire system enhances the efficient energy conversion and accurate motor control, making it convenient for renewable energy-based applications.

3.1 PV system

The PV cell modelling consists of the step calculations of power-voltage (P-V) and current-voltage (I-V) characteristics. The solar cells quality are monitored and the performance of the PV systems are determined relatively by the level accuracy from I-V and P-V characteristics

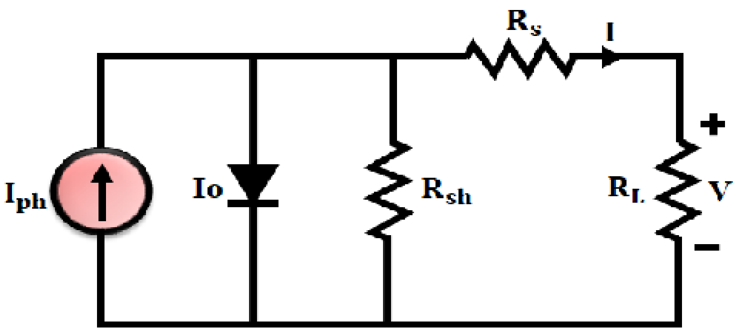

Figure 2: *Equivalent PV system.*

The conventional equation for the PV system with I-V characteristic derived from General Shockley equation are,

$$I = I_L - I_0\left[exp\left(\frac{(I_{Rs})}{a}\right) - 1\right] - \frac{(I_{Rs})}{R_{sh}} \tag{1}$$

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The modelling and characterization of PV system encompasses 5 parameters: Lighting diode current (I_l), reverse saturation current(I_0), modified ideality factor(a), series resistance (R_s) and shunt resistance (R_{sh}).The equation (1) shows the main PV characteristic, which is described by I-V characteristic curve. As the 5 parameter model are reported to provide improved accuracy that other models.

Lighting diode current (I_l) is directly proportional to irradiation and highly depend on operative cell temperature (T) value, can be defined as:

$$I_L = (C_2 + C_3T - C_4). G \tag{2}$$

The effectiveness of reverse saturation current(I_0) is affected by the cell temperature (T) linearly, (I_0) is expressed as:

$$I_0 = C_5. exp(-\frac{C_6}{T}) \tag{3}$$

The series resistance (R_s) depends on the effective cell temperature (T) is defined as:

$$R_s = C_7 - \frac{C_8}{T}. exp(-\frac{T}{C_0}) \tag{4}$$

The shunt resistance (R_{sh}) value is directly obtained from the slope at short circuit current $I_{sc}$is as follows:

$$R_{sh} = R_{sho} = -(\frac{dv}{dt})I_{sc} \tag{5}$$

Due to the limitations in determining the precise values of diode ideality factor(n), if$C = \frac{q}{nk}$, then,

$$a = \frac{T_C}{C_1} \tag{6}$$

The output from PV is low due to the ecological changing scenarios, in order to boost it into higher level, interleaved Boost converter is deployed as below.

3.2 Interleaved Boost Converter

The individual conventional boost converters are connected in parallel, is the interleaved boost converter. The circuit diagram shows the two-phase IBC in which two boost converters are connected in parallel consists of S_1,S_2 switches, L_1, L_2 inductors andD_1,D_2 diodes, a capacitor C, and “R” a load resistor.

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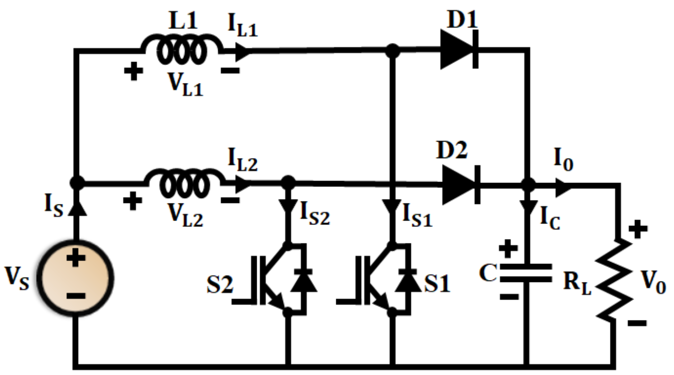

Figure 3: *Circuit diagram of Interleaved Boost Converter*

Mode 1: In **Mode I** of the Interleaved Boost Converter, the switches S_1 and $S_2$are turned **ON**, while the diodes $D_1$and D_2 are reverse-biased. During this mode, the input power source supplies energy to the inductors L_1, L_2 as shown in configuration for this mode in Figure 4a.

$$V_{L1} = V_{in} \tag{7}$$

$$V_{L2} = V_{in} \tag{8}$$

Where,

$$V_{L1} = L_1 \frac{di_{L1}}{dt} \, and \, V_{L2} = L_2 \frac{di_{L2}}{dt} \tag{9}$$

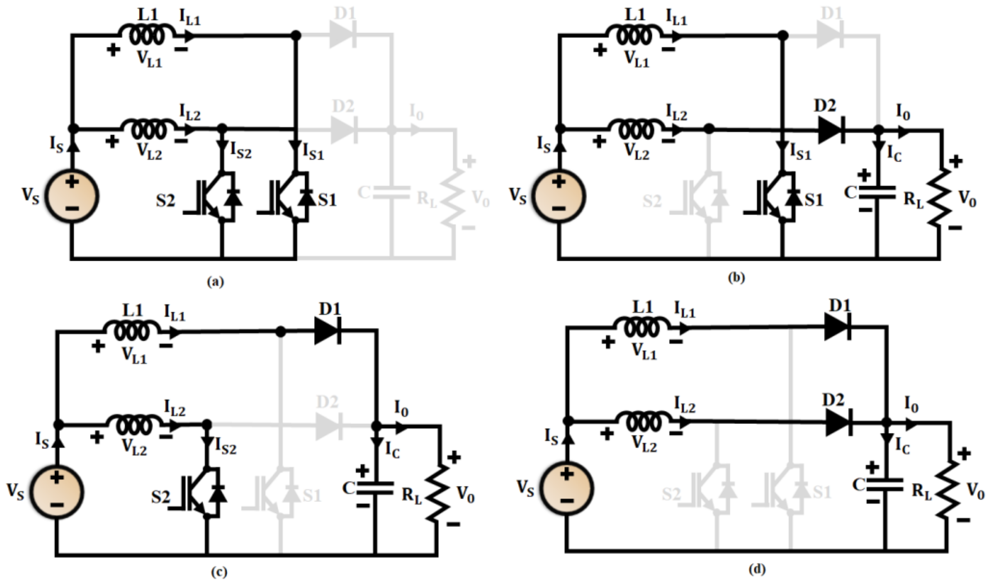

Figure 4: *Operating Modes of Interleaved boost converter*

Mode 2 Interleaved Boost Converter, switch S_1 is closed**, while switch $\boldsymbol{S_2}$ is** open. As a result, diode D_1 is reverse-biased, and diode D_2 becomes forward-biased. During this mode, the input

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power source continues to supply energy to the inductor L_1, causing its current L_1, to increase as schematic in Figure 4b.

$$V_{L1} = V_{in} \tag{10}$$

$$V_{L2} = V_{in} - V_0 \tag{11}$$

Mode 3: In **this mode,** switch S_1 is **open** while switch S_2 is **closed**. In this mode, diode D_1becomes forward-biased, and diode D_2 is reverse-biased. The inductor L_1 discharges and supplies energy to the load. Simultaneously, the input source provides energy to inductor L_2, causing its current to increase. The circuit configuration for this mode is illustrated in Figure 4c.

$$V_{L1} = V_{in} - V_0 \tag{12}$$

$$V_{L2} = V_{in} \tag{13}$$

Mode 4: the power switches S_1 and S_2 are in conduction mode, while $D_1$and D_2 are in forward biased, thus it conduct. In this mode, the inductors L_1, L_2discharge simultaneously, supplying energy to the load, shown in Figure 4d. This results in a decrease in the currents L_1, L_2. The rate of change of inductor currents during this discharge phase is mathematically expressed as,

$$V_L = V_{in} - V_0 \tag{14}$$

$$\frac{di_{L1}}{dt} = \frac{di_{L2}}{dt} = \frac{V_{in}-V_0}{L} \tag{15}$$

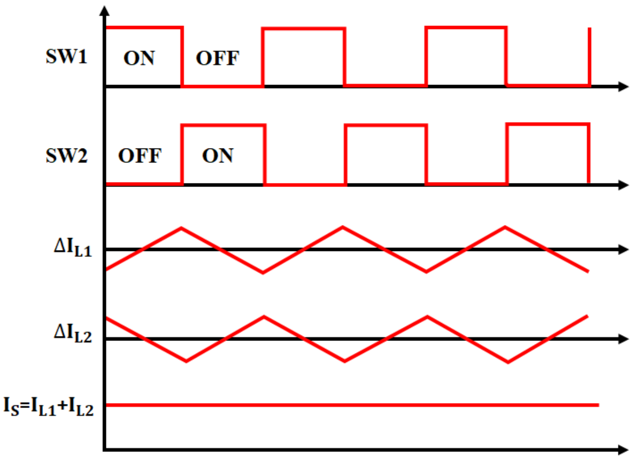

Figure 5: *Switching waveform of Interleaved Boost Converter*

For Steady-state operation,

$$V_0 = \frac{V_{in}}{(1-\delta)} \tag{16}$$

The minimum inductor values L_{1min} *and* L_{2min} is specified as:

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$$L_{1min} = L_{2min} = \frac{V_{in}\delta T}{2\Delta i_L} \quad (17)$$

The minimum inductance value of L_1 is L_{1min} and the minimum inductance value of L_2 is L_{1min} . The capacitor C is given by,

$$C_{min} = \frac{\delta}{R(\frac{\Delta V_0}{V_0})f_s} \quad (18)$$

The switching waveform of proposed converter is illustrated in Figure 5. With the assistance of proposed converter topology, the output of PV gets highly enhanced with better efficiency and voltage gain. Following this, the converter stabilization is essential for providing minimized oscillation output, thus PI controller is utilized as follows.

3.3 PI controller

The PI controller acts as voltage controller to minimize the voltage error and to find optimal solution using the current signal. For tuning the PI controller, the proportional and integral gain $K_p$and K_i is used, represented in Figure 6. The basic block diagram of PI controller is given by,

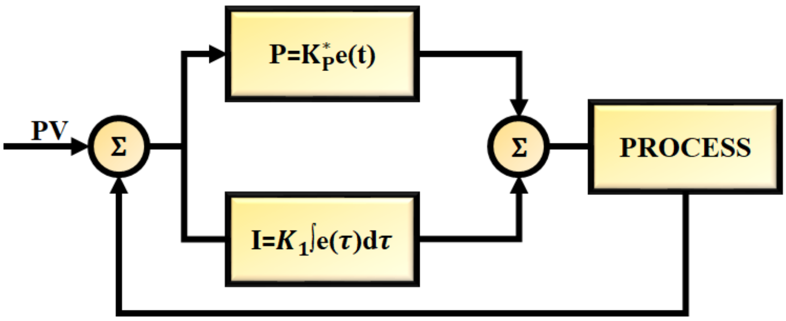

Figure 6: *Block diagram of PI controller*

$$u(t) = K_p.e(t) + K_i.\int_0^t e(t)dt \quad (19)$$

As the output response depends upon few conditions of the integral of the actuating signal, it works as integral error compensator. The PI controller proposes a type of compensation which consists of two terms, one is proportional to the actuating signal and the other one is integral to the actuating signal. This controller is known as proportional plus integral controller or PI controller.

3.4 PMBLDC motor

The PMBLDC motor is a type of electric motor creates magnetic field instead of relying in the field windings. In the BLDC motor, to generate the back emf waveform, the phase windings are represented in the trapezoidal manner and only two phases gets conducted at any point of time. While switching the phase, current enters in one winding, current exits in another winding and one winding has a non-energized condition. As torque is generated by the generation of

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magnetic field between the interaction of permanent magnet and stator coils. An ideal torque is produced only when the 2 fields are 90^0 to each other.

In PMBLDC motor, is functioned by a constant torque with enhanced energy efficiency and speed control. Here, constant torque is maintained by a constant current in the stator winding of the PMBLDC as the speed is regulated by varying terminal voltage. The simplified equation of PMBLDC motor of Phase stator resistance R, a, b, c phase currents are$i_{a,b,c}$, total flux linkage of a, b, c are $\lambda_{a,b,c}$ is given as:

$$\begin{aligned} V_{an} &= R_{ia} + p\lambda_a + e_{a,} \qquad \lambda_a = L_s i_a - M(i_b + i_{c,}) \\ V_{bn} &= R_{ib} + p\lambda_b + e_b, \qquad \lambda_b = L_s i_b - M(i_a + i_{c,}) \\ V_{cn} &= R_{ic} + p\lambda_c + e_c, \qquad \lambda_c = L_s i_a - M(i_a + i_{b,}) \end{aligned} \tag{20}$$

By substituting $i_a + i_b + i_c = 0$ in the above equation.

$$\lambda_a = i_a(L_s + M)\ \lambda_b = i_b(L_s + M) \tag{21}$$
$$\lambda_c = i_c(L_s + M)$$

The torque developed is given as,

$$T_e = (e_a i_a + e_b i_b + e_c i_c)/W \tag{22}$$

The speed control is regulated by the production of back EMF, and then fed into the PI controller.

4 Results and discussions

The overall outcomes for the proposed energy efficient PV based motor drive with IBC for EV from the Matlab/Simulink detailed overview is discussed in this section. Furthermore, the comparative analysis is made over with the traditional methods and obtained outcome of the proposed work are examined to expose the significance of the developed work. Following Table 1 illustrates the parameter specification for the proposed topology.

Table 1: *Specification of PV based IBC converter*

Parameters	Values
PV system	
Power Ratings	5kW
V_{sc}, V_{oc}, I_{sc}	12V, 22.6 V, 8.33 A,
Power	2000W
Total count of panels	20 panels, 100W
IBC	
Inductor L_1, L_2	5.5mH
Capacitor C	870μF

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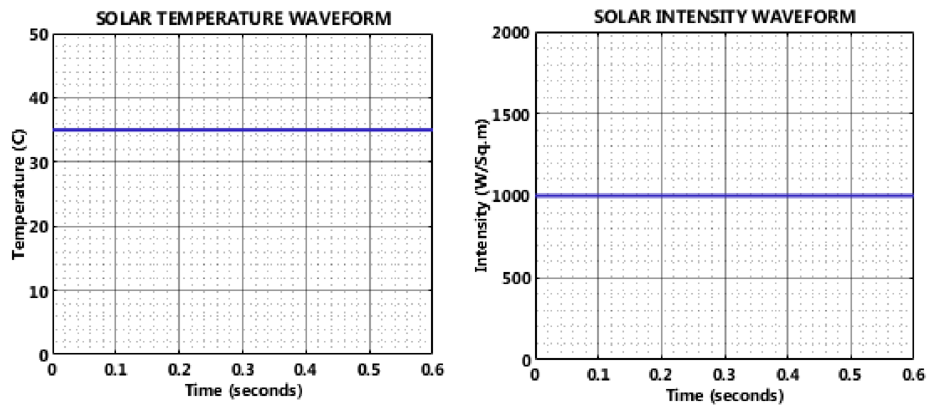

Figure 7: *Waveform illustration of PV panel Temperature and Intensity*

Figure 7 shows the temperature and intensity waveforms produced through the PV system. It is indicates that a steady temperature of 35°C is maintained constant throughout the system. The intensity waveform specifies that it is stable at 1000(W/Sq.m) without any fluctuations.

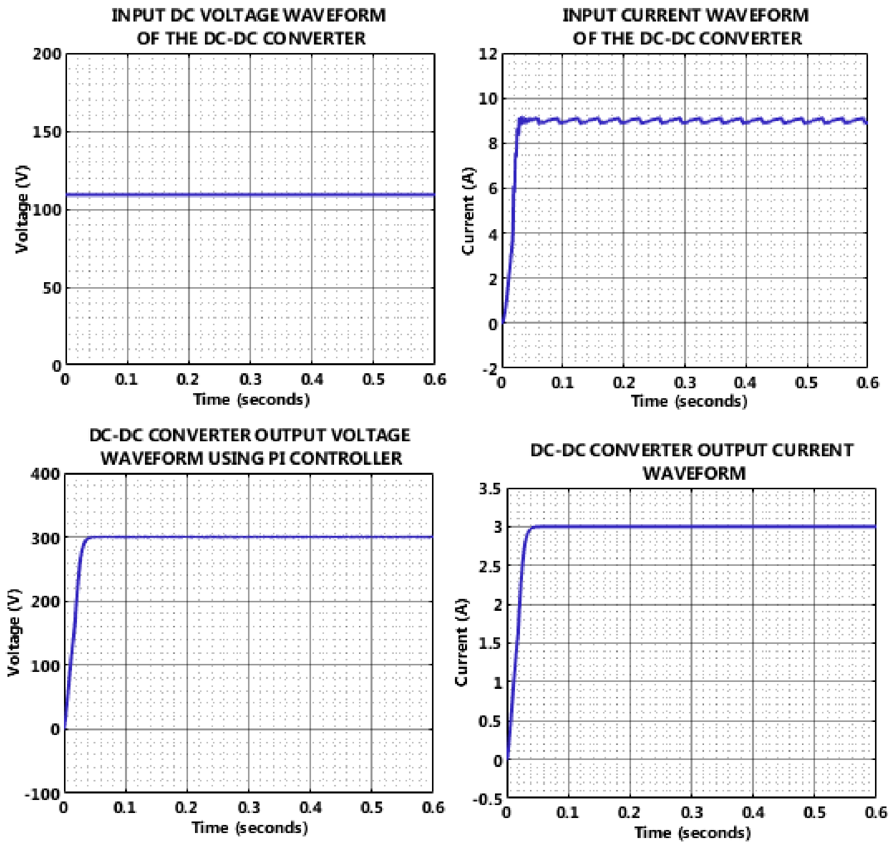

Figure 8: *Waveform illustration of Converter Input and Output*

The figure 8 shows the converter input and output waveforms. The input voltage of the converter shows stabilized voltage of 110V owing to constant condition, whereas the input

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current is noticed be maintain at 9A without any variations. In response to this converter results with stabilized voltage of 300V followed by current maintaining at 3A respectively.

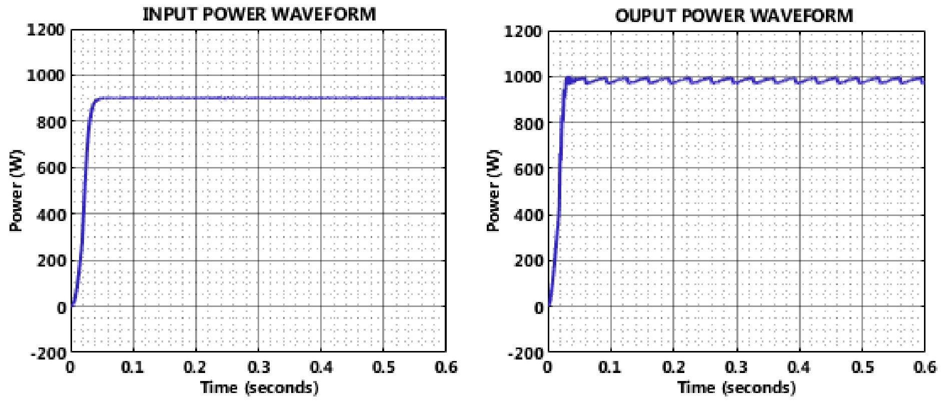

Figure 9: *Input and Output Power waveform*

The input and output power is illustrated in the above Figure 9. With respect to input power of 925W, the proposed converter output power is observed to be maintained at 1000W, highlighting the converter performance.

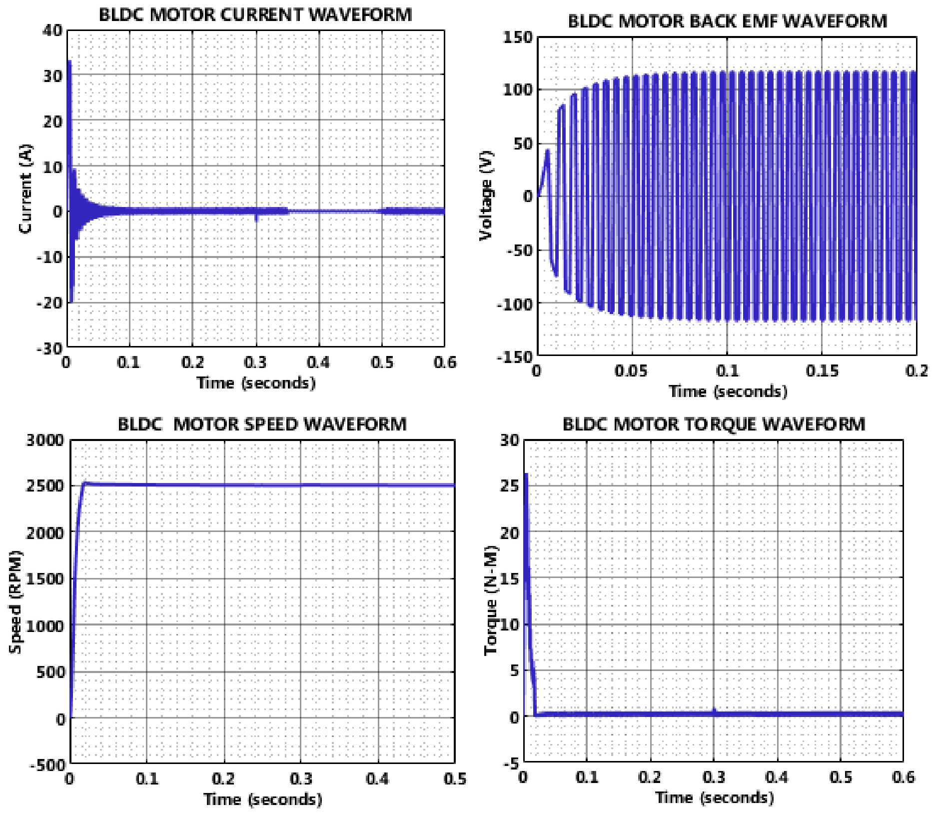

Figure 10: *PMBLDC motor current, back emf, speed and torque waveform*

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The performance of BLDC motor is illustrated in Figure 10. The PMBLDC motor waveform attains high current in early phase, but after few seconds, the current flows at the range of (2A-3A). Similarly, the waveforms for a PMBLDC motor back EMF 115V is attained, and the rear emf has a trapezoidal form. The PMBLDC motor speed waveform is regulated by PI controller. The motor speed 2500 rpm and is noticed be maintained at constant. The torque waveform of the PMBLDC motor shows that the torque increases during the initial phase, and after 0.02 seconds, the ripple torque gets eliminated.

Table 2: *Comparison of converter Efficiency*

Converters	Efficiency (%)
Boost	86%
Modified Boost	91%
Proposed converter	93%

The proposed Interleaved Z-source converter efficiency is compared with the other classical approaches for proving the proficiency of developed topology. From the Table 2, it is clearly known that the proposed converter topology attains higher efficiency of 93% compared to the other approaches.

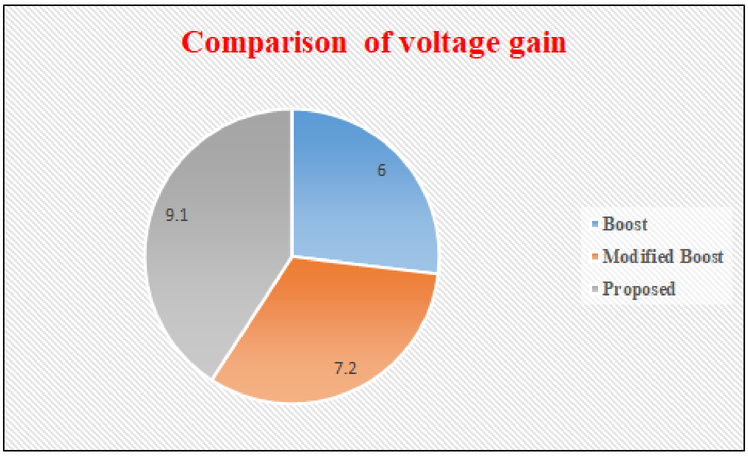

Figure 11: *Comparison of Voltage gain*

The voltage gain comparison for the proposed Interleaved Boost converter is illustrated in Figure 11. The proposed converter performs higher voltage gain by comparing with the other classical topologies, thereby the performance of the EV motor is enhanced.

5 Conclusion

In this paper, an efficient PV based Interleaved Boost converter is designed for the PMBLDC motor in EV. With the assistance of Interleaved Boost converter, the low output of PV is enhanced with higher efficiency and voltage gain. Also, the PI controller greatly regulates the converter output for providing stable output without any oscillations. Three phase VSI converts DC-AC supply and the PMBLDC motor speed gets effective regulation by the PI controller.

The obtained outcomes from the MATLAB/Simulink, the proposed converter, is compared with the other classical topologies for proving the proficiency of developed topology. The outcome demonstrates that the compared to other topologies proposed converter achieves higher efficiency of (93%) and voltage gain, which pave the way for effectual transportation of EV.

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