

Boost Converter with Optimized PI Controller Design for Grid Tied PV Based Electric Vehicle

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Abstract

The growing demand of clean energy along with the depletion of fossil fuel usage have paved the way for electric vehicles (EV) to emerge as a significant alternative in automobile sector. Reduction of air pollution and reliance of fossil fuels thereby improving energy security are termed as the primary goals of EV. The adoption of EV facilitates emission free transportation and addresses the environmental crisis caused due to climatic changes and pollution. The integration of EVs with renewable energy sources (RES) supports decarbonized energy production contributing to cleaner environment. The abundant availability in nature enables the solar system to be widely used for the integration with EVs. The intermittent nature of photovoltaic systems (PV) is solved by the inclusion of efficient DC-DC converters along with grid supply which in turn enables the constant power flow in the charging system. The focus of this study is to develop an effective charging system for EVs which contributes a crucial role in achieving a pollution free future. A novel Trans Z-source Luo converter is used to enhance the PV output voltage thereby lessening the number of PV panels used. The proposed converter exhibits the benefits like excellent efficiency, lesser voltage stress and high conversion range. The operation of the proposed converter is regulated with the aid of Lion Grey Wolf Optimized Proportional Integral (LGWO-PI) controller which significantly strengthens the converter operation in terms of settling time, total harmonic distortion (THD) and peak overshoot. The obtained converter output energizes the Brushless Direct Current (BLDC) motor of EV after its conversion to AC form by a Voltage Source Inverter (VSI). A conventional PI controller is used for the effective speed control of BLDC motor. At times of power unavailability from PV systems, a VSI fed grid is used to energize the BLDC motor. Overall, the complete charging setup provides a constant power supply for EVs. The presented work is simulated using MATLAB and the outputs indicate the enhanced functioning of the charging system. Comparisons are carried out with existing converters and control approaches in which the proposed system delivers a reduced THD of 2.1% and an optimal efficiency of 97.6%.

Keywords: PV system, Boost converter, LGWO-PI controller, BLDC motor, PI controller, single phase VSI, three phase VSI, EV charging

INTRODUCTION

In 21st century, we have learned a lot from the breakouts of pandemics. We have adjusted to the new standard despite the many shifts that have taken place. However, the level of air pollution did not change. Electric vehicles, sometimes known as EVs, are widely regarded as the means of transportation of the foreseeable future [1]. The Paris Agreement Declaration on Electro-Mobility and Climate Change and Call to Action, which took place on the 12th of December 2015 and went into effect on the 4th of November 2016, called for the deployment of 100 million electric vehicles around the globe by the year 2030. Many people believe that the growing popularity of electric cars (EVs) represents a positive development that should be

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encouraged. Because of this Electrical Revolution, Internal Combustion Engines will be rendered obsolete within the next 10 to 15 years. We are moving in the direction of electric vehicles since they do not have recurring costs or costs associated with maintenance [2]. The primary benefit is that it is better for the environment, which results in less ozone layer depletion. If IC Engines were upgraded, there would unquestionably be a drop in the number of pollutants produced. Also, everything that had to do with the cooling of the internal combustion engine, the exhaust system, and the radiators were converted into rechargeable batteries, and a single motor was installed in the rear wheels [3]. Additionally, there is a decrease in the amount of carbon emissions and air pollution. However, there has been a significant rise in the number of electric vehicles and charging stations that have issues with high voltage quality and harmonic distortion, which negatively affects the efficiency of integrated renewable energy. Electric vehicles (EVs) are far more fuel-efficient than gasoline-powered automobiles, and they do not create any pollutants from their tailpipes [4, 5]. They have a drive train that is much easier to use, far less noisy, and requires very little maintenance. To live a greener lifestyle, you should adopt practices that are more environmentally friendly in order to promote the use of electric mobility, and we should become more involved with technological developments in order to hasten the spread of E-Mobility-related research. This study is to expand the electrical Charging Network to bring green transformation by creating smart and efficient Solar based Grid tied EV Chargers [6].

Electric vehicles have attracted a lot of attention in several countries due to the increasing need for clean energy and the necessity to get fossil fuels. Air pollution reduction, increased energy security and decreased reliance on fossil fuels are the main objectives of EVs. The preceding standards are only satisfied when EVs are combined with RESs [7]. Because of their plentiful availability in surroundings and absence of carbon emissions, solar PV based EV charging solutions are highly favoured among other RESs [8].

It is suggested to use high gain dc-dc conversions to maximize the output voltage over a larger range because the low voltage of PV is insufficient to meet the demand. The output voltage of the PV system changes over time depending on the climate, including temperature and solar insolation. As a result, the PV system's power generation is not reliable, and a suitable control plan must be put in place to improve the converter's efficiency by reducing THD, achieving a power factor that is close to reducing steady state error, unity and resolving peak overshoot problems. In PV grid-tied systems, the conversion is operated using the traditional controller, which has typically been the simplest and most practical controller [9]. The DC link voltage is more successfully regulated by this controller with the least amount of THD when used within the designated operating range. Nevertheless, because of the intermittent nature of the PV system, estimating the right PI controller settings is thought to be a challenging procedure. By utilizing metaheuristic algorithms, which are simple, reliable, and simple to execute, problems associated with standard PI controllers are eliminated, and performance is improved. For improving the unregulated DC voltage output generated from the PV, a boost converter is constructed in this study. For improving the output of the converters, an improved PI controller is put into practice. Following that, the single-phase grid and three phase BLDC motor are both fed with the PV electricity that was generated. Use of a PI controller ensures control over the BLDC motor speed.

PROPOSED SYSTEM DESCRIPTION

Due to the depletion of fossil fuels and the requirement to reduce carbon emissions to slow the rate of global warming, the idea of PV based EVs that support decarbonized energy generation and transportation is receiving a lot of attention these days. Due to their beneficial qualities such a direct design, high efficiency, outstanding speed control capabilities, minimal losses and low maintenance cost, BLDC motors are the most popular motors used in EVs [10]. In this study, as shown in Figure 1, a PV supplied BLDC motor drive for an EV is developed with a PI/GWO-PI/LGWO-PI controller. Solar irradiation and temperatures affect the PV system-based electricity generation, which is not consistent. Using only a DC-DC Boost Converter with a PI/GWO-PI/LGWO-PI controller as the basis, the variable photovoltaic panel's output voltage is controlled as a stable DC output of the voltage level

[11]. The output voltage is supplied to the 3-VSI for conversion to AC voltage, which is subsequently supplied to the EV motors. A PI controller is used to achieve the main goal of managing the motor speed. The motor's error speed is given as the input to the PI controller after being compared to the motor's actual and reference speeds. The controller output is pumped into the PWM generator, which is responsible for providing the required pulses, to regulate the switching function of the VSI. A 1 ϕ VSI is used to convert the converter's voltage to AC voltage prior to getting delivered to the 1-grid. PI controllers are used to synchronize the grid voltage. When there is no PV during the nights, the BLDC motor is driven by grid power [12–14].

PROPOSED SYSTEM MODELLING PV fed TZSBLC

The Boost converter is generally recognized as having a simple design and allowing minimal energy current flow. For the development of a constant voltage, this might utilize a variety of acceptable control strategies. In the converters, energy is transferred using an energy discharging phase and energy storage phase. When the switch is activated, the inductance energy will be stored while the load is powered by the output capacitor. When the switch is open, the energy from the inductor is transferred to the capacitors, recharging it [15–18].

Eventually, the Boost converter will have an offset current because of the inductor's charging period. The inductive charging technique of the Boost converter has the drawback of being useless in the case of a sudden change in the demand for higher output power [19]. Due to the Boost converter's design, the inductor is unable to increase its voltage level quickly without reducing the output voltage. Because of this, Boost converters are typically used in applications that require a slower charging time phase. The benefit of the boost converter design is that a decreased input ripple can be achieved by enabling the inductance to drain current during the on and off cycles of operation.

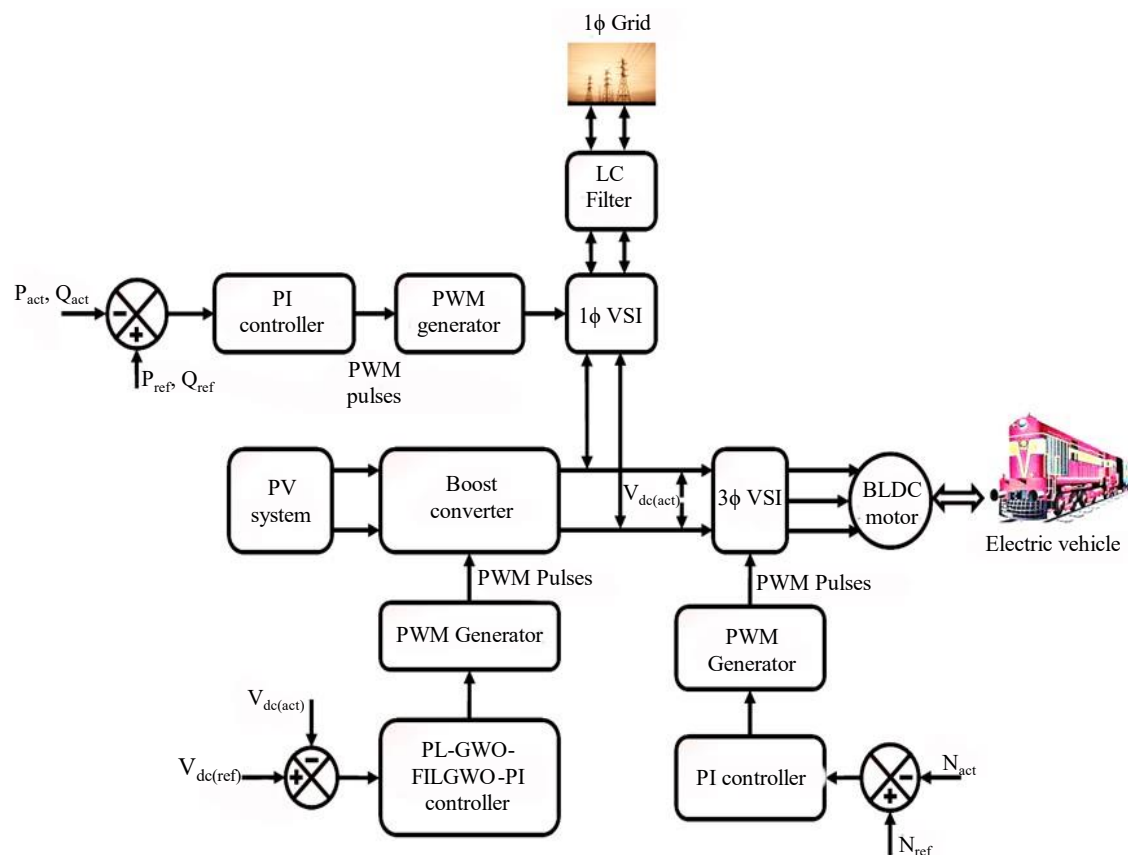


Figure 1. Proposed system.

To increase the power gained from the PV system, a typical boost converter is utilized because the electricity produced by the solar system needs to be processed before being applied to the loads. Figure 2 depicts the equivalent circuit for the PV system [20].

Mode 1

In mode 1, the switch is in the ON condition, and the variables represent the system parameters (Figure 3). Since the current that flows through the inductor has increased, energy is now being stored there. Upon turning the switch OFF, the load receives the stored energy [21]. As the current flowing through the inductor decreases, the voltage across it increases to create a voltage across the load by increasing to the voltage source.

The corresponding equations are presented as:

$$\frac{dI_L}{dt} = \frac{V_L}{L} \tag{1}$$

$$\frac{dV_o}{dt} = \frac{-V_o}{RC} \tag{2}$$

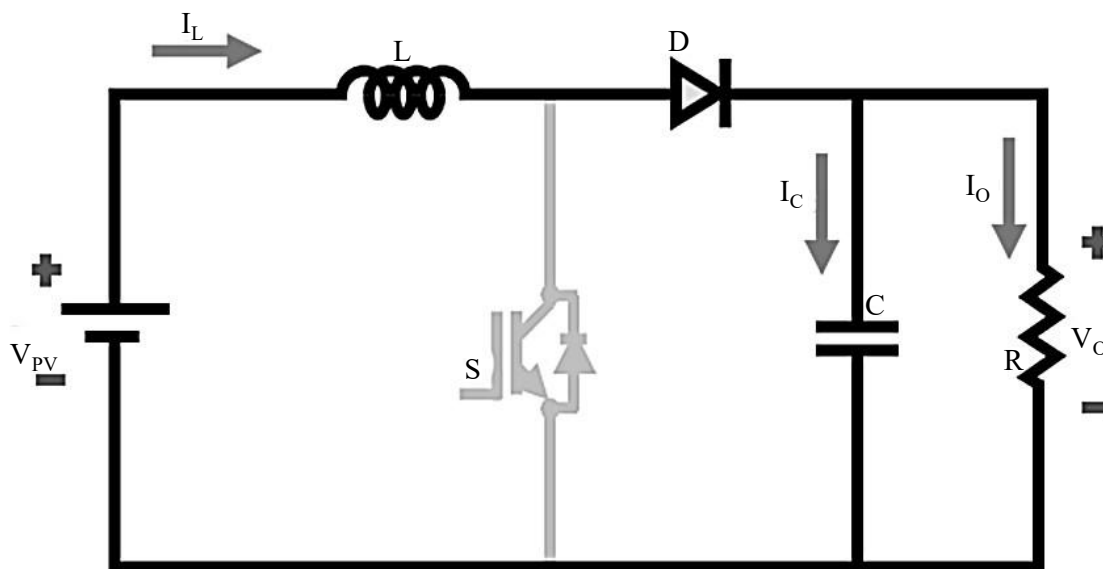


Figure 2. Boost converter.

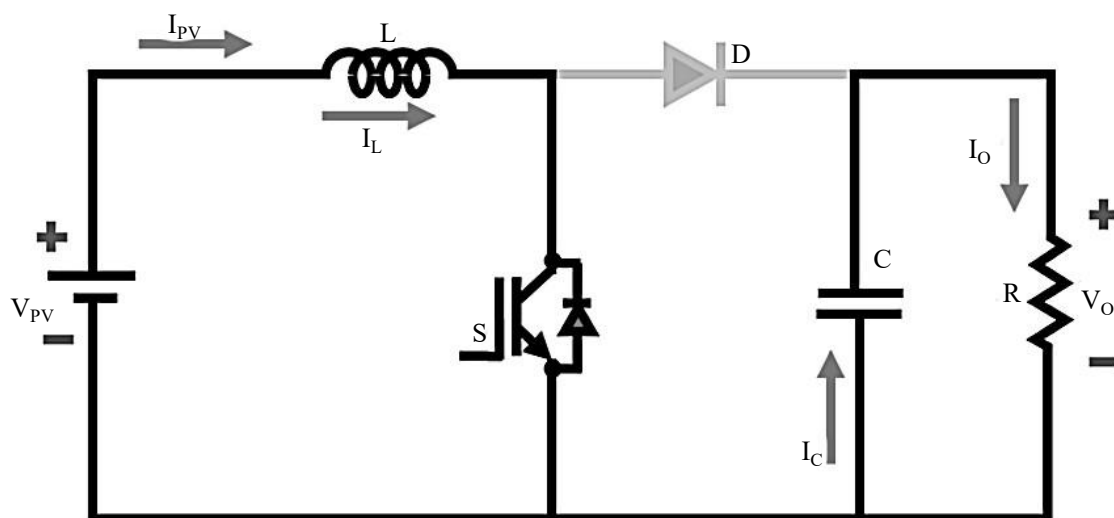


Figure 3. Mode 1.

Mode 2 (Figure 4)

The equations when the switch is in OFF condition are given by:

$$\frac{dI_L}{dt} = \frac{V_L}{L} - \frac{V_0}{L} \quad (3)$$

$$\frac{dV_0}{dt} = \frac{I_L}{C} - \frac{V_0}{RC} \quad (4)$$

According to the Boost converter's inductance and capacitance values are expressed as:

$$L = \frac{RD(1-D)^2}{2f} \quad (5)$$

$$C = \frac{D}{Rf\Delta V_0/V_0} \quad (6)$$

The Boost converter's duty cycle can be calculated using,

$$D = 1 - \frac{V}{V_0} \quad (7)$$

The waveforms for the Boost converter are shown in Figure 5. The voltage attained from the PV system is improved by the Boost converter and the attained DC link voltage with the aid of optimized control is applied for energizing the BLDC motor of EV [22, 23]. Nevertheless, the Boost converter only increases the PV voltage to a certain extent and makes a lot of noise and warmth while it is running, so this needs to be improved. The unstable DC output voltage obtained from the converter is optimized and made stable with the assistance of LGWO-PI controller.

RESULTS AND DISCUSSION

The result simulated using MATLAB for the proposed work is described in the following section. Table 1 demonstrates the parameter specifications of the proposed Boost converter which is utilized for effective functioning of the system.

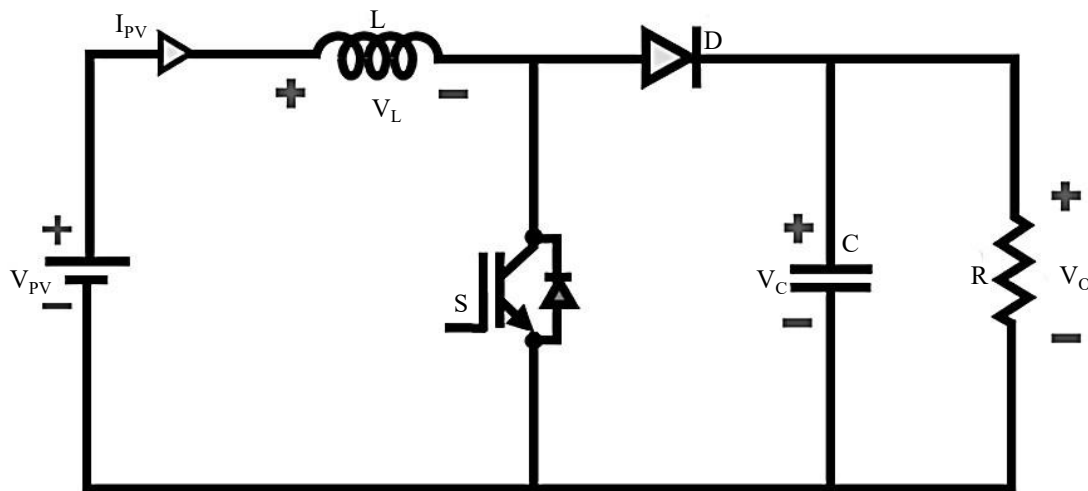


Figure 4. Mode 2.

Table 1. Specifications of boost converter.

Boost converter specifications	
Inductor	1.5mH
Capacitor	2200μF
Frequency	10KHz
Switch	IGBT

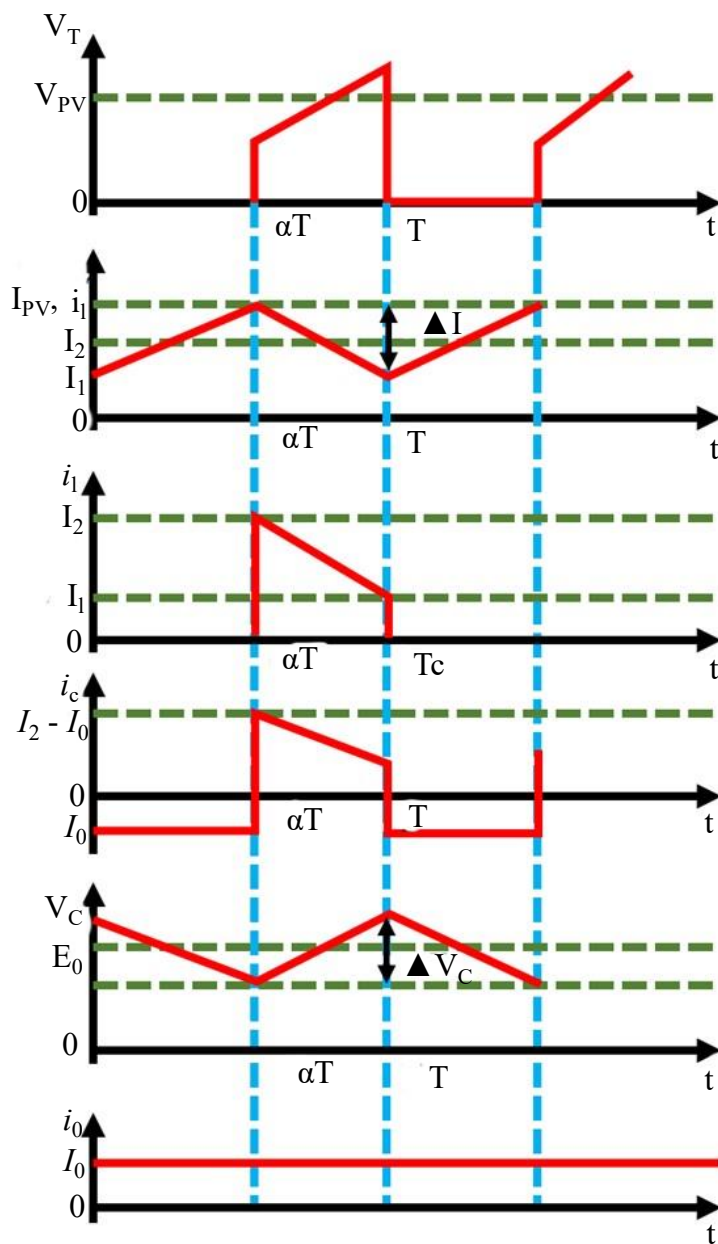


Figure 5. Waveforms for boost converter.

The waveform representing solar irradiation is depicted in Figure 6. It is observed that a 750 W/m^2 of energy is emitted initially and at 0.1 s ; due to intermittent nature, the solar energy rises and reaches a value of 1000 W/m^2 and continues to maintain stable.

The voltage generated using solar panel is depicted in Figure 7. Utilizing the solar energy, the solar panel absorbs the energy and generates a voltage of 115 V at the initial stage. After 0.1 s , owing to observation of more energy in the panel, a voltage of 120 V is obtained, which is further maintained constant.

Similar to voltage generated by PV panel, the waveform depicted in Figure 8 demonstrates the output current obtained using Solar Panel. It is noticed that a minimum current of 12.5 A is maintained at initial and later at 0.1 s , the current gets increased by 13 A and continues to maintained stable further.

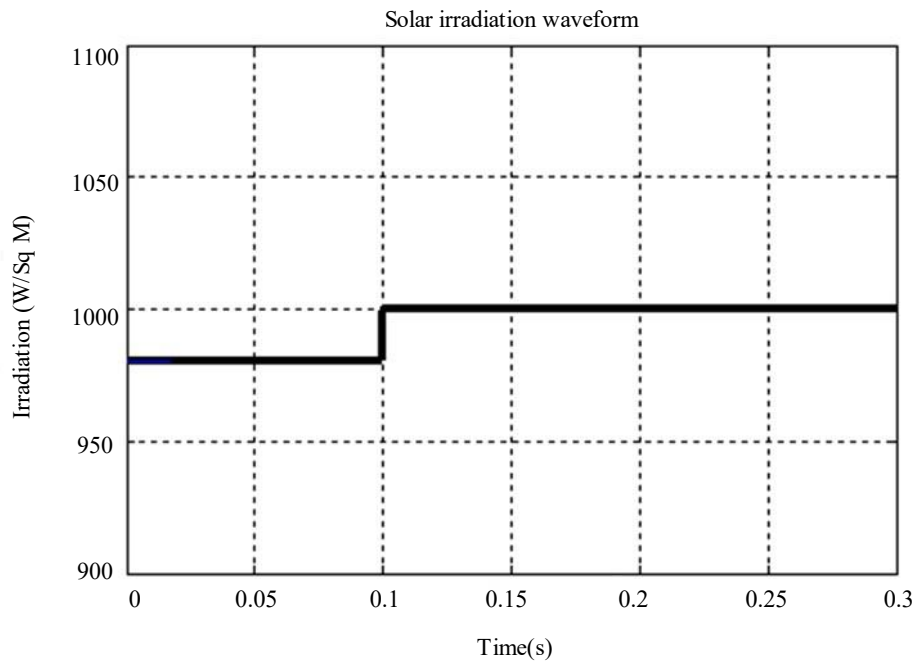


Figure 6. Irradiation waveform.

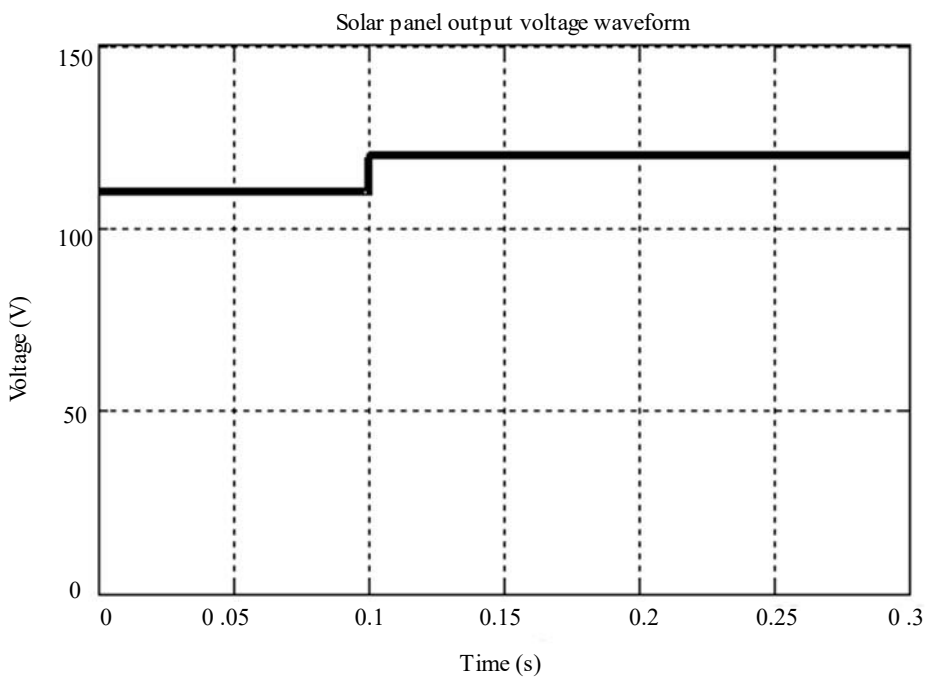


Figure 7. PV output voltage waveform.

The power obtained using Solar PV panel is represented as waveform in Figure 9. Initially, 1360 W power is maintained till 0.1 s, after that the power gets enhanced and tends to continue at 1500 W.

Efficient controller along with controller approaches result in enhanced converter output. Figure 10 demonstrates the output voltage waveform obtained by Boost converter with the assistance of PI controller [24]. It is observed from the waveform that voltage fluctuates at initial stage and reaches a peak value of 330 V and decrease gradually and starts fluctuating again. Later at 0.28 s, the voltage gets stabilized and a constant of 260 V is maintained.

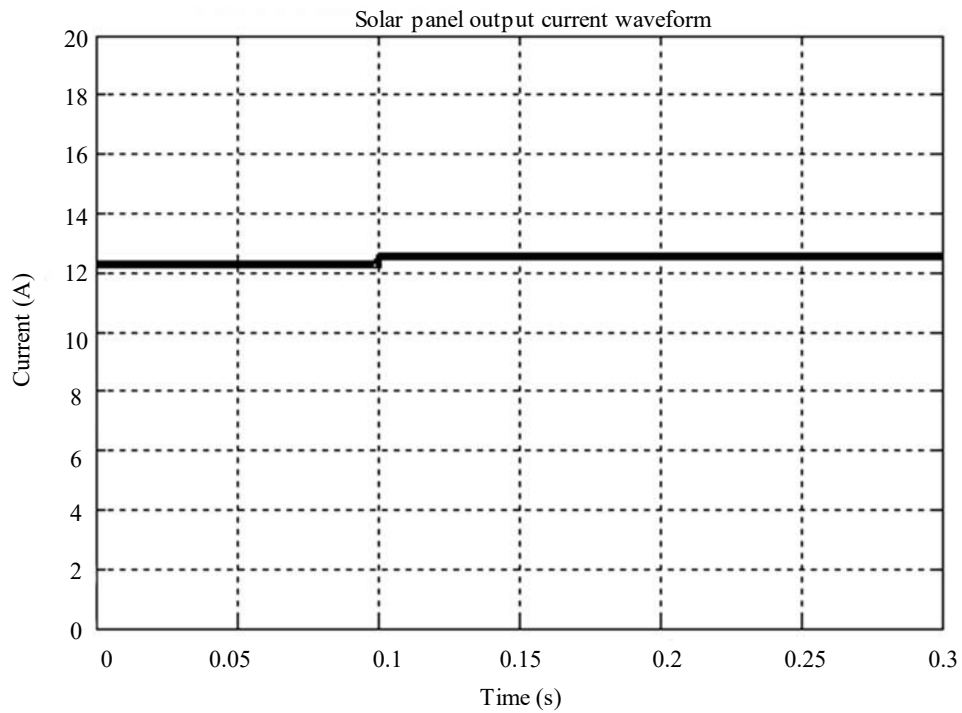


Figure 8. PV current waveform.

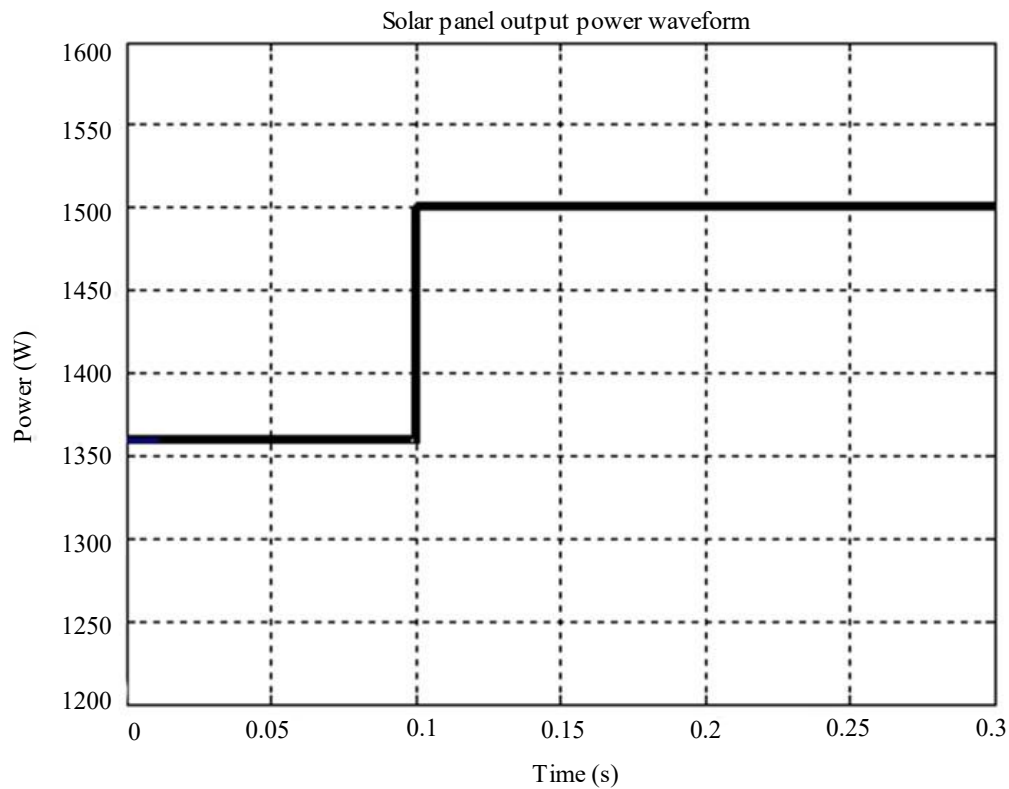


Figure 9. PV power waveform.

As like PI controller, to enhance the output voltage the Boost converter is controller utilizing GWO algorithm. The voltage reaches a maximum of 300 V at 0.05 s and maintained with slight fluctuations [25]. At 0.22 s the voltage gets stable and tends to continue as shown in Figure 11.

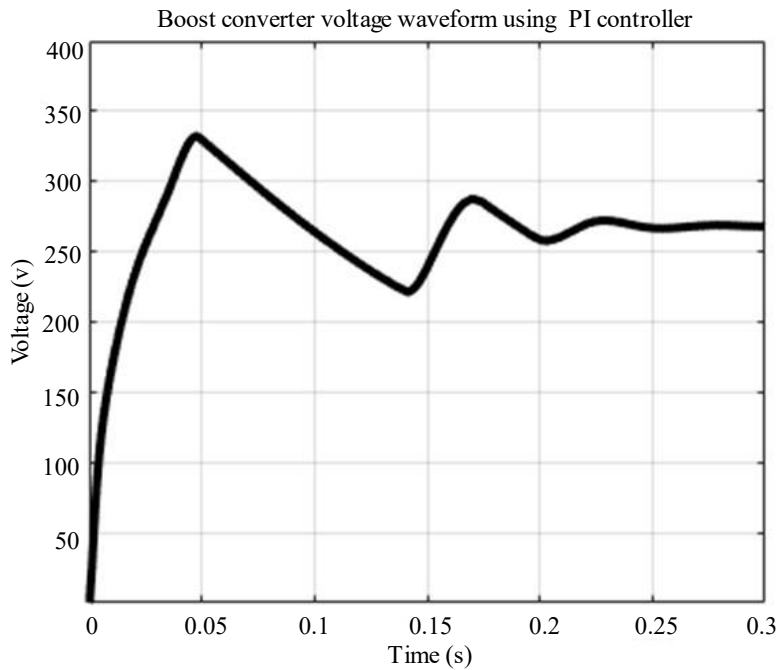


Figure 10. Boost converter tuned using PI controller.

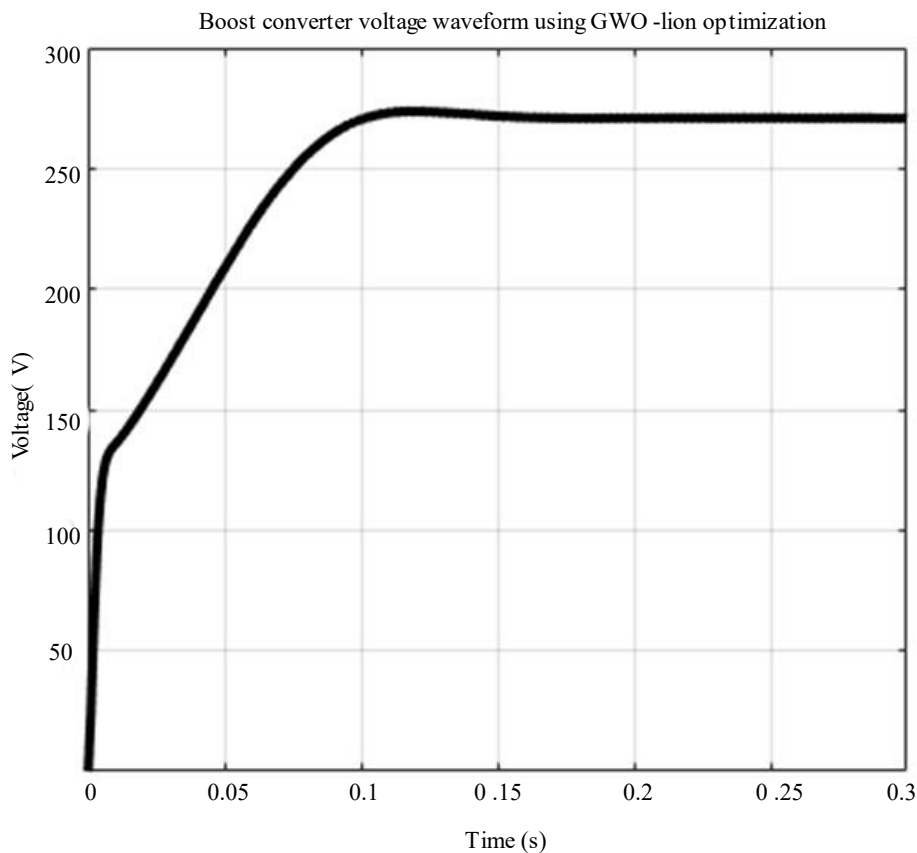


Figure 11. Boost converter tuned using GWO.

The proposed boost converter is utilized with hybrid optimization approach to attain better output voltage as illustrated in Figure 12. Initially with gradual rise in voltage with slight distortion a 260 V stable voltage is obtained after 0.20 s and tends to continue further.

A waveform representing single phase grid voltage is depicted in Figure 13. It is observed that a constant of 230 V is maintained stable during positive and negative half cycle.

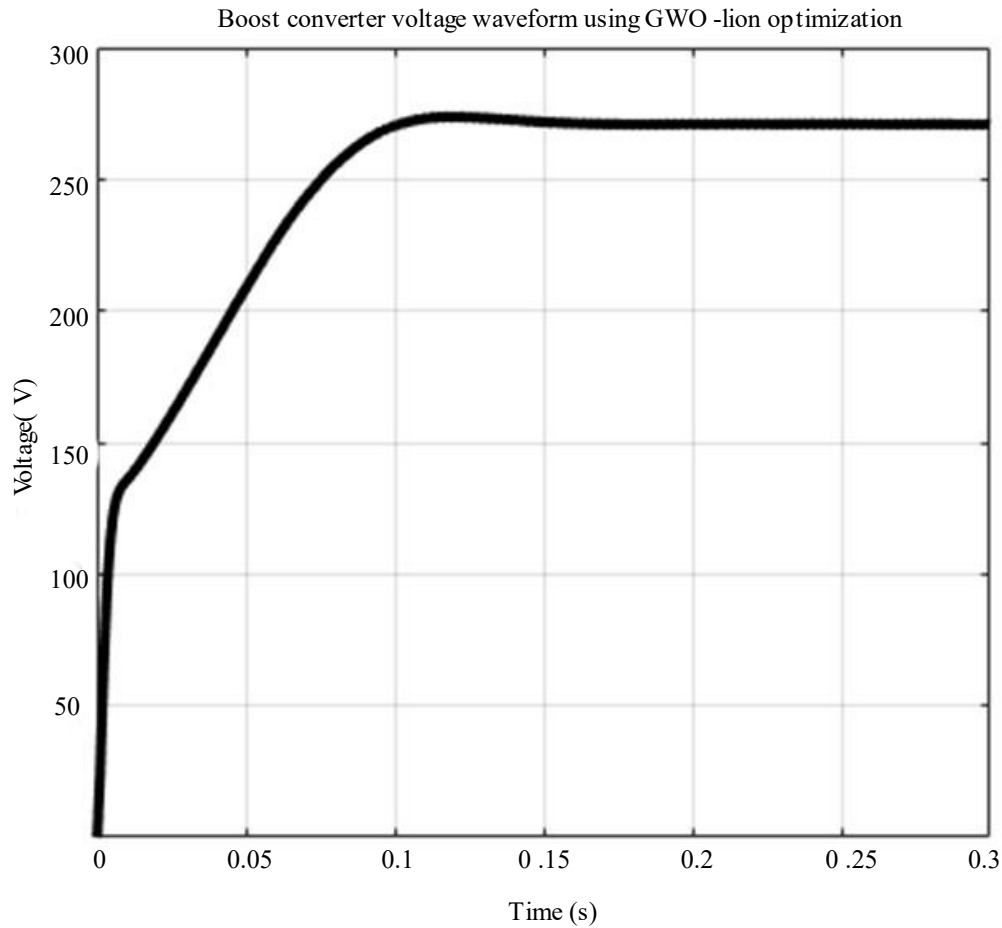


Figure 12. Boost converter tuned using GWO-LION optimization.

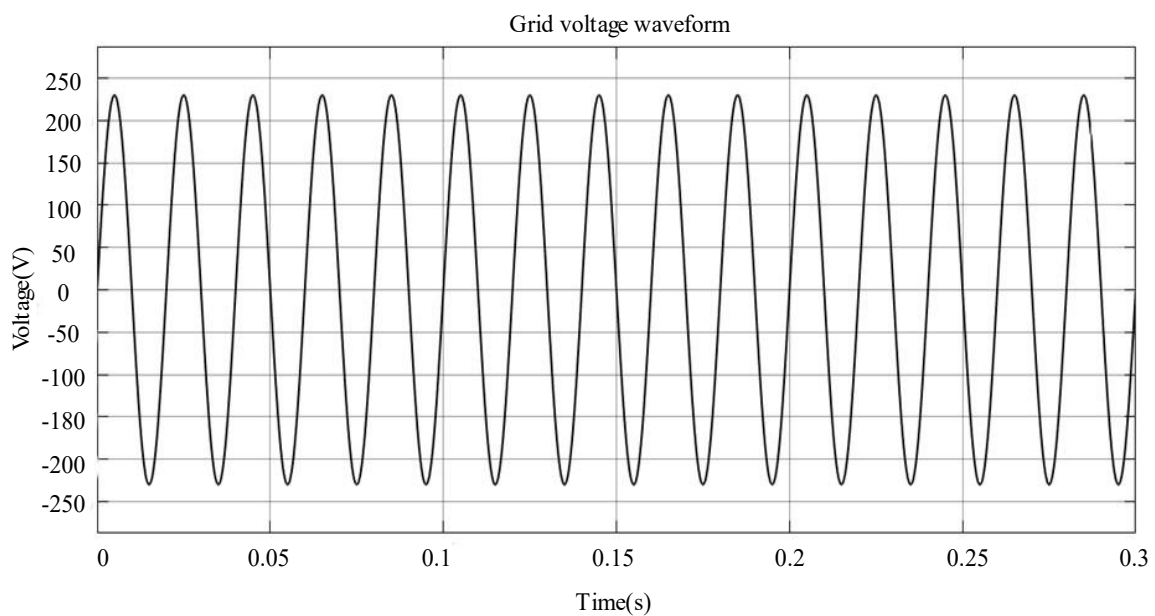


Figure 13. Grid voltage waveform.

Waveform demonstrating grid current is illustrated in Figure 14. It is observed that with rise in current from negative half cycle a constant of 5 A is maintained after 0.03 s and tends to maintain constant.

The obtained waveform illustrating real power is shown in Figure 15. It is observed that the real power tends to increase from negative and reaches a maximum of 600 W and decreases gradually. After 0.1 s, a constant of 500 W, real power is maintained stable and tends to continue.

The demonstration of reactive power obtained from the proposed work is depicted in Figure 16. With the rise in peak power of 1350 W, the power gradually decrease and maintained at minimum level after 0.1 s without any distortions.

The waveform illustrating the current produced by BLDC motor is depicted in Figure 17. Initially, the current fluctuates higher and maintained at a minimum level with minor distortion. After 0.25 s, a constant current of 5 A is maintained constant and tends to continue.

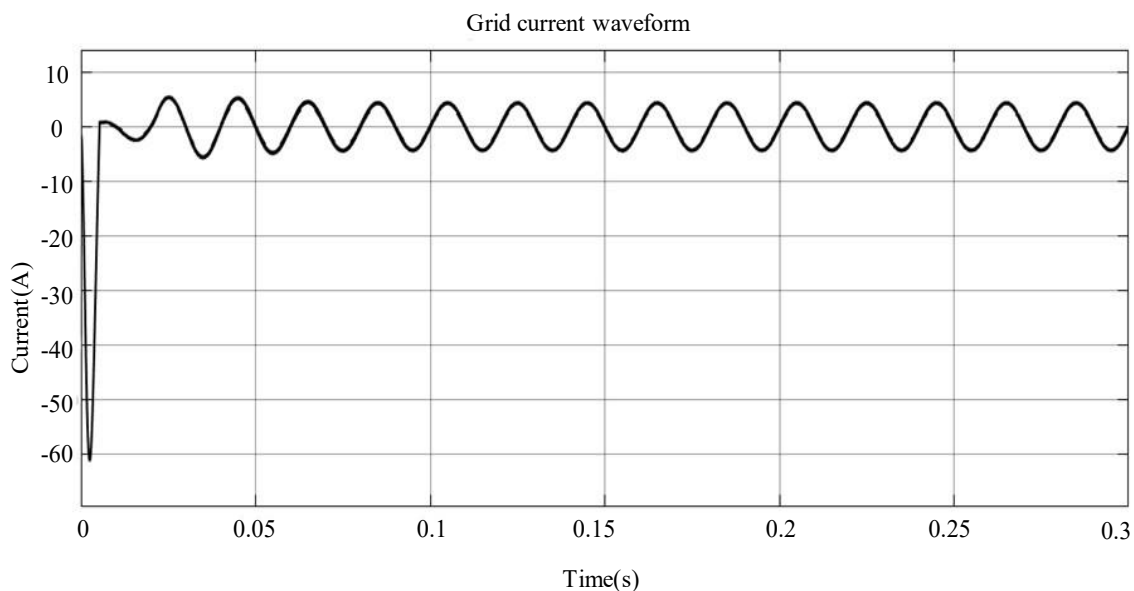


Figure 14. Grid current waveform.

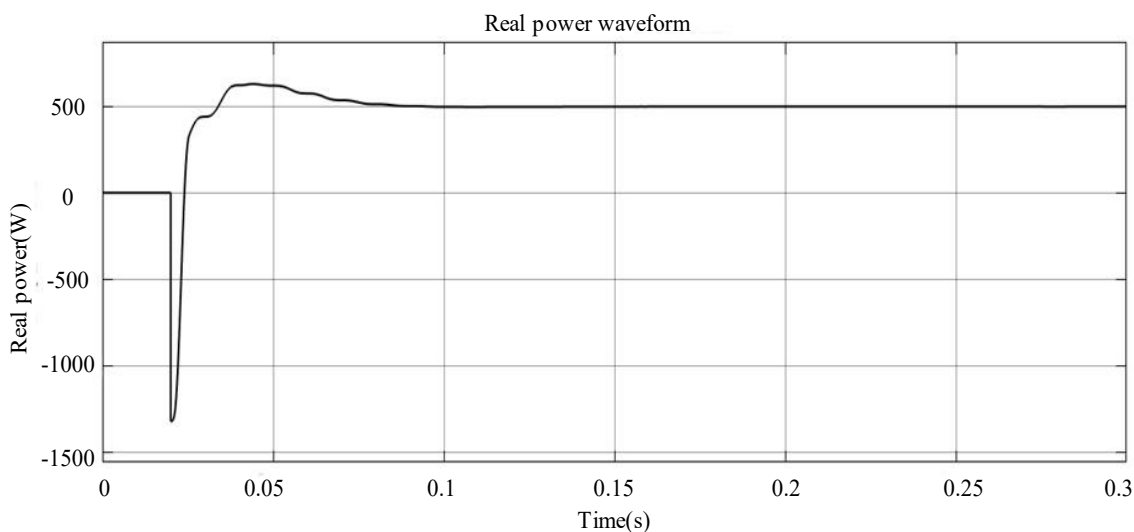


Figure 15. Waveform representing real power.

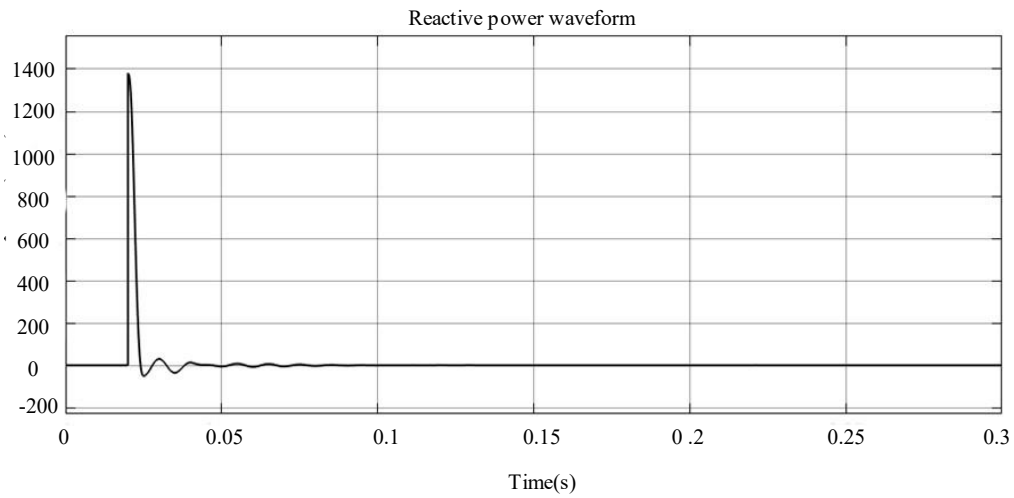


Figure 16. Waveform representing reactive power.

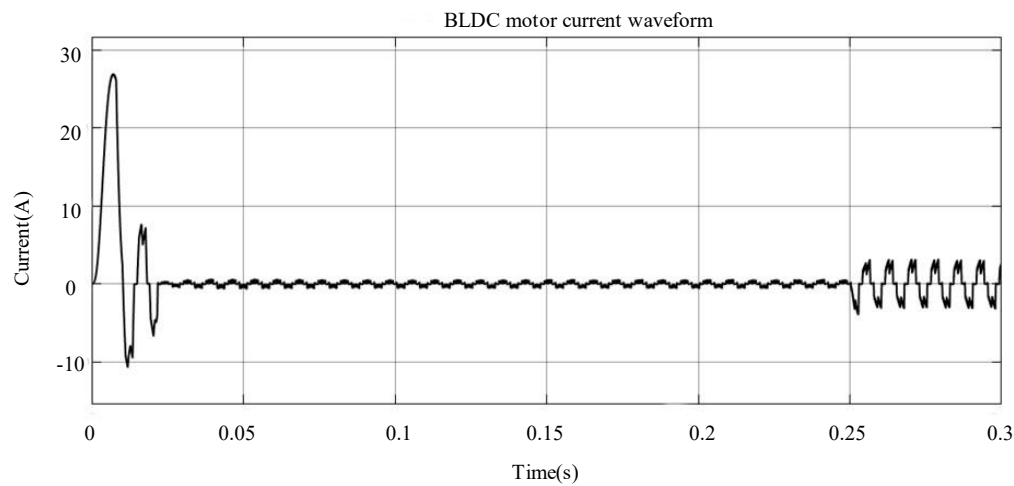


Figure 17. Current waveform of BLDC motor.

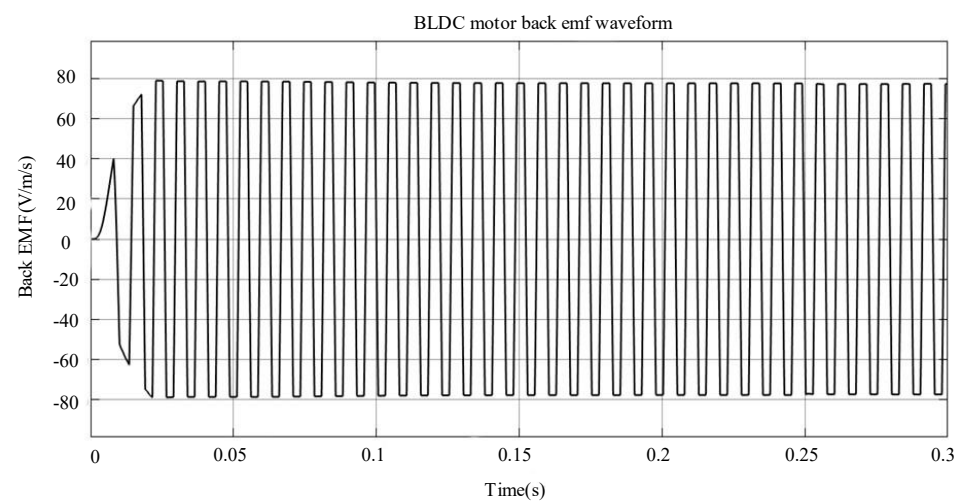


Figure 18. Back EMF waveform.

The waveform demonstrating back EMF is illustrated in Figure 18. usually, back emf is a measure of voltage generated using rotor of BLDC motor, which neglects the applied voltage and generates

sinusoidal AC voltage which is maintained at a constant of 80 V after 0.03 s. The waveform representing rotational velocity is illustrated in Figure 19. It is observed that the speed increases gradually and maintains at 2000 rpm after 0.05 s, resulting in speed of axis rotation for number of complete rotations.

The waveform describing torque of BLDC motor is illustrated in Figure 20. It is noticed that the torque rises initially and reaches a peak value of 20 Nm at 0.02 s and later decreases. At 0.05 s, a minimum torque is maintained with minor distortion and tends to increase at 3 Nm after 0.24 s. The harmonics obtained in the proposed work is illustrated in Figure 21. It is observed that utilizing Boost converter, THD value of 4.43% is obtained which is lower and meets the IEEE standard requirement.

Hardware Analysis

The hardware prototype is developed for the proposed boost converter with grid tied solar EV charging system and the control part is implemented in real time with the help of Spartan 6E controller and obtained the results which are analysed and compared subsequently. The hardware prototype is designed, which is portrayed in Figure 22 in an optimal manner [26, 27].

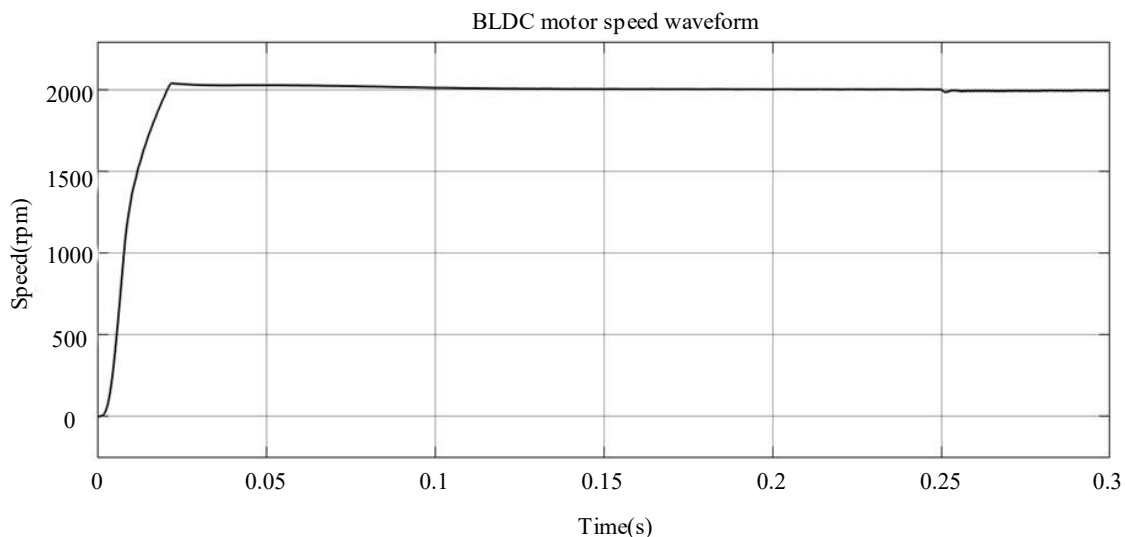


Figure 19. Speed of BLDC motor.

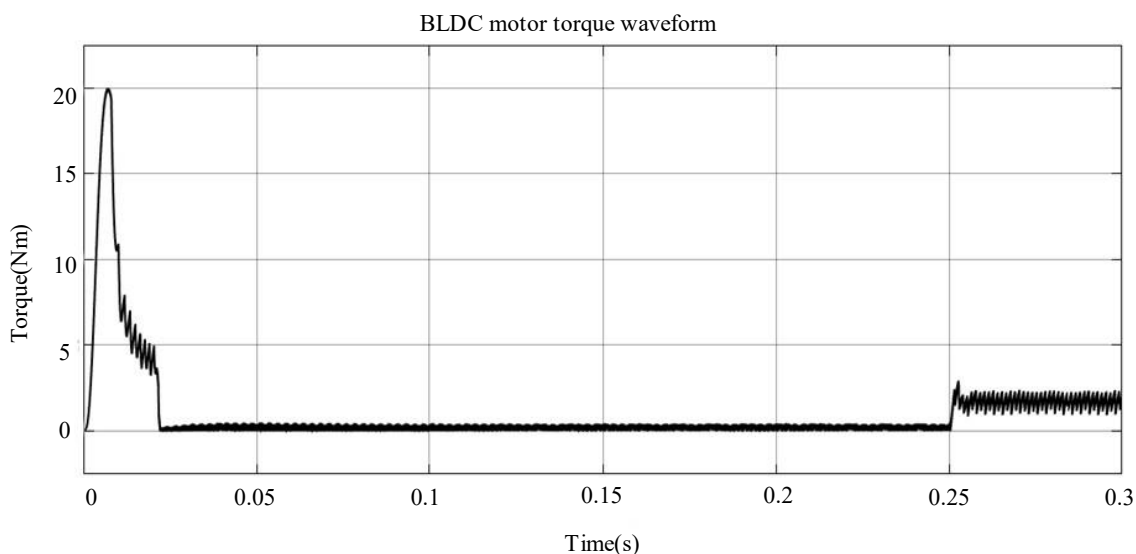


Figure 20. BLDC motor torque waveform.

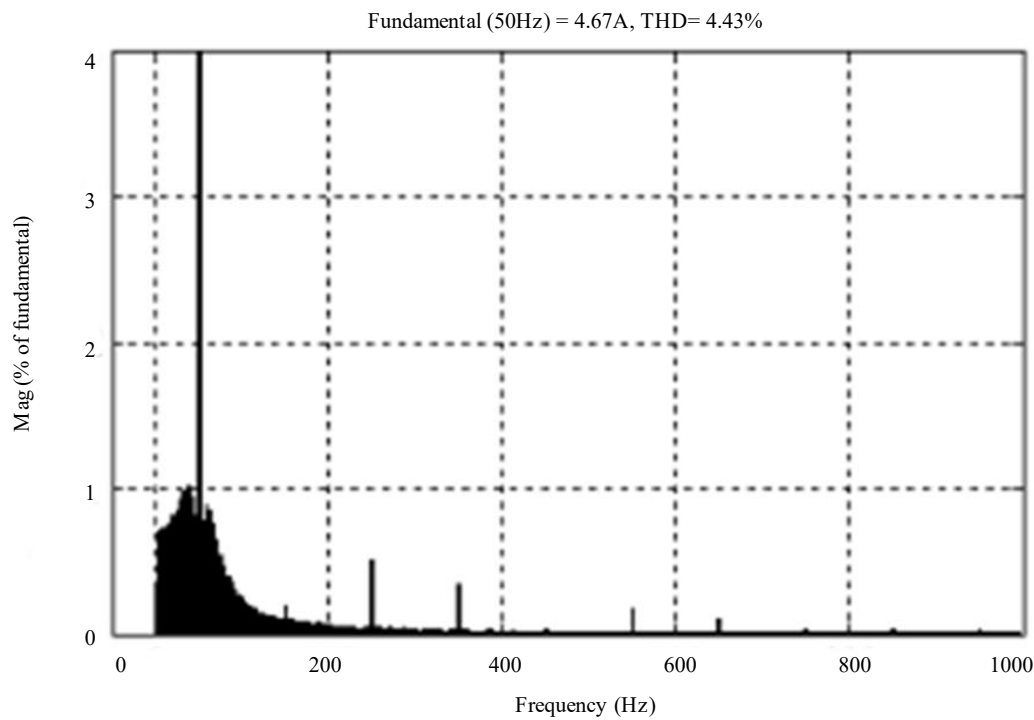


Figure 21. THD waveform.

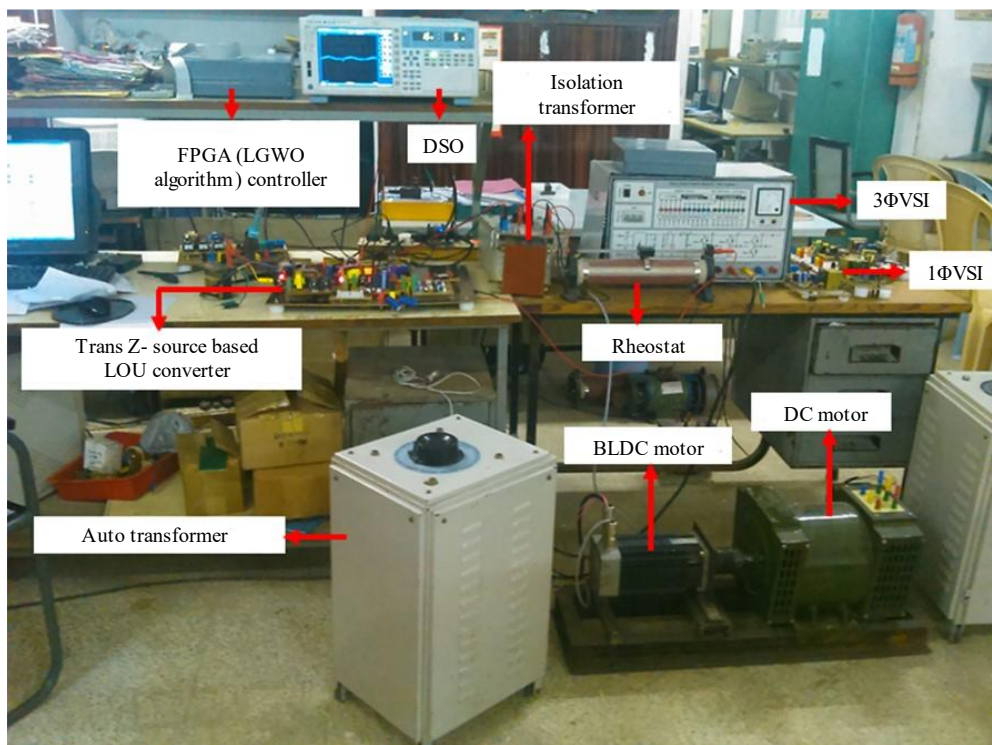


Figure 22. Hardware prototype implementation design.

CONCLUSION

Boost converter with appropriate control approaches is adopted for the efficient charging of BLDC motor for EVs. A detailed analysis of Boost converter is presented in this work with its modelling. The results for the proposed system are provided with detailed analysis. However, the Boost converter can enhance the voltage obtained from the PV system to a limited extent. The need for zero-emission

mobility is satisfied by advent of EVs, while the growth of solar-powered PV systems meets the requirement for decarbonized power generation. Therefore, an efficient PV-based EV charging system is established that helps us move closer to a pollution-free future. To overcome the inherent nature associated with PV, Trans Z Source based Luo converter is engaged which provides significant performance in enhancing the voltage obtained from PV. In addition, a unique robust hybrid LGWO-PI controller is implemented to improve the effectiveness of voltage obtained from PV system, which is also a main source of power supply for charging station. The emergence of optimal control mechanism for grid-connected solar EV charging stations aims to increase the adoption of EVs while reducing over-dependence on grid. A high effective TZSBLC and hybrid LGWO-PI controller are included in control scheme for stabilising and enhancing the output from PV system. The BLDC motor drive that has been chosen for electric vehicles offers good speed regulation, great efficiency, and requires minimal maintenance. A PI controller is used to manage the BLDC's speed. When the PV-based power supply is unavailable, the BLDC motor receives its power from the grid. The installation of a grid ensures a constant supply of power, which increases the charging station's dependability. Using MATLAB simulation, the performance of the suggested PV-based BLDC motor using TZSBLC and LGWO-PI controller is evaluated, and the results are clearly analysed. A comparative analysis is performed in terms of voltage gain, efficiency, THD and settling time for converters along with control approaches. By utilizing TZSBLC the model achieves an efficiency of 97.6%, voltage gain value of 1:16 and THD of 2.1% resulting in reduced harmonics with high system performance. Similarly, with the utilization of TZSBLC along with LGWO-PI controller provides remarkable performance in stabilizing voltage at a minimized settling time of 0.15 s is achieved by which the voltage settles earlier in contrast to state of art method. The findings of this research conclude that the proposed system has advantages like enhanced system performance, improved stability, reduced harmonics and high converter efficiency.

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The authors received no specific funding for this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest to report regarding the present study.

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