Design of an Optimized FOPID Controller for Modern Power Converters of Brushless DC Motor Based Electric Vehicles

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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 adopting 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 main focus of this paper is to develop an effective charging system for EV which contributes a crucial role in achieving a pollution free future. An advanced Trans Z-source Luo converter technology is employed enhance the PV output voltage thereby reducing the required numbers of PV panels. 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 streamlined Proportional Integral (LGWO-PI) controller which considerably strengthens the converter function in terms of settling time, total harmonic distortion (THD) and peak overshoot. The output from the converter powers the EC after being transformed into AC by a voltage source inverter (VSI). A PI controller is utilized for precise speed control of the BLDC motor. At times of power unavailability from PV systems, a VSI fed grid is used to energize the BLDC motor. On the whole, 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: EV charging, Boost converter, BLDC motor, LGWO-PI controller, PI controller.

1 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. Many people believe that the growing popularity of electric cars (EVs) represents a positive development that should be encouraged. Because of this Electrical Revolution, Internal Combustion Engines will be rendered obsolete within the next ten to fifteen years. We are moving in the direction of electric vehicles since they do not have recurring costs or costs associated with maintenance. 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 amount of pollutants produced. Also, everything that had to do with the cooling of the internal combustion engine, the exhaust system, and the radiators was converted into rechargeable batteries, and a single motor was installed in the rear wheels.

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. They have a drive train that is much easier to use, far less noisy, and require very little maintenance. In order 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 researches. This paper is to expand the electrical Charging Network to bring green transformation by creating smart and efficient solar based Grid tied EV Chargers.

2 Methods and Materials

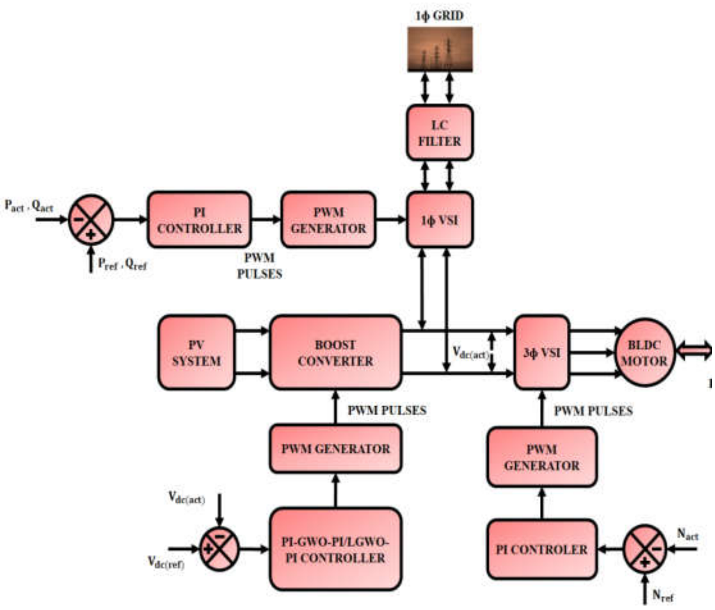


Figure 1: Proposed system

2. Modeling of the Proposed System

2.1 PV fed TZSBLC

The boost converter known for its minimalistic design, enables efficient current transmission. For the development of a constant voltage, this might utilize a variety of acceptable control strategies. Energy transfer in converters occurs via an energy storing phase followed by a discharging phase. When the switch is turned on, energy is stored in the indicator while the local is supplied by the output capacitor. When the button is open, the energy from the inductor is transferred to the capacitors, recharging it. Eventually, the Boost converter will have an equalize 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 an unexpected change in the demand for amplified energy output. Due to the Boost converter's plan, 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 phase. One benefit of the boost converter design is that a decreased input ripple can be achieved by enabling the inductance to drain current via the on and off cycles of process.

To raise 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.

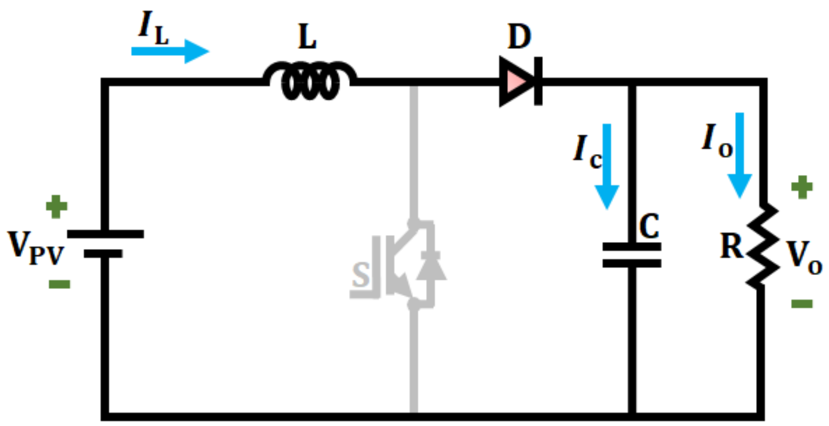


Figure 2: Boost converter

2.1.1 Mode 1

In mode 1, when the switch is in ON condition and the variables and represent the system parameters. 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. 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.

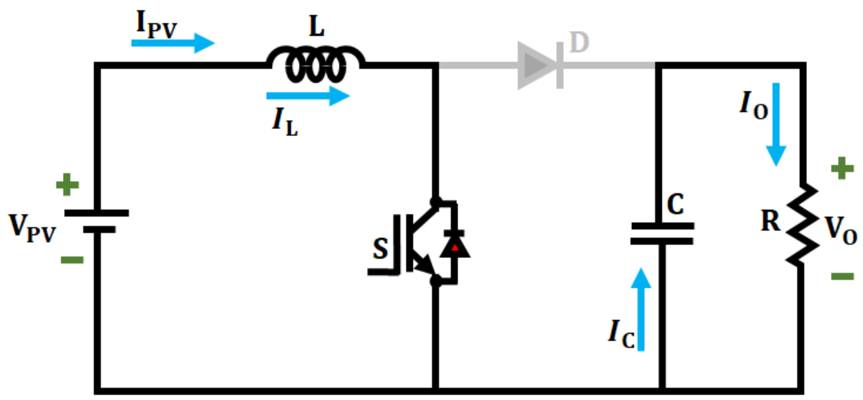


Figure 3: Mode 1

The corresponding equations are presented as

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

$$\frac{dV_0}{dt} = \frac{-V_0}{RC} \tag{2}$$

2.1.2 Mode 2

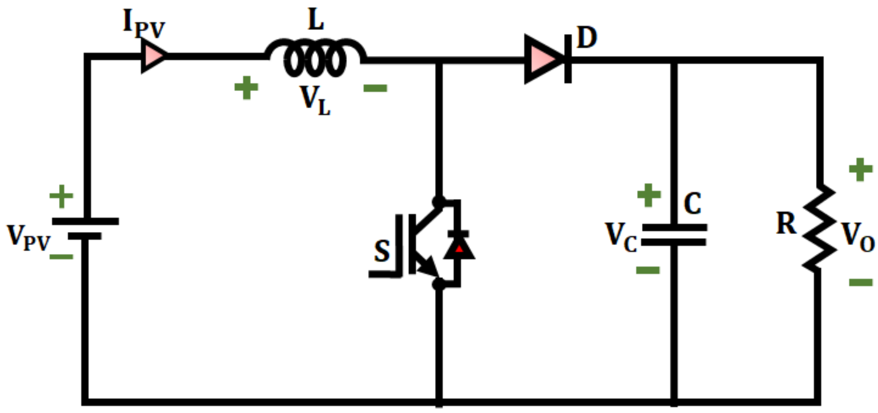


Figure 4: Mode 2

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

$$\frac{dI_L}{dt} = \frac{V_L}{L} - \frac{V_0}{L} \tag{3}$$

$$\frac{dV_0}{dt} = \frac{I_L}{C} - \frac{V_0}{RC} \tag{4}$$

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

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

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

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

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

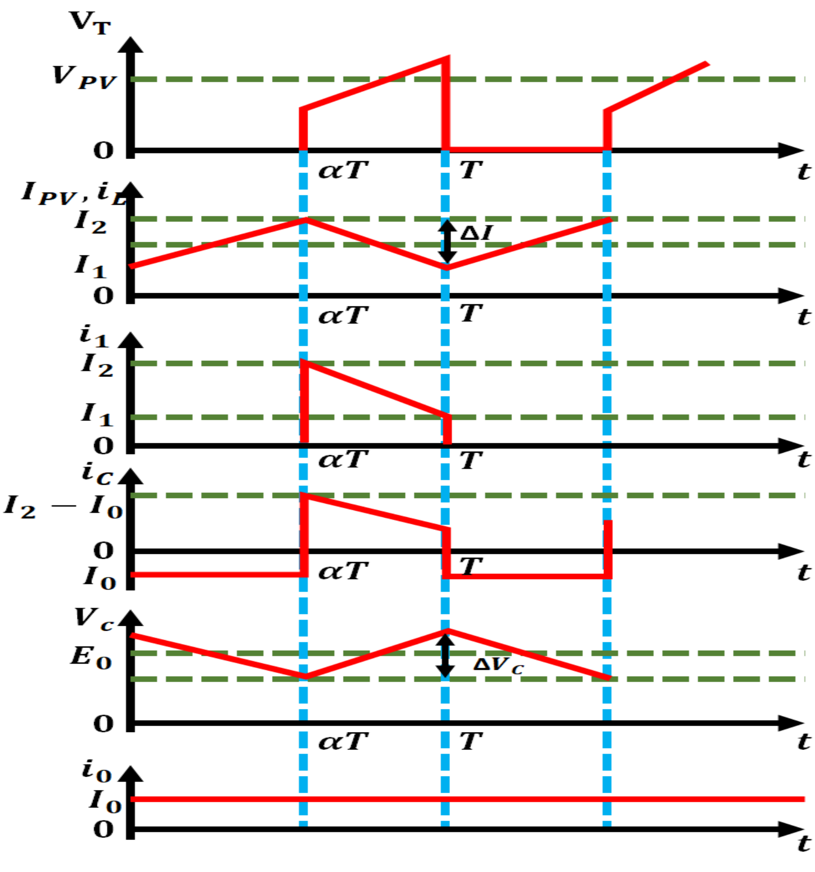


Figure 5: Waveforms for Boost converter

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. 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 inconsistent DC voltage generated by the converter is effectively optimized and made stable with the assistance of LGWO-PI controller.

3. Results and Discussions

Table 1:

Specifications of Boost Converter

Boost converter specifications	
Inductor	$1.5mH$
Capacitor	$2200\mu F$
Frequency	$10KHz$
Switch	$IGBT$

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

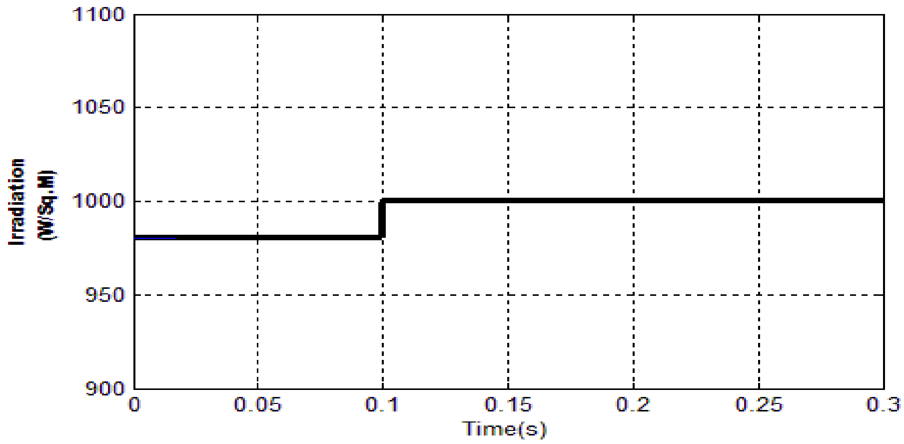


Figure 6: Irradiation Waveform

The waveform representing solar irradiation is depicted in Figure 6. It is observed that a of energy is emitted initially and at due to intermittent nature the solar energy gets rises and reaches a value of and continues to maintain stable.

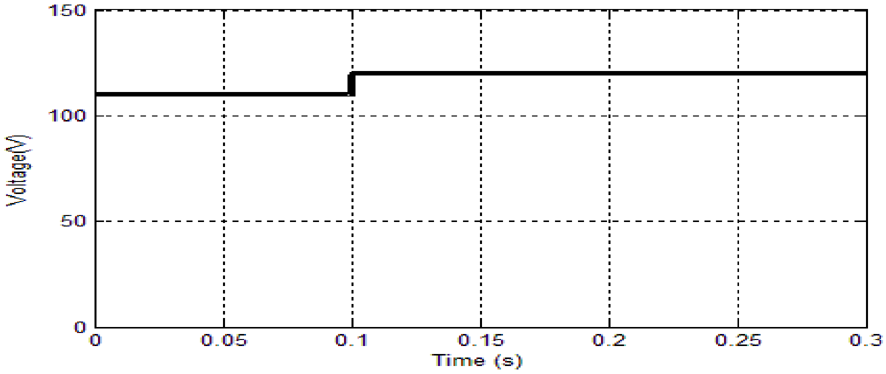


Figure 7: PV Output Voltage Waveform

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

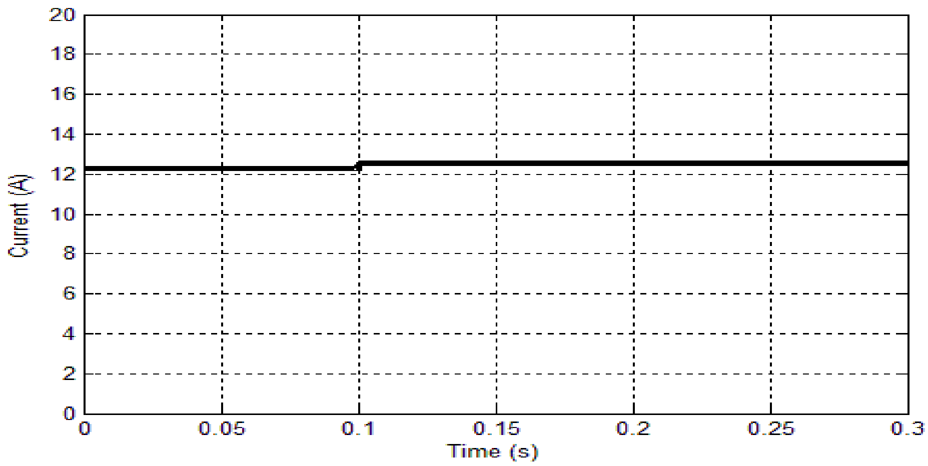


Figure 8: PV Current Waveform

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 12.5A is maintained at initial and later at0.1s, the current gets increased by 13A and continues to maintained stable further.

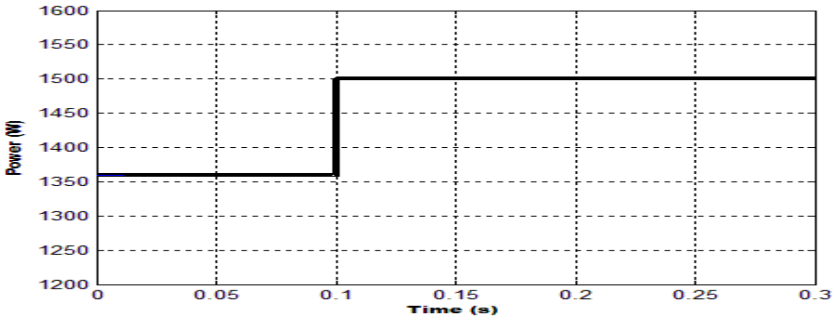


Figure 9: PV Power Waveform

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

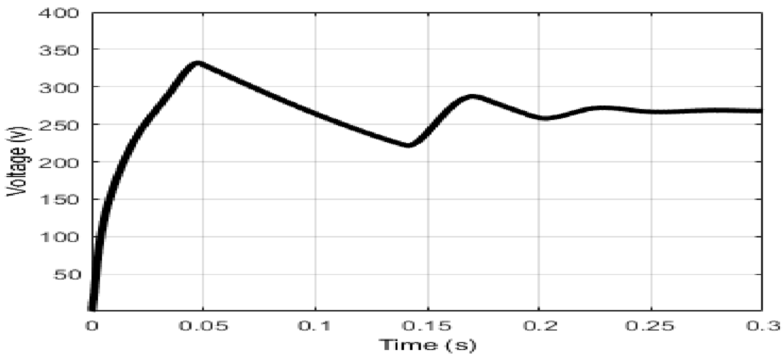


Figure 10: Boost Converter Tuned Using PI Controller

Efficient controller along with controller approaches result in enhanced converter output. Figure 10, the resulting voltage waveform from the boost converter under the regulation of a PI controller. It is observed from the waveform that, voltages fluctuates at initial stage and reaches a peak value of 330V and decrease gradually and starts fluctuating again. Later at 0.28s, the voltage gets stabilizes and a constant of 260V is maintained.

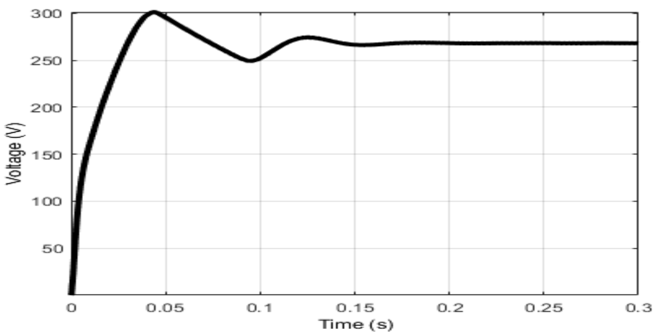


Figure 11: Boost Converter Tuned Using GWO

As like PI controller, the GWO algorithm is employed to control the boost converter for increasing the output voltage. The voltage reaches a maximum of 300V at 0.05s and maintained with slight fluctuations. At 0.22s the voltage gets stable and tends to continue as shown in Figure 11.

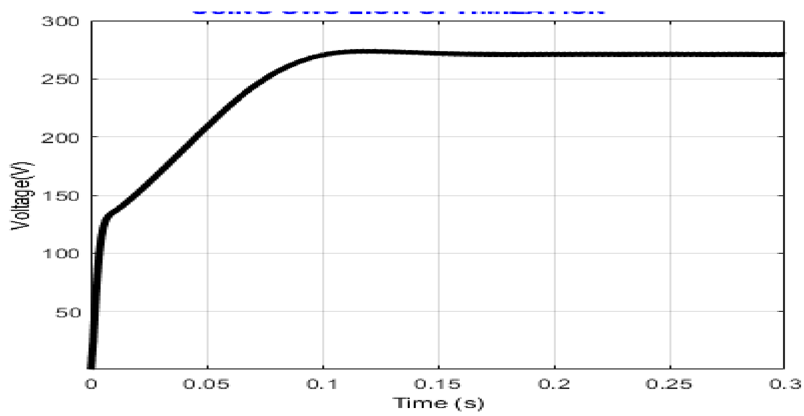


Figure 12: Boost Converter Tuned Using GWO-LION Optimization

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 260V stable voltage is obtained after 0.20s and tends to continue further.

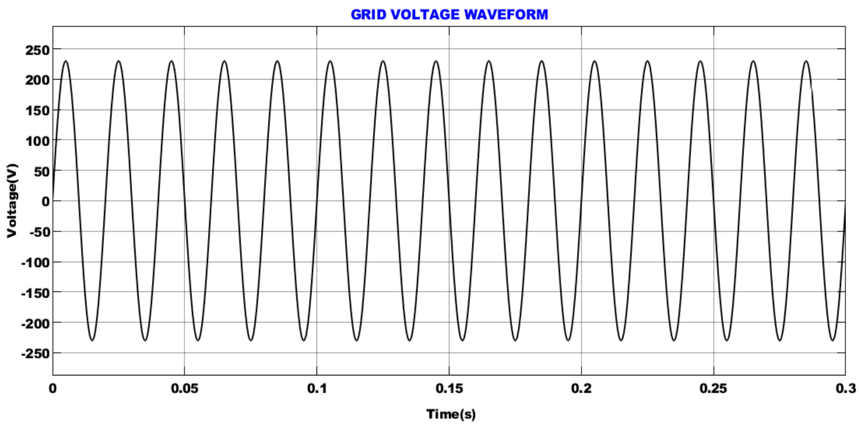


Figure 13: Grid Voltage Waveform

Figure 13, illustrates the waveform of a single phase grid voltage. Where a study 230V is consistently maintained throughout both the positive and negative half cycle.

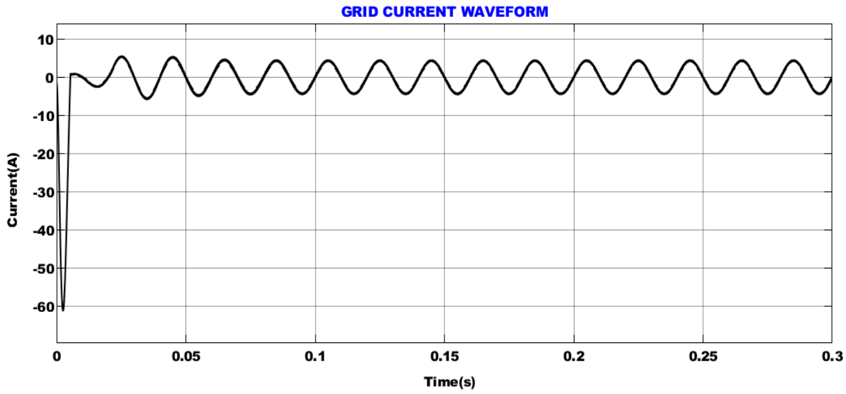


Figure 14: Grid Current Waveform

Waveform demonstrating grid current is displayed in Figure 14. It is observed that the current gradually improved during the negative half cycle, a constant of 5A is maintained after 0.03s and tends to maintain constant.

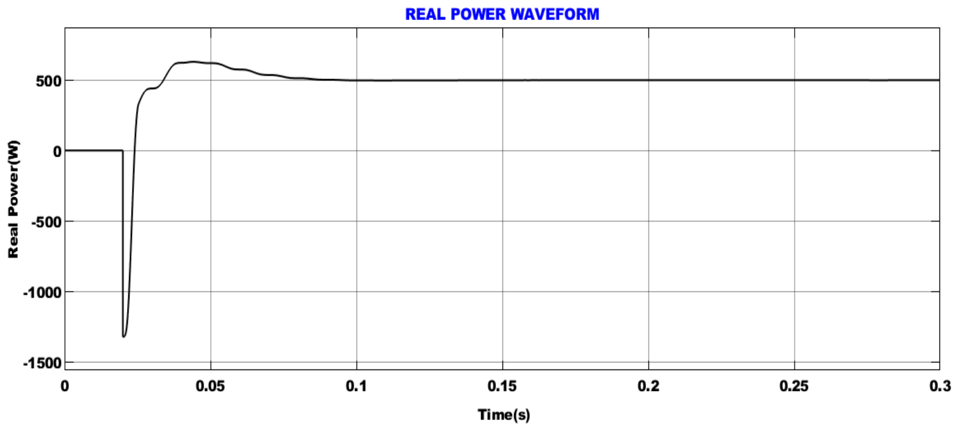


Figure 15: Waveform Representing Real Power

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 600W and decreases gradually. After 0.1sa constant of 500W real power is maintained stable and tends to continue.

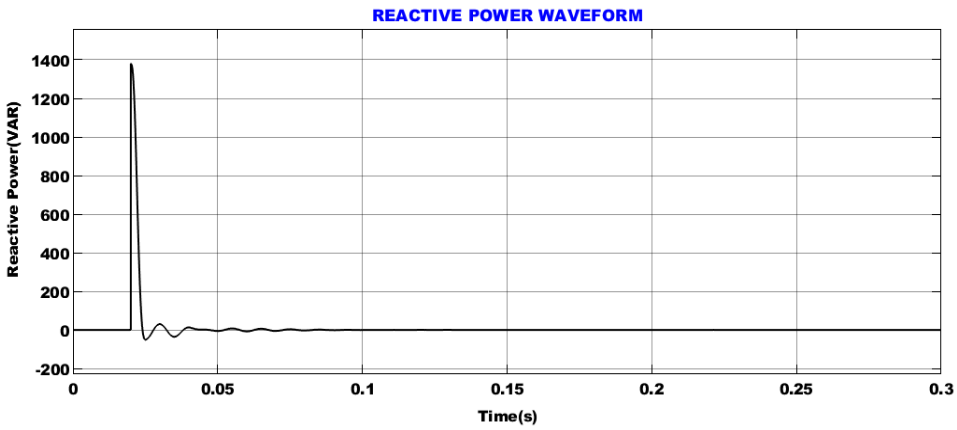


Figure 16: Waveform Representing Reactive Power

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

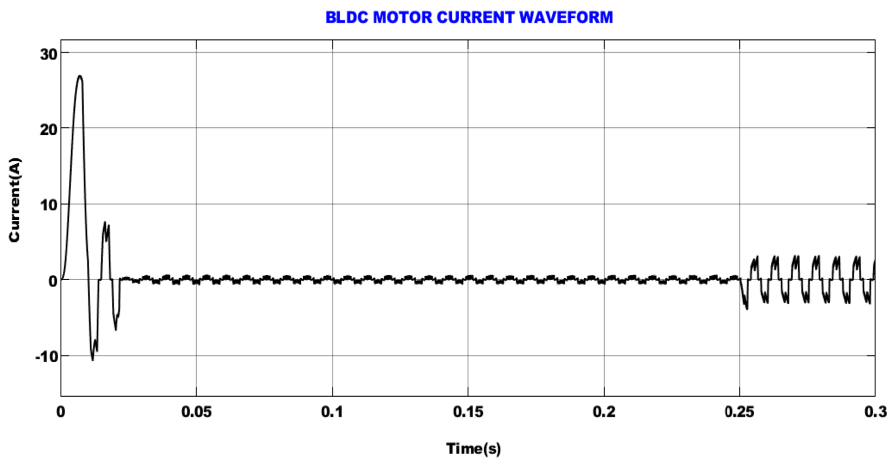


Figure 17: Current Waveform of BLDC Motor

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 0.25sa constant current of 5A is maintained constant and tends to continue.

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 80V after 0.03s.

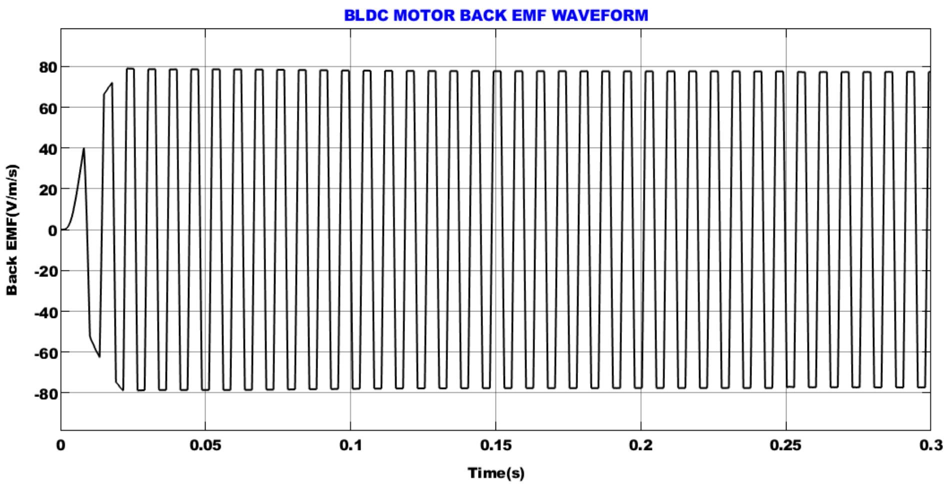


Figure 18: Back EMF Waveform

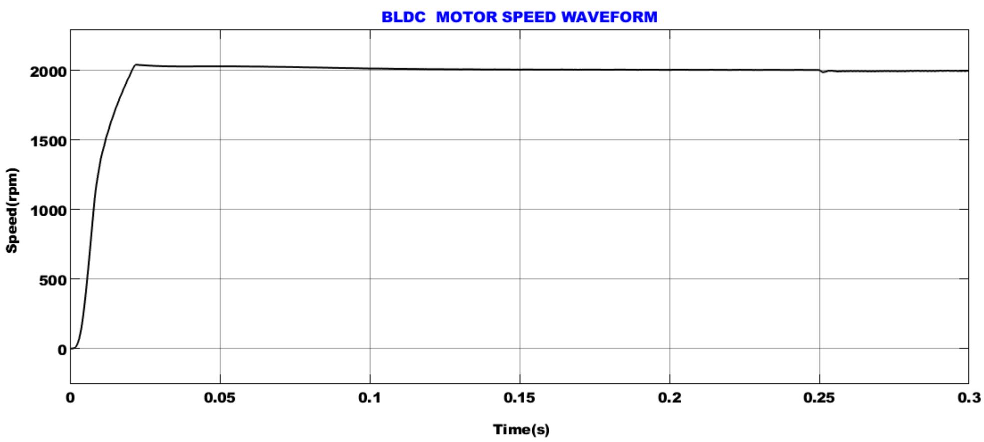


Figure 19: Speed of BLDC Motor

The waveform representing rotational velocity is portrayed in Figure 19. It is observed that the speed increases gradually and maintains at 2000rpmafter0.05s, resulting in speed of axis rotation for number of complete rotation.

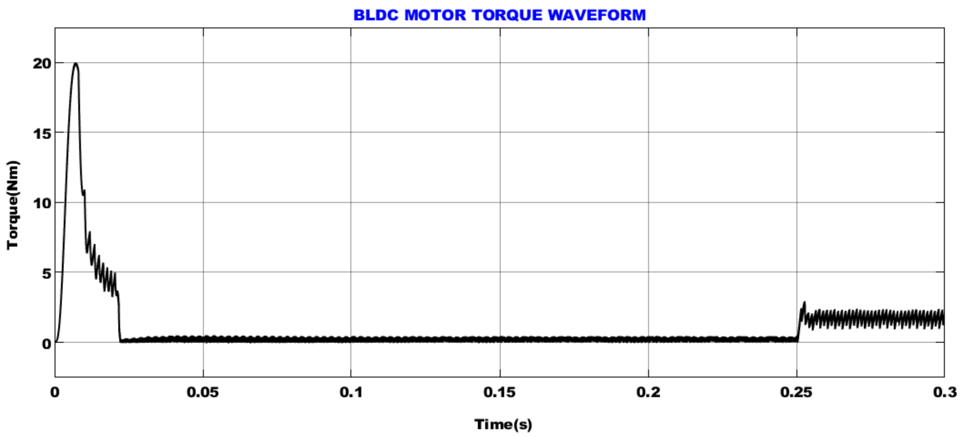


Figure 20: BLDC Motor Torque Waveform

The waveform describing torque of BLDC motor is illustrated in Figure 20. It is noticed that. At the start, the torque rises and attains a peak of 20N mat at 0.02 seconds before decreasing thereafter. At 0.05s a minimum torque is maintained with minor distortion and tends to increase at 3Nm after0.24s.

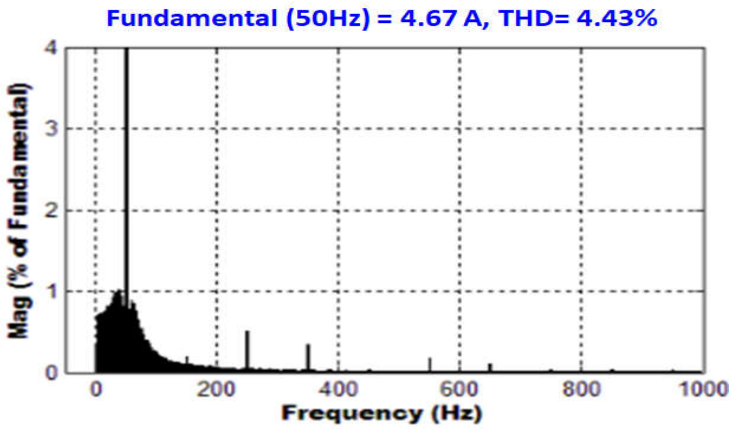


Figure 21: THD Waveform

The harmonics obtained in the proposed work is portrayed in Figure 21. It is observed that utilizing Boost converter, THD value of 4.43% is obtained with is lower and meets the IEEE standard requirement.

4.1 Hardware Analysis

A hardware boost converter has been constructed for the proposed boost converter integrated with grid connected solar EV charging system. The control mechanism is executed in real time using Spartan 6E controller, and the resulting data is analyzed and compare accordingly. An effectively designed hardware prototype is shown in Figure 22.

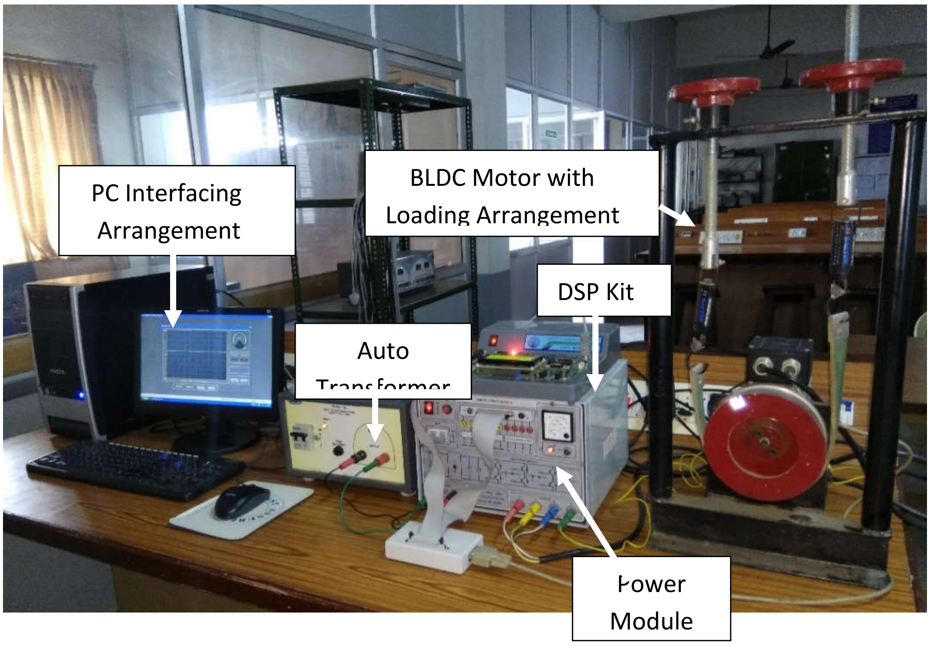
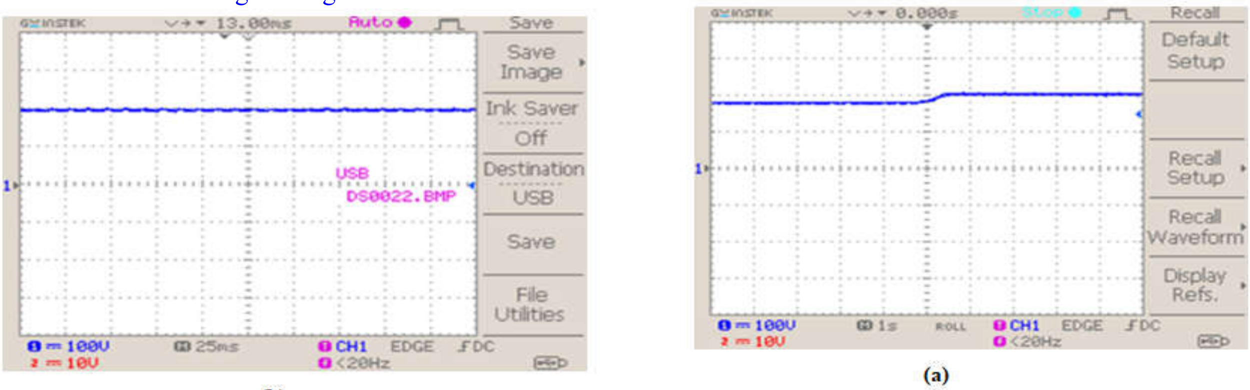


Figure 22 (a) Hardware Prototype setup

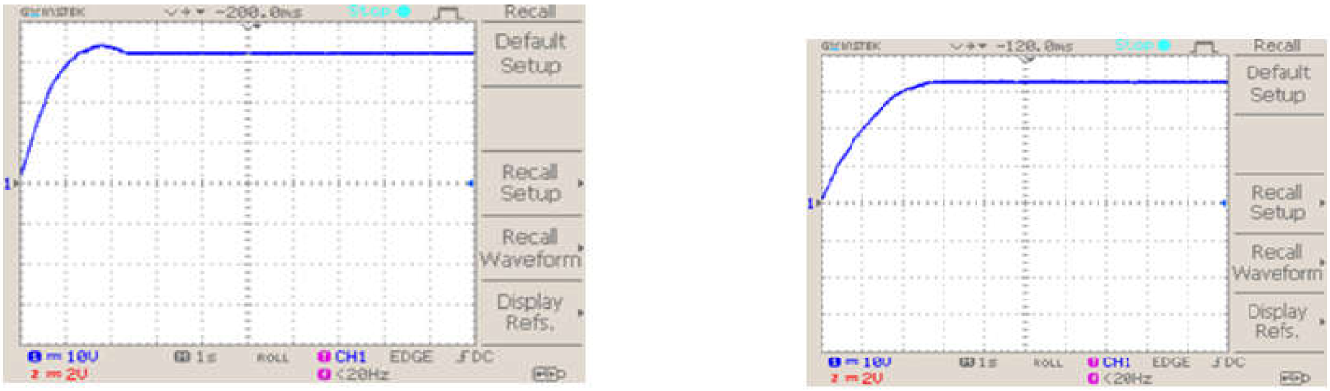
The FPGA Spartan 6E controller is employed to perform the hardware evaluation of the proposed grid connected solar EV charging system based on the TZSBLC, and the results are then thoroughly examined. Figure 22 presents the hardware prototype in a clear and effective way.

Figure 23 Hardware Prototype setup



(b) (a)

Figure 24: Photovoltaic System (a) Voltage and (b) Current Waveform

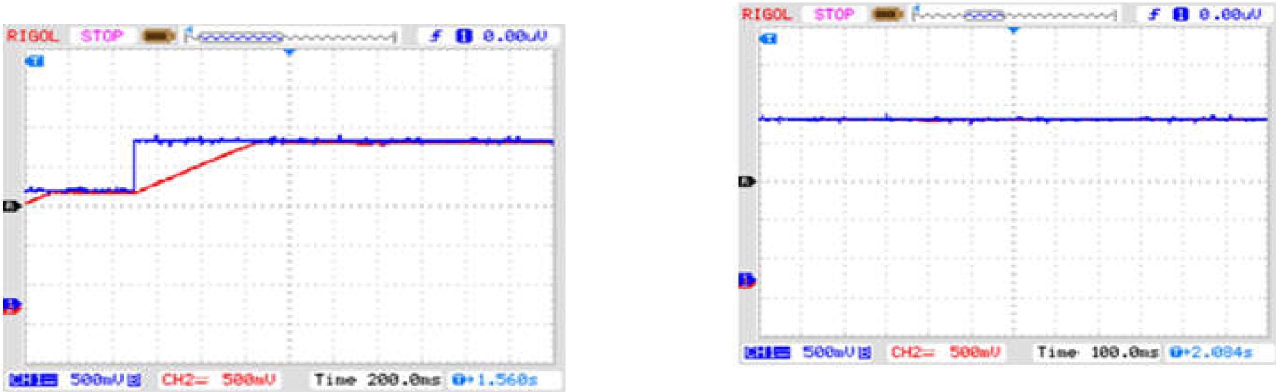


(a) (b)

Figure 25: Converter Output (a) Without Optimization (b) With Optimization

In Figure 24, the hardware findings for the PV's voltage and current output are shown. The output of the PV system increases as the temperature rises. Even with small fluctuations, the PV's output current is stable.

In Figure 25, the waveforms for TZSBLC's output voltage with and without optimization are shown. Without optimization, peak overshoot circumstances have an impact on the converter output, as shown in the figure, but with the use of an appropriate optimization technique, the transient peat problem has been mitigated, and a consistent output voltage of 330V is achieved.



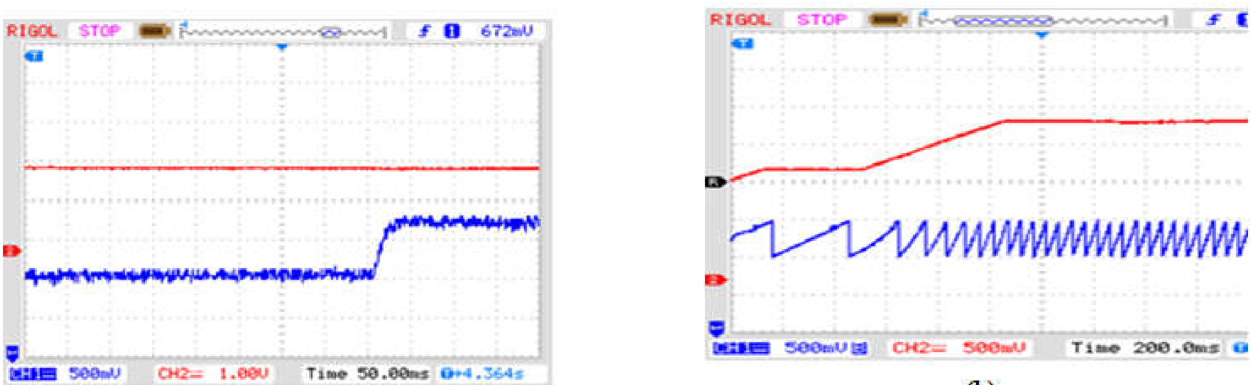
(a) (b)

Figure 26 : Speed Waveform at 1500rpm (a) without optimization controller (b) with optimization controller

The BLDC motor is reference speed is configured to 1500 rpm. After using suggested hybrid optimal controller, the speed is successfully controlled and remains stable, as shown in Figure 26. (b). The BLDC motor's is speed response is illustrated in Figure 26 (a) ,with the actual and reference speeds represented by blue and red lines, respectively, in the absence of an optimization controller.

As depicted in Figure 27 the advised closed-loop speed control technique successfully regulates and stabilizes the torque response and rational speed of the BLDC motor without experiencing peak overshoot problems.

In case D as shown in Figure 28, the BLDC motor's speed response highlights the effectiveness of the FOPID controller optimized using WOA, even under fluctuating load and reference speed conditions. From the experimental findings, it is evident that the proposed controller delivers outstanding tracking performance.



(a) (b)

Figure 27: BLDC Motor (a) Speed and (b) Torque Waveform

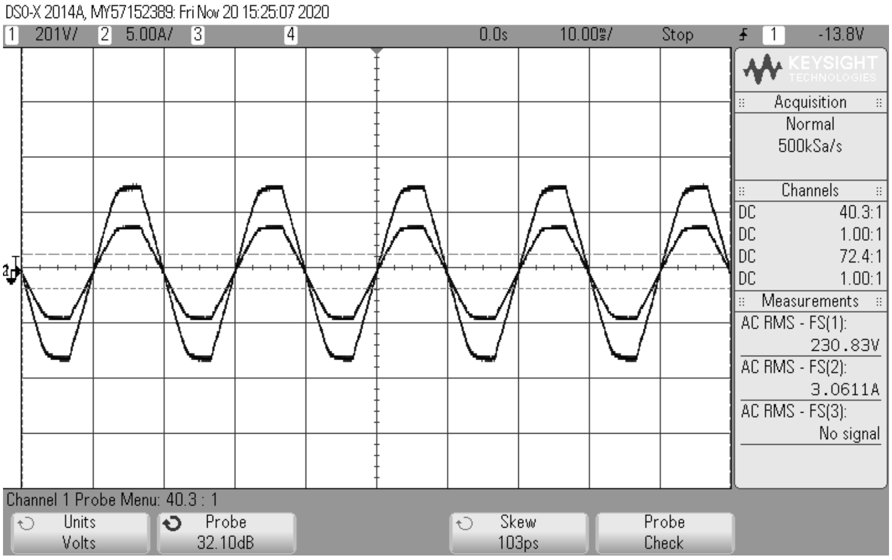


Figure 28: Grid Voltage and Current Waveform

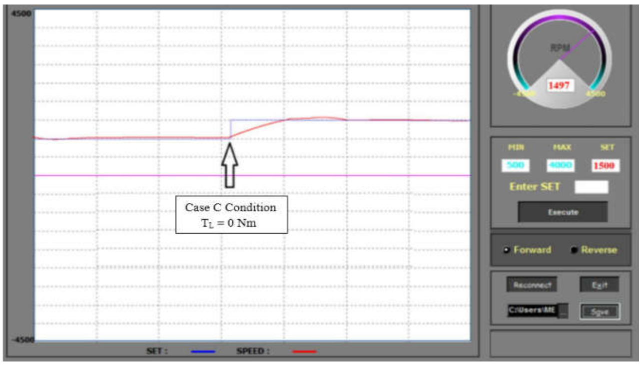


Figure 29 (a) Speed response under load condition

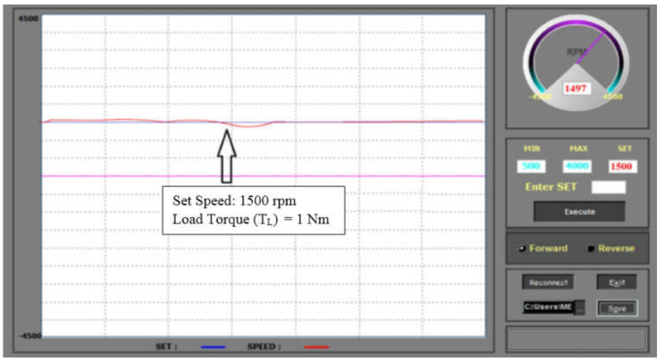


Figure 29 (b) Speed response for case C condition

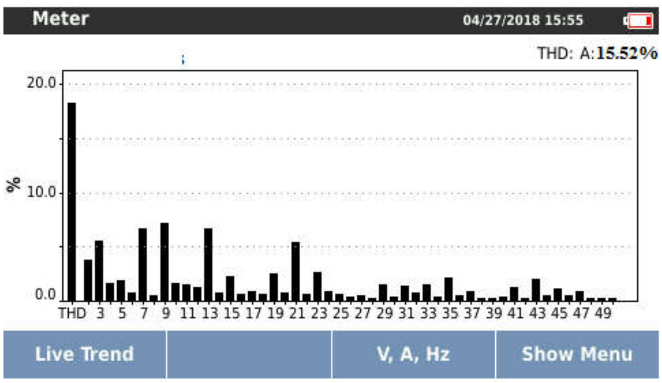
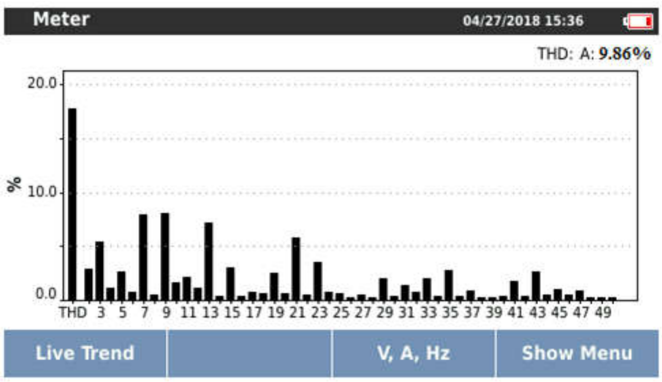


Figure 30 : (a) THD for GWO-FOPI controller



(b) THD for WOA-FOPI controller

Effective grid voltage synchronization is accomplished using PI controller, as illustrated in Figure 30, the inverter delivers a steady 230V AC supply to the grid.

5. 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 this modeling. The results for the proposed system are provided with detailed analysis. However, the boost converter is capable of increasing voltage is 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 advanced PV- driven system for EV system is established that help us move closer to a emission free future. To address the inherent limitations of PV systems, Trans Z-source based Luo converter is employed, offering notable improvement in boosting the voltage derived from the PV source. Furthermore, a robust hybrid LGWO-PI controller is integrated to enhance the voltage regulation performance of the PV system, which functions as the primary power source for the charging station. The implementation of optimal control mechanisms for grid connected solar EV charging stations aims to promote widespread adoption of EVs while simultaneously reducing excessive dependence on the conventional power grid. The control scheme incorporates an enhanced Trans Z-source based Luo converter (TZSBLC) along with a hybrid LGWO-PI controller to ensure improved stability and optimized performance of the PV system output. 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. In the absence of PV based power supply, the BLDC motor draws power directly from the utility grid. The commissioning of the grid, ensures a constant supply of power, which increases the charging station's dependability. The performance of the proposed PV-powered BLDC motor system, employing the TZABLC and by LWO-PI controller is evaluated through MATLAB simulations and the results are clearly analyzed. A comparative analysis is performed in terms of voltage gain, efficiency, THD and settling time for converters along with control approaches. By utilizing TZSBLC 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 0.15s 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 advantageous like enhanced system performance, improved stability, reduced harmonics and high converter efficiency.

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Author contributions Dr. Gunasekaran R (corresponding author): worked in conceptualization, methodology, and original draft preparation. Dr Saravanan C.: worked in supervision. Mr. Kavin R: worked in supervision. Dr. Vanchinathan K.: helped in methodology, and model draft preparation.

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Data availability: The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare no competing interests.

Ethical approval This article contains no research that any of the authors have done with human participants.

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