

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

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Abstract

There is a huge requirement for installing EV chargers all over the globe since the depletion of fossil fuels which are edging. There is a need to find alternative advanced converter to boost the output from PV. The solar energy is the recommended alternative energy to generate electrical energy without any pollution. Also, In the present scenario, we need to go for Scalable & Sustainable Electric Vehicle (EV) charging infrastructure for the fast adoption of Evs. EV charging can be a true zero-net emission solution only if it is powered by solar or other renewable sources of energy. In this paper the main focus is to develop a efficient EV charging system which can contribute for achieving a zero pollution in the environment. 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. A 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 Motor (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. 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 - PV system; Luo converter; LGWO-PI controller; BLDC motor; PI controller; single phase VSI; three phase VSI. EV charging

INTRODUCTION

As seen by the continuous need for petroleum, cars are now seen as essential components of daily life for both individual transportation and the transport of commodities. Such a demand, rising fuel prices, rising environmental analysis due to air pollution and climate change has raised concerns. As a result, many governments have challenged automakers to develop low-emission and ecofriendly transportation options. Electric vehicles (EVs) have been produced and used in this environment to reduce reliance on fossil fuels, which has reduced emissions of greenhouse gases and other pollutants [1-3]. Additionally, in order to prevent environmental harm from conventional automobiles, automotive emission standards have

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been implemented. Several nations have also adopted requirements for transportation networks to reduce vehicle emissions. In this situation, there has been a dramatic 99% reduction in the gross percentage of "atmospheric aerosol particles" generated by vehicle exhaust [4].

Due to this paradigm shift, internal combustion engine vehicles are losing ground to electric vehicles in terms of cost. Conscious of an effectiveness of EVs, many number of nations have developed a number of resolutions and provided significant funds to promote a widespread use of EVs. In reality, improvement of a battery technology and growth of battery charging points effort to meet energy needs are the factors that led to a rising popularity and use of EVs. In order to promote EVs, the basic structure of the charging system is crucial [5-8]. The biggest drawback of EV charging infrastructures is that they exclusively use grid as a power source, considering their use unfavorable to the environment. Since that EV charging can be managed and that renewable energy sources are distributable and time-limited, it follows both RES and EVs best work combined [9].

The main factors behind emergence of EVs as a possible mode of transportation is anticipated shortage of fossil fuels as well as increasing environmental issues. To gain over consumers, an EV industry must overcome some obstacles. The charging time of EVs is a major problem for potential buyers, as it was stated in [10]. Consequently, research interest in creating quick charging stations has increased. Due to its durability and ease of use in generating electricity, PV energy represents one of the most efficient alternative energy sources and is receiving a large amount of attention. Moreover, a PV power output suffers from intermittent nature which exist over a very short period of time in addition to inconsistency across a day of operations [11].

Due to increase need for clean energy and to go above restrictions of fossil fuels, EVs have attracted a lot of attention in several nations. Reducing air pollution, reducing reliance on fossil fuels, and enhancing energy safety are the main objectives of EVs. Only if EVs are linked with RESs the above requirements are satisfied. Solar PV-based EV charging systems are generally recognized among various RESs due to their unlimited availability in nature and lack of carbon emissions. Since PV's low voltage is inadequate to fulfil a demand, large efficiency dc-dc converters are recommended in order to maximize output voltage across a larger range [12-15].

The output voltage of a PV system changes over time depending on a climate, including temperature and solar insulation. As a result, a PV system's electricity production is not reliable, therefore a suitable control method must be developed in order to improve a converter's efficiency by reducing THD, achieving a power factor which is close to unity, reducing steady state error, and resolving peak overshoot problems [16]. For managing the operation of converters in PV grid-tied systems, a traditional PI controller has generally been the most basic and practical controller. When utilized within a designated range, this controller controls a DC link voltage more effectively and with a lesser THD. However, determining proper PI controller values is thought to be a challenging task [17].

In this study, a Luo Converter is created to improve PV's production of unregulated DC voltage. The optimized PI controller is used to improve the output of a converter. Single phase grid and 3-phase BLDC motor are the subsequent devices to receive a PV electricity which was produced. A PI controller is used to ensure control over a BLDC motor speed.

PROPOSED SYSTEM DESCRIPTION

Due to depletion of fossil fuels and required to reduce carbon emissions in order to slow an effects of global warming, an idea of PV-based EVs that support decarbonized energy generation and transportation is receiving a lot of attention nowadays [18]. Due to their beneficial qualities, such as their simple design, high efficiency, outstanding speed control capabilities, low losses, and minimal maintenance requirements, BLDC motors are the most widely used motor in EVs. In this study, a PV supplied BLDC motor drive for an EV is constructed with a PI/GWO-PI/LGWO-PI controller, as shown in Figure 1.

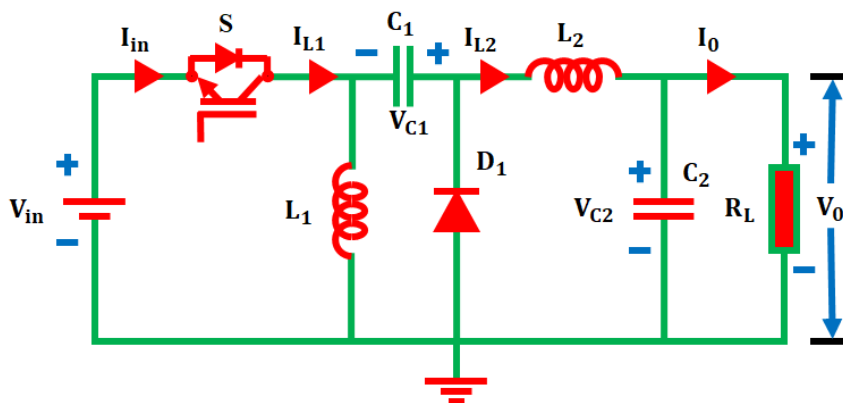


Figure 2. Luo converters circuit.

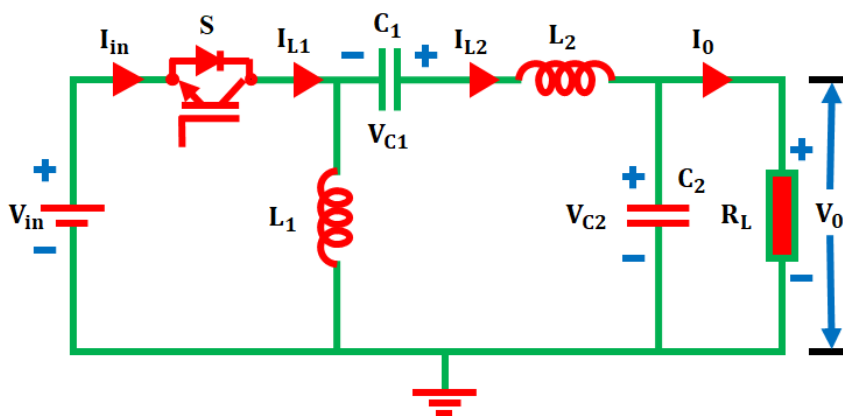


Figure 3. Operation at Mode 1.

Mode 2

The Luo converters circuit diagram of mode 2 is illustrated in Figure 4.

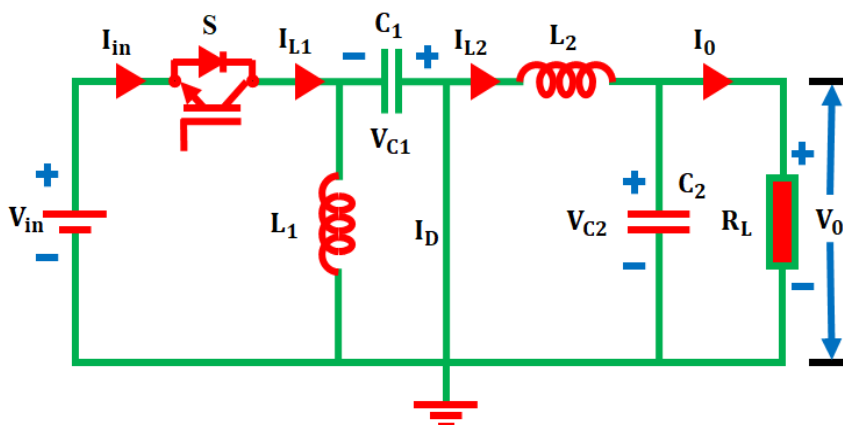


Figure 4. Operation at Mode 2.

In this situation, a switch (S) is opened, and the diode (D) is forward biased. In this mode, an input PV current is equal to 0 while the capacitance (C_1) is charged by an inductive current (I_{L1}), which flows through diode (D). An inductive currents (I_{L1}) and (I_{L2}) drop as a result of inductive current (I_{L2}) passing through a capacitance (C_2) and a resistive load (R_L) in an interval. As a result, both inductive currents (I_{L1}) and (i_{L2}) becomes $i_{L1} \approx I_{L1}$ and $i_{L2} \approx I_{L2}$, respectively. (I_{L1}) and (I_{L2}) are defined as average inductive currents which flow through L_1 and L_2 respectively.

At open condition, a charge on capacitance C_1 rises. It is expressed as,

$$Q_{+(1-D)I_{L1}} \quad (1)$$

At closed condition, a charge on capacitance C_1 reduces. It is expressed as,

$$Q_{-DI_{L2}} \quad (2)$$

Wherever the duty cycle of switch (S) is detailed as $D = \frac{T_{on}}{T}$,

In an whole cycle, Q_{+Q_-} , by using this relation, an inductive current I_{L2} is resulting. It is expressed as,

$$I_{L2} = \frac{1-D}{D} I_{L1} \quad (3)$$

Since the capacitance ($C|2$) acts as a LPF, a current output (I_0) is specified in Equation (4).

$$I_{L2} = I_0 \quad (4)$$

At closed condition, an input PV current is specified as $i_{PV} = I_{L1} + I_{L2}$, where during open condition $i_{PV} = 0$. As a result, an average input PV current I_{PV} is expressed as,

$$I_{PV} = D * i_{PV} = D(I_{L1} + I_{L2}) = D \left(1 + \frac{1-D}{D}\right) I_{L1} = I_{L1} \quad (5)$$

An output current (I_0) is expressed as,

$$I_0 = \frac{1-D}{D} I_{PV} \quad (6)$$

An output voltage V_0 is expressed as,

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

Where the output voltage is specified as V_0 , the output current is specified as I_0

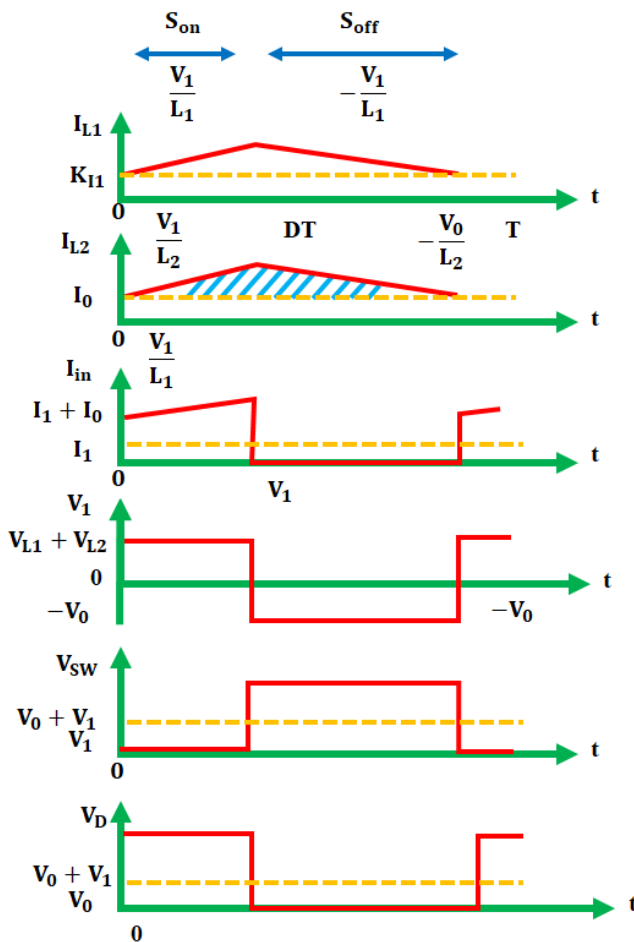


Figure 5. Waveforms of Luo converter.

The current waveforms of Luo converter and voltage for different modes were shown in figure 5. The voltage boosted using Luo converter is further made stabilized with the support of optimal controller approach. Hence the boosted voltage is supplied to BLDC motor for providing supply to electric vehicle.

RESULTS AND DISCUSSIONS

The simulated result for the proposed system approach using MATLAB Simulink are as follows. Table 1 represents the specifications of Luo converter used in this work.

Table 1. Specifications of Luo Converter

Specifications	Values
Inductances (L_1, L_2)	4mH, 6mH
Capacitances (C_1, C_2)	220 μ F, 100 μ F
Switching Frequency (f_s)	25KHz
Resistive Load (R_L)	15 Ω

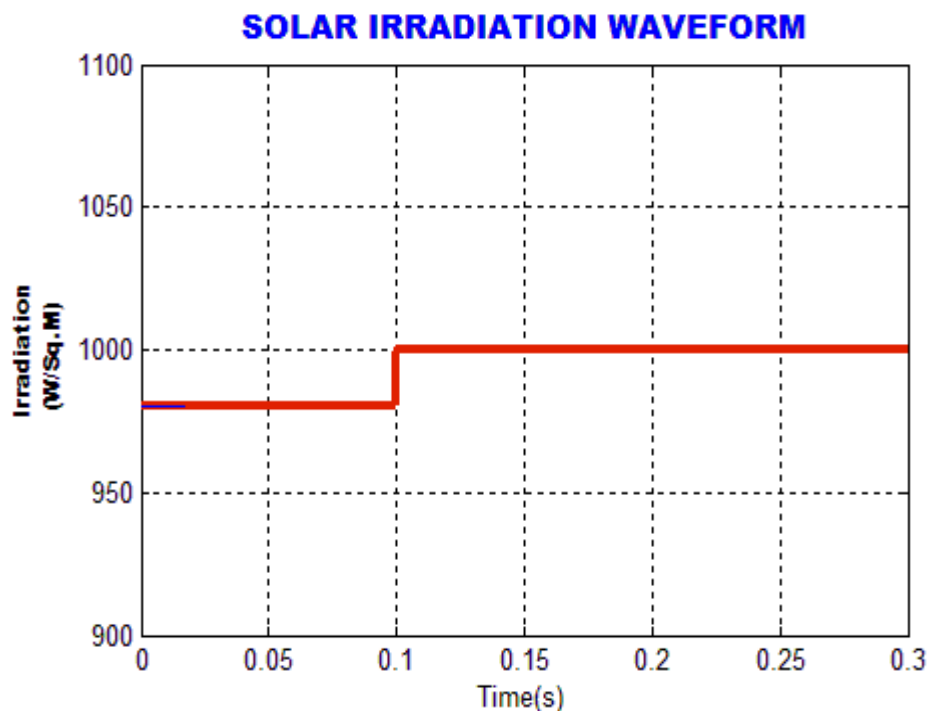


Figure 6. Solar Irradiation Waveform

The waveform representing solar irradiation is depicted in Figure 6. It is noticed that, the solar intensity is maintained at a maximum of 970 $W/Sq.M$ at its initial stage. After 0.1s the solar intensity rises and reaches a maximum of 1000 $W/Sq.M$ and continues to maintain stable.

The waveform illustrating solar output voltage is depicted in Figure 7. It is observed that, with respect to solar irradiance a minimum of 90V is maintained till 0.1s. Due to increase in irradiance after 0.1s the voltage level gets rise to 100V.

Similar to PV voltage, the output current obtained from PV system is illustrated in Figure 8. Initially due to low solar irradiance, the current at initial stage is minimum with 14.5A. And later at 0.1s, due to increase irradiance the current gets boosted to 15A.

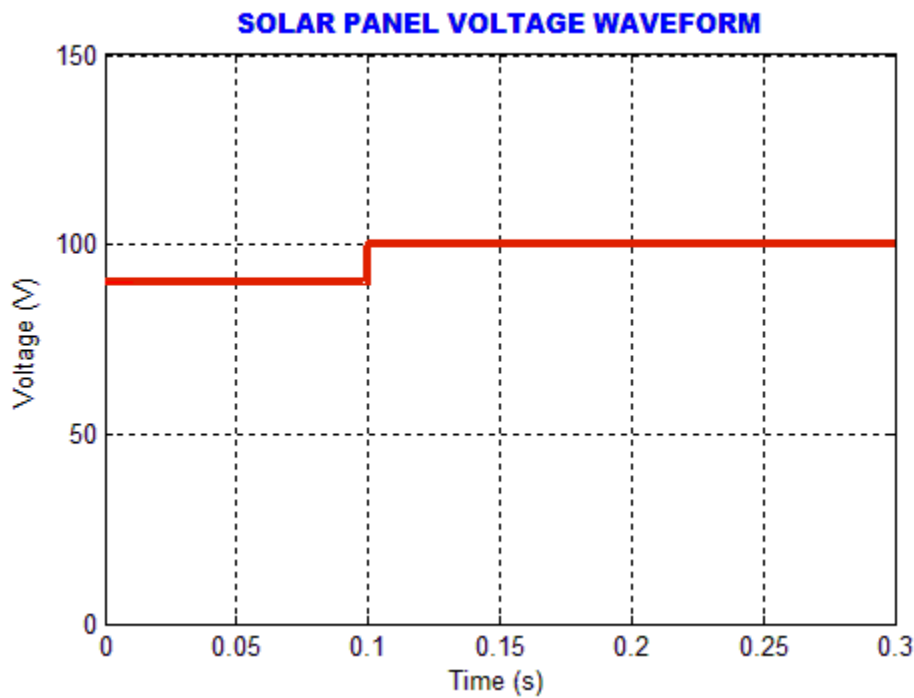


Figure 7. PV Voltage waveform.

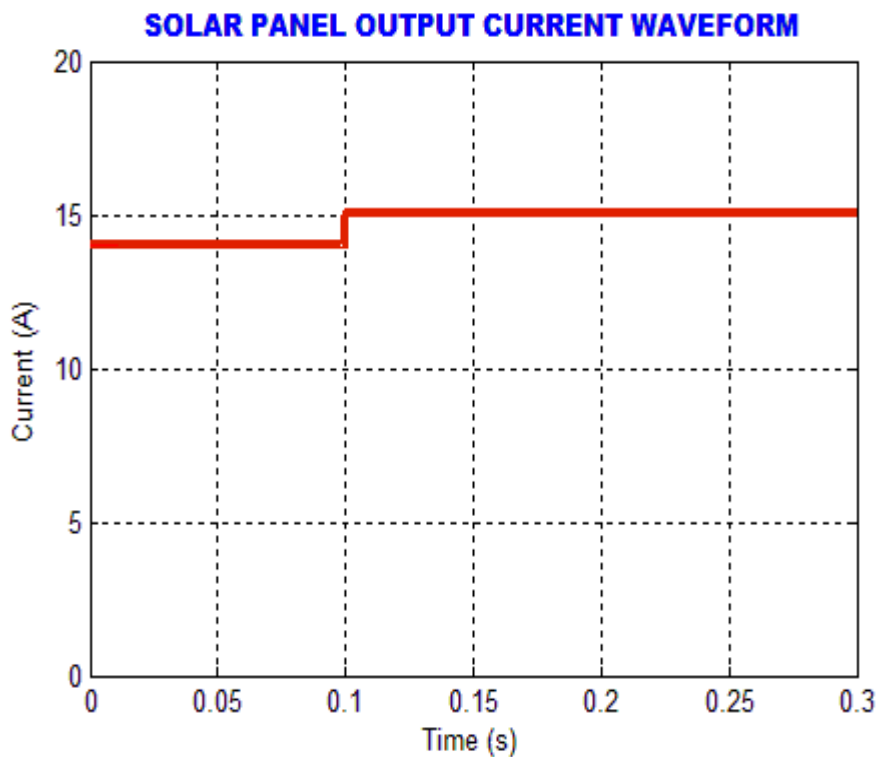


Figure 8. PV Current Waveform.

The representation of solar power waveform is shown in Figure 9. Initially, a power of 1300W is maintained and later at 0.1s the intermittent nature of the sun tends to emit more energy therefore the power gets rise to a maximum of 1500W and maintained stable and tends to continue further.

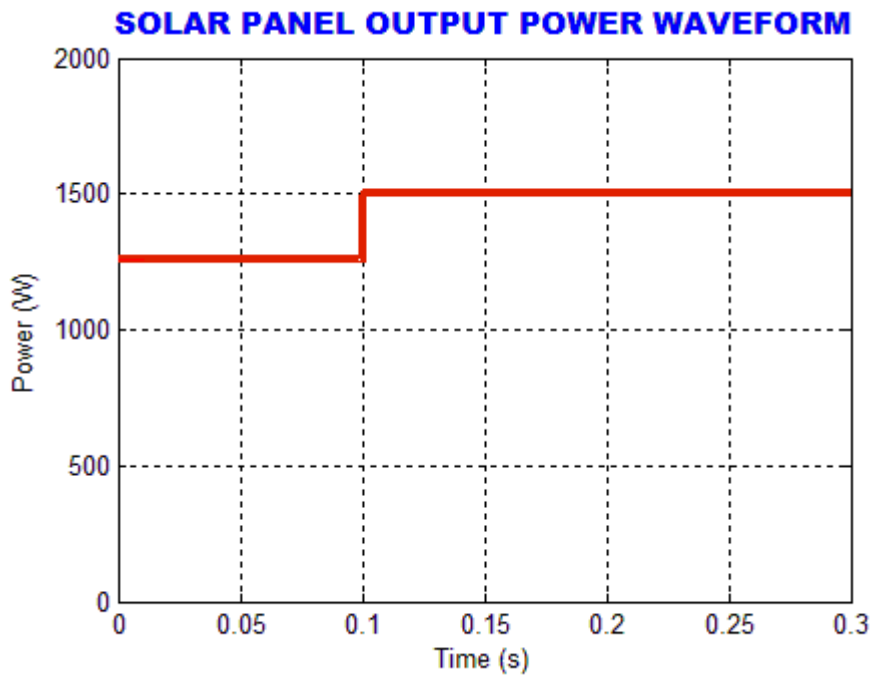


Figure 9. PV Output Power Waveform.

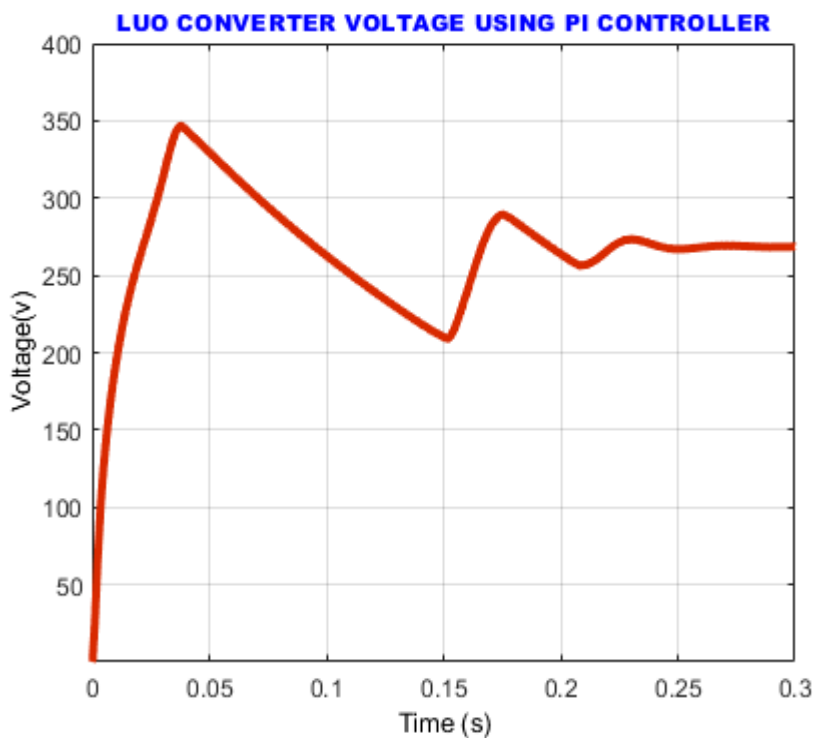


Figure 10. Luo Converter using PI controller.

Voltage enhancement is required to attain sufficient voltage for further applications. In the proposed work, Luo converter is utilized for enhancing voltage. Hence, utilization of controller supports in attaining effective stabilized voltage. The waveform illustrating Luo converter with the aid of PI controller is depicted in Figure 10. It is observed that, with fluctuations at the beginning a stabilized voltage of 260V is attained after 0.27s and tends to continue further.

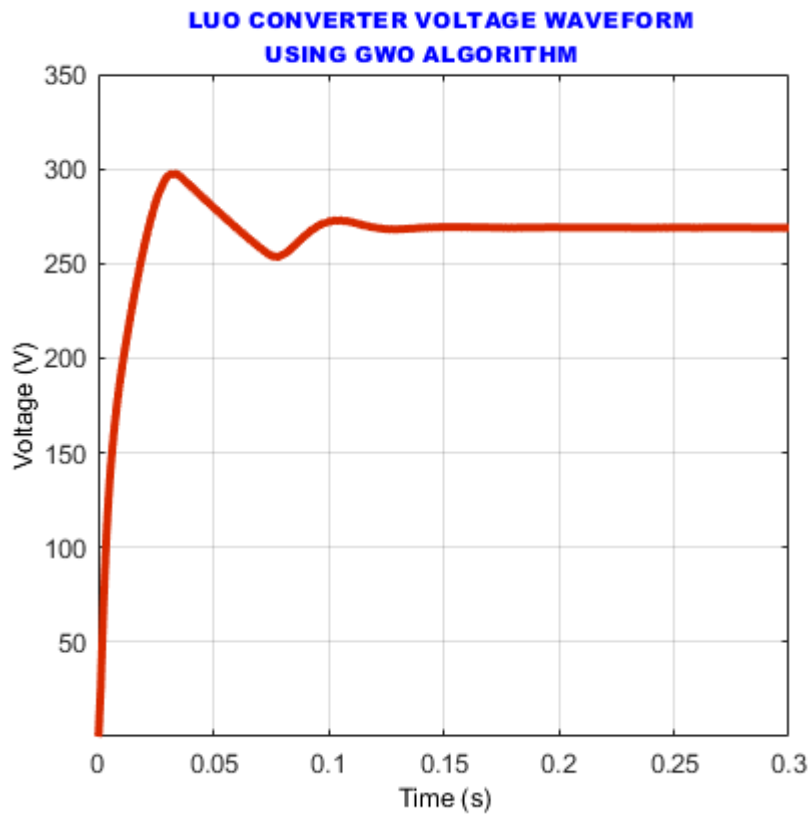


Figure 11. Luo Converter using GWO Algorithm.

Likewise, Luo converter with the assistance of GWO algorithm is depicted in Figure 11. It is observed that, with distortion at the initial stage a stable voltage of 270V is attained after 0.20s and continue further.

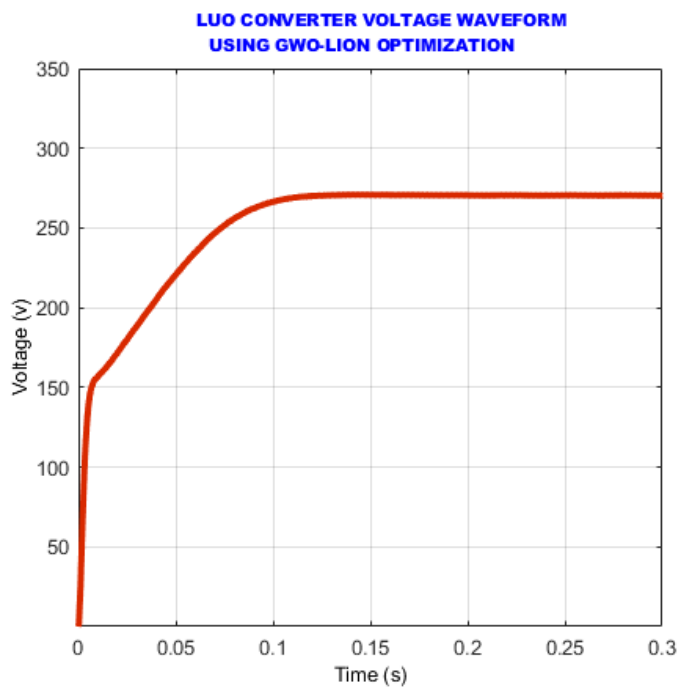


Figure 12. Luo Converter using GWO-LION Optimization.

The representation of waveform using hybrid approach is illustrated in Figure 12. It is noticed that, by utilizing hybrid GWO-LION optimization approach the voltage fluctuates slightly at the beginning and maintained stable at attain maximum voltage at lower computational time of 0.17s.

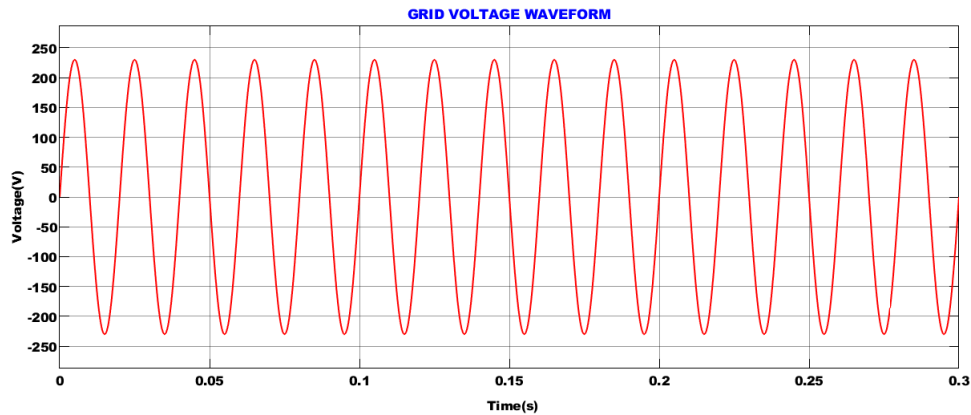


Figure 13. Grid Voltage Waveform.

The waveform illustrating single phase grid voltage is shown in Figure 13. It is analysed that, the using proposed Luo converter a stable grid voltage of 230V is maintained stable without any distortions.

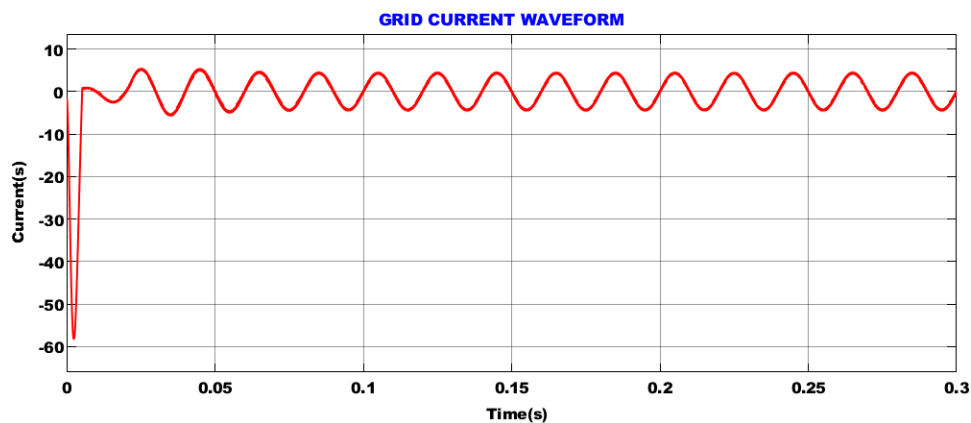


Figure 14. Grid Current Waveform.

The waveform of single phase grid current is illustrated in Figure 14. It is observed that, a constant grid current of 5A is maintained stable throughout the system with minor distortions at the beginning.

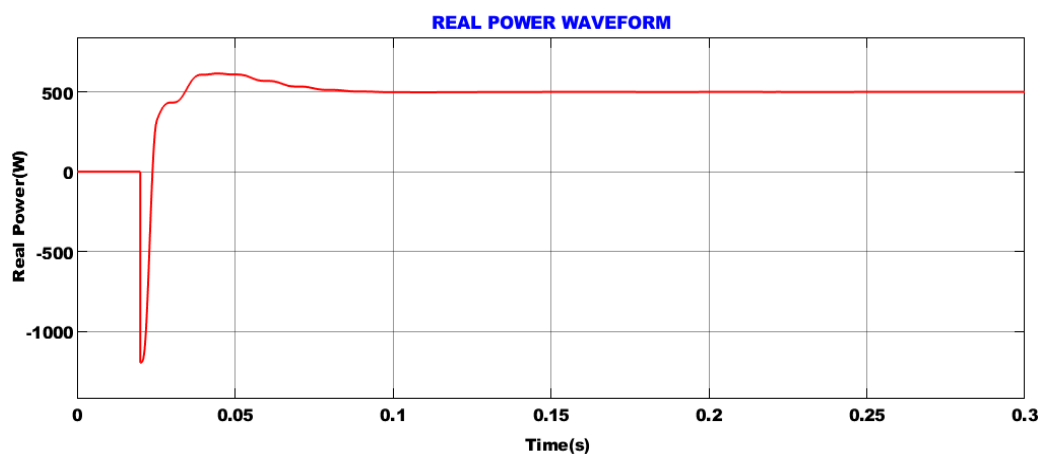


Figure 15. Real Power Waveform.

The waveform representation of real power is depicted in Figure 15. It is analysed that utilizing Luo converter a real power of 500W is obtained after 0.1s and tends to remain the same further.

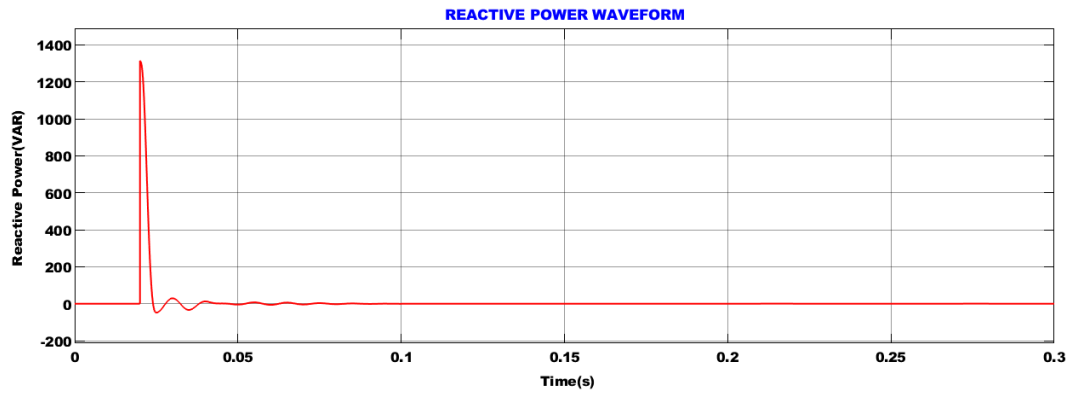


Figure 16. Reactive Power Waveform.

The waveform illustrating reactive power is depicted in Figure 16. From Figure it is analysed that, with initial rise in reactive power at 0.03s, the power starts fluctuating till 0.08s. After 0.1s a minimum reactive power is maintained stable and tends to continue further.

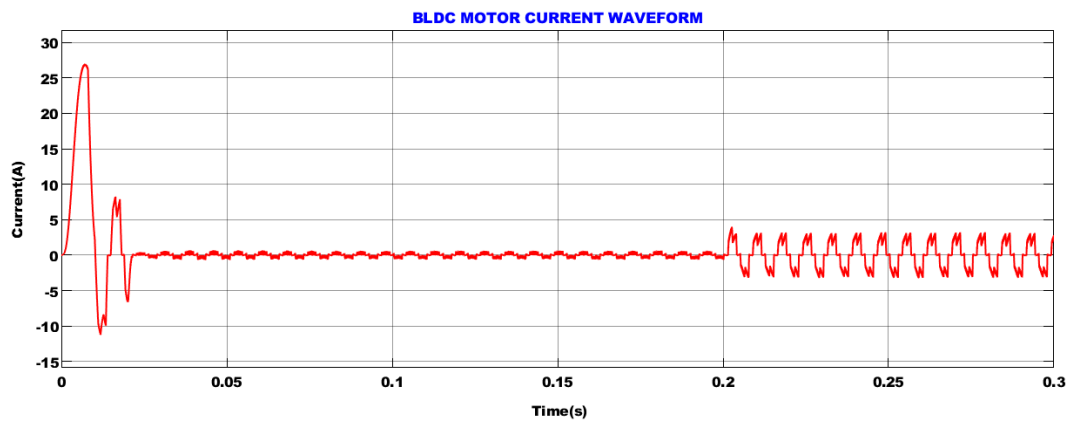


Figure 17. Motor Current Waveform.

The representation of BLDC motor current waveform is illustrated in Figure 17. It is noticed that, the motor current fluctuates at the initial stage and decreases to a minimum level with minor fluctuation and later after 0.23s a stable current of 4A is maintained and tends to continue further.

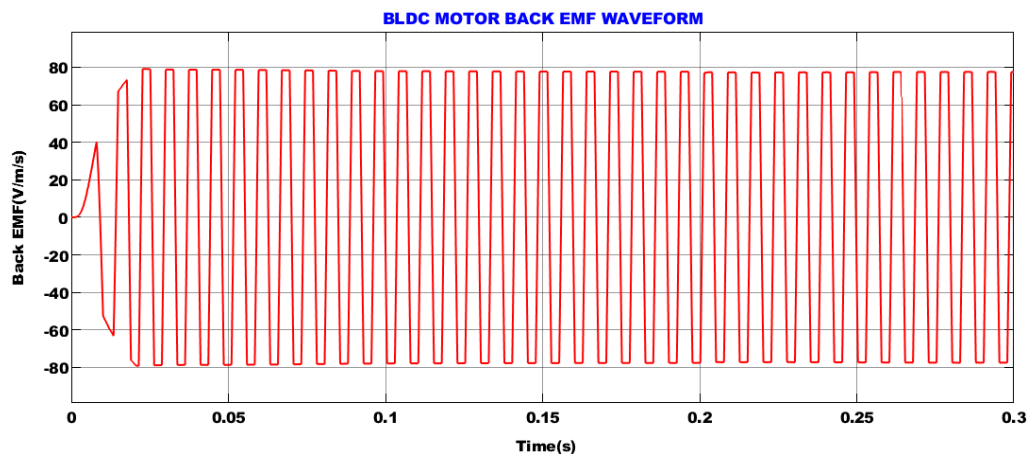


Figure 18. Back EMF Waveform.

The waveform demonstrating back EMF of BLDC motor is shown in Figure 18. Back emf is often a measurement of the voltage produced by a BLDC motor's rotor. This motor ignores the applied voltage and instead produces sinusoidal AC voltage, which is sustained at a constant 80V after 0.03s.

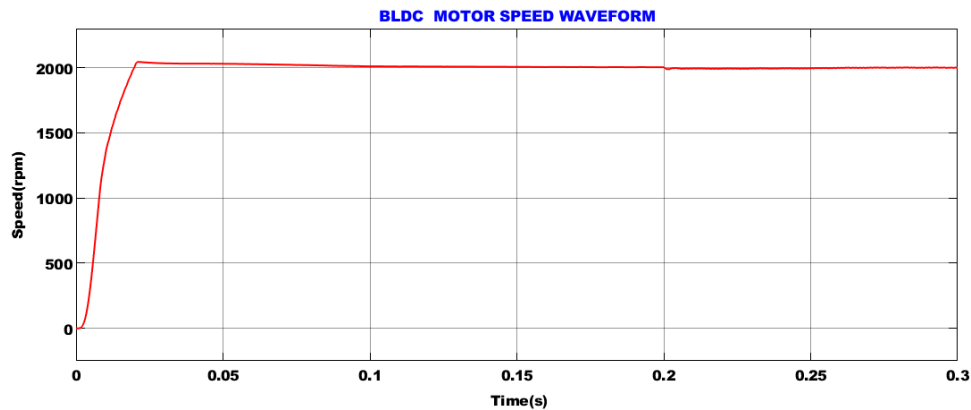


Figure 19. Speed Waveform of BLDC Motor.

The rotational velocity for determining speed of BLDC motor is illustrated in Figure 19. It is seen that the speed progressively rises and then maintains itself at 2000 rpm after 0.05s, giving the axis rotation speed for the number of full rotations.

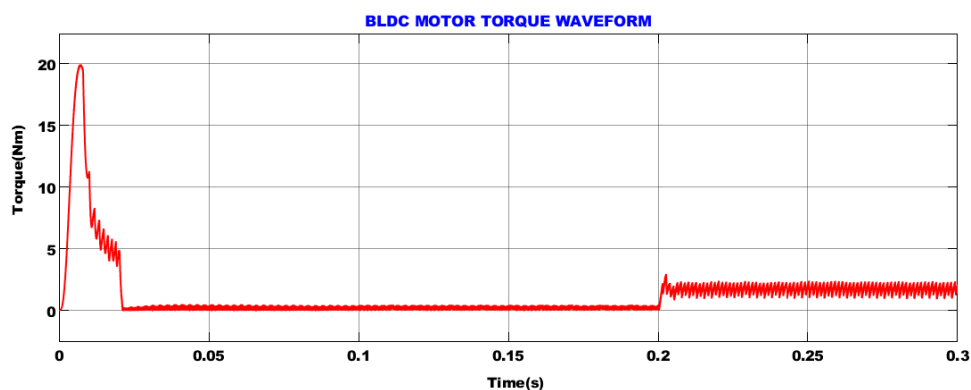


Figure 20. Torque Waveform of BLDC Motor.

The waveform demonstrating Torque of BLDC motor is illustrated in Figure 20. It is evident that torque increases gradually, peaks at 20 Nm at 0.02 seconds, then starts to decline. A minimal torque is maintained at 0.05 s with only slight distortion, and after 0.24 s, it tends to rise to 3 Nm.

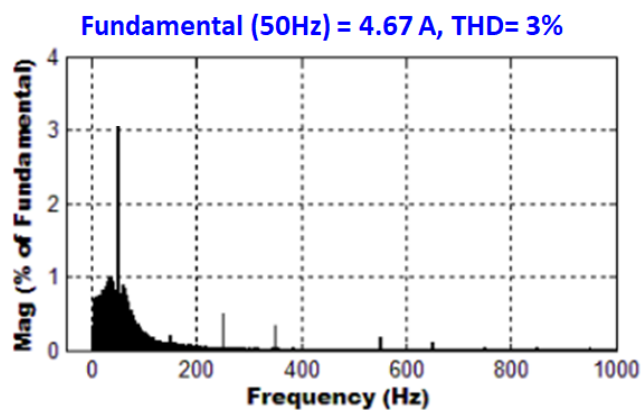


Figure 21. THD Waveform.

The total harmonic distortion attained from the proposed work is depicted in Figure 21. It has been noted that using a boost converter results in a reduced THD value that complies with IEEE standards at 3%.

Hardware Analysis

The hardware prototype is developed for the proposed Luo converter with grid tied solar EV charging system and the controller is implemented in the real time scenario with the help of Spartan 6E controller and obtained the results which are analysed and noted subsequently. The hardware prototype is designed, which is portrayed in Figure 22 in an optimal manner.

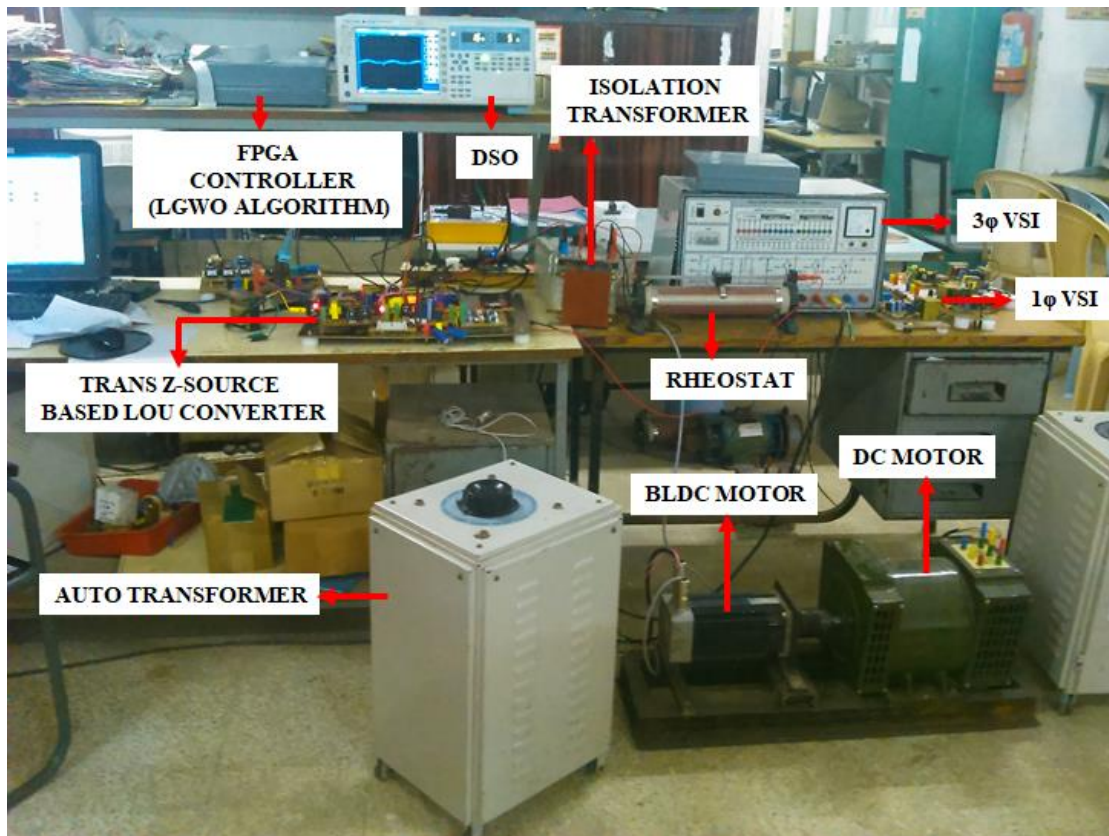


Figure 22. Hardware Prototype implementation design.

CONCLUSION

This paper encloses the complete operation of proposed work with the utilization of Luo converter. The results simulated for PV, BLDC motor, converter and grid are demonstrated using waveform. Nevertheless, the voltage boosted using Luo converter with appropriate control approach is sufficient. 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 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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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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