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Revolutionizing EV Battery Charging: Enhancing Power Factor with Modified Bridgeless Landsman Converter

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Abstract

The work focuses on the design and implementation of an innovative battery charger for electric vehicles (EVs) with a significant improvement in the power factor at the front end. The existing EV chargers often suffer from poor power factor, leading to increased losses and reduced efficiency. An altered Landsman power factor correction (PFC) converter is used in place of the traditional diode bridge rectifier (DBR) in order to solve this problem. The modified Landsman converter cascaded with a flyback converter with RCD clamp, resulting in several advantages over the conventional system, including improved power quality, reduced device stress, and minimized input and output current ripple. An RCD clamp circuit is usually used in flyback converters, in order to limit the voltage spikes caused by leakage transformer inductance. Oscillation ringing appears due to the clamp diode, which deteriorates the converter's power rate. This study describes this ringing phenomenon and the use of an RC-RCD clamp circuit for damping the clamp diode's oscillation. This clamp circuit is capable of improving a flyback converter's power ratio.

Keywords: Electric vehicles, power quality, modified landsman converter, RCD clamp

INTRODUCTION

Because of their excellent efficiency, low operating costs, and environmental friendliness, electric vehicles (EVs) have become more and more popular. The world is increasingly recognizing the importance of transitioning to cleaner energy sources. In the fight against climate change and the reduction of greenhouse gas emissions, EVs are crucial. However, for EVs to truly be sustainable, we need efficient and eco-friendly charging methods. As combustion engine vehicles contribute significantly to pollution, transitioning to EVs can help mitigate environmental impact. EV owners expect convenient and hassle-free charging experiences. Prolonged charging durations may cause range anxiety, which deters prospective customers. Wait times are shortened and user satisfaction is increased with efficient charges. However, efficient charging solutions are essential to ensure the widespread adoption of EVs, efficient battery charging solutions are pivotal for environmental sustainability, user satisfaction, grid stability, and overall EV market growth. In this context, maintaining a unity power factor during battery charging is crucial; our work aims to achieve precisely that by enhancing the power factor at the front end of the EV battery charger.

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EXISTING TOPOLOGY

In a conventional converter with a diode bridge rectifier, the primary challenges arise from a poor power factor caused by non-linear elements. These non-linear elements distort current and voltage waveforms, resulting in increased losses and reduced efficiency. Conventional converter with

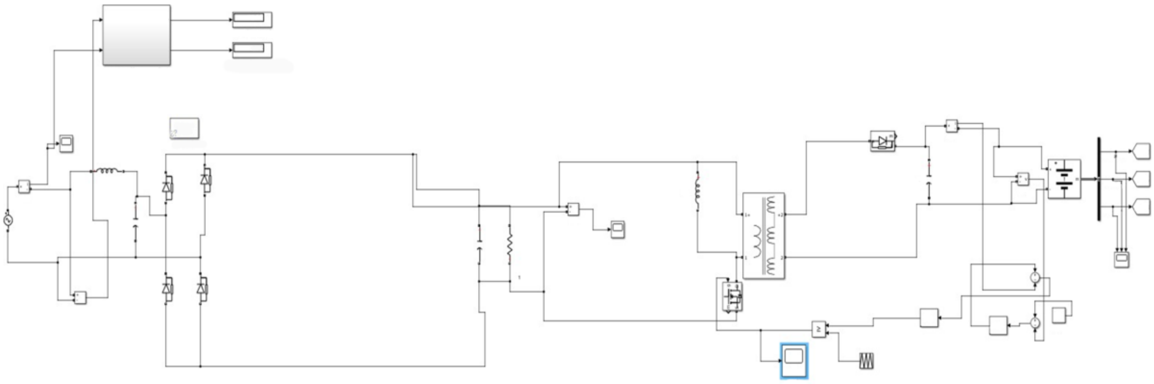

Figure 1. Conventional converter with DBR connected to EV battery charger.

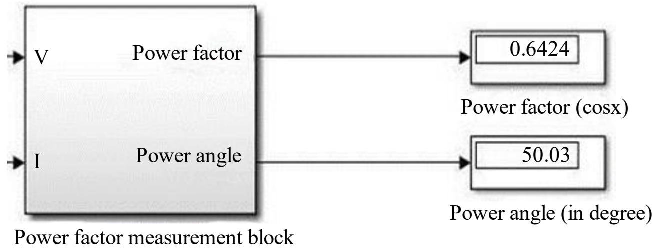

Figure 2. Values of PF from PF measurement block.

DBR connected to EV battery charger is shown in Figure 1. Harmonic stress is another main cause the DBR configuration suffers leading to high harmonics and high current stress [1].

Consequently, we introduce the proposed solution, which consists of a modified flyback converter with an RCD clamp and a modified bridgeless Landsman converter. Values of PF from PF measurement block are shown in Figure 2, which can improve the distorted power factor in an existing EV battery charger to enhance the power quality [2]. The proposed topology aims to improve the overall power quality in electric vehicle (EV) battery charging systems. We guarantee effective energy transfer from the electrical system to the EV battery by raising the power factor and reduced device stress in the modified bridgeless Landsman converter, combined with a flyback converter and an RCD clamp [3], which minimizes stress on components. This decrease in stress increases the charging technique's longevity and dependability. Additionally, low input and output current ripple makes the integrated design result in smoother input and output current waveforms. Reduced ripple ensures stable operation and prevents unnecessary wear on components. Low input current harmonics can adversely affect the grid and other connected loads. The proposed solution aims to minimize input current harmonics, contributing to a cleaner power supply. In summary, this work focuses on achieving better power factors, reduced stress, and improved current waveforms in EV battery charging systems, ultimately benefiting both users and the grid. Input current waveform obtained on a conventional converter is shown in Figure 3.

RELATED WORKS

Kadam *et al*. suggested creating and utilizing a new charger for battery-powered electric cars (EVs). They addressed the poor power factor issue in existing EV chargers. A modified Landsman power factor correction (PFC) converter was used in place of the traditional diode converter. They cascaded the modified Landsman converter with a flyback converter to provide output DC power to the EV battery [1]. The development and implementation of a novel charger with improved power factor at the front end powered by batteries in electric vehicles (EVs) is the focus of Kushwaha and Singh [4]. The improved Landsman power factor correction (PFC) converter replaces the traditional diode converter at the source end of the current EV battery charger in the recommended arrangement [4].

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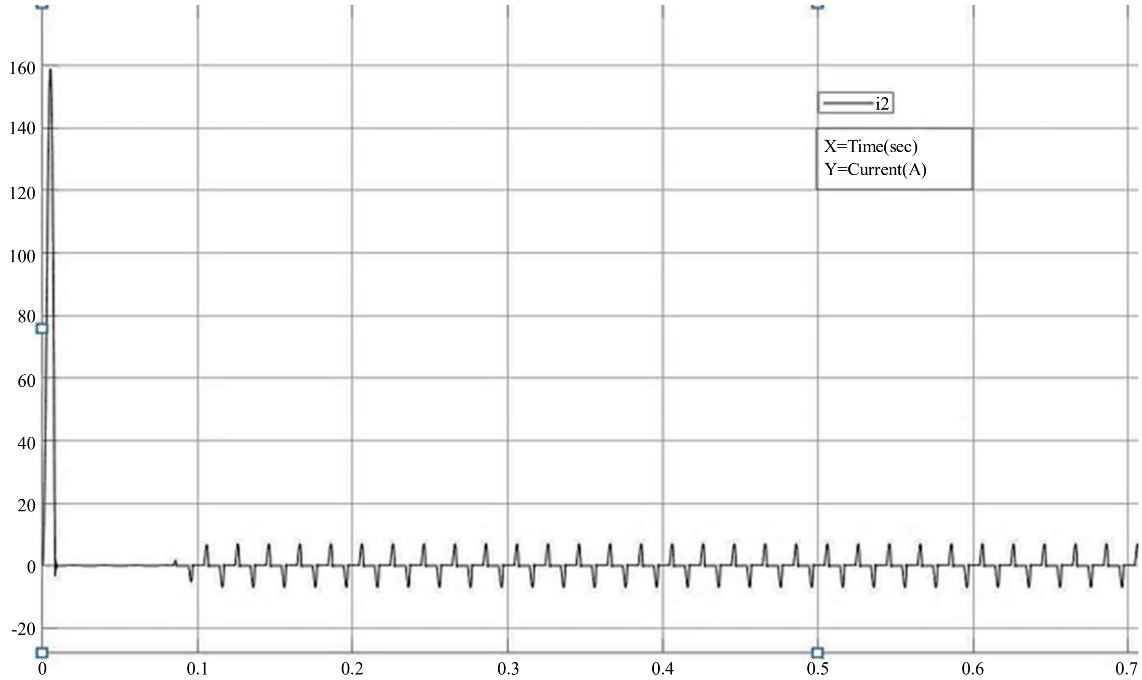

Figure 3. Input current waveform obtained on a conventional converter.

The PFC Converter Comparison [5] evaluated the differences in performance between the SEPIC PFC converter and the bridgeless Cuk converter. This was assessed in terms of efficiency, power factor, and total harmonic distortion (THD), pertinent to enhancing the quality of power in EV battery chargers.

A novel control strategy was presented by Sahoo and Jariwala to correct for the harmonic current produced by the diode rectifier in order to control the DC-bus voltage and get a power factor that is closer to unity [6]. In order to offset the harmonic current drawn by the single phase diode rectifier, this method uses a single PFC Boost Converter that is linked in shunt with the diode rectifier [6].

Battery-Powered Electric Vehicle (BpEV): centered on creating a new BpEV through design and construction. Shi *et al*. improved the input AC power factor by swapping out the common diode converter for a superior Landsman converter; power-factor tweaking was emphasized [7].

An Alternative View discusses the development and application of a novel charger for battery-operated electric vehicles, emphasizing the improvement in power factor at the input.

METHODOLOGY

Modified Bridgeless Landsman Converter

The new topology proposes modified bridgeless Landsman converter-based EV battery charger to address the existing challenges. Depending on whether low cost or low device stress is required for the application, the redesigned converter's operation is chosen to operate in DCM or CCM mode [8]. These days, the primary factor in battery charger selection is the cost, hence a DCM mode is used in this application. In addition, the flyback converter uses fewer sensors in the circuit to accomplish battery control during the discontinuous phase of the switching cycle [4, 6]. As a result, the proposed charger's size concerns are also reduced. The salient characteristics are as follows: the power factor correction (PFC) in the modified bridgeless Landsman converter for the EV battery charger, as shown in Figure 4.

Replacing the DBR with a modified Landsman PFC converter improves power factor and reduces losses. The Modified Bridgeless Landsman Converter is an advanced version of the traditional Landsman converter, designed to enhance power factor correction in various applications, including EV battery

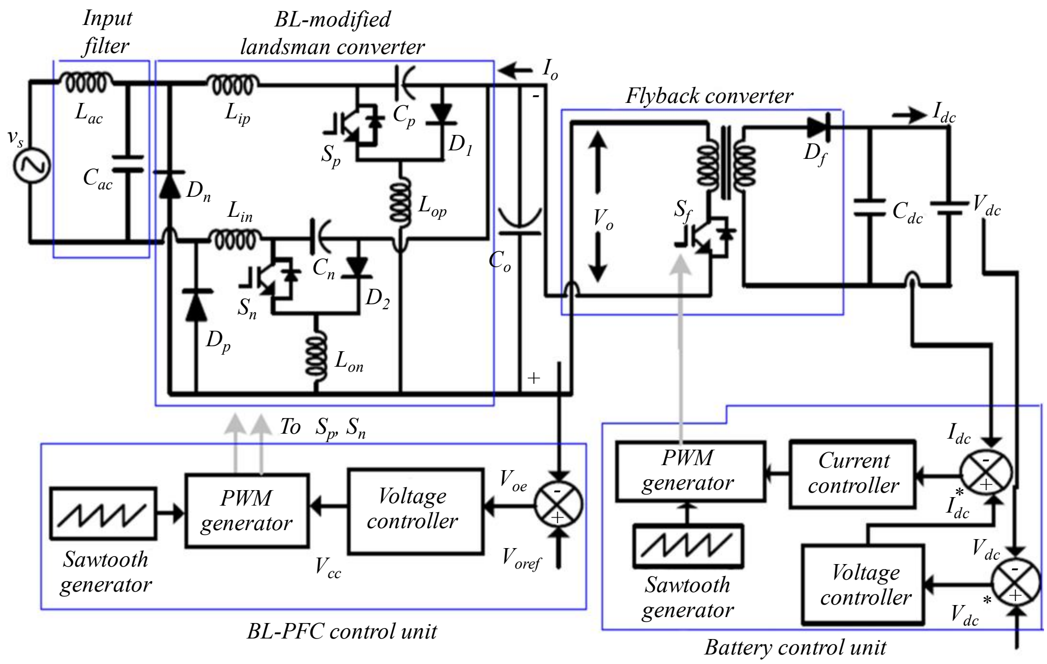

Figure 4. PFC in modified bridgeless landsman converter fed EV battery charger [4].

charging systems. This converter stands out for its ability to improve power quality, reduce device stress, and minimize input and output current ripple, along with lower input current harmonics [1].

Modes of Operation

- *Mode P-I (t0–t1):* The converter operates in mode P-I during the positive half cycle of the mains voltage. When the upper line-connected switch Sp is in the ON position, the inductor Lop begins to charge along the path depicted in Figure 5(a). Co discharges via the isolated converter linked to the load side at this precise moment in time, causing the intermediate DC link capacitor. Nevertheless, because of the inductor's stored charge, the high frequency diode D1 has no conducting channel at this time and has a reverse bias voltage across it [4].
- *Mode P-II (t1–t2):* When the gate pulse to the switch is inhibited, the high frequency diode D1 works in mode P-II. To discharge via it, the inductor Lop finds the path shown in Figure 5(b). For every switching cycle, the flyback converter is supplied at the output and the DC link capacitor, Co, begins charging [4].
- *P-III Mode (t2–t3):* At the conclusion of the switching cycle in mode P-III operation, the stored charge in the inductor Lop is totally depleted. For the remainder of the switching cycle, the inductor current becomes discontinuous. The intermediate DC link capacitor supplies the output power during this period, discharging via the path shown in Figure 5(c) [4]. As illustrated in Figure 5(d–f), the suggested updated BL converter uses the same shifting mechanism for the lower switch Sn, inductor, Lon, and diode, D2 in the negative half cycle of the mains potential. Operating principle of the modified bridgeless Landsman converter: (a)–(c) Operation during the positive line cycle: Mode P-I, Mode P-II, and Mode P-III; (d)–(f) Operation during the negative line cycle: Mode N-I, Mode N-II, and Mode N-III [4].

Flyback Converter Configuration for Power Factor Correction

Cascaded Flyback Converter with RCD Clamping

In order to supply the EV battery with output DC power, a flyback converter is cascaded with a modified Landsman converter. A buck-boost converter's basic structure is used to create a flyback converter. It uses coupled inductors (like gapped core transformers) in place of filter inductors. It focuses on power factor improvement in EV battery charging, which is quite significant. The flyback

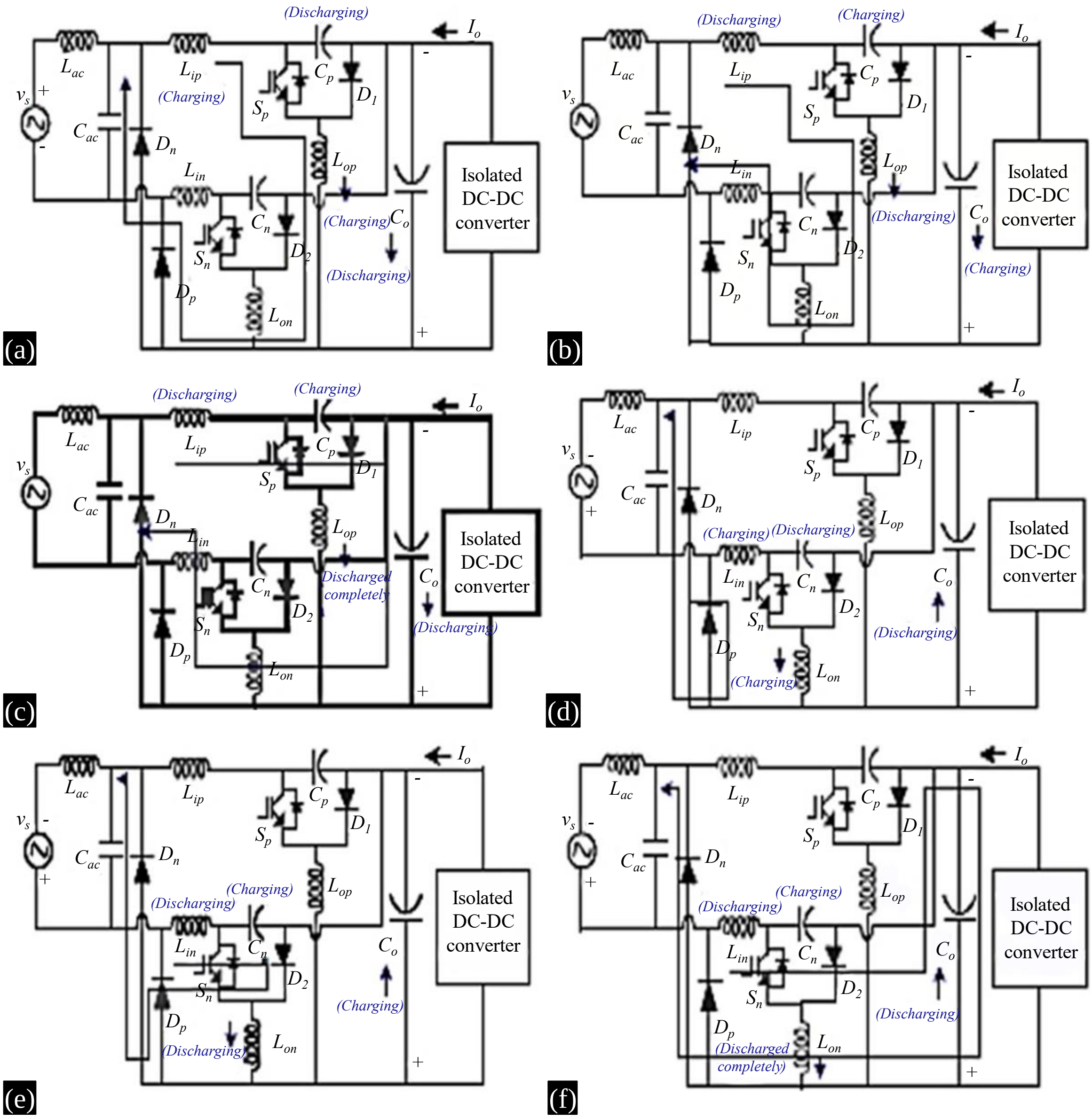

Figure 5. Operating principle of modified bridgeless landsman converter. (a)–(c) Operation for positive line cycle: Mode P-I, Mode P-II, and Mode P-III; (d)–(f) Operation for negative line cycle: Mode N-I, Mode N-II, and Mode N-III [4].

converter plays a crucial role in several aspects like, power factor correction (PFC) since, Flyback converters are commonly used for PFC due to their advantages of low current ripple and high power density. They can be optimized for high efficiency with low-cost devices across the full-load range. Implementing an active clamp system, can improve efficiency and reduce total harmonic distortion (THD), which is beneficial for power factor improvements [3]. Thermal Management that is achieved by increasing the efficiency of the flyback converter, you can reduce the heat sink volume, which is a critical factor in power-dense applications like EV battery chargers.

The primary issue is the voltage spikes [9], which happen on the drain pin of a flyback converter when the MOSFET in the converter shuts off. The resonance between the MOSFET's output capacitor (COSS) and the main transformer's leakage inductor (Llk) is what causes this spike. The MOSFET may be harmed by an avalanche breakdown caused by an excessive voltage on the drain pin. We require an extra circuit to clamp the voltage in order to stop this [10].

Design of RCD Snubber

The overvoltage caused by resonance is suppressed by the RCD (Resistor-Capacitor-Diode) snubber. This is how it operates: The primary current quickly charges the MOSFET's COSS when the MOSFET shuts off.

The secondary diode switches on if the voltage across COSS (Vds) is greater than the input voltage plus the reflected output voltage (Vin+nVo). Next, nVo is attached to the voltage that passes through the magnetizing inductor (Lm). There is a resonance between Llk1 and COSS, resulting in high-frequency and high-voltage surges [3]. The functioning of a circuit with a snubber in Continuous Conduction Mode (CCM) as opposed to Discontinuous Conduction Mode (DCM) indicates that in CCM, the MOSFET is gated ON while the secondary diode stays ON. The secondary diode's reverse recovery current increases the primary current during MOSFET turn-on. The secondary current in DCM runs out before a switching period ends. Resonance between the MOSFET's Lm and COSS happens in this instance. A well-designed RCD snubber ensures that the excessive voltage due to resonance is suppressed to an acceptable level, protecting the main switch (MOSFET) from failure. And the RCD clamp circuit is useful for all flyback converters, reducing stress. The flyback converter with RCD clamping is shown in Figure 6, focusing on the power FET. Ensure that the clamp restricts the voltage under worst-case operating conditions to less than the voltage rating of the component [3].

IMPLEMENTATION

Design of Modified Landsman Converter

The AC voltage at the power stage of proposed BL converter, is given as [11]:

$$V_s(t) - V_{s.pk}\sin(2\pi f_L t) - 220\ \times\sqrt{2}\sin(314t)$$

Where, Vs pk and fL represent the maximum value of source voltage and input frequency (Hz), respectively [11]. T Therefore, the input voltage (vin) is given by the modulus of (1) as follows:

$$v_{in}(t) = |V_{s.pk}\sin\,(\omega_L t)| - |220\sqrt{2}\sin(314t)|$$

The intermediate DC-link voltage (Vo) for proposed modified BL Landsman converter, is given as:

$$V_o - \frac{D}{1-D}v_{in}$$

Where, D is the required duty ratio of PFC converter to control the DC-link voltage at 300 V. Therefore, the duty cycle, D for proposed modified unity power factor converter, is calculated as [4]:

$$D - \frac{V_o}{v_{in}-V_o}$$

Input Inductor Design (Lip and Lin)

$$L_{ip}(-\,L_{in}) =\ \frac{v_{in}\,D}{0.2\ i_{Lip}f_{sL}} - \frac{R_{in}\,D_a}{0.2f_{sL}} = \left(\frac{V_s min^2}{P_i}\right)\frac{D_a}{0.2f_{sL}}$$

$$L_{ip}(-\,L_{in}) = \left(\frac{V_s min^2}{P_i}\right)\frac{1}{0.2f_{sL}}\frac{V_o}{v_{in}+V_o} = \left(\frac{160^2}{850}\right)\frac{1}{0.2\times 20000}\frac{300}{160\sqrt{2}+300} =\ 4.2\ mH$$

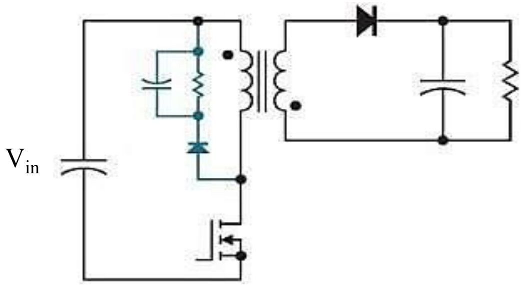

Figure 6. Flyback converter with RCD clamping [3].

Design of Energy Transfer Capacitances (Cp and Cn)

$$C_p(-C_n) = \frac{V_o}{\gamma\sqrt{2}\,V_s max f_{sL}(\frac{V_0^2}{P_i})}\frac{V_o}{\sqrt{2}\,V_{smax}+V_o} = \frac{P_i}{\gamma\sqrt{2}\,V_{smax} f_{sL}(\gamma\sqrt{2}\,V_{smax}+V_o)}$$

$$= \frac{850}{0.1\times 260\sqrt{2}\times 20000(260\sqrt{2}+300)} = 1.73\ \mu F$$

Output Inductor Design (L_{opc} and L_{onc})

$$L_{opc}(-L_{onc}) = \frac{v_{in}\,D_a}{0.2\,i_{Lip} f_{sL}} - \frac{R_{in}\,D_a}{2f_{sL}} - \left(\frac{V_s min^2}{P_i}\right)\frac{D_a}{2f_{sL}}$$

$$L_{opc}(-L_{onc}) = \left(\frac{V_s min^2}{P_i}\right)\frac{1}{2f_{sL}}\frac{V_0}{v_{in}+V_0}$$

$$\left(\frac{160^2}{850}\right)\frac{1}{2\times 20000}\frac{300}{160\sqrt{2}+300} = 429.21\ \mu H$$

Design of Intermediate DC-Link Capacitor Co

$$C_o - \frac{I_0}{2\omega_L \Delta V_0} = \frac{\frac{P_i}{V_0}}{2\omega_L \Delta V_0} = \frac{P_i}{2\omega_L \Delta {V_0}^2}$$

Design of Line Filter

$$C_{ac\,max} = \frac{I_{s.pk}}{\omega_L V_{s.pk}}\tan\theta = \frac{\frac{P_i\sqrt{2}}{V_s}}{\omega_L\sqrt{2V_s}}\tan\left(cos^{-1}DPF\right)$$

$$C_{ac\,max} = \frac{\frac{850\sqrt{2}}{220}}{314\times 220\sqrt{2}}\tan 1^\circ = 976\text{nF}$$

SIMULATION AND RESULTS

Simulation of Modified BL Landsman Converter is shown in Figure 7. The variation in supply current total harmonic distortion (THD) with changes in input power for the conventional diode bridge rectifier (DBR), the DBR with PFC Landsman converter, and the proposed bridgeless Landsman converter-based EV charger. PF from PF Measurement block shown in Figure 8. It is to be noted that the current THD in the conventional scheme is seen to be 55.3%, which violates the IEEE standards for harmonics. Input current waveform obtained on our proposed model is shown in Figure 9. In Figure 10, all the three cases are considered to show the input power factor with respect to variation in input power. It can be seen that the conventional DBR fed charger has less performance in terms of power quality. Now it can be seen that the THD of the proposed model is only 3.42% till the 7th harmonics. So now, by replacing DBR by Landsman converter modifies the circuit as a whole. THD curve is obtained from simulation.

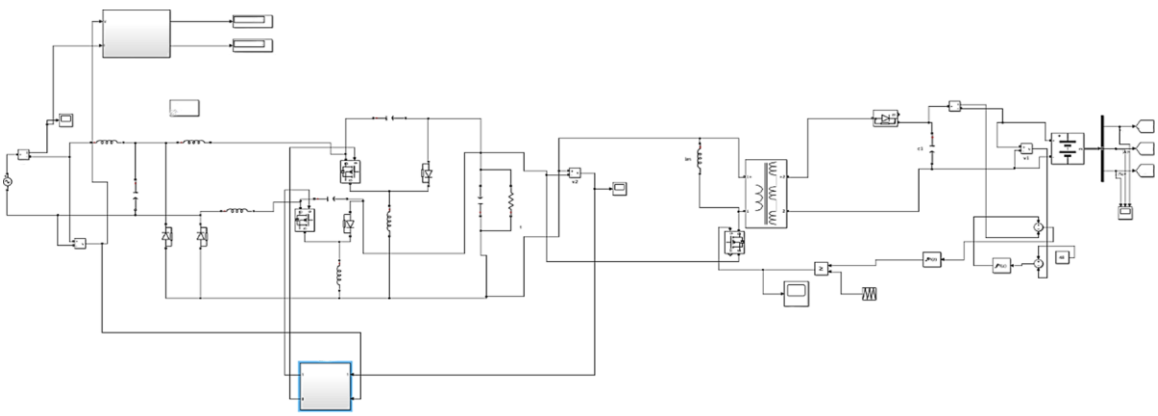

Figure 7. Simulation of modified BL landsman converter.

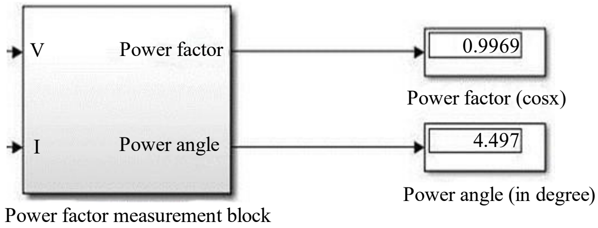

Figure 8. PF from PF measurement block.

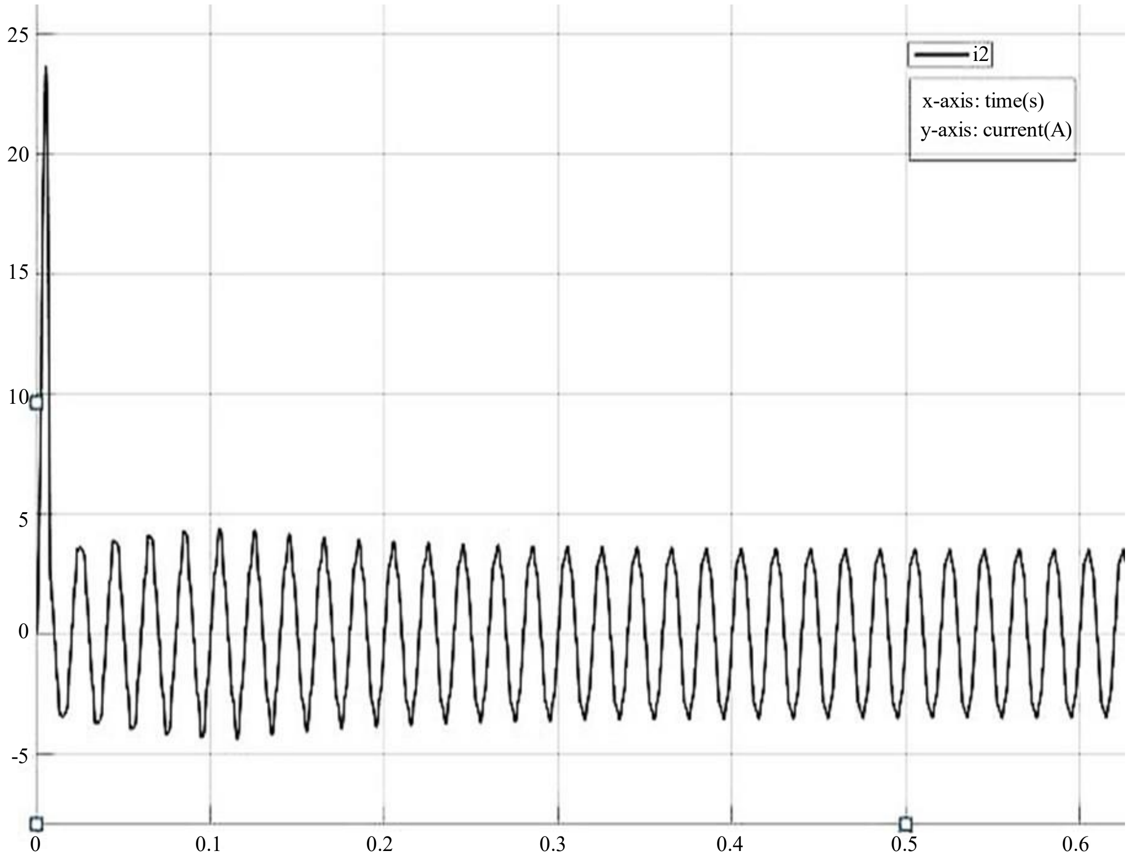

Figure 9. Input current waveform obtained on our proposed model.

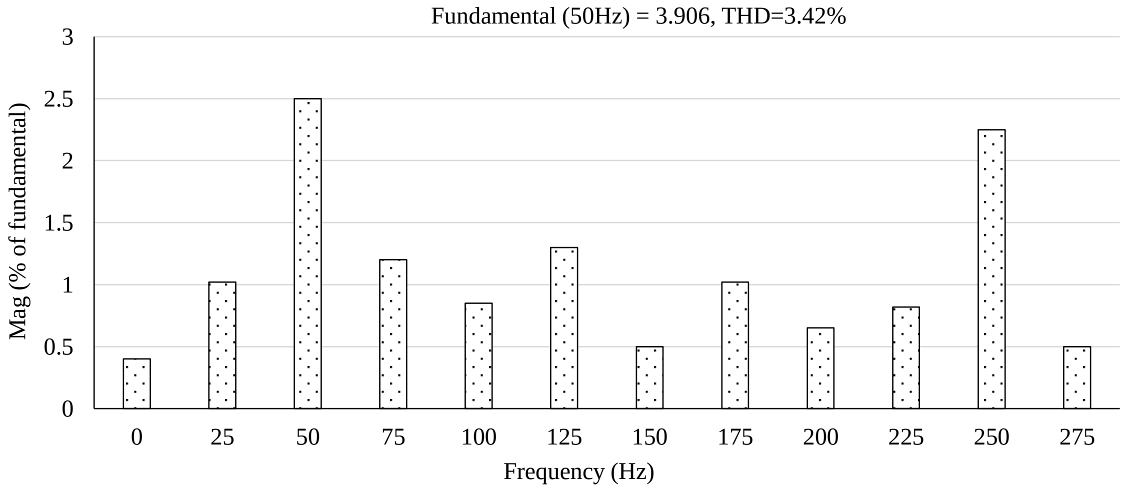

Figure 10. THD curve obtained from simulation.

CONCLUSION

The proposed system demonstrates significant advancements in the efficiency and reliability of EV battery charging systems. The integration of the modified bridgeless Landsman converter with RCD clamping effectively mitigates voltage spikes, ensuring the protection of electronic components and enhancing the overall power quality. This innovative approach aligns with the global shift towards sustainable transportation solutions, offering a promising outlook for the future of electric vehicles. The project's findings contribute valuable insights into the development of more efficient power conversion techniques, paving the way for greener and more energy-efficient technologies in the automotive industry.

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