Analysis and Mitigation of Power Quality Issues in Electric Vehicle Charging System

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Abstract- *Harmonics in Electric Vehicle (EV) charging systems adversely affect power quality, leading to voltage distortion, increased losses, and reduced efficiency. This paper proposes a compact LC filter design aimed at minimizing Total Harmonic Distortion (THD) in EV chargers. Both simulation and experimental results demonstrate that the proposed filter effectively suppresses harmonics, thereby enhancing power quality, reducing system losses, and improving overall charging efficiency. The design is simple, cost-effective, and can be easily integrated into existing charging infrastructure. These findings highlight the filter's potential for large-scale adoption in EV charging networks to ensure reliable and sustainable grid performance.*

Keywords: **Electric Vehicle, Harmonics, LC Filter, Power Quality, Total Harmonic Distortion (THD).**

1. Introduction

The rapid adoption of Electric Vehicles (EVs) has created a growing demand for reliable charging infrastructure. However, EV chargers typically rely on rectifiers and power converters, which generate harmonics that distort current waveforms and compromise grid performance. These harmonics can result in conductor overheating, voltage instability, and electromagnetic interference with sensitive equipment. Moreover, excessive Voltage Total Harmonic Distortion (THD) reduces system efficiency and accelerates the aging of EV batteries and power electronic components. Recognizing these challenges, regulatory standards such as IEEE-519 mandate stringent limits on harmonic levels, underscoring the importance of effective mitigation strategies. To address this, the present study focuses on the design of an LC filter aimed at suppressing harmonics and enhancing overall power quality.

The proposed LC filter operates by providing a low-impedance path for harmonic currents, thereby attenuating high-frequency distortions while allowing the fundamental component to pass with minimal losses. Its simple structure, cost-effectiveness, and ease of implementation make it a practical solution for EV charging systems. Furthermore, optimizing the filter parameters is essential to balance harmonic suppression, efficiency, and system stability. Through simulation and analysis, this study evaluates the effectiveness of the LC filter in reducing THD and demonstrates its potential to significantly improve both grid reliability and the operational lifespan of EV charging infrastructure.

2. Literature Survey

A comprehensive review of existing research is essential to understand the impact of EV charging on power quality and the effectiveness of various harmonic mitigation techniques. Md. Mostafa Faruk, et.al., [1] analyzes the impact of Electric Vehicle (EV) charging on distribution grid performance, focusing on Total Harmonic Distortion (THD), power factor, and overall power quality. Using simulation studies, it highlights how uncontrolled EV charging can increase THD and reduce grid efficiency. The study further emphasizes the need for mitigation techniques to maintain stability and reliability in future EV-integrated power

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systems. The paper [2] discusses the application of passive power filters for improving power quality in electrical systems. It emphasizes how these filters effectively reduce harmonic distortion, enhance voltage stability, and improve system efficiency. The study highlights their simplicity, cost-effectiveness, and suitability for practical implementation compared to active filtering methods. Aman and Datta (2023) [3] proposed an effective filter design for single-phase inverters to enhance output waveform quality. Their study focused on reducing harmonics and minimizing Total Harmonic Distortion (THD) through optimized filter parameter selection. Simulation results validated the approach, showing improved efficiency and overall power quality in inverter applications. Hu et al. (2023) [4] presented a comprehensive overview of harmonic source modeling and characterization in modern power systems. The paper analyzed different harmonic generation mechanisms, their effects on grid stability, and various modeling approaches for accurate assessment. It further highlighted the importance of advanced harmonic characterization techniques for improving power quality in evolving power networks. Upanya et al. (2025)[5] investigated harmonic mitigation techniques using both active and passive filters in power systems. Their work compared the performance of different filter configurations in reducing Total Harmonic Distortion (THD) and improving voltage stability. The study concluded that hybrid approaches combining active and passive filters offer superior effectiveness in maintaining power quality. Islam et al. (2025) [6] examined the impact of battery storage–based EV chargers on the harmonic profile of power system networks. The study analyzed both current scenarios and projected future trends, highlighting how EV chargers contribute to increased Total Harmonic Distortion (THD) and potential grid instability. It also discussed mitigation strategies and design considerations to minimize harmonics and enhance overall power quality. Wan Bunyamin et al. (2025) [7] investigated power quality issues in electric buggy battery charger systems, focusing on harmonic generation and voltage distortions. The study analyzed the sources of disturbances and their impact on system efficiency and reliability. It also proposed mitigation strategies, including filter implementation, to improve overall power quality in EV charging applications. Patil and Ramteke (2015) presented the design and implementation of an LC filter for DC–MLI (Multilevel Inverter) applications. The paper compared the performance of the filter under various PWM techniques, focusing on harmonic reduction and output waveform quality. Results demonstrated that the LC filter effectively minimized Total Harmonic Distortion (THD) and enhanced overall inverter performance.

In summary, the reviewed studies highlight the critical impact of EV chargers and inverter systems on power quality, particularly in terms of harmonic distortion and voltage stability. While passive LC filters provide a simple and cost-effective solution for low-frequency harmonics, active and hybrid filtering techniques offer superior performance for higher-order harmonics. These insights underscore the need for optimized filter design, simulation validation, and practical implementation to ensure efficient, reliable, and standards-compliant EV charging infrastructure.

3. Scope of Work

The scope of this work encompasses the design, modeling, and performance evaluation of an LC filter specifically tailored for EV charging applications. The study involves analyzing harmonic generation in typical EV charger circuits, selecting appropriate filter parameters, and validating the filter's effectiveness through simulation-based case studies. The focus is on minimizing Total Harmonic Distortion (THD), improving voltage stability, and enhancing overall power quality while ensuring cost-effectiveness and ease of integration into existing charging infrastructure. This work also aligns with regulatory requirements such as IEEE-519, thereby contributing to the development of more reliable and efficient EV charging systems. This work focuses on addressing power quality issues in Electric Vehicle (EV) charging systems, with emphasis on reducing Voltage THD through a simple and cost-effective LC filter design. It also includes both simulation and hardware implementation to validate the proposed solution.

Key points of the scope include:

- Harmonic Distortion Analysis: Investigation of Voltage Total Harmonic Distortion (VTHD) produced by rectifiers and converters in EV charging systems.
- Filter Design: Formulation of an LC filter to attenuate higher-order harmonics and ensure a smoother DC output.
- Simulation Study: Modeling and evaluating the proposed system in MATLAB/Simulink to assess harmonic mitigation performance.
- Hardware Implementation: Development of a prototype EV charging circuit with real-time THD measurement capability.
- Performance Evaluation: Comparative analysis of VTHD levels with and without the LC filter to verify compliance with IEEE harmonic standards.

4. PROPOSED SYSTEM

4.1 Block Diagram of proposed system

The figure 3.1 illustrates the block diagram of a DC power supply system, comparing the configuration without any filter and with an LC filter for improved power quality and voltage regulation.

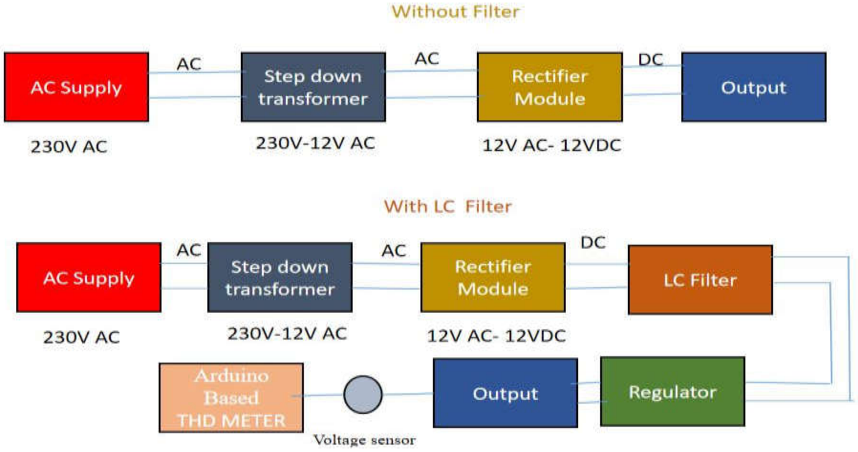

Figure 3.1 LC Filter Integration in Charging System

The 230V AC supply is stepped down to 12V AC using a step down transformer, then converted to 12V DC through a rectifier module, and directly fed to the output. In contrast, the setup with the LC filter includes an additional filtering stage after rectification, where the LC filter helps smooth the DC output by reducing ripple and harmonic content. This filtered voltage is then passed through a regulator to maintain a stable output. A THD meter and a voltage sensor are also included to monitor the system's power quality. This improved system highlights the effectiveness of LC filtering in enhancing voltage stability and minimizing harmonic distortions in power supply applications.

4.2 Filters in Electric Vehicle System

In electric vehicle systems, especially in charging infrastructure and power converters, harmonic distortion is a critical issue that affects power quality and system efficiency. To mitigate these harmonics, various types of filters are employed based on the application and level of distortion. Different type of filters to reduce harmonics in Electric Vehicle system, including passive filters (single-tuned, double-tuned, and high-pass) and active filters (shunt, series, and hybrid). These filters work by selectively filtering out harmonic frequencies or actively cancelling them out.

In this work, an LC filter (Inductor-Capacitor filter) is employed, consisting of an inductor and a capacitor arranged to smoothen the DC output from rectifiers or converters. Such filters are effective in minimizing voltage and current ripples, making them particularly suitable for suppressing low-frequency harmonics. They are widely adopted due to their simple structure, reliability, and cost-effectiveness. However, their performance is limited when it comes to mitigating higher-order harmonics, which may require more advanced filtering techniques.

4.3 Selection of LC Filter

An LC filter is selected in this work because it offers a simple, reliable, and cost-effective solution for reducing harmonics in EV charging systems. Its ability to attenuate low-frequency harmonics and smooth voltage and current waveforms makes it highly suitable for improving power quality without requiring complex control circuits.

Compared to more complex solutions like active or hybrid filters, the LC filters consume no additional power for operation, are easier to design and implement, and require lower maintenance with minimal control circuitry, making it ideal for experimental and small-scale implementations. It also offers sufficient performance to demonstrate the impact of filtering on output voltage quality, making it a practical choice for validating harmonic reduction in EV charging systems. Additionally, it serves as a foundational filter type, helping us understand the core effects of passive filtering before exploring more advanced methods.

5. METHODOLOGY

The methodology adopted in this study begins with analyzing the harmonic distortion introduced by rectifiers and converters in EV charging systems. Based on this analysis, an LC filter is designed by selecting appropriate inductance and capacitance values to target low-frequency harmonic suppression. The proposed system is modeled and simulated in MATLAB/Simulink to evaluate its performance under different load conditions and to measure the resulting Total Harmonic Distortion (THD). Following simulation validation, a hardware prototype of the EV charging circuit integrated with the LC filter is developed, and real-time THD measurements are carried out. Finally, the performance of the system with and without the filter is compared to verify compliance with IEEE-519 standards.

Step 1: A 230V, 50Hz AC mains supply is used as the input to the system. This serves as the standard electrical power source commonly available in residential and industrial settings. The methodology of this work is carried out in the following steps:

Step 2: The 230V AC is stepped down to 12V AC using a step-down transformer. This transformation ensures the voltage is reduced to a safer level suitable for low-voltage electronic components.

Step 3: The 12V AC output from the transformer is fed into a full-wave bridge rectifier circuit. This rectifier converts the AC voltage into a pulsating DC signal by allowing current to flow in only one direction.

Step 4: The rectified output is a 12V pulsating DC voltage. Though the current is unidirectional, it still contains ripples due to the alternating nature of the input source.

Step 5: An LC filter is designed and connected at the output of the rectifier. The inductor (L) resists sudden changes in current, and the capacitor (C) minimizes voltage variations. Together, they function as a low-pass filter to reduce ripple and harmonics, producing a cleaner DC output.

Step 6: A microcontroller is employed to measure the THD in the filtered DC output. It samples the voltage waveform and performs harmonic analysis using algorithms such as Fast Fourier Transform (FFT).

Step 7: The calculated THD value is displayed on an LCD module connected to the microcontroller. This provides real-time feedback on the effectiveness of the LC filter in suppressing harmonics and improving power quality.

Based on this analysis, an LC filter is designed by selecting suitable inductance and capacitance values to suppress low-frequency harmonics. The EV charging system with the designed filter is then modeled in MATLAB/Simulink to analyze Total Harmonic Distortion (THD), followed by the development of a hardware prototype to validate the simulation results. Finally, real-time THD measurements are carried out, and the performance of the system with and without the LC filter is compared to ensure compliance with IEEE-519 standards.

6. WORK CARRIED-OUT

6.1 Software Implementation

The figure 5.1 represents circuit diagrams designed in MATLAB Simulink for a single-phase rectifier system, showcasing configurations both with and without LC filters for an R-load.

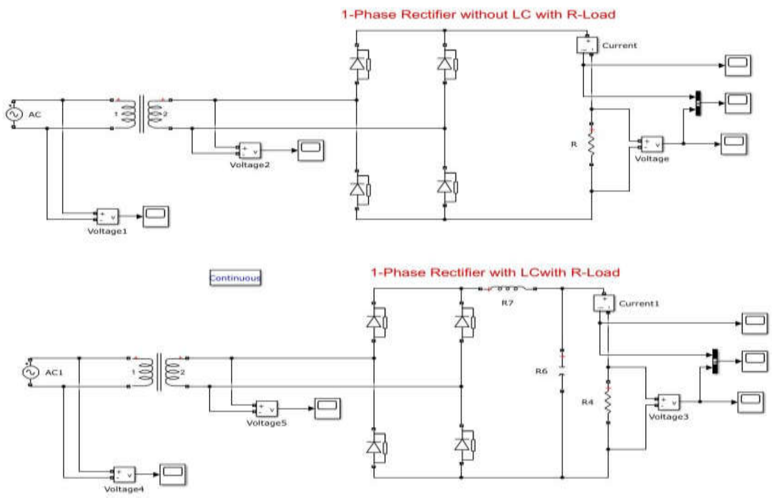

Figure 5.1 Simulation of Single-Phase Rectifier Circuits With and Without LC Filters Using MATLAB/Simulink

The single-phase rectifier circuits, both with and without LC filters, are designed and simulated using MATLAB/Simulink to analyze the impact of filtering on the output voltage and current characteristics for an R-load.

6.2 Simulation Result

The following simulation results illustrate the behavior of filters in a charging system, comparing their performance with and without the filter to highlight the impact on efficiency and stability.

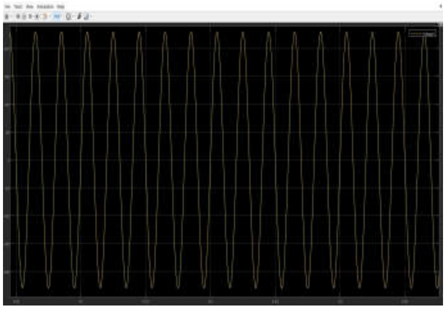

Fig 5.2.1 AC Input voltage Waveform

The figure 5.2.1 represents the simulated waveform of a 230-volt AC input voltage.

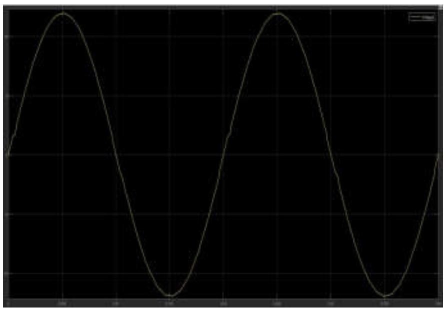

Fig 5.2.2 AC Step down voltage Waveform

The figure 5.2.2 represents the simulated waveform of a 230-12volt step down AC voltage.

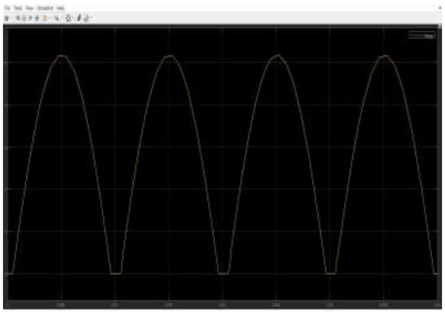

Fig 5.2.3 Rectified DC Output voltage

The figure 5.2.3 represents the simulated waveform of a Rectified DC output voltage.

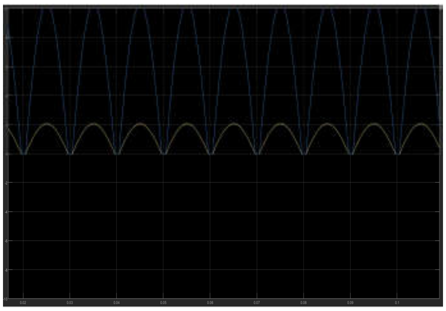

Fig 5.2.4 Output voltage and current waveform without filter

The figure 5.2.4 represents the simulated waveform of output voltage and current waveform without filter.

Fig 5.2.5 Output voltage and current waveform with LC filter

The figure 5.2.5 represents the simulated waveform of output voltage and current waveform with LC filter.

6.3 Hardware Implementation

The figure 5.3 shows the practical setup of an LC filter circuit designed to smooth the output of a rectified signal, integrated with an Arduino for monitoring and control, and an LCD display for real-time output visualization.

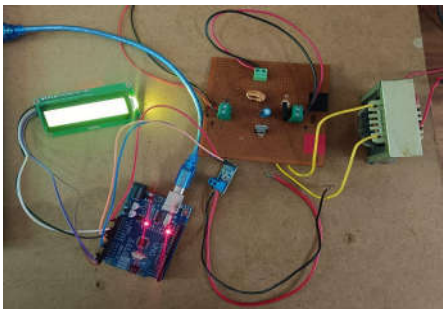

Fig 5.3 Hardware Implementation of LC Filter Circuit with Arduino Interface and LCD Display

6.4 Hardware Result

The hardware output, with and without the filter, is shown, highlighting the THD, ripple, and voltage levels.

Fig 5.4.1 Output in THD Meter as observed Without filter

Figure 5.4.1 represents the output without the LC filter, where the LCD display shows a voltage of 13.03V, a ripple voltage of 41.02V, and a significantly increased THD of **41%.**

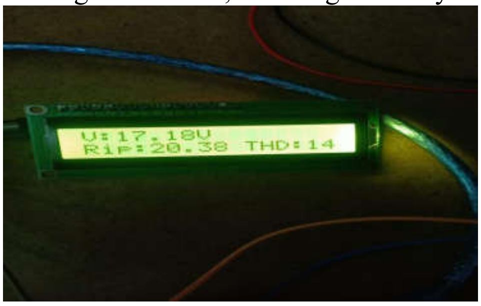

Fig 5.4.2 Output in THD Meter as observed With filter

Figure 5.4.2 represents the output with the LC filter, where the LCD display shows a voltage of 17.18V , a ripple voltage of 20.38V, and a significantly decreased THD to **14%.**

The final results indicate that, without the LC filter, the system exhibits a voltage of 13.03V, a ripple voltage of 41.02V, and a THD of **41%.** However, when the LC filter is applied, the ripple voltage decreases to 20.38V, and the THD is significantly reduced to **14%,** demonstrating the effectiveness of the filter in improving performance with a net reduction of **65.85%** of THD.

7. CONCLUSION

The results demonstrate that the addition of the LC filter plays a crucial role in improving the performance of the system. Simulation results in MATLAB/Simulink, supported by hardware validation, confirm a significant reduction in VTHD, bringing performance closer to IEEE-519 standards. By reducing ripple voltage and THD, the filter enhances voltage stability and overall efficiency. This shows the importance of incorporating such filters in systems where power quality and performance are critical. The findings underline how simple modifications can lead to significant improvements in system behavior and reliability.

The filter's simplicity, cost-effectiveness, and reliability make it a practical solution for improving grid stability and extending the lifespan of EV batteries and power electronic components. Although LC filters have limitations in eliminating higher-order harmonics, the achieved reduction highlights their suitability for medium- and low-power EV charging applications.

8. Future Scope

The scope of this work can be extended by focusing on improvements in key performance parameters such as power factor, voltage stability, and overall system efficiency. Further evaluation may also include the design and testing of filters for different EV charger ratings to enhance scalability. In addition, future research can explore advanced solutions such as active or hybrid filters, AI-based control strategies, and the integration of renewable energy sources with EV chargers to achieve more efficient, intelligent, and sustainable charging systems.

REFERENCES

[1] *"Analysis of the Impact of EV Charging on THD, Power Factor and Power Quality of Distribution Grid", Md. Mostafa Faruk; Nazifa Tabassum Khan; Md. Abdur Razzak, 2021 Innovations in Power and Advanced Computing Technologies (i-PACT), DOI: 10.1109/i-PACT52855.2021.9697024.*

[2] *"Power Quality Enhancement Using Passive Power Filters", Gunjan Varshney, Udit Mittal, and Abhilasha Pawar, Macromolecular Symposia - February 2023, DOI:10.1002/masy.202100442*

[3] *"An Effective Filter Design For Single-Phase Inverters", Yaheya Al Aman, Asim Datta, 2023 IEEE Guwahati Subsection Conference (Gcon), DOI:10.1109/Gcon58516.2023.10183529*

[4] *"Harmonic Sources Modeling and Characterization in Modern Power Systems: A Comprehensive Overview", Zhe Hu, Yang Han, Amr S. Zalhaf, Siyu Zhou, Ensheng, Zhao, Ping Yang , Electric Power Systems Research, Volume 218, May 2023, https://doi.org/10.1016/j.epsr.2023.109234.*

[5] *"Harmonic Mitigation Using Active and Passive Filters", M Upanya, S Anushree, Mohammed Masood, G N Deekshitha, K P Naveena Kumara, 2025 International Conference on Sustainable Energy Technologies and Computational Intelligence (SETCOM), 10.1109/SETCOM64758.2025.10932454.*

[6] *Effect of battery storage based electric vehicle chargers on harmonic profile of power system network, current scenario and future scope, Shirazul Islam, S.M. Muyeen, Atif Iqbal, Farhad Ilahi Bakhsh, Lazhar Ben-Brahim, Journal of Energy Storage, Volume 131, Part B, 30 September 2025, doi.org/10.1016/j.est.2025.117563*

[7] *"Investigating power quality issues in electric buggy battery charger systems: analysis and mitigation strategies", Wan Muhamad Hakimi Wan Bunyamin, Samshul Munir Muhamad, Wan Salha Saidon, Rahimi Baharom, International Journal of Electrical and Computer Engineering (IJECE) Vol. 15, No. 3, June 2025, pp. 2534~2544 ISSN: 2088-8708, DOI: 10.11591/ijece.v15i3.pp2534-2544.*

[8] *"L-C filter design implementation and comparative study with various PWM techniques for DCMLI", Manoj D. Patil, Rohit G. Ramteke, 2015 International Conference on Energy Systems and Applications, DOI: 10.1109/ICESA.2015.7503369.*