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Optimizing Power Quality in Electric Vehicles with AI-Driven Series Active Filters

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Abstract

This paper explores the enhancement of power quality in electric vehicles (EVs) through the application of artificial intelligence (AI) in series active filters. As EVs become increasingly prevalent, maintaining high power quality is crucial for their efficient operation and longevity. Traditional methods of power quality management face limitations in adaptability and real-time performance. By integrating AI algorithms with series active filters, this research aims to develop a more responsive and intelligent system capable of dynamically adjusting to varying power conditions. The proposed approach leverages machine learning techniques to optimize filter performance, reduce harmonics, and improve overall system stability. Preliminary results demonstrate significant improvements in power quality metrics, showcasing the potential of AI-driven solutions in advancing EV technology. The demand for improving power quality, particularly in single-phase systems with various loads, has led to the simulation and analysis of a hybrid series active filter in the MATLAB environment. Unlike conventional setups, this hybrid configuration excludes a transformer in its circuit. The objective of this study is to address power quality issues and devise effective solutions, contributing to the mitigation of power-related problems. With a primary focus on power quality challenges associated with electrical vehicular transportation and diverse loads connected to the grid, this paper aims to provide insights into energy utilization and power quality optimization. The analysis centers on formulating a control strategy specifically tailored to reduce harmonic distortions in current waveforms, particularly concerning nonlinear and critical loads connected to the utility grid.

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The proposed control scheme not only targets the enhancement of power quality but also seeks to improve the power factor.

Keywords: Electric Vehicles, Filter performance, AI driven model

1. Introduction

This hybrid series active filter configuration is anticipated to be highly beneficial in mitigating common power system issues, including voltage-based sags, swells, and interruptions. By presenting a novel approach to power quality enhancement, this study contributes to the ongoing efforts to create resilient and efficient power systems, crucial for the seamless integration of electrical vehicles and various loads into the utility grid.

The increasing adoption of electrical energy-based charging stations for vehicular applications necessitates a comprehensive study of the potential adverse effects arising from the connection of charging units to the utility grid. This paper addresses the critical concern of power distribution, specifically focusing on the harmonic voltage and current levels associated with these charging systems. The surge in harmonic content, particularly induced by non-linear loads from electric vehicles, poses a significant threat to the stability of the power grid, potentially leading to increased heating losses and system failures [1-2].

To mitigate the impact of power electronics devices on the grid, the utilization of active filter circuits becomes imperative. This study explores the application of active filters, differentiating between series and shunt active filters, with a particular emphasis on the underexplored area of single-phase systems. While series filters, such as the Dynamic Voltage Restorer, are effective for voltage-related issues in specific applications, the paper introduces the concept of a hybrid active filter without a transformer [3-4].

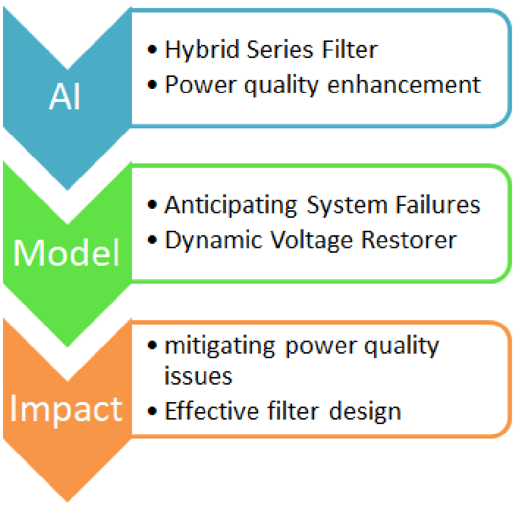

Figure: 1 Optimizing Power Quality in Electric Vehicles

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With a dearth of literature addressing single-phase systems and harmonic-related analyses, this research fills a crucial gap by simulating and examining the performance of a single-phase hybrid filter in MATLAB. The objective is to evaluate the effectiveness of this filter in reducing disturbances and mitigating power quality issues associated with harmonic content, ultimately contributing to the development of resilient and efficient power systems in the era of electric vehicle charging stations [5-6].

2. System Configuration

The proposed system configuration involves the integration of a single-phase hybrid active filter into the power distribution network to address the adverse effects of electrical energy-based charging stations for electric vehicles. This configuration aims to mitigate the potential harmonic distortions introduced by non-linear loads associated with vehicular charging applications. The hybrid active filter, distinctively designed without the inclusion of a transformer, serves as a proactive solution to reduce disturbances and improve power quality within the single-phase system. The choice of a hybrid filter allows for a versatile and efficient approach to combating harmonic-related challenges, which are particularly critical in the context of the increasing demand for electric vehicle charging infrastructure. The simulation of this system in MATLAB enables a comprehensive analysis of its performance, offering valuable insights into its effectiveness in minimizing the impact of voltage and current harmonics on the power grid and enhancing the overall stability and reliability of the electrical system [7-8].

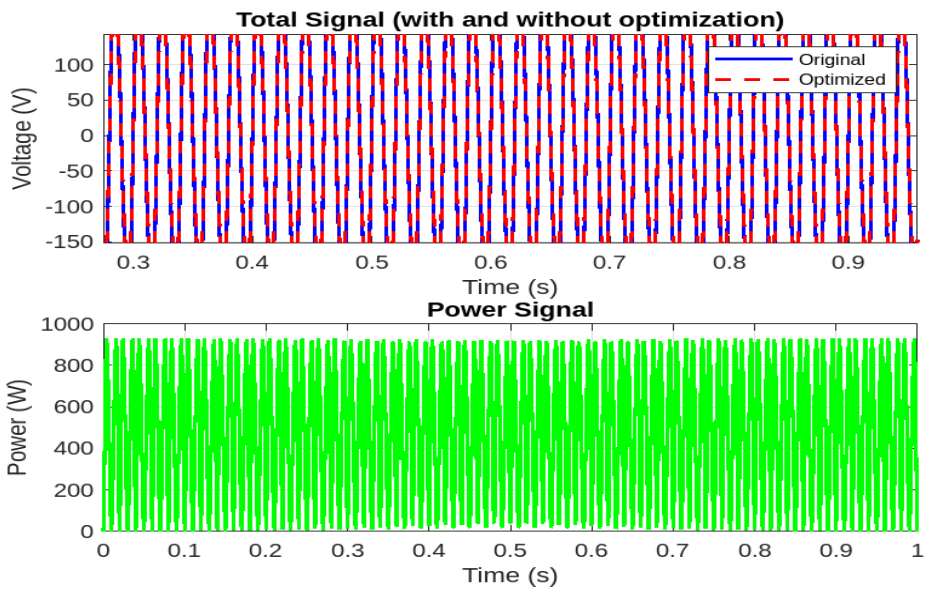

Figure: 2 Power Signal with active filter and grid representation

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Fig. 2 illustrates the comprehensive system configuration comprising an active filter connected to a metering unit, with the meter further linked to the utility grid. The series Active Power Filter plays a pivotal role in harmonics compensation within the system, enhancing power quality. The control strategy involves regulating the voltage injected by the active power filter to achieve the desired compensation. To execute this control strategy, the first step involves generating a reference voltage, which, when injected by the active power filter, serves as a benchmark for the compensation task. The actual output voltage of the series active filter is then controlled using a Proportional-Integral (PI) controller to match the reference value.

It provides an overview of the overall block diagram, featuring an H-bridge converter circuit connected in series between the source and load. A shunt passive capacitor facilitates a low-impedance path for current harmonics. Additionally, a DC additional power source is integrated to inject power during voltage sag conditions. The hybrid series active filter configuration is adept at compensating various distortions associated with current from non-linear loads, showcasing its utility in improving power quality [9-11].

3. Proposed Methodology

The presence of non-linear loads supplying the grid is shown in figure 3, thereby introducing disturbances into the system. To mitigate these disturbances, the implementation of a hybrid series active filter without transformer circuitry is proposed. This configuration proves crucial in reducing the impact of nonlinear loads on the grid. The H-bridge converter, employing semiconductor devices like Insulated Gate Bipolar Transistors (IGBT), plays a pivotal role in the circuit.

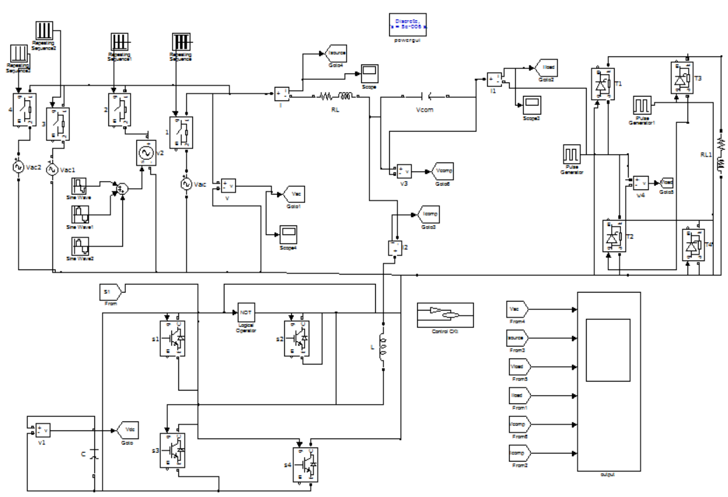

Figure: 3 MATLAB simulated circuit model

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A digital controller facilitates the transfer of pulses to the switching devices, ensuring precise control of the entire system. The combination of IGBTs with diodes allows for rapid and efficient switching, contributing to the overall effectiveness of the active filter.

Additionally, an additional power supply is incorporated into the circuit to enable the injection or absorption of power to and from the utility grid. This feature enhances the adaptability and responsiveness of the hybrid series active filter to varying conditions within the grid.

Artificial Intelligence (AI) has revolutionized various industries, and the automotive sector is no exception. The integration of AI-enabled Series Active Filters in vehicles represents a significant leap forward in enhancing vehicle performance, efficiency, and overall driving experience. Series Active Filters, equipped with advanced AI algorithms, actively monitor and analyze real-time data from various sensors and systems within the vehicle. This intelligent filtering system enables the vehicle to adapt dynamically to changing road conditions, traffic patterns, and driver behavior. By continuously optimizing power distribution, engine performance, and other critical parameters, AI-enabled Series Active Filters contribute to improved fuel efficiency, reduced emissions, and enhanced safety. Moreover, these filters can learn from historical data, making them capable of predicting and preemptively addressing potential issues, leading to a more reliable and resilient automotive ecosystem. As AI continues to evolve, the integration of Series Active Filters in vehicles not only transforms how they operate but also sets the stage for a smarter, more interconnected transportation future.

A tuned passive filter is an integral component of the circuit, serving the essential function of compensating for current-related issues and maintaining a consistent voltage at the load side, free from distortions. This configuration, with its advanced control mechanisms and tuned passive filter, positions itself as a robust solution to enhance power quality by effectively addressing disturbances introduced by non-linear loads in the electrical grid

4. Simulation Results

The electrification of transportation, particularly the widespread adoption of electric vehicles (EVs), has become a pivotal aspect of sustainable energy initiatives. As the demand for EVs grows, the associated power systems face challenges related to power quality, necessitating advanced solutions for efficient and reliable operation. This study focuses on the simulation analysis of a series active filter designed to address power quality issues in the context of an electric vehicle's power system. Electric vehicles, while contributing to reduced carbon emissions, introduce dynamic and nonlinear loads to the power grid. These loads can result in power quality issues such as harmonic distortions, voltage fluctuations, and unbalanced conditions. The series active filter emerges as a promising technology to mitigate these challenges by actively compensating for disturbances and harmonics within the EV power

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system.

This research delves into the simulation analysis of a series active filter, exploring its effectiveness in enhancing power quality and maintaining a stable and efficient electrical environment for electric vehicles. The study aims to provide valuable insights into the application of advanced filtering technologies, offering a pathway for the integration of electric vehicles into power systems with minimal impact on overall power quality.

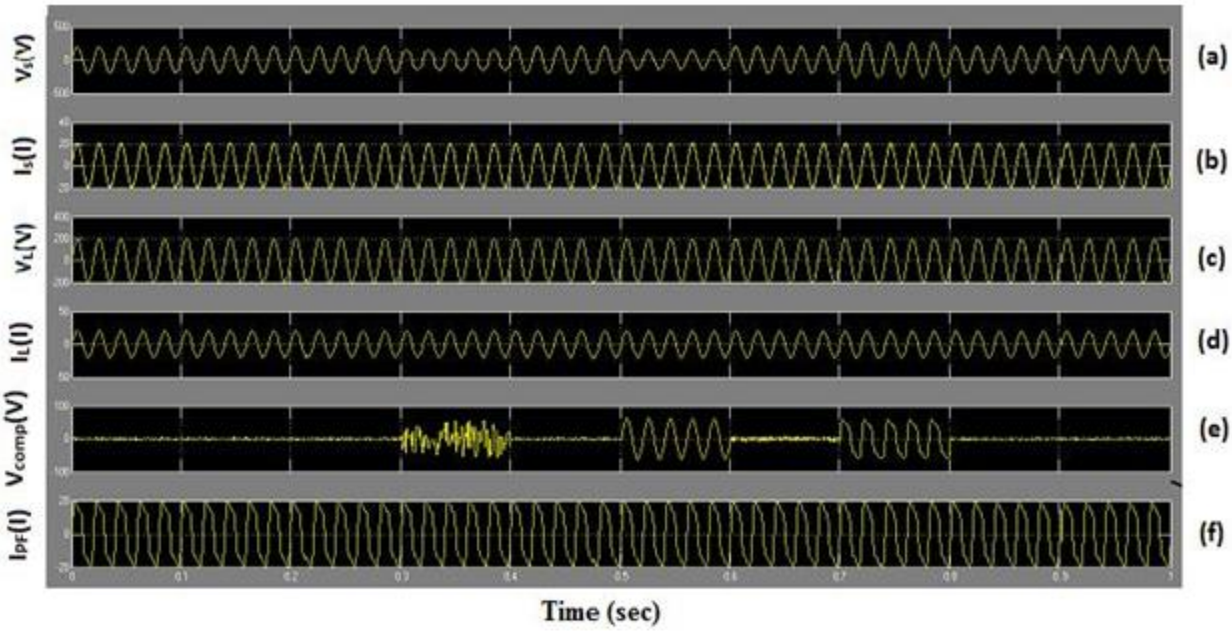

Figure: 4 Simulation of whole system along with the filter circuit compensating current

The provided figures offer a dynamic representation of the system behavior over time, depicting significant events and responses within the electrical network. At t = 0.3 seconds, this illustrates the formation of harmonics in the source voltage, showcasing the disturbances introduced to the system. This is a critical time point where the quality of the source voltage is compromised. At t = 0.5 seconds, the system experiences sags in the source voltage, as depicted, indicating a temporary reduction in voltage levels. Subsequently, at t = 0.7 seconds, swells occur, further disrupting the normal voltage profile. These variations in source voltage can lead to adverse effects on the connected loads.

Figure illustrates the source current, providing insights into how the system responds to the disturbances in the source voltage. Concurrently, Figure 6(c) displays the load voltage, showcasing the successful clearance of disturbances and the restoration of a normal voltage profile. This is a significant achievement, demonstrating the efficacy of the implemented hybrid series active filter in mitigating the adverse effects of harmonics, sags, and swells.

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Figure shows the load current, reflecting the impact of disturbances on the current drawn by the load. Finally, Figure 4 presents the compensating voltage. At t = 0.3 seconds, the compensating voltage is activated, effectively reducing the harmonics present in the source voltage. Similarly, at t = 0.5 seconds and t = 0.7 seconds, the compensating voltage works to

alleviate voltage distortions caused by sags and swells, contributing to the overall improvement of power quality in the system. These dynamic visualizations provide a comprehensive understanding of the hybrid series active filter's effectiveness in maintaining a stable and high-quality electrical environment.

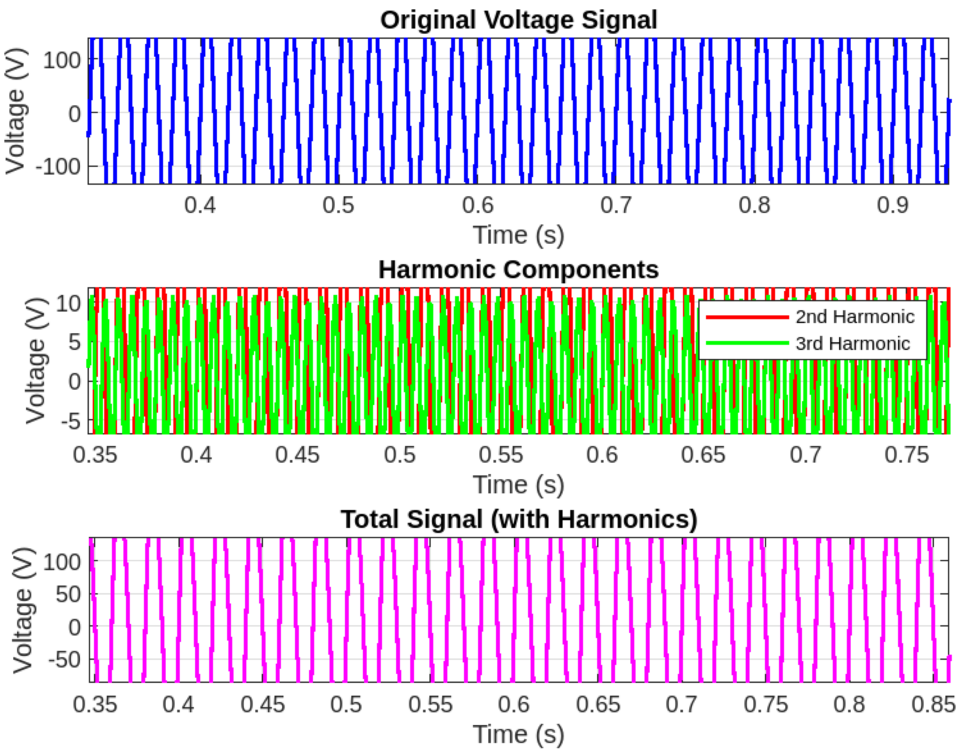

Figure: 5 Simulation of whole system along with the filter circuit voltage

5. Conclusion

This paper suggested and simulated a hybrid-based series active filter that notably excludes transformer circuitry. The primary focus is on investigating the effects of non-linear loads on the utility grid, with a specific emphasis on charging units in electric vehicle applications. The charging stations, integral to electric vehicle infrastructure, are identified as potential sources of harmonics injected into the grid. Consequently, the paper delves into effective methods for

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mitigating the impact of power electronics-based circuits on the grid. The highlighted circuit configuration, as presented in this paper, offers a solution that eliminates source harmonic currents, thereby enhancing the power quality of the grid. Notably, this improvement is achieved without the need for bulky and complex series transformers. By providing a simulation model for the hybrid-based series active filter, this paper contributes valuable insights into the development of efficient and compact solutions to address power quality issues arising from non-linear loads, particularly in the context of electric vehicle charging stations

References

[1] L. Jun Young and C. Hyung Jun, "6.6 kW Onboard Charger Design Using DCM PFC Converter with Harmonic Modulation Technique and Two Stage DC/DC Converter," IEEE Transactions of Industrial Electronics, volume. 61, pp: 1243-1252, 2014.

[2] P. T. Staats, W. M. Grady, A. Arapostathis, and R. S. Thallam, "A statistical analysis of the effect of electric vehicle battery charging on distribution system harmonic voltages," IEEE Transactions of Power Delivery, volume. 13, pp. 640-646, 1998.

[3] Z. Amjadi and S. S. Williamson, "Modeling, Simulation, and Control of an Advanced Luo Converter for Plug-In Hybrid Electric Vehicle Energy-Storage System," IEEE Transactions of Vehicular Technology, volume. 60, pp. 64-75, 2011.

[4] B. Singh and J. Gupta, "Improved Power Quality On-Board Charging Solution for Light Electric Vehicles," 2021 IEEE Transportation Electrification Conference & Expo (ITEC), Chicago, IL, USA, 2021, pp. 462-467, doi: 10.1109/ITEC51675.2021.9490189.

[5] T. Yadav and D. Yadav, "Integration of Electric Vehicle and Renewable Generation to Improve the Power Quality Problems in Distribution System," 2018 5th IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON), Gorakhpur, India, 2018, pp. 1-5, doi: 10.1109/UPCON.2018.8596941.

[6] R. Dwivedi, S. Singh and B. Singh, "A Single Phase Modified Bridgeless Single Ended Primary Induction Converter Based EV Battery Charger with Enhanced Power Quality," 2020 IEEE Students Conference on Engineering & Systems (SCES), Prayagraj, India, 2020, pp. 1-6, doi: 10.1109/SCES50439.2020.9236769.

[7] J. Gupta, R. Kushwaha and B. Singh, "An Isolated Improved Power Quality Battery Charger for a Light Electric Vehicle," 2020 IEEE International Conference on Power Electronics, Smart Grid and Renewable Energy (PESGRE2020), Cochin, India, 2020, pp. 1-6, doi: 10.1109/PESGRE45664.2020.9070696.

[8] U. Sharma and B. Singh, "A Bidirectional Electric Vehicle Charger for Wide Output Voltage Range Application," 2022 IEEE 2nd International Conference on Sustainable Energy and Future Electric Transportation (SeFeT), Hyderabad, India, 2022, pp. 1-6, doi: 10.1109/SeFeT55524.2022.9908943.

Power System Technology
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Received: 06-06-2024 *Revised: 15-07-2024* *Accepted: 28-08-2024*

[9] Deb and A. K. Jain, "Coordinated Charging Strategy of Electric Vehicles using Receding Horizon Technique to Maintain the Power Quality of Distribution Grid," 2022 IEEE 6th International Conference on Condition Assessment Techniques in Electrical Systems (CATCON), Durgapur, India, 2022, pp. 230-234, doi: 10.1109/CATCON56237.2022.10077706.
[10] H. V. M, D. Kumar and C. Kumar, "Dynamic Voltage Control Using Unified Power Quality Conditioner with Storage," 2021 IEEE 15th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG), Florence, Italy, 2021, pp. 1-6, doi: 10.1109/CPE-POWERENG50821.2021.9501203.
[11] Yeniu Qian, Zonghui Yuan, Peng Li, Jian Sun, Dongqiang Jia and Yan Zhang, "Flywheel energy storage UPS power supply vehicle and its application in Beijing security of power supply," 2016 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC), Xi'an, 2016, pp. 2514-2522, doi: 10.1109/APPEEC.2016.7779941.