



Design & Development Of Advanced Harmonic Mitigation Techniques For Grid-Connected Electric Vehicle Charging Stations: A Comprehensive Review

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Abstract

The rapid growth of electric vehicle (EV) adoption has introduced significant power quality challenges in modern distribution networks. Grid-connected EV charging stations, particularly fast chargers, behave as nonlinear loads that inject harmonic currents, increase Total Harmonic Distortion (THD), and degrade voltage quality. With increasing EV penetration, aggregated harmonic effects can lead to transformer overheating, additional power losses, and malfunction of sensitive equipment. This review paper examines harmonic generation in EV charging infrastructures and evaluates advanced mitigation techniques to maintain grid stability. Existing solutions including passive filters, active power filters (APFs), smart charging coordination, and renewable energy-assisted compensation are critically analyzed. Special attention is given to photovoltaic (PV)-assisted shunt active power filters and multilevel inverter-based compensation strategies that simultaneously supply clean energy and reduce harmonics. The review highlights control techniques such as synchronous reference frame theory, instantaneous power theory, and model predictive control for real-time harmonic cancellation. Key challenges including DC-link voltage stability, fluctuating renewable generation, and regulatory limitations are also discussed. The study concludes that integrated PV-storage active filtering solutions offer an effective and sustainable approach for harmonic mitigation in future high-density EV charging networks.

Keywords: Electric Vehicle Charging Stations, Harmonic Mitigation, Shunt Active Power Filter, Photovoltaic Integration, Power Quality etc.

1. Introduction

The global transition toward sustainable transportation has accelerated the adoption of electric vehicles (EVs) as a cleaner alternative to conventional fuel-powered automobiles. Governments and energy agencies worldwide are promoting EV deployment to reduce greenhouse gas emissions, improve urban air quality, and decrease dependence on fossil fuels. As EV adoption rises, the demand for reliable and efficient charging infrastructure has grown significantly. Grid-connected EV charging stations, particularly fast-charging systems, are increasingly being deployed in residential, commercial, and public locations to support this expanding fleet [1].

Despite their environmental benefits, EV charging stations introduce new technical challenges to power distribution networks. Most EV chargers rely on power electronic converters to convert AC supply to regulated DC power suitable for battery charging. These converters behave as nonlinear loads, drawing distorted currents that inject harmonic components into the grid [2]. Harmonic distortion degrades power quality by causing voltage waveform distortion, overheating of transformers and cables, increased system losses, and malfunction of sensitive electronic equipment [3]. Total Harmonic Distortion (THD) levels vary depending on charger topology, power rating, and operating conditions, with reported values ranging between 2% and 12% [4].

Fast chargers, typically rated between 43 kW and 150 kW, pose greater harmonic challenges due to high current demand and rapid switching operations. When multiple fast chargers operate simultaneously, harmonic currents may accumulate, increasing voltage distortion and reducing network efficiency [5]. With the projected growth of EV penetration, aggregated harmonic effects are expected to become a critical concern for distribution utilities and grid operators [6]. International standards such as EN 50160 specify that supply voltage THD should remain below 8% to ensure acceptable power quality; however, these standards often do not fully address harmonic impacts under high EV penetration scenarios [7].

Various techniques have been proposed to mitigate harmonics generated by EV charging systems. Passive filters have traditionally been used due to their simplicity and low cost, but they suffer from fixed compensation characteristics, resonance risks, and reduced effectiveness under varying harmonic spectra [8]. Active Power Filters (APFs), particularly shunt active power filters, offer dynamic harmonic compensation by injecting equal and opposite harmonic currents at the point of common coupling [9]. These filters can adapt to changing load conditions and provide reactive power support, improving overall system performance.

Recent research emphasizes the integration of renewable energy sources, especially photovoltaic (PV) systems, into EV charging stations. PV systems can supply clean energy while their inverters function as active filters to mitigate harmonics and provide reactive power compensation [10]. Multilevel inverter topologies, such as Neutral Point Clamped (NPC) inverters, have demonstrated superior harmonic suppression capabilities due to improved output waveform quality and reduced switching stress [11]. Advanced control strategies—including synchronous reference frame theory, instantaneous power theory, and model predictive control—enable real-time harmonic detection and precise compensation under dynamic operating conditions [12].

Although significant progress has been made in harmonic mitigation techniques, challenges remain in achieving continuous compensation under fluctuating renewable generation, maintaining DC-link voltage stability, and addressing aggregated harmonic effects in high-density EV charging environments. Therefore, a comprehensive review of harmonic mitigation techniques and integrated solutions is essential to support reliable and sustainable EV charging infrastructure development.

This review paper aims to examine harmonic generation in EV charging systems, evaluate existing mitigation strategies, and highlight emerging PV-assisted active filtering approaches for improving power quality in future smart grids.

2. Problem Identification

- Rapid growth of Electric Vehicles (EVs) has significantly increased the number of nonlinear charging loads connected to low-voltage distribution networks.
- EV chargers, especially fast chargers, draw distorted currents due to power electronic converters, causing high Total Harmonic Distortion (THD).
- Measured THD levels vary widely across EV models, ranging from 2–12%, making grid behavior unpredictable and difficult to manage.
- Some chargers exceed harmonic limits when operated below rated current (e.g., 32A chargers operating at 13A), violating standards for low-current modes.
- Accumulated harmonic injection from simultaneous EV charging can overload transformers, increase power losses, and reduce system efficiency.
- Existing grid regulations such as EN 50160 do not fully address harmonic challenges arising from high-density fast charging installations.
- High penetration of EV charging stations may cause voltage distortion, reduced power factor, and instability in weak distribution networks.
- Lack of built-in harmonic mitigation in commercial EV chargers necessitates an external active filtering solution.

- Conventional passive filters are bulky, nonlinear, and ineffective under dynamic EV charging conditions.

3.Literature Survey

A) *Literature Review*

Popescu, M. (2024), This topical review synthesizes developments in three-phase, three-wire shunt active power filters (SAPFs). It compares topologies, control strategies, reference current extraction methods, and practical implementation challenges. The authors highlight advances in multilevel inverters, predictive control, and reduced-switch-count SAPFs, and discuss trade-offs between harmonic compensation performance, control complexity, and semiconductor losses. Important attention is given to real-world deployment issues such as DC-link management, sensor requirements, and grid synchronization under unbalanced/ distorted conditions. The review concludes that predictive and adaptive control algorithms combined with multilevel topologies significantly improve compensation performance for modern nonlinear loads, while practical adoption depends on cost, reliability, and scalability.

Dash, D. K.; et al. (2023), review examines how active power filters (APFs) integrate with grid-connected renewable systems—especially PV—and their dual role as power inverters and harmonic compensators. It covers inverter topologies, MPPT-coupled boost converters, control methods (p-q theory, synchronous reference frame, predictive control), and energy-storage integration for continuity of compensation. The authors report that PV inverters with APF functionality can successfully reduce current harmonics, supply reactive power, and provide grid support but emphasize the need for advanced DC-link management and accurate harmonic detection under fluctuating PV generation. The review encourages co-design of MPPT and APF control to maximize both energy harvesting and power-quality services.

Srivastava, A.; et al. (2023), survey EV integration impacts on distribution networks, focusing on harmonics, voltage deviation, and hosting capacity. The review categorizes uncontrolled and controlled charging strategies, summarizes statistical methods and load-flow-based harmonic assessments, and compares mitigation techniques including smart charging, distributed storage, passive and active filters. Key findings indicate that harmonics from aggregated EV chargers can degrade voltage quality in weak feeders, and that coordinated solutions (smart charging + localized APFs) are more robust than isolated strategies. The paper stresses the importance of accurate modelling of on-board charger behaviour and regulatory updates to account for aggregated harmonic effects.

Nutkani, I.; et al. (2024), colleagues review EV charging impacts on feeder loading, thermal limits, voltage regulation and power quality. The paper synthesizes research on planning, siting, and grid upgrades, and discusses mitigation—demand response, energy storage, local generation and power electronics-based compensation. Findings highlight that harmonics are a localized but significant issue for hosting capacity and that fast chargers create distinct transient and harmonic challenges compared to slow charging. The review calls for combined strategies: network reinforcement where feasible, and smart, market-driven charging control plus APFs and distributed generation to preserve hosting capacity without costly upgrades.

K. V. Govardhan Rao et. al. (2024). review systematically surveys APF developments for harmonic reduction. It classifies APF implementations by topology (three-phase, single-phase, multilevel), control (SRF, p-q, instantaneous power, model-predictive), and optimization techniques. The review highlights that model predictive control (MPC) and adaptive reference extraction yield faster response and improved THD under dynamic loading. It points out practical limitations—sensor noise, computation burden, and DC-link energy requirements—and recommends hybrid APF designs with energy storage to maintain compensation during source interruptions or low renewable generation.

Draz, A.; et al. (2024), focus on distribution-level harmonic consequences of mass EV adoption. The review compares simulation-based studies that estimate voltage THD under various EV penetration scenarios, considers transformer and feeder heating impacts, and evaluates mitigation techniques

(passive filters, APFs, coordinated control, PV-assisted filtering). The authors find that PV-assisted SAPFs and local energy storage are particularly promising—providing both energy and dynamic harmonic compensation—while passive filters struggle with variable harmonic spectra typical of EV charging. The review highlights the need for standardized test protocols for charger harmonic emission and better aggregation models.

Kolantla, D.; et al. (2020), review analyzes inverter topologies for PV systems, including multilevel, NPC, and modular designs, emphasizing their performance as grid-interfacing converters and potential for APF duties. The paper compares efficiency, THD, switching complexity, and fault tolerance. It identifies three-level NPC and cascaded H-bridge multilevel inverters as favorable for low-distortion outputs and easier harmonic cancellation due to more voltage levels. The review recommends topology selection based on power rating and multifunctionality (energy injection + power-quality support), noting that control sophistication is essential to exploit topological advantages for harmonic mitigation.

Mehmood, A.; et al. (2025), present a recent assessment of modelling approaches for EV-driven power-quality issues and propose efficient grid models for rapid assessment. The review focuses on practical mitigation, concluding that coordinated PV+storage+APF systems enable significant THD reduction with lower distribution upgrades. It outlines control strategies for maintaining DC-link voltage amid fluctuating PV, and evaluates real-time compensation algorithms. The authors advocate integrated planning tools combining stochastic EV arrival models with power-quality assessment to devise cost-effective mitigation and regulatory strategies.

Tayri, A.; et al. (2025), compile recent research on EV grid impacts, emphasizing harmonic injection, peak demand, and network resilience. The review compares mitigation techniques—smart charging, vehicle-to-grid, local generation, and APFs—while evaluating their effectiveness under different network topologies. Key conclusions: APFs (including PV-assisted SAPFs) are highly effective for harmonic mitigation at local nodes; smart charging reduces peak-related stress but does not directly handle harmonics; combined strategies yield best outcomes. The paper recommends policy updates for charger harmonic limits and incentivizing multifunctional inverters at EV charging hubs.

Azizi, A.; et al. (2025), review surveys multilevel inverter topologies (NPC, flying capacitor, cascaded H-bridge) and control methods for high-power applications. The study highlights that multilevel NPC inverters deliver superior harmonic performance, reduced filter size, and compatibility with active filtering tasks. Control strategies assessed include predictive, space-vector modulation, and advanced balancing algorithms for capacitor voltages in NPC designs. Findings emphasize that implementing SAPF functions in multilevel inverters is practical and beneficial for high-power EV charging stations, provided robust DC-link balancing and high-speed control are deployed. The review encourages research on cost-effective semiconductor solutions to enable widespread adoption.

B) Literature Summary

Recent research highlights that electric vehicle (EV) charging stations introduce significant harmonic distortion due to nonlinear power electronic converters used in charging systems [1]. Studies show that Total Harmonic Distortion (THD) levels vary depending on charger topology, power rating, and operating conditions, with fast chargers producing higher harmonic currents [4][5]. The cumulative impact of multiple chargers can degrade voltage quality, increase transformer heating, and reduce distribution network efficiency [6]. Traditional passive filters have been widely used for harmonic mitigation; however, they suffer from resonance issues and fixed compensation characteristics [8]. Active Power Filters (APFs) provide dynamic compensation by injecting counteracting harmonic currents, improving power quality and reactive power support [9]. Recent works emphasize integrating photovoltaic (PV) systems with active filtering capabilities to supply clean energy while mitigating harmonics [10]. Multilevel inverter topologies such as Neutral Point Clamped (NPC) inverters enhance harmonic suppression and efficiency [11], while advanced control techniques enable accurate real-time harmonic detection and compensation [12].

C) *Research Gap*

Although existing studies provide valuable insights into harmonic mitigation in EV charging systems, several research gaps remain. Most investigations focus on individual chargers rather than large-scale charging stations where aggregated harmonic effects become significant [5][6]. Passive filtering methods remain widely discussed despite their limitations under dynamic EV charging conditions and varying harmonic spectra [8]. While active power filters offer improved compensation, limited research addresses integrated PV-assisted filtering systems capable of continuous harmonic mitigation during fluctuating solar generation [10]. Additionally, the performance of multilevel inverters such as NPC topology in EV charging environments requires further optimization for DC-link stability and capacitor voltage balancing [11]. Many studies emphasize harmonic detection techniques but provide limited analysis of adaptive real-time control under rapidly changing load conditions [12]. Furthermore, existing power quality standards do not fully consider high EV penetration scenarios, highlighting the need for scalable and coordinated harmonic mitigation strategies for future smart grid infrastructure [7].

4. Research Methodology

A) *Criteria for selecting this study:*

The selection of studies for this review is based on their relevance to harmonic distortion issues in grid-connected electric vehicle (EV) charging systems and the effectiveness of mitigation techniques. With the rapid growth of EV adoption and fast-charging infrastructure, maintaining power quality has become a critical research priority. Therefore, emphasis is placed on recent peer-reviewed research that addresses harmonic generation, advanced filtering methods, renewable energy integration, and smart grid compatibility. Studies focusing on photovoltaic (PV)-assisted active filtering, multilevel inverter topologies, and adaptive control strategies are prioritized due to their potential to provide sustainable and scalable solutions. Additionally, research examining real-world performance, simulation validation, and compliance with power quality standards is included to ensure practical applicability.

- Published in peer-reviewed journals and reputed conferences.
- Focus on EV charging harmonic distortion and power quality improvement.
- Inclusion of active filtering, PV integration, and smart grid approaches.
- Emphasis on multilevel inverter and advanced control strategies.
- Studies with simulation, experimental validation, or real-world case analysis.
- Recent publications to capture emerging technologies and trends.

B) *Method of analysis:*

This review adopts a systematic analytical approach to evaluate harmonic mitigation techniques used in grid-connected EV charging stations. The analysis begins by examining harmonic generation characteristics of EV chargers and their impact on distribution networks. Various mitigation strategies—including passive filters, active power filters (APFs), smart charging coordination, and PV-assisted compensation—are compared based on performance metrics such as Total Harmonic Distortion (THD) reduction, reactive power compensation, system efficiency, and implementation complexity. Special attention is given to multilevel inverter-based active filtering and advanced control techniques due to their superior harmonic suppression capability. The analysis also considers operational reliability under varying solar irradiance, dynamic loading conditions, and grid disturbances. Comparative evaluation helps identify the most effective and sustainable solutions for future EV charging infrastructure.

- Review harmonic generation patterns and charger characteristics.
- Compare mitigation techniques based on THD reduction and efficiency.
- Evaluate PV-assisted active filtering performance.
- Analyze inverter topology and control strategy effectiveness.
- Assess system stability under dynamic grid and solar conditions.
- Identify limitations and future improvement opportunities.

E) *Highlighting trends, advancements, and challenges*

Emerging Trends

- Rapid growth of EV adoption increasing harmonic stress on distribution networks.
- Expansion of fast-charging infrastructure demanding improved power quality solutions.

- Integration of renewable energy sources, especially PV, in EV charging stations.
- Increasing use of smart grid technologies for coordinated charging management.
- Shift toward multifunctional converters providing both power delivery and harmonic mitigation.

Recent Advancements

- Development of PV-assisted shunt active power filters for harmonic compensation.
- Adoption of multilevel inverter topologies for improved waveform quality.
- Advanced control methods such as SRF, p-q theory, and model predictive control.
- Real-time harmonic detection and adaptive compensation algorithms.
- Integration of battery storage systems for continuous filtering support.

Key Challenges

- Aggregated harmonic effects under high EV penetration remain insufficiently addressed.
- Maintaining DC-link stability during fluctuating solar generation.
- High cost and complexity of advanced active filtering systems.
- Lack of universal standards for harmonic limits in fast-charging stations.
- Ensuring reliable performance under dynamic load and grid disturbance conditions.

5. Discussion

A) Existing Configuration

Because of their effective generators, capacity to store excess energy to feed the grid, and the grid-to-capabilities, that promote peak periods and advance cleaner technology, plug-in electric cars, or PEVs, are growing in popularity. The public's desire, government laws, and technological developments have all helped to lower greenhouse gas emissions. Unfortunately, major voltage quality & harmonic distortion concerns have been brought about by the rapid rise of PEVs & the non-linearity of electricity transmission at charging stations. These issues have an impact on smart grid power transmission networks as well as alternative energy sources like wind and solar power.

Serious power quality issues, such as flicker, resonance, equipment disruption, transmission line losses, being heated, vibrations, sound, breakdowns, and defects in metering and delicate equipment, have been brought on by this proliferation in delivery feeders. Charging station currents, both sinusoidal and non-sinusoidal, greatly increase harmonic or fundamental losses. In order to address these problems, it is recommended to install an active filter in conjunction with charging stations. This will lessen the harmonics that the stations introduce and avoid temperature rise and additional damage.

PEVs are usually charged at power outlets, in customers' houses, or in parking lots, both public and private. The modernization of intelligent grids, which seek to modernise century-old transmission architectures to meet changing electrical needs, depends on this infrastructure for charging. Due to their high rating for rapid charging PEVs, charging stations, particularly those in suburban or light industrial regions, can stress the distribution systems by causing abrupt spikes in power consumption.

In addition, the demand for EVs has been strengthened by the volatile price of crude oil, which has increased the allure of electric vehicles. The distribution system's installation of charging points has increased as a result of this trend. Nevertheless, there may be an increase in power losses if multiple charging stations are installed haphazardly. These issues are further made worse by harmonic distortion brought on by the electronics control mechanisms at charging stations that change alternating current (AC) into direct current (DC). Reduced efficiency, a lower energy factor, greater insulation heat voltage, shorter insulation existence, and higher heating losses are just a few of the negative consequences that might result from this distortion.

Total distortion of harmonics, reactive energy distribution, and simultaneous voltage profile control are the subjects of one field of research. A lot of work has gone into integrating client-side needs into smart grids in order to lower peak demand and enhance the load profile of the system. The goal of this research is to ensure that intelligent grids can efficiently handle the changing demands of current electricity

consumption by addressing the issues brought about by the rapid deployment of PEVs & the accompanying infrastructure.[11], [12].

B) Proposed Configuration work

In order for Plug-in electric vehicle (PEVs) to compete with traditional gas stations as a long-distance transportation option, they must be widely deployed in a variety of places. These stations allow PEVs to be fast-charged in the same way as fuel-powered cars. Fig. 1 shows an example of a charging station intended for 10 fast electric car chargers. A 500 KVA step-down 20/0.4 kV the mains distribution transformer is used to link this station to the distribution network. Through the use of a sizable voltage diode rectifying device with the same rating, the transformer transforms AC power into the direct current (DC) energy required for battery charging.

Ten rapid charger sections, each with a standard DC bus, can fit in the suggested charging station. Ten PEVs can only be charged at a time at the station; this is comparable to the ability of ten traditional petrol stations. 50 kW is the maximum power that may be used to charge these 10 EVs. A 50 kW solar (PV) power plant is also included in the charging station. A high-frequency switch charger built into this PV system is intended to counteract high-order harmonics.

When these 10 EVs are linked for charging, the PV inverter is crucial in minimising harmonics. In addition to supporting the electric grid, the combination of a PV system and a high-frequency switch charge at the charging station helps to reduce harmonic distortion that is commonly brought on by numerous EV chargers operating at the same time. With this configuration, PEVs are guaranteed to charge effectively and consistently, which makes them a more sensible choice for long-distance driving and a step towards a cleaner energy economy.

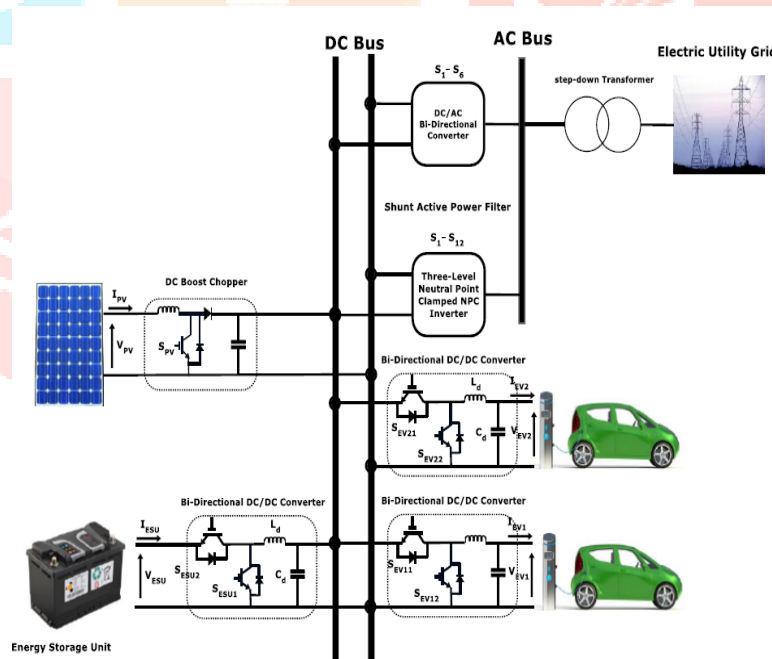


Fig.1. The proposed Electric Motor Plug-In charging station with ten (10) fast electric vehicle chargers.

The accompanying figure shows the suggested arrangement for the PV-centered shunt powered filters. This configuration consists of a bi-directional, two-phase DC/DC converter and a DC/AC converter, which work together to charge the battery. in a reversible chopper fashion. A three-level Neutral Position Clamped (NPC) inverter linked to the main grid is another element of the system. Each leg of the inverter has two clamping diodes and four adjustable switches (S_1 – S_4). At the AC terminal output from the inverter, there are three levels of voltage ($V_{DC}/2$, $-V_{DC}/2$, and 0) due to the equivalency of the two capacitance currents, V_{DC1} and V_{DC2} , within the DC connection.

In order to provide reactive and harmonic currents that balance out the nonlinear loads and reduce harmonic currents, the shunt active electricity filter works in tandem with a nonlinear load. The source current is effectively brought in phase with the input voltage, decreasing current harmonics, by introducing harmonic currents at the point of regular coupling that have identical but distinct phases to those of the nonlinear load.

As an inverter shunt supply for DC voltage, the suggested system combines a photovoltaic array with a DC-DC boost converter that offers Maximum Power Point Tracking (MPPT). The system has a converter from DC to DC that adapts to abrupt variations in weather that impact solar irradiation level and cell temperature settings since solar energy production is a variable process. The active power filter for PV shunts operates in three modes:

Inverter Mode: The system shares the regular load and adjusts for reactive or harmonic energy during the day or during periods of solar radiation. The PV array's extra capacity concurrently charges the battery.

In the compensator mode, the PV array does not receive active power as the unit makes up for variations in voltage, current, and reactive power. To guarantee constant compensation, the battery-connected DC-DC boost converter controls the DC-link.

UPS Mode: Using the solar panels and battery bank, the PV-Filter continuously supplies power to key loads day or night, even during voltage disturbances.

The major objectives of this system are to share the load, use renewable energy sources, keep the three-level neutral-point clamped inverters' DC link voltage constant for continuous compensation, and supply important loads with continuous power. The PV array contributes to voltage growth and stable DC link voltage by being coupled to a high-step-up DC-DC boosting converter. The PV array shares the electricity generated with the electrical grid during the day, and any extra power that isn't needed for compensation charges goes to the battery. During the night, the battery functions as the boost converter's DC source, guaranteeing constant compensation.

Furthermore, the approach reduces the requirement for UPSs and stabilisers for particular devices. To maximise the use of the PV setup, a low step-up converter from DC to DC featuring maximum voltage monitoring is installed between the photovoltaic system and battery. Results from experiments and simulations confirm that the suggested strategy works well.

Table 2: Main Parameters Considered for Study

Parameter	Description	Significance in Study
Total Harmonic Distortion (THD)	Measure of harmonic distortion present in current and voltage waveforms.	Indicates power quality level and effectiveness of harmonic mitigation techniques.
EV Charger Power Rating	Charging capacity (e.g., 3 kW slow charging, 50 kW fast charging).	Determines harmonic magnitude and grid loading impact.
Charging Mode	Different operating modes such as 13A, 32A, or fast DC charging.	Helps evaluate harmonic variation under different operating conditions.
Number of Connected EVs	Total EV chargers operating simultaneously.	Assesses aggregated harmonic impact on the distribution network.
DC-Link Voltage Stability	Voltage level across the inverter DC link.	Ensures stable inverter operation and continuous harmonic compensation.
PV Power Generation	Power produced by the photovoltaic system.	Supports load sharing and enables active filtering during daylight operation.
Solar Irradiance Variation	Changes in sunlight affecting PV output.	Evaluates system performance under dynamic renewable energy conditions.

Reactive Power Compensation	Ability to supply or absorb reactive power.	Improves power factor and enhances grid voltage stability.
Inverter Switching Frequency	Frequency at which inverter switches operate.	Influences harmonic suppression efficiency and system losses.
Grid Voltage Profile	Voltage stability at point of common coupling (PCC).	Determines overall power quality and system reliability.

C) *Analysis of data*

- **Data Collection:** Review datasets are gathered from e-commerce platforms containing review text, ratings, timestamps, and reviewer details.
- **Data Cleaning:** Irrelevant characters, stop words, duplicates, and noise are removed to improve data quality.
- **Text Preprocessing:** Reviews are tokenized and normalized through lowercasing and stemming to standardize textual content.
- **Feature Extraction:** Word frequency, keyword occurrence, review length, and sentiment polarity are extracted as key features.
- **Behavioral Analysis:** Reviewer activity patterns such as posting frequency, rating deviations, and repeated submissions are examined.
- **Labeling Process:** A portion of the dataset is labeled as spam or non-spam to support supervised learning.
- **Training Data Analysis:** Patterns and probabilities of word usage in spam and genuine reviews are computed.
- **Model Testing:** The trained classifier evaluates unseen reviews to determine classification accuracy.
- **Error Evaluation:** Misclassified reviews are analyzed to identify weaknesses and improve model performance.
- **Performance Metrics:** Accuracy, precision, recall, and error rate are calculated to assess system effectiveness.

6. Conclusion

The rapid expansion of e-commerce platforms has made online reviews a crucial factor influencing consumer purchasing decisions. However, the increasing presence of spam and deceptive reviews poses significant challenges to trust, transparency, and fair market competition. Fake reviews mislead customers, damage brand reputation, and distort product rankings, highlighting the urgent need for reliable detection mechanisms.

This review examined various approaches for detecting spam reviews, including linguistic analysis, behavioral modeling, machine learning classifiers, and deep learning techniques. Traditional methods such as Naïve Bayes, Support Vector Machines, and Decision Trees provide efficient and interpretable solutions, while advanced deep learning and network-based approaches enhance detection accuracy by capturing contextual patterns and coordinated spam behavior. Feature extraction techniques and reviewer behavior analysis further improve classification performance.

Despite significant progress, challenges remain due to evolving spam strategies, limited labeled datasets, and computational complexity. Future research should focus on hybrid, scalable, and explainable models capable of real-time detection and spammer community identification. Implementing such intelligent systems will improve consumer trust, support fair competition, and strengthen the reliability of e-commerce platforms.

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