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MITIGATION GRID HARMONICS IN A DISTRIBUTED ENERGY RESOURCE BASED EV CHARGING STATION THROUGH ADVANCED CONTROL STRATERGY

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ABSTRACT

The increasing demand for electric vehicles (EVs) requires the development of efficient and flexible EV charging stations that can seamlessly integrate with the electric grid. This paper presents a distributed energy resource (DER)-based EV charging station that leverages renewable energy sources such as solar and wind, along with battery storage systems. The proposed system ensures a seamless connection to the grid, allowing for bidirectional power flow, grid support, and energy optimization. An Artificial Neural Network (ANN) controller is utilized to optimize the power management strategy of the charging station. The ANN-based controller enables realtime adaptive control, balancing the power flow between the DERs, energy storage, and the grid to meet the dynamic demand of the EVs while maintaining grid stability. The controller ensures voltage regulation, current control, and minimization of power losses, thereby enhancing the overall efficiency and performance of the system. It also enables the charging station to supply power back to the grid in case of excess energy. Simulation and experimental results demonstrate the effectiveness of the proposed system in terms of improved energy efficiency, reduced charging time, and stable integration with the grid. This approach presents a promising solution for the development of sustainable EV charging infrastructure, supporting smart grid technologies and renewable energy integration

KEYWORDS—Adaptive comb-filter, distribution network, EV charging, fuel cell stack, grid connected mode, islanded mode, power quality, seamless power transfer, solar PV array, Artificial Neural Network(ANN).

1.INTRODUCTION

These distributed generations based on micro-generation sources provide an effective solution for power quality, technical, environmental and economic issues. The solar PV generation is gaining

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importance due to the abundant and inexhaustible supply of solar power. Furthermore, solar power generation guarantees low-carbon energy being fed into the grid. However, the unstable and intermittent nature of PV power affects the stability of system. Among different modes of PV power generation, rooftop PV array is gaining importance due to its ability to serve local loads, thereby, improving the system performance by reducing stress on the distribution feeder. Moreover, the encouragement provided by the government in the form of subsidies can also be attributed as a big factor in its increased usage. Due to the intermittent nature of the solar power, energy storage requirements are paramount, so that energy can be stored/delivered as per the requirements. In view of this, the utilization of battery is an efficient option, as uninterrupted power is also guaranteed to the critical loads.

The fuel cells are also gaining importance as eco-friendly energy sources, due to the reduced generation of nitrogen oxide and carbon dioxide gases per kilowatt of power, high efficiency and low fuel oxidation temperature Therefore, in order to fulfill the power demand along with the improvement in environmental conditions, the usage of distributed energy resources in a hybrid form complementing the variability of each is of paramount importance. In addition, the increase in the utilization of electric vehicles (EVs) is attributed to the fact that EVs act as highly flexible loads and, therefore, provide additional storage capacity in microgrids. In the changing solar insolation conditions are presented, which shows that during single mode of operation either islanded mode (IM) or grid mode (GM) the effects are worse. Thus, depending upon charging demand and PV generation, the charging station is designed here to operate in both modes. In addition, seamless change between the modes is ascertained in accordance with the controller design to utilize maximum PV power and to minimize the effect of erratic insolation. Thus, if only EV charging is achieved from the charging station, the underutilization of charging station resources is obtained.

The adaptive nature of the filter coefficients in correspondence with the error between the desired and output signals provides the key advantages in utilizing adaptive filters. Thus, the role of the adaptive comb-filter is to converge to an optimal state for reducing the error with a fast convergence rate and reduced complexity. In addition, the simplicity in structural implementation along with reduction in computational

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complexity are also obtained. Furthermore, the synchronization capability is also enabled, which in case of grid presence utilizes the utility grid as energy source/sink. However, during grid absence/outage, the solar PV and fuel cell stack systems provide power to the local loads, thereby, ensuring continuity in service. Thus, satisfactory performance is obtained with the utilization of control algorithms according to IEEE-1547 standard. Moreover, during the grid connected mode, harmonics are mitigated and the power quality improvement is achieved in accord with the IEEE-519 standard. Furthermore, fast charging of EVs is obtained here with the usage of common DC bus charging infrastructure, as the power is delivered directly to the EV battery, thereby, bypassing the on-board charger of EVs. Artificial Neural Networks, also known as "Artificial neural nets", "neural nets", or ANN for short, are a computational tool modeled on the interconnection of the neuron in the nervous systems of the human brain and that of other organisms. Artificial neural nets are a type of non-linear processing system that is ideally suited for a wide range of tasks, especially tasks where there is no existing algorithm for task completion. ANN can be trained to solve certain problems using a teaching method and sample data. In this way, identically constructed ANN can be used to perform different tasks depending on the training received. With proper training, ANN are capable of generalization, the ability to recognize similarities among different input patterns, especially patterns that have been corrupted by noise.

1.1 PROJECT OVERVIEW:

The increasing penetration of Electric Vehicles (EVs) and Distributed Energy Resources (DERs), such as solar photovoltaic systems, presents both opportunities and challenges for the power grid. While these technologies offer numerous benefits, the uncontrolled integration of EV charging stations, particularly those employing power electronic converters, can inject significant harmonic currents into the grid. These harmonics, which are distortions in the voltage and current waveforms, can lead to a cascade of problems, including increased power losses, equipment malfunction, reduced power factor, and even resonance phenomena.

This project aims to address this critical issue by developing and implementing an advanced control strategy, leveraging the power of Artificial Neural Networks

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(ANNs), to mitigate grid harmonics in a DERintegrated EV charging station. The project will begin with a thorough analysis and modeling of the harmonic generation characteristics of such a system, considering various operating conditions like different charging loads and DER output levels. This modeling phase will involve simulating the complex interactions between the grid, DERs, and EV chargers, accurately capturing the harmonic contributions of each component. Building upon this foundation, the project will then focus on designing an intelligent control strategy based on ANNs. The ANN will be trained to predict and dynamically compensate for the harmonic currents, effectively acting as a smart filter.

This involves selecting an appropriate ANN architecture, training it with simulated or experimental data, and meticulously optimizing its parameters for performance and efficiency. A crucial aspect of the project will be the real-time implementation and validation of the proposed control strategy. The performance of the ANN-based control strategy will be rigorously evaluated in terms of harmonic reduction, improvements in power quality metrics like Total Harmonic Distortion (THD), and overall system efficiency. These results will be compared with conventional control techniques to demonstrate the advantages of the proposed approach. Finally, the project will focus on optimizing the ANN architecture and control parameters to achieve the best possible performance, balancing harmonic mitigation effectiveness with computational efficiency for practical implementation. The successful completion of this project will contribute significantly to the development of a more robust and sustainable power grid, enabling the seamless integration of EVs and DERs while maintaining power quality and stability.

1.2 PROJECT OBJECTIVE:

The primary objective of a distributed energy resources (DER) based EV charging station with a seamless connection to the grid is to create a sustainable and efficient EV charging infrastructure. This involves reducing strain on the existing electricity grid by utilizing DERs like solar panels or battery storage, especially during peak charging times. The project aims to increase the use of renewable energy for EV charging, thereby minimizing reliance on fossil fuels. Furthermore, it seeks to improve grid resilience by providing backup power through DERs in case of outages. Optimizing energy costs for both EV owners and charging station operators is another key

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objective. Ultimately, the project aims to create an EV charging station that is smart, and helps to make the electrical grid cleaner and more stable.

2.LITERATURE SURVEY

In "Battery Energy Storage System (BESS) and Battery Management System (BMS) for Grid-Scale Applications," M. T. Lawder, proposes the current electric grid is an inefficient system that wastes significant amounts of the electricity it produces because there is a disconnect between the amount of energy consumers require and the amount of energy produced from generation sources. Power plants typically produce more power than necessary to ensure adequate power quality. By taking advantage of energy storage within the grid, many of these inefficiencies can be removed. When using battery energy storage systems (BESS) for grid storage, advanced modelling is required to accurately monitor and control the storage system.

A battery management system (BMS) controls how the storage system will be used and a BMS that utilizes advanced physics-based models will offer for much more robust operation of the storage system. The paper outlines the current state of the art for modeling in BMS and the advanced models required to fully utilize BMS for both lithium-ion batteries and vanadium redox-flow batteries. In addition, system architecture and how it can be useful in monitoring and control is discussed. A pathway for advancing BMS to better utilize BESS for grid-scale applications is outlined. In"Robust Energy Management for Microgrids with High-Penetration Renewables," Y. Zhang, N. Gatsis and G. B. Giannakis, explains due to its reduced communication overhead and robustness to failures, distributed energy management is of paramount importance in smart grids, especially in microgrids, which feature distributed generation (DG) and distributed storage (DS). Distributed economic dispatch for a microgrid with high renewable energy penetration and demand-side management operating in grid-connected mode is considered in this paper. To address the intrinsically stochastic availability of renewable energy sources (RES), a novel power scheduling approach is introduced.

The approach involves the actual renewable energy as well as the energy traded with the main grid, so that the supply-demand balance is maintained. The optimal scheduling strategy minimizes the microgrid net cost, which includes DG and DS costs, utility of dispatchable loads, and worst-case

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transaction cost stemming from the uncertainty in RES. Leveraging the dual decomposition, the optimization problem formulated is solved in a distributed fashion by the local controllers of DG, DS, and dispatchable loads. Numerical results are reported to corroborate the effectiveness of the novel approach. In "Optimal Offering Strategy for Concentrating Solar Power Plants in Joint Energy, Reserve and Regulation Markets," G. He, Q. Chen, C. Kang and Q. Xia, describes a concentrating solar power plant with thermal energy storage could also provide ancillary service in the reserve and regulation markets. On one hand, providing AS contributes to the flexibility of the power systems and increases the revenue of CSP plants.

On the other hand, the flexibility of CSP plants to accommodate solar energy, which is of great uncertainty, might be significantly weakened by an inappropriate offering strategy, e.g., offering excessive AS. Insufficient flexibility might cause massive solar energy curtailment and reduce the potential revenue. This paper develops a general model framework on the optimal offering strategy for CSP plants in joint day-ahead energy, reserve and regulation markets, which is robust for solar energy uncertainty and stochastic for market price uncertainty. On this basis, given the optimal day-ahead offering strategy, the offering curves to provide incremental In "Grid integration of three-phase single-stage PV system using adaptive laguerre filter based control algorithm under non-ideal distribution system," P. Shukl and B.

Singh, presents a single stage, three phase grid connected solar PV (Photovoltaic) system. The MPPT (Maximum Power Point Tracking) based on P&O (Perturb and Observe) technique is used to obtain maximum power of the PV array. An adaptive Laguerre filter based control algorithm is used for the control of VSC (Voltage Source Converter). For sustaining the voltage of DC link with the reference value, a PI (Proportional Integral) controller is used. The behavior of the grid connected solar PV system is studied on a laboratory prototype.

3.METHODOLOGY

The methodology for mitigating harmonics in DER-based EV charging stations involves a comprehensive approach integrating advanced power electronics, real-time monitoring, and dynamic control systems to minimize harmonic distortion and improve power quality. The system begins by addressing the harmonic generation in EV

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chargers, which are typically nonlinear loads that draw power in pulses, leading to harmonic currents. To mitigate these distortions, advanced power electronics, such as multilevel inverters and active power filters (APFs), are incorporated.

Multilevel inverters are utilized to convert DC power from renewable energy sources or the grid into AC power for EV charging. These inverters provide a smoother voltage waveform compared to traditional inverters, reducing the Total Harmonic Distortion (THD). The use of multilevel inverters ensures that harmonic distortion is minimized, improving the quality of power supplied to EV chargers. Additionally, active power filters are employed to dynamically filter out harmonic currents generated by the EV chargers. These filters operate in real-time, compensating for harmonic components by injecting compensating currents into the system.

The system also relies heavily on real-time power quality monitoring and control. Sensors are installed throughout the system to continuously monitor voltage, current, and harmonic levels. This data is sent to a centralized control system, which analyzes the harmonic content and takes corrective actions. The control system employs machine learning algorithms that predict the charging patterns of EVs and optimize the operation of the charging station to reduce harmonic distortion. These algorithms help anticipate peak charging times and adjust charging rates or schedules to prevent excessive harmonic generation. The control system uses feedback loops to adjust the inverter settings, filter operation, and energy storage systems in response to real-time power quality data.

Energy storage systems (ESS) are also integrated into the system to help smooth out fluctuations in power demand and reduce harmonic distortion. The ESS acts as a buffer, absorbing excess power during low demand periods and discharging it during high-demand periods. The control system manages the ESS dynamically to ensure that power fluctuations, and consequently harmonic distortion, are minimized. In addition to this, vehicle-to-grid (V2G) technology is employed, allowing EVs to supply power back to the grid during peak demand periods. The control system ensures that this reverse energy flow does not introduce additional harmonic distortions by adjusting the discharge rates of EVs as needed.

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The proposed system is designed to be scalable, meaning it can grow with the increasing demand for EV charging and renewable energy integration. The system architecture is modular, allowing easy expansion without affecting the harmonic mitigation performance. The flexibility of the system allows it to adapt dynamically to varying grid conditions and charging demands. As the number of EV chargers and renewable energy sources increases, the system can adjust to manage higher loads and more complex grid interactions effectively.

4.PROPOSED SYSTEM

The proposed system for mitigating harmonics in DER-based EV charging stations is designed to address the challenges of harmonic distortion caused by the growing adoption of electric vehicles and the integration of renewable energy sources. The system aims to provide a robust solution that ensures optimal power quality, stability, and scalability by utilizing advanced power electronics, real-time control strategies, and energy storage systems. The key features of the proposed system include advanced inverters, active power filters, predictive control algorithms, energy storage integration, and vehicle-to-grid (V2G) capabilities.

At the core of the proposed system is the use of multilevel inverters, which replace traditional inverters in the charging stations. These inverters generate smoother voltage waveforms by using multiple voltage levels, reducing the Total Harmonic Distortion (THD) significantly compared to conventional inverters. The use of multilevel inverters ensures better power quality by minimizing the generation of harmonics at the source, leading to cleaner power delivered to both the EV chargers and the grid.

In addition to multilevel inverters, the system integrates active power filters (APFs) that work in real-time to mitigate harmonic currents generated by the charging process. These filters actively measure the harmonic distortion and inject compensating currents into the system, effectively canceling out unwanted harmonic components. The dynamic nature of active filters makes them superior to passive filters, which are less adaptive to fluctuating load conditions and harmonic frequencies.

A central feature of the proposed system is the implementation of AI-based predictive control algorithms. These algorithms utilize

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machine learning techniques to predict the charging patterns of EVs and forecast grid demand, allowing the system to optimize the operation of the entire charging station. By analyzing historical charging data, the control system can anticipate peak demand periods and adjust charging rates or schedules to minimize harmonic generation during these times. The adaptive nature of the control system allows it to make real-time adjustments to the inverters, active filters, and other system components to ensure that harmonic distortion remains within acceptable limits.

5.EXISTING SYSTEM

The existing system for mitigating harmonics in DER-based EV charging stations primarily relies on traditional methods such as passive filters, basic inverters, and static power factor correction mechanisms. While these methods provide some level of harmonic mitigation, they are often insufficient for handling the growing complexity and load variations in modern charging stations. Existing systems typically focus on addressing harmonic issues in a reactive manner, without fully considering real-time grid dynamics or offering scalable solutions for the future expansion of EV charging infrastructure. Here's an overview of the existing systems:

One of the most commonly used methods in the existing systems is **passive harmonic filters**. These filters typically consist of inductors and capacitors designed to filter out specific harmonic frequencies generated by nonlinear loads, such as EV chargers. While passive filters are relatively inexpensive and easy to implement, they have limitations. For instance, they can only filter out a limited range of harmonics and are not adaptable to dynamic changes in the system, such as varying load conditions or different harmonic frequencies. Furthermore, passive filters may become less effective when the load conditions change over time, leading to potential inefficiencies in harmonic mitigation.

Another component of existing systems is **static power factor correction (PFC)**. PFC is used to improve the power factor by ensuring that the voltage and current waveforms are in phase. While PFC can reduce the overall reactive power, it does not directly address harmonic distortion. In fact, conventional power factor correction techniques, such as capacitive compensation, can sometimes exacerbate harmonic problems, especially when the

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charging load consists of high-frequency components or non-linear loads like EV chargers. Therefore, PFC alone is insufficient to mitigate harmonics effectively in DER-based charging stations.

Traditional grid-connected inverters are also part of the existing systems. These inverters convert DC power from renewable energy sources or storage systems into AC power for the EV charging process. While these inverters do provide some level of harmonic control by using pulse-width modulation (PWM), they are not always capable of adjusting to varying load conditions. In particular, basic inverters are often unable to optimize harmonic reduction in real-time, which results in higher Total Harmonic Distortion (THD) when the charging load fluctuates or during peak demand periods. This lack of flexibility means that traditional inverters are not well suited for the dynamic and growing needs of modern DER-based charging stations.

Additionally, **energy storage systems (ESS)** are sometimes used in existing systems to smooth out power fluctuations, but their integration is not always optimized for harmonic mitigation. In many cases, ESS are not dynamically controlled to reduce harmonic distortion during charging. They are typically used to store and discharge energy to balance intermittent renewable power generation or to support grid stability, but without specific controls for harmonic management, their impact on power quality can be limited.

Finally, **grid monitoring and control systems** in existing setups are usually simplistic, lacking the sophistication needed for dynamic or real-time harmonic mitigation. These systems primarily monitor overall power flow but do not have the advanced capabilities to assess and correct for specific harmonic issues. They are reactive in nature, meaning that harmonic mitigation is often implemented only after a problem has been identified, rather than proactively adjusting system settings to prevent harmonic distortion from occurring in the first place.

6.SIMULATION RESULTS

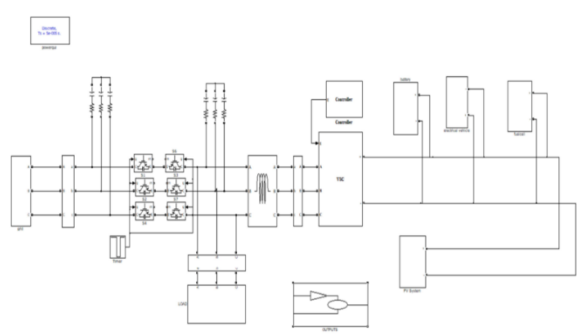

Fig: 1MATLAB Circuit Design

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This circuit depicts a controlled three-phase rectifier system designed for battery charging. Three-phase AC power is stepped down by a transformer, then converted to DC by a controlled rectifier (using IGBTs). A DC link capacitor smooths the rectified voltage. A DC-DC converter regulates the voltage and current to match the battery's charging needs. A PI controller ensures precise charging control. The system is modeled in MATLAB/Simulink for analysis and design. Performance of common DC bus charging of EVs with distributed microgrid consisting of solar PV array, battery and fuel cell sources is presented here, where an adaptive comb-filter and ANN Controller are utilized in order to improve the power quality and to reduce the grid harmonics.

The Simulation results are:

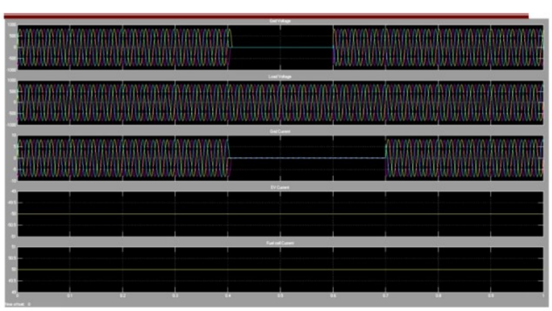

Fig:(a) Grid-Load-DVR-Fuel Cell Response Waveforms

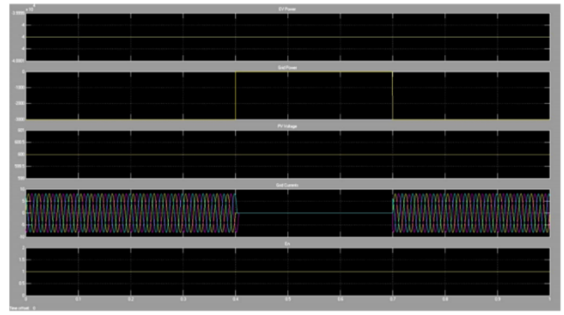

Fig:(b) Integrated EV Charging System Performance Waveforms with PV and Grid Dynamics

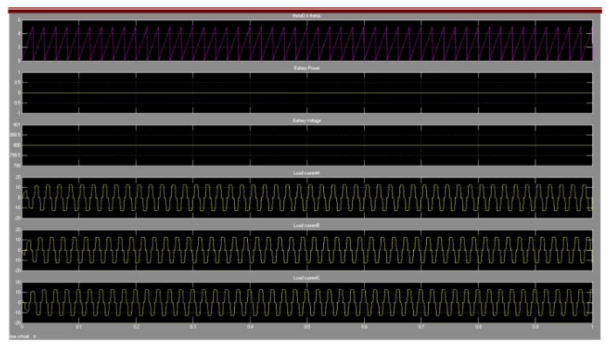

Fig:(c) DC Link, Battery, and Load Performance Waveforms

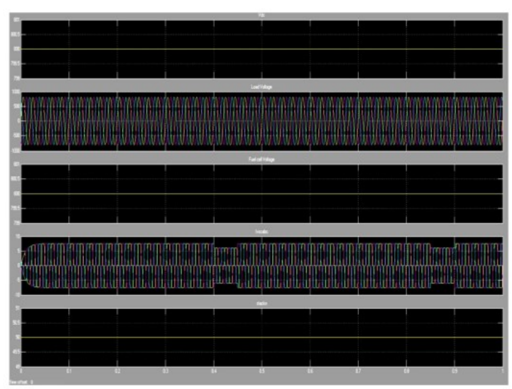

Fig:(d) Fuel Cell System Stability and Load Performance Waveforms

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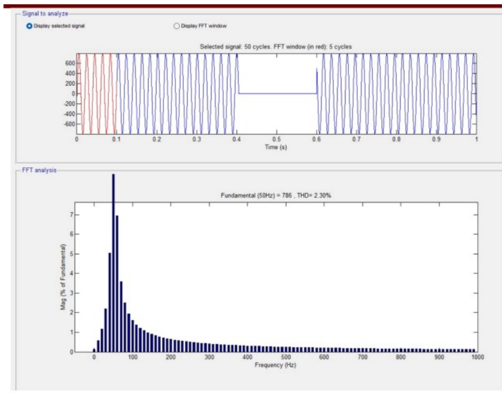

Fig: (e)FFT Analysis of Existing System

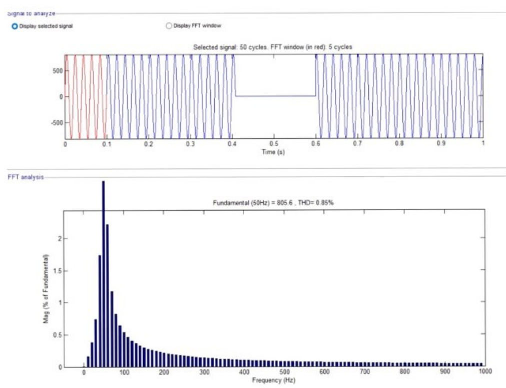

Fig:(f)FFT Analysis of Proposed System

7.CONCLUSION

Building upon the demonstrated performance of a common DC bus EV charging infrastructure utilizing hybrid Distributed Energy Resources (DERs) and adaptive combfilter based PI control, this project extends the analysis by implementing an Artificial Neural Network (ANN) based control strategy. The existing system, while effective in reducing inconsistencies from renewable sources and enabling fast EV charging, exhibited a Total Harmonic Distortion (THD). In this extension, the PI controller responsible for grid interconnection and standalone mode voltage control was replaced with an ANN controller. The FFT analysis of the proposed system, presented, demonstrates a significant reduction in THD, highlighting the superior harmonic mitigation capabilities of the ANN-based approach. This improvement not only enhances the power quality of the system but also ensures compliance with stringent IEEE standards, crucial for grid stability, where the integration of DERs and EV charging infrastructure is rapidly expanding. The successful implementation of the ANN controller showcases the potential of intelligent control strategies in optimizing EV charging infrastructure and facilitating a more reliable and sustainable power grid.

8.FUTURE SCOPE

1.Advanced Power Electronic Converters

- Development of advanced inverters and converters for EV chargers that are capable of filtering and reducing harmonic distortion.

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- Multilevel Inverters (MLI): These inverters can be used to reduce the Total Harmonic Distortion (THD) by producing higher-quality output voltage waveforms, which is crucial in a DER environment.
- Active Power Filters (APFs): These filters can be integrated into EV charging stations to actively mitigate harmonic currents generated by EV charging.

2. Artificial Intelligence and Machine Learning (AI/ML) in Control

- Predictive control algorithms: AI/ML can be used to predict the charging patterns of EVs and optimize the operation of the charging station, minimizing harmonic distortion in real-time.
- Adaptive control systems: AI can help to adapt the power flow and manage charging loads more efficiently while minimizing harmonic generation by adjusting charging cycles or load distribution.
- Harmonic detection and correction: Machine learning algorithms can detect harmonic issues early and make adjustments in real-time, improving the overall grid stability.

3. Integration of Energy Storage Systems (ESS)

- Energy Storage for harmonic mitigation: Energy storage systems, such as batteries or capacitors, can be used to absorb or release power to smooth out voltage fluctuations and reduce harmonics.
- Advanced control strategies for ESS: These systems can be controlled intelligently to support the grid by compensating for harmonics caused by the charging process.

4. Hybrid DER Systems

- Combined renewable energy sources and EV charging: Integrating hybrid systems of solar, wind, and battery storage in the EV charging stations can help minimize the grid’s reliance on non-renewable sources, and control harmonics more efficiently by distributing power generation locally.
- Optimized DER management using advanced controllers can dynamically manage the flow of energy from multiple

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sources, ensuring reduced harmonic emissions.

5. Demand Response and Load Management

- Demand-side management (DSM) strategies: These strategies could be used to control the charging cycles of EVs based on real-time grid conditions to minimize harmonics. By shifting charging times to off-peak hours, harmonic distortion can be reduced during peak demand times.
- Load balancing techniques within the charging station can also optimize harmonic mitigation by spreading out charging activities.

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