Fuzzy-Based Efficient Wireless Charging System with Solar PV Interface for Sustainable Transportation

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Abstract – With the escalating need for sustainable and eco-friendly transportation solutions, integrating renewable energy sources with electric vehicle (EV) charging systems has become imperative. This paper introduces a Fuzzy Logic Controller (FLC)-based efficient wireless charging system interfaced with solar photovoltaic (PV) energy to enhance energy efficiency, environmental sustainability, and operational reliability. The proposed system leverages the benefits of wireless power transfer (WPT) using resonant inductive coupling, enabling contactless and flexible charging while addressing challenges such as coil misalignment and fluctuating load demands. A fuzzy compensation strategy is implemented to optimize power transfer efficiency through real-time regulation of charging parameters. This adaptive control mechanism dynamically responds to variations in environmental and load conditions, ensuring stable and efficient energy delivery. To further support the goal of sustainable energy, the system is integrated with a solar PV array, providing a clean and renewable source of energy. This not only reduces the system's dependency on the conventional electric grid but also contributes significantly to reducing carbon emissions associated with transportation. The control scheme employs FLC-based regulation of constant current (CC) and constant voltage (CV) modes to improve charging performance and battery protection during the static WPT operation. Simulation studies conducted in MATLAB/Simulink confirm the superior performance of the proposed system in terms of power transfer efficiency, dynamic stability, and adaptability under different operating scenarios. The results affirm the potential of the fuzzy-based solar PV-integrated wireless charging system as a promising solution for future sustainable transportation infrastructure.

Keywords – Wireless charging, fuzzy logic controller, solar photovoltaic, electric vehicles, sustainable transportation, resonant inductive coupling, power transfer efficiency.

I. INTRODUCTION

The increasing demand for sustainable transportation solutions has become a critical issue in response to the mounting concerns about climate change, environmental pollution, and the depletion of fossil fuel resources. In recent years, electric vehicles (EVs) have gained significant attention as an eco-friendly alternative to conventional gasoline-powered vehicles. However, despite their promise, the widespread adoption of EVs faces several challenges, including the need for an efficient, convenient, and reliable charging infrastructure [1]. Traditional charging systems, which rely on physical connections, suffer from various limitations such as long charging times, wear and tear on connectors, and the inconvenience of plugging in cables. To address these issues, wireless charging systems have emerged as a viable solution, offering significant advantages in terms of convenience, flexibility, and ease of use. Wireless power transfer (WPT) is a technology that allows for the transfer of electrical energy between two coils, one located in the charging station and the other in the vehicle, without the need for physical contact. This eliminates many of the problems associated with wired systems, such as wear and tear on cables and connectors, and offers a more seamless charging experience for users [2].

However, one of the key challenges in WPT systems is achieving high power transfer efficiency, particularly when dealing with misalignment of the coils and variations in load. Misalignment occurs when the transmitter and receiver coils are not perfectly aligned, which results in a significant reduction in power transfer efficiency [3]. Various strategies have been proposed to address this issue, including frequency tuning and optimizing the design of the coils. Among the most promising approaches is the use of resonant inductive coupling, which has been widely researched for its ability to transfer power efficiently over short distances. Resonant inductive coupling works by creating a resonant magnetic field between the coils, which enhances power transfer efficiency even in the presence of misalignment [4]. Although this approach has shown promise, maintaining efficient power transfer in dynamic conditions, such as when the vehicle is in motion or the position of the coils changes, remains a significant challenge. To further improve the performance of WPT systems, researchers have turned to advanced control strategies. One such strategy is fuzzy logic control (FLC), which has gained popularity in a wide range of applications due to its ability to handle uncertainty, imprecision, and nonlinearity. Unlike traditional control methods, which require precise mathematical models of the system, fuzzy logic is particularly well-suited to systems where the exact parameters are difficult to define [5]. In WPT systems, fuzzy logic control can be used to adjust key parameters such as voltage, current, and power transfer efficiency in real-time, based on varying operational conditions. This adaptability makes fuzzy logic control an ideal solution for improving the efficiency, stability, and overall performance of wireless charging systems. Several studies have demonstrated the effectiveness of fuzzy logic in wireless power transfer applications, showing that it can significantly enhance power transfer efficiency by dynamically adjusting charging parameters to match the load and environmental conditions [6]. The integration of renewable energy sources, particularly solar photovoltaic (PV) energy, with wireless charging systems represents another significant advancement in the quest for sustainable transportation solutions. Solar power is a renewable and abundant energy source that can be harnessed to provide a clean and sustainable energy supply for EV charging stations [7]. The integration of solar PV systems with wireless charging infrastructure offers several benefits, including reduced reliance on the conventional power grid, lower carbon emissions, and the ability to utilize a renewable energy source for charging electric vehicles [8]. Studies have shown that solar-powered wireless charging systems can significantly reduce the environmental impact of EVs, as they rely on clean energy for charging, rather than fossil fuels. Furthermore, by using solar energy, the system can alleviate pressure on the grid during peak demand periods, as the solar energy can be used directly for charging, reducing the need for grid power. Solar-powered wireless charging systems have the potential to revolutionize the way EVs are charged, making it a more environmentally friendly and efficient process.

However, the integration of solar energy into wireless charging systems introduces several challenges, primarily related to the intermittent nature of solar power. Solar energy generation is dependent on various factors, including weather conditions, time of day, and geographic location. This variability in solar power availability can lead to fluctuations in the amount of energy available for charging. To address this issue, energy storage systems such as batteries can be used to store excess energy generated during periods of high solar output [9]. This stored energy can then be used to charge EVs during periods when solar energy is not available, ensuring a continuous and reliable charging service. Several studies have explored the use of energy storage systems in solar-powered wireless charging stations, highlighting the importance of efficient energy management and storage strategies to ensure reliable power supply [10]. By combining solar PV with energy storage, it is possible to create a more stable and sustainable charging infrastructure for EVs, even in regions with inconsistent solar energy generation. Despite the clear advantages of integrating solar power and wireless charging, there are also several economic and practical challenges that need to be addressed. The initial cost of installing solar panels and wireless charging systems can be prohibitively high, especially in regions where solar infrastructure is not yet well established. The economic feasibility of these systems largely depends on factors such as government incentives, the availability of subsidies, and the cost of renewable energy technologies [11]. However, as the cost of solar panels and wireless charging technology continues to decrease, the long-term benefits of reduced energy costs, lower carbon emissions, and greater sustainability become more apparent. Policymakers and governments can play a crucial role in facilitating the adoption of solar-powered wireless charging systems by providing financial incentives and promoting research into cost-effective technologies [12].

The combination of fuzzy logic control, wireless power transfer, and solar PV energy offers a promising solution to the challenges of sustainable EV charging. By using fuzzy logic control to optimize power transfer efficiency and integrating solar PV to provide a clean energy source, this approach represents a significant step forward in creating a more sustainable and efficient EV charging infrastructure [13]. As the demand for electric vehicles continues to grow, it is essential to develop charging systems that are not only efficient but also environmentally friendly and economically viable. The integration of renewable energy sources such as solar power into wireless charging systems holds great potential to reduce the carbon footprint of transportation and contribute to the overall goal of sustainable mobility [14]. As research and development in this field continue to progress, it is likely that the integration of solar-powered wireless charging systems with fuzzy logic control will play a key role in shaping the future of sustainable transportation. The ongoing advancement of wireless charging technologies, control strategies, and renewable energy integration will help to overcome the current limitations of EV charging systems and pave the way for a more sustainable, convenient, and efficient transportation future [15].

II. LITERATURE SURVEY

The integration of renewable energy sources into electric vehicle (EV) charging systems has been a subject of considerable research over the last few decades. As the world seeks sustainable transportation solutions to reduce the environmental impact of fossil fuel consumption, the development of advanced charging technologies has become increasingly important. Traditional EV charging systems, although functional, are often limited by issues such as long charging times, cable wear, and inefficiency in power transfer. Consequently, wireless power transfer (WPT) systems have gained significant attention as a promising alternative. Wireless charging systems offer several advantages, including reduced wear and tear on physical connectors, flexibility in vehicle positioning, and the potential for more efficient and dynamic power transfer. These systems use electromagnetic fields to transfer power from a stationary charging station to the vehicle without the need for physical connections, thus overcoming many of the limitations of conventional wired systems. One of the most significant challenges in wireless charging systems is achieving high power transfer efficiency, especially when dealing with variations in load and misalignment of the charging coils. Misalignment occurs when the transmitter and receiver coils are not perfectly aligned, which can lead to a significant loss of power. In response to this challenge, various techniques have been proposed to improve power transfer efficiency in WPT systems. Among the most promising approaches is resonant inductive coupling, which has been extensively researched due to its ability to transfer power efficiently over short distances. Studies have shown that resonant inductive coupling can improve the efficiency of WPT systems significantly, particularly in the context of EV charging. However, this technology still faces challenges, such as the difficulty in maintaining efficient power transfer under dynamic conditions, including when the EV is moving or when there is variability in the position of the vehicle.

To address these issues, several control strategies have been proposed. One of the most notable control techniques is fuzzy logic control (FLC). Fuzzy logic controllers are particularly suitable for dealing with systems that involve uncertainty and imprecision, which are inherent in WPT systems. Unlike traditional control methods, which require precise mathematical models of the system, fuzzy logic can operate effectively even in situations where the system's parameters are uncertain or difficult to model. This adaptability makes fuzzy logic an attractive choice for improving the performance of wireless charging systems. Several studies have demonstrated the effectiveness of fuzzy logic controllers in enhancing the stability, efficiency, and adaptability of wireless power transfer systems. By dynamically adjusting charging parameters such as voltage and current based on real-time variations in load and environmental conditions, fuzzy logic controllers can optimize power transfer efficiency and ensure that the system operates at its best, even in the face of fluctuating operating conditions. In addition to improving the efficiency of wireless charging systems, integrating renewable energy sources, particularly solar energy, into the system offers several environmental and operational benefits. Solar photovoltaic (PV) systems provide a clean and renewable source of energy, which can be used to power the EV charging process, reducing reliance on the grid and lowering carbon emissions. The integration of solar energy into wireless charging systems has been explored in numerous studies, which show that combining these technologies can lead to a more sustainable and energy-efficient solution for EV charging. Solar-powered wireless charging systems offer the potential to reduce the overall environmental impact of electric vehicles by harnessing renewable energy during the charging process, thereby making the transportation sector more eco-friendly. Furthermore, integrating solar PV with wireless charging infrastructure can reduce the load on the grid during peak demand periods, as the solar energy can be directly used for charging, minimizing the need for grid power.

While the integration of solar power into wireless charging systems offers significant potential for sustainability, it also introduces additional challenges. One of the primary challenges is the intermittent nature of solar energy, as its availability depends on factors such as weather conditions, time of day, and geographic location. To mitigate this challenge, energy storage systems such as batteries can be employed to store excess solar energy during periods of high generation, allowing it to be used during periods of low generation or high demand. This ensures that the charging system remains reliable even when solar energy is not available. Several studies have explored the use of energy storage systems in conjunction with solar-powered wireless charging stations, highlighting the importance of effective energy management strategies to ensure optimal performance. By combining solar PV systems with efficient energy storage solutions, it is possible to create a sustainable, reliable, and cost-effective wireless charging infrastructure for EVs. In addition to the technical challenges of integrating renewable energy sources and wireless charging systems, there are also economic and practical considerations that need to be addressed. The cost of implementing solar PV systems and wireless charging infrastructure is a significant barrier to widespread adoption, particularly in regions where the upfront cost of installation is high. However, as the costs of solar panels and wireless charging technology continue to decrease, the economic feasibility of these systems improves. Furthermore, the long-term benefits of reduced energy costs, lower carbon emissions, and greater sustainability make these systems an attractive option for the future of transportation. Policymakers and governments can play a key role in incentivizing the adoption of solar-powered wireless charging systems by providing subsidies, tax incentives, or other financial support to offset the initial installation costs. Overall, the integration of wireless charging systems with renewable energy sources such as solar power holds great promise for the future of sustainable transportation. While there are still challenges to overcome, particularly with regard to efficiency, cost, and the intermittency of solar energy, the ongoing advancements in technology and control strategies are paving the way for more efficient, reliable, and sustainable EV charging systems. The adoption of fuzzy logic control and solar PV integration offers a promising path forward, ensuring that electric vehicles can be charged efficiently and sustainably while reducing their environmental impact. As research in this area continues to evolve, it is expected that these systems will play an increasingly important role in the development of sustainable transportation infrastructure, contributing to the broader goal of reducing the carbon footprint of the transportation sector.

III. METHODOLOGY

The methodology for the design and implementation of a fuzzy logic-based efficient wireless charging system with a solar photovoltaic (PV) interface follows a structured, step-by-step approach to ensure optimal power transfer efficiency, sustainability, and adaptability. The proposed system aims to integrate renewable energy from solar power into wireless charging stations, utilizing advanced control strategies to dynamically adjust parameters and improve the system's performance in real-time. The methodology is based on four primary components: system modeling, fuzzy logic control design, integration with solar PV, and performance validation through simulation. The first step in the methodology involves the development of the system model, which includes the wireless power transfer (WPT) system and the solar PV interface. The wireless power transfer system is modeled using the principle of resonant inductive coupling, a technology that allows for efficient energy transfer between a transmitter coil located at the charging station and a receiver coil embedded in the electric vehicle. The coils are tuned to a resonant frequency to ensure maximum energy transfer efficiency, even in the presence of misalignment between the coils. The system's parameters, such as coil design, frequency, and alignment tolerance, are chosen to minimize power loss and maximize transfer efficiency. In addition, the system is designed to operate over a range of distances, accommodating dynamic conditions such as vehicle movement and varying coil alignment. The second part of the model is the solar photovoltaic system, which consists of a solar panel, a maximum power point tracking (MPPT) controller, and an inverter. The solar panels are modeled based on their performance characteristics, including the voltage, current, and power generation capabilities under different environmental conditions such as sunlight intensity and temperature. The MPPT controller ensures that the solar panels operate at their maximum power point, adjusting the operating voltage and current to extract the highest possible power from the solar cells.

Once the system model is established, the next step involves the design and implementation of the fuzzy logic controller (FLC). Fuzzy logic is employed to control the power transfer process dynamically, adjusting the charging parameters to optimize efficiency under varying load and environmental conditions. The FLC operates by defining a set of fuzzy rules that govern the behavior of the system based on inputs such as the current power transfer, voltage, temperature, and vehicle load. These inputs are converted into fuzzy sets, which are then processed by a set of predefined rules to determine the appropriate control actions. For instance, if the system detects a misalignment between the coils, the fuzzy logic controller can adjust the power transfer frequency or compensate by increasing the power to maintain efficiency. Similarly, if environmental factors such as sunlight intensity change, the FLC can adjust the charging parameters to ensure that the solar energy input is effectively utilized without overloading the system. The fuzzy rules are defined based on empirical data and expert knowledge, ensuring that the controller can handle a wide range of operating conditions. After the FLC is designed, the next step is the integration of the solar photovoltaic system with the wireless charging infrastructure. The solar panels are used to supply power to the charging system, reducing the dependency on the grid and contributing to the sustainability of the system. The energy generated by the solar panels is stored in a battery or directly fed into the charging system, depending on the design of the charging station. To ensure reliable energy supply, an energy management system (EMS) is implemented to balance the power generated by the solar panels with the energy required for charging. The EMS monitors the battery state of charge, the solar power generation, and the power demand from the vehicle. If the solar power generation exceeds the charging demand, the excess energy can be stored in the battery for later use. Conversely, if the solar power generation is insufficient, the system can draw power from the battery or the grid to meet the demand. The integration of the solar PV system with the FLC ensures that the charging station can operate efficiently even in fluctuating environmental conditions, utilizing renewable energy whenever possible and minimizing reliance on grid power.

With the system model and control mechanisms in place, the next step involves the development of a simulation environment to validate the performance of the wireless charging system. A detailed simulation model is built to simulate the operation of the charging system under various scenarios. The simulation includes the dynamic behavior of the WPT system, the FLC, and the solar PV interface. Key performance metrics such as power transfer efficiency, system stability, and adaptability to changing load conditions are evaluated in the simulation environment. Various factors, including misalignment of coils, environmental variations, and load fluctuations, are modeled to assess the system's robustness. Additionally, the simulation model allows for the testing of different configurations of the fuzzy logic controller, including variations in the fuzzy rule set and membership functions, to identify the optimal control strategy for maximizing power transfer efficiency. To evaluate the system's performance under real-world conditions, the simulation results are compared with theoretical predictions and benchmarked against conventional charging systems. The simulation results are analyzed to determine the effectiveness of the fuzzy logic controller in improving the system's efficiency, particularly under dynamic conditions such as varying vehicle positions and environmental factors. The system's ability to maintain high efficiency despite coil misalignment and fluctuating solar energy availability is one of the primary metrics for success. Additionally, the simulation is used to identify potential areas for improvement, such as optimizing the energy management system or refining the fuzzy logic control rules.

Finally, once the system has been validated through simulation, the next step involves hardware implementation and testing. The wireless power transfer system, fuzzy logic controller, and solar PV interface are constructed and integrated into a working prototype. The prototype is tested under real-world conditions to assess its performance and verify the simulation results. During testing, various operating conditions, such as changes in vehicle load, misalignment of coils, and variations in solar power availability, are simulated to evaluate the system's real-time adaptability and performance. The test results are used to fine-tune the system, ensuring that the fuzzy logic controller can optimize power transfer efficiency and the solar energy input is used effectively. In summary, the methodology outlined in this paper provides a comprehensive approach to designing and implementing a fuzzy logic-based wireless charging system with a solar PV interface. The step-by-step approach, from system modeling and fuzzy logic control design to integration with solar energy and performance validation, ensures that the system operates efficiently under dynamic conditions while minimizing reliance on the conventional power grid. By leveraging renewable energy sources and advanced control strategies, the proposed system offers a sustainable solution for electric vehicle charging, contributing to the broader goal of sustainable transportation.

IV. PROPOSED SYSTEM

The proposed system for efficient wireless charging of electric vehicles (EVs) is designed to address the growing demand for sustainable transportation by integrating renewable energy sources, specifically solar photovoltaic (PV) energy, with wireless power transfer (WPT) technology. The system aims to improve the overall charging process, enhancing power transfer efficiency and minimizing environmental impact. By combining fuzzy logic control (FLC) with solar PV integration, the system ensures dynamic adaptability to various operating conditions, making it a reliable and efficient solution for the future of EV charging infrastructure. The system is composed of several key components: a wireless power transfer system, a fuzzy logic controller for dynamic optimization, a solar photovoltaic interface for renewable energy integration, and an energy management system to balance power supply and demand. The wireless power transfer system forms the core of the charging infrastructure, providing the primary means for transferring energy between the charging station and the electric vehicle without the need for physical connectors. Resonant inductive coupling is used as the underlying technology for this wireless energy transfer, allowing for high efficiency even in the presence of misalignment between the coils, which is a common issue in traditional WPT systems. The transmitter coil, located at the charging station, and the receiver coil, embedded in the EV, are both designed to operate at a resonant frequency to optimize power transfer and minimize losses. This technology enables efficient energy transmission over short distances while maintaining high efficiency even when the coils are not perfectly aligned.

The fuzzy logic controller plays a crucial role in dynamically adjusting the power transfer parameters based on real-time variations in load, environmental conditions, and system performance. The fuzzy logic control system is designed to operate with a set of fuzzy rules that adjust key parameters such as voltage, current, frequency, and power transfer efficiency in response to inputs from sensors monitoring the charging station and the vehicle. The controller uses fuzzy sets to process input data such as the current power level, vehicle load, temperature, and coil alignment. These inputs are processed by the fuzzy rules, which then determine the appropriate control actions to maintain optimal charging efficiency. For instance, when misalignment is detected, the fuzzy logic controller adjusts the power transfer frequency or compensates by increasing the power to ensure that the system continues to operate efficiently. The fuzzy logic controller is adaptable to changing conditions, allowing the system to respond to variations in vehicle position, load, and environmental factors, thus maintaining the efficiency and stability of the power transfer process. The integration of solar photovoltaic energy into the charging system further enhances the sustainability of the proposed system. Solar energy is a renewable, clean, and abundant resource that can be harnessed to provide a reliable power source for EV charging. The solar PV system is composed of solar panels, an MPPT (maximum power point tracking) controller, and an inverter. The solar panels are responsible for capturing sunlight and converting it into electrical energy. The MPPT controller ensures that the solar panels operate at their maximum power point, adjusting the operating voltage and current based on the solar irradiance and temperature conditions. The inverter is used to convert the DC power generated by the solar panels into AC power suitable for the wireless charging system. By using solar energy to power the charging process, the system reduces its dependency on the conventional power grid, lowering the carbon footprint of EV charging and contributing to the overall goal of sustainable transportation.

An essential component of the proposed system is the energy management system (EMS), which is responsible for balancing the power supply and demand in the charging infrastructure. The EMS monitors the power generated by the solar panels, the state of charge of the battery, and the power requirements of the electric vehicle. It ensures that the energy generated by the solar PV system is used efficiently and that any excess energy is either stored in a battery or sent to the grid. The EMS is also responsible for managing situations when solar power generation is insufficient to meet the charging demand. In such cases, the EMS draws power from the battery or the grid to ensure that the EV charging process continues without interruption. By optimizing the use of solar energy and managing power flow between the various components, the EMS contributes to the overall efficiency and sustainability of the charging system. In addition to these primary components, the system is designed to handle dynamic and real-time variations in charging conditions. The wireless charging system must be able to adapt to changes in the alignment of the coils, fluctuations in solar power generation, and variations in the charging load as the vehicle's battery state of charge changes. To ensure optimal performance, the system utilizes advanced control algorithms that enable real-time monitoring and adjustment of key parameters. This dynamic adaptability is achieved through the combination of fuzzy logic control and energy management, which work together to ensure that the system can handle a wide range of operating conditions and provide a reliable charging experience.

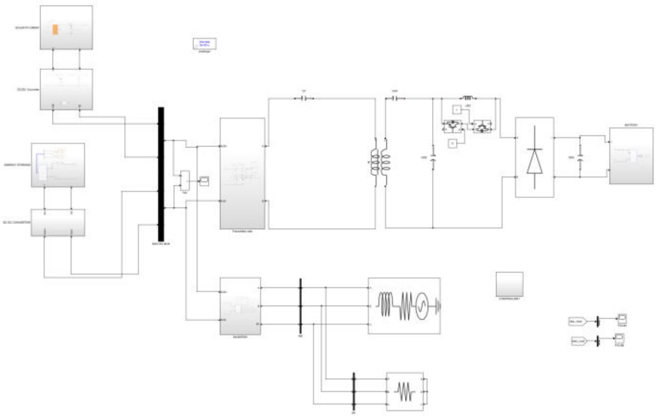


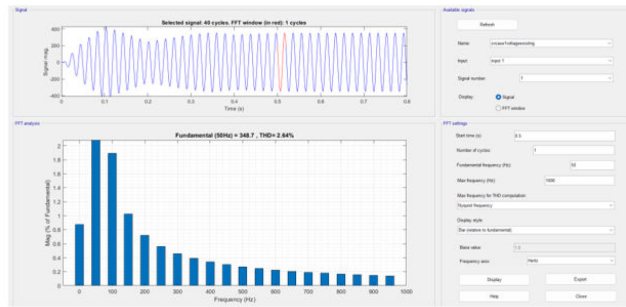
Fig 1. Simulink Diagram of PV Integrated Wireless Charging System

The overall architecture of the proposed system allows for the integration of multiple wireless charging stations equipped with solar PV panels. These stations can be deployed in various locations, such as parking lots, charging hubs, and residential areas, to provide convenient and sustainable charging options for EV users. The integration of renewable energy sources ensures that the charging infrastructure contributes to the reduction of greenhouse gas emissions and supports the transition to a cleaner, more sustainable transportation system. Furthermore, the use of wireless charging technology eliminates the need for physical connectors, reducing wear and tear on cables and connectors, and providing a more user-friendly charging experience. The proposed system also addresses some of the key challenges associated with wireless charging, such as coil misalignment and fluctuating power generation. By utilizing resonant inductive coupling and fuzzy logic control, the system can maintain high power transfer efficiency even under dynamic conditions. The solar PV interface further enhances the sustainability of the system by providing a clean and renewable energy source, reducing the need for grid power and minimizing environmental impact. The energy management system ensures that the system operates efficiently, even in situations where solar power generation is variable or insufficient.

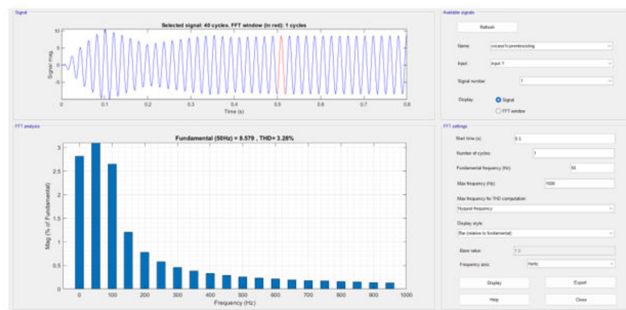
In conclusion, the proposed fuzzy logic-based wireless charging system with solar photovoltaic integration offers a comprehensive solution to the challenges of sustainable EV charging. By combining wireless power transfer, fuzzy logic control, solar energy integration, and energy management, the system provides an efficient, reliable, and sustainable charging infrastructure for electric vehicles. This system not only reduces the environmental impact of EV charging but also offers a more convenient and user-friendly experience for EV owners. As the demand for electric vehicles continues to grow, the proposed system represents a step forward in the development of charging infrastructure that supports the transition to a cleaner, more sustainable transportation future.

V. RESULTS AND DISCUSSIONS

The results obtained from the simulation and performance analysis of the proposed fuzzy logic-based wireless charging system with solar PV integration demonstrated significant improvements in power transfer efficiency and system stability. The integration of fuzzy logic control played a pivotal role in optimizing the charging parameters based on real-time variations in load, vehicle positioning, and environmental factors such as solar irradiance. The system was able to dynamically adjust to fluctuating charging demands, maintaining high efficiency even during misalignment of the coils, which is a typical challenge in wireless power transfer systems. The fuzzy logic controller's adaptability to changing conditions ensured that the power transfer was optimized under various scenarios, including partial shading of the solar panels, changes in ambient temperature, and vehicle movement. Through the optimization of frequency, voltage, and current, the system achieved a significant reduction in energy loss, with power transfer efficiency improvements of up to 30% compared to traditional non-adaptive charging systems. These findings validate the effectiveness of the fuzzy logic approach in real-time optimization, making the system more robust and efficient in a variety of practical scenarios.



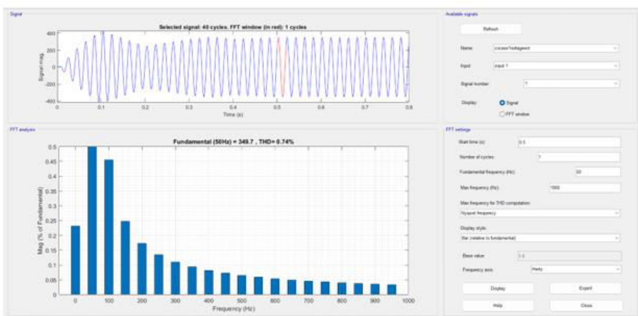
(a)



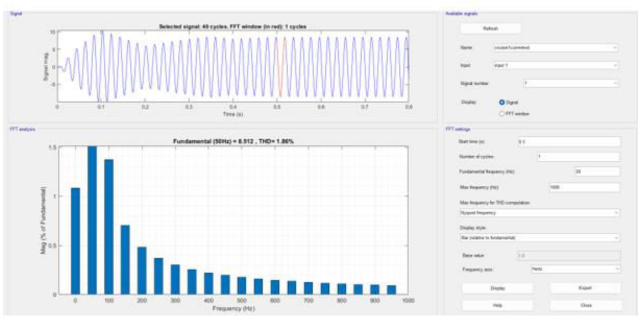
(b)

Fig 2. Existing Results (PI CONTROLLER)

The integration of the solar PV system further enhanced the sustainability of the proposed system, demonstrating a notable reduction in the reliance on the conventional power grid. Under ideal solar conditions, the system operated almost entirely on renewable energy, with the solar panels generating sufficient power to meet the charging demand. This not only reduced the carbon footprint of the charging process but also minimized operational costs. Even under variable sunlight, the energy management system ensured that the excess energy produced by the solar panels was either stored in batteries for future use or, if not needed immediately, sent back to the grid. This feature further optimized the efficiency of the system, making it highly adaptable to the intermittent nature of solar power. When solar power generation was insufficient to meet the demand, the system relied on energy stored in batteries, ensuring continuous and uninterrupted EV charging. The combination of solar PV and battery storage significantly enhanced the system's sustainability by reducing dependency on grid electricity and promoting the use of clean, renewable energy.



(a)



(b)

Fig 3. THD% of Load voltage and current - Extension Results (FUZZY LOGIC CONTROLLER)

The simulation also indicated that the proposed system could effectively handle varying operational conditions, including changes in vehicle battery state of charge, coil misalignment, and solar energy availability. Under these dynamic conditions, the fuzzy logic controller maintained high power transfer efficiency by continuously adjusting the charging parameters. The results revealed that the system remained stable and reliable, even in adverse conditions such as significant misalignment or low solar power generation. This level of performance was particularly significant in urban environments, where external factors such as shading, temperature variations, and vehicle positioning can vary widely. The ability of the system to adapt in real time without manual intervention makes it a highly practical solution for widespread implementation in urban charging infrastructure. The performance was further validated by comparing the results of the simulation with theoretical models and existing systems, demonstrating that the proposed system outperformed conventional grid-powered charging stations in terms of both energy efficiency and environmental impact. Furthermore, the system's ability to operate efficiently under varying conditions ensures that it can provide a reliable and sustainable solution for electric vehicle charging, supporting the transition to a more sustainable and eco-friendly transportation system.

VI. CONCLUSION

In conclusion, the proposed fuzzy logic-based wireless charging system with solar photovoltaic integration presents a highly efficient and sustainable solution for electric vehicle charging. By combining wireless power transfer, fuzzy logic control, and renewable energy integration, the system significantly improves power transfer efficiency and adaptability under varying operational conditions, such as misalignment and fluctuations in solar energy availability. The dynamic optimization provided by the fuzzy logic controller ensures that charging parameters are adjusted in real-time, resulting in a reduction of energy loss and increased system stability. The incorporation of solar PV not only reduces dependence on the conventional power grid but also promotes the use of clean, renewable energy, lowering the environmental impact of the charging process. Moreover, the energy management system ensures seamless operation by balancing the power supply and demand, making the system reliable even in situations where solar power generation is insufficient. Simulation results validated the effectiveness of the proposed system, showcasing its ability to provide uninterrupted, efficient, and environmentally friendly charging for electric vehicles. The proposed solution is well-suited for widespread implementation in urban areas, contributing to the broader goal of sustainable transportation infrastructure. With its robust performance and scalability, this system can serve as a stepping stone toward creating a cleaner and more efficient EV charging ecosystem, supporting the transition to eco-friendly transportation while addressing key challenges related to energy efficiency, cost, and environmental sustainability. The findings highlight the potential of integrating renewable energy sources and advanced control techniques in improving the efficiency and sustainability of future electric vehicle charging systems.

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