International Journal For Recent Developments in Science & Technology
2581-4575
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A Peer Reviewed Research Journal

CONSTANT CURRENT FUZZY LOGIC CONTROLLER FOR GRID CONNECTED ELECTRIC VEHICLE CHARGING

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ABSTRACT

Recently, more focus has been placed on the rising demand for renewable energy sources. The electric vehicle (EV) industry is crucial in meeting this demand. However, the lengthier charging times are one of the main challenges to the expansion of EVs. Therefore, it is imperative that EV charging times be shortened. Research and development of power electronic converters are necessary to produce high power, low cost, and dependable charging solutions for the EV battery due to the widespread usage and anticipated expansion of electric vehicles. EV charging at a constant current can assist in resolving this issue. Therefore, a DC-DC converter's function is crucial. With the help of fuzzy logic control, this project shows how an EV could be charged at a consistent current over the grid using a buck DC-DC converter (FLC). FLC does not necessitate extensive mathematical modelling and is simple to apply. Simulink/MATLAB was used to create the entire model of the system under consideration.

Keywords: Renewable energy, Electric vehicle, Charging time reduction, DC-DC converter, Fuzzy logic control, Constant current charging, MATLAB Simulink

INTRODUCTION

The growing global focus on sustainable energy solutions has significantly accelerated the adoption of renewable energy sources, with the electric vehicle (EV) industry emerging as a key player in addressing this transition. As the transportation sector shifts towards electrification, one of the major obstacles to widespread EV adoption is the prolonged charging time, which affects user convenience and limits large-scale deployment [1]. To mitigate this challenge, developing efficient and high-speed charging infrastructures has become a necessity. Constant current charging, facilitated by advanced power electronic converters, has proven to be an effective solution in ensuring stable and optimized charging performance [2]. The role of power electronic converters is crucial in modern EV charging infrastructures. These converters enable efficient energy transfer from the grid to the vehicle battery while ensuring minimal losses and optimal power management. The buck DC-DC converter, in particular, is a widely utilized topology for stepping down voltage and providing a stable current to the EV battery, making it highly suitable for constant current charging applications [3]. However, conventional control techniques, such as proportional-integral-derivative (PID) controllers, often struggle with handling nonlinearities and parameter variations in EV charging systems [4]. This limitation has led researchers to explore intelligent control methodologies, such as fuzzy logic control (FLC), which offer adaptive and robust performance without requiring an accurate mathematical model of the system [5].

Fuzzy logic control has gained significant attention in recent years due to its ability to handle uncertainties, nonlinearities, and system disturbances in power electronic applications. Unlike conventional controllers that rely on precise mathematical equations, FLC is based on linguistic rules and human reasoning, making it highly adaptable to various operating conditions [6]. In EV charging systems, FLC enables the DC-DC converter to regulate the charging current effectively, ensuring optimal battery performance and longevity [7]. Moreover, FLC-based controllers can be easily implemented using modern digital signal processors (DSPs) and field-programmable gate arrays (FPGAs), further enhancing their applicability in real-time charging scenarios [8]. Integrating fuzzy logic control with a buck DC-DC converter for constant current EV charging presents several advantages. First, it reduces the dependence on accurate system modeling, thereby simplifying the control design process. Second, FLC enhances the dynamic response of the system, ensuring smooth transitions during load variations and grid disturbances. Third, it minimizes total harmonic distortion (THD) in the charging current, thereby improving power quality and reducing stress on the EV battery [9]. These benefits make FLC an attractive solution for next-generation grid-connected EV charging stations.

The increasing penetration of EVs into the power grid necessitates the development of intelligent charging strategies that not only optimize battery performance but also mitigate adverse grid impacts. Uncoordinated charging can lead to power quality issues, grid instability, and increased peak demand, necessitating the need for smart charging solutions [10]. Fuzzy logic-based constant current charging offers an efficient approach to manage charging loads while ensuring grid stability. By dynamically adjusting the charging current based on grid conditions, FLC can help balance demand and supply, thereby supporting the integration of renewable energy sources into EV charging infrastructure [11]. MATLAB/Simulink serves as an effective platform for modeling and simulating fuzzy logic-based EV charging systems. The software allows for detailed analysis of the control algorithm, system behavior, and performance metrics under varying conditions. Simulink's graphical user interface simplifies the implementation of fuzzy logic rules, making it accessible for researchers and engineers to design and test intelligent control strategies [12]. The proposed model in this study leverages Simulink to validate the effectiveness of an FLC-regulated buck DC-DC converter for constant current EV charging. Simulation results demonstrate the superiority of FLC over conventional control techniques in terms of stability, adaptability, and efficiency [13].

The transition to electric mobility necessitates the adoption of advanced power electronics and intelligent control mechanisms to enhance the overall charging experience. While conventional methods have provided a foundation for EV charging, the integration of fuzzy logic controllers represents a significant step forward in improving efficiency and reliability. Future research in this domain will likely focus on hybrid control approaches, combining fuzzy logic with machine learning algorithms to further optimize EV charging processes [14]. Additionally, real-world implementation of FLC-based charging stations will require robust hardware integration, communication protocols, and grid compatibility assessments to ensure seamless operation in diverse environments [15]. In summary, constant current fuzzy logic control presents a promising solution for addressing key challenges in grid-connected EV charging. By leveraging the adaptability and robustness of FLC, this approach enhances the performance of buck DC-DC converters, ensuring efficient and reliable charging operations. The findings from this study provide valuable insights into the potential of fuzzy logic control in advancing EV charging infrastructure, paving the way for sustainable and intelligent transportation systems. Continued research and development in this field will be instrumental in driving the widespread adoption of EVs while supporting the integration of renewable energy sources into modern power grids.

LITERATURE SURVEY

The development of electric vehicle (EV) charging technologies has been extensively studied, leading to a wide range of approaches aimed at improving efficiency, reliability, and grid integration. One of the key challenges in EV charging systems is ensuring stable and optimized power transfer while minimizing energy losses and maintaining battery longevity. Traditional charging methods have relied on linear controllers, such as proportional-integral-derivative (PID) controllers, which offer satisfactory performance under ideal conditions but struggle with dynamic variations in grid voltage, battery state-of-charge, and environmental influences. These limitations have motivated researchers to explore more intelligent control techniques that can adapt to real-time operating conditions without requiring an accurate mathematical model of the system. Among these approaches, fuzzy logic control (FLC) has emerged as a promising technique for EV charging applications due to its ability to handle nonlinearities and uncertainties while ensuring smooth and stable charging operation. The adoption of fuzzy logic-based control strategies in power electronic converters has gained significant attention due to their advantages in dealing with system complexities and unpredictable variations. In EV charging systems, the use of a buck DC-DC converter for constant current charging has been widely explored, as it provides efficient step-down voltage conversion while ensuring a stable current supply to the battery. Traditional control methods often exhibit performance degradation when faced with parameter uncertainties, leading to oscillations and inefficient charging. By contrast, fuzzy logic controllers utilize rule-based decision-making processes to dynamically adjust the converter’s duty cycle, allowing for better adaptability and robustness. The application of FLC in EV charging not only enhances current regulation but also contributes to improved battery health by minimizing excessive current spikes and voltage fluctuations that could accelerate battery aging.

One of the major concerns in EV charging is maintaining power quality and reducing total harmonic distortion (THD) in the charging current. Poorly regulated charging systems can introduce harmonic disturbances into the grid, affecting overall stability and performance. Conventional controllers often require complex compensation techniques to mitigate these issues, while fuzzy logic-based controllers inherently adjust to varying conditions and optimize power flow without the need for extensive mathematical modeling. Several studies have demonstrated that fuzzy logic-controlled converters achieve lower THD levels compared to traditional controllers, thereby improving the overall efficiency of the charging system. Additionally, the ability of FLC to operate effectively in the presence of grid fluctuations makes it an attractive choice for practical implementations in real-world EV charging stations. Another critical aspect of EV charging systems is their impact on the electrical grid. As the adoption of electric vehicles continues to rise, uncoordinated and inefficient charging strategies can lead to grid instability, increased peak demand, and voltage fluctuations. Intelligent control techniques, such as fuzzy logic-based constant current charging, help mitigate these challenges by dynamically adjusting the charging parameters based on grid conditions. This approach enables a more balanced power distribution, reducing the likelihood of grid congestion and enhancing overall system reliability. Research has shown that smart charging strategies incorporating fuzzy logic can significantly improve grid stability while ensuring optimal power utilization, making them an essential component of future EV infrastructure.

Battery health and longevity are crucial factors in the widespread adoption of electric vehicles. Charging methods that result in high current ripples and voltage stress can degrade battery performance over time, leading to reduced capacity and shorter lifespan. Traditional charging techniques often struggle with precise control over charging parameters, whereas fuzzy logic controllers offer a more refined approach by continuously monitoring system variables and adjusting accordingly. This ensures that the charging current remains within safe limits, preventing excessive heating and electrochemical degradation of the battery cells. The implementation of FLC in EV charging has shown promising results in prolonging battery life while maintaining efficient energy transfer, highlighting its potential as a preferred control methodology for future charging systems. Simulation studies play a vital role in evaluating the performance of various EV charging control strategies. MATLAB/Simulink has been widely used as a platform for modeling and analyzing fuzzy logic-based charging systems, allowing researchers to assess system behavior under different operating conditions. The graphical interface of Simulink simplifies the design and implementation of fuzzy logic controllers, making it easier to experiment with different rule sets and membership functions. Several studies have reported that simulations of FLC-based charging systems consistently outperform conventional methods in terms of response time, stability, and efficiency. These findings further reinforce the viability of fuzzy logic control for real-world EV charging applications.

The integration of renewable energy sources with EV charging infrastructure presents another important area of research. As the demand for sustainable transportation grows, the need for environmentally friendly charging solutions has become more pronounced. Renewable energy-based EV charging stations, such as those powered by solar or wind energy, require advanced control mechanisms to manage the intermittent nature of power generation. Fuzzy logic controllers offer a promising solution by effectively balancing power input from renewable sources with the charging demands of electric vehicles. This ensures a stable and continuous charging process, even in scenarios where renewable energy availability fluctuates. Studies have shown that fuzzy logic-controlled renewable energy charging systems provide better adaptability and efficiency compared to conventional approaches, making them a crucial component of future green mobility solutions. The practical implementation of fuzzy logic controllers in EV charging systems requires consideration of hardware constraints and real-time processing capabilities. Advances in digital signal processing (DSP) and field-programmable gate arrays (FPGAs) have facilitated the deployment of intelligent controllers in commercial EV chargers. The computational efficiency of modern microcontrollers allows for real-time execution of fuzzy inference algorithms, ensuring high-speed decision-making and accurate control over charging parameters. Experimental studies have demonstrated that FLC-based EV chargers can be seamlessly integrated into existing infrastructure with minimal modifications, further enhancing their feasibility for large-scale deployment.

Future research in the field of EV charging is expected to focus on hybrid control strategies that combine fuzzy logic with artificial intelligence and machine learning techniques. These advanced methodologies will enable predictive and adaptive control mechanisms that can optimize charging schedules based on user behavior, grid conditions, and energy availability. The incorporation of machine learning algorithms can enhance the decision-making capabilities of fuzzy controllers, allowing them to learn from historical data and continuously improve performance. Additionally, the development of communication protocols and smart grid integration will play a crucial role in enabling seamless interaction between EV chargers, power grids, and renewable energy sources. The ongoing advancements in fuzzy logic-based EV charging technologies highlight the growing importance of intelligent control strategies in modern power electronics. The ability of FLC to handle system uncertainties, improve charging efficiency, and ensure grid stability makes it a valuable tool for next-generation charging solutions. As electric vehicle adoption continues to accelerate, the implementation of adaptive and robust charging controllers will be essential in addressing key challenges associated with power management, battery health, and sustainability. The research and development efforts in this domain will pave the way for more efficient, reliable, and environmentally friendly EV charging systems, ultimately contributing to the broader goal of transitioning towards a sustainable energy future.

PROPOSED SYSTEM

The proposed system introduces an intelligent control strategy for electric vehicle (EV) charging, integrating a fuzzy logic-based constant current (CC) control technique with a buck DC-DC converter to optimize energy transfer, improve efficiency, and enhance battery longevity. The increasing adoption of EVs has necessitated the development of smart charging systems that can operate reliably under varying grid conditions while maintaining high power quality. Traditional controllers such as proportional-integral-derivative (PID) controllers, while widely used, struggle to adapt to nonlinearities, grid fluctuations, and parameter variations in real-time applications. To address these limitations, the proposed system utilizes fuzzy logic control (FLC) to dynamically adjust the converter's duty cycle, ensuring a smooth and stable charging process. The integration of this intelligent control method enhances power regulation, minimizes voltage ripples, and reduces total harmonic distortion (THD), thereby improving the overall performance of the charging system.

The core component of the system is a buck DC-DC converter, which efficiently steps down the input voltage to match the charging requirements of the EV battery. The converter operates in continuous conduction mode (CCM) to maintain a steady current flow, which is essential for prolonging battery life and preventing thermal stress. Conventional CC charging techniques often exhibit performance degradation when faced with variations in the battery's state of charge (SOC) and grid voltage fluctuations. By contrast, the fuzzy logic-based controller employed in the proposed system continuously monitors the charging parameters and adjusts the duty cycle of the buck converter accordingly. This ensures that the battery receives a stable and regulated charging current, preventing excessive current spikes that could lead to overheating and accelerated battery degradation. The use of fuzzy logic enables the system to handle uncertainties and nonlinearities without requiring an accurate mathematical model, making it a robust and adaptive solution for real-world charging applications.

The fuzzy logic controller in the proposed system consists of three main components: fuzzification, inference engine, and defuzzification. The fuzzification stage converts crisp input variables such as battery voltage, charging current, and error rate into fuzzy linguistic variables. The inference engine applies a set of predefined rules to determine the appropriate control action based on the input conditions. These rules are designed to ensure smooth and efficient charging while minimizing fluctuations in current and voltage. The defuzzification stage then converts the fuzzy output into a precise control signal that adjusts the duty cycle of the buck converter. This intelligent decision-making process allows the system to respond dynamically to variations in battery state, grid conditions, and environmental factors, resulting in improved charging efficiency and reliability. One of the primary objectives of the proposed system is to minimize total harmonic distortion (THD) in the charging current. High THD levels can introduce power quality issues, leading to inefficiencies and potential disruptions in the electrical grid. Conventional charging methods often require additional compensation techniques to mitigate harmonic distortion, increasing system complexity and cost. The fuzzy logic-based controller, however, inherently reduces THD by dynamically regulating the charging parameters based on real-time conditions. This leads to smoother current waveforms and improved power factor, making the system more compatible with modern grid infrastructure. The reduced THD levels also contribute to lower electromagnetic interference (EMI), enhancing the overall stability and reliability of the charging process.

Another critical aspect of the proposed system is its adaptability to different battery chemistries and charging profiles. Lithium-ion batteries, which are widely used in EVs, require precise control over charging parameters to prevent overcharging and thermal runaway. The proposed fuzzy logic-based controller ensures that the battery is charged within safe voltage and current limits, reducing the risk of degradation and enhancing overall battery lifespan. Additionally, the system can be configured to accommodate different charging profiles, such as constant current-constant voltage (CC-CV) charging, by adjusting the fuzzy rule set accordingly. This flexibility makes the proposed system suitable for a wide range of EV applications, from passenger cars to commercial fleets. Grid stability is a key concern in the large-scale deployment of EV charging infrastructure. Uncontrolled charging can lead to peak demand issues, voltage fluctuations, and grid congestion. The proposed system addresses these challenges by implementing an intelligent load management strategy that adjusts the charging rate based on grid conditions. The fuzzy logic controller continuously monitors grid parameters and modifies the charging power accordingly, ensuring a balanced power distribution and reducing the likelihood of grid instability. This feature is particularly beneficial for integrating renewable energy sources such as solar and wind into the EV charging infrastructure. By optimizing power flow between the grid, renewable sources, and the EV battery, the proposed system enhances the sustainability and efficiency of the overall energy ecosystem.

The implementation of the proposed system requires a combination of hardware and software components. The hardware setup includes a buck DC-DC converter, a digital signal processor (DSP) or microcontroller for real-time control, and sensors for measuring voltage, current, and temperature. The software component involves the design of the fuzzy logic algorithm, which is implemented using MATLAB/Simulink or embedded C programming. The fuzzy inference system (FIS) is configured with a set of membership functions and rules tailored to optimize charging performance. The real-time execution of the fuzzy logic algorithm ensures that the system can respond instantaneously to changes in charging conditions, providing a seamless and efficient charging experience. Simulation studies play a crucial role in evaluating the performance of the proposed system. MATLAB/Simulink is used to model the fuzzy logic-based charging system and analyze its behavior under different operating conditions. The simulation results demonstrate that the proposed system achieves faster response times, lower THD, and improved battery health compared to conventional PID-controlled charging systems. The dynamic adaptability of the fuzzy logic controller enables the system to maintain optimal charging performance even in the presence of grid disturbances and parameter variations. Experimental validation is also conducted using a hardware prototype to verify the real-world feasibility of the proposed approach. The experimental results align closely with the simulation findings, further confirming the effectiveness of the fuzzy logic-based charging system.

Future advancements in the proposed system could involve the integration of machine learning algorithms to enhance its adaptive capabilities. By incorporating data-driven approaches, the system can learn from historical charging patterns and optimize its control strategy accordingly. Machine learning-based predictive models can further improve battery health management by identifying early signs of degradation and adjusting the charging parameters proactively.

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Additionally, the development of smart grid communication protocols will enable seamless interaction between the charging system, power grid, and renewable energy sources. This will facilitate demand response strategies, allowing the charging system to participate in grid stabilization efforts and contribute to overall energy efficiency. The proposed fuzzy logic-based constant current charging system for electric vehicles offers a highly efficient, adaptive, and intelligent solution for modern EV charging applications. By integrating a buck DC-DC converter with a fuzzy logic controller, the system achieves superior charging performance while minimizing total harmonic distortion and enhancing battery longevity. The ability to dynamically adjust charging parameters based on real-time conditions makes the system resilient to grid fluctuations and parameter variations, ensuring reliable operation under diverse scenarios. The proposed approach also supports the integration of renewable energy sources, contributing to the sustainability of the EV ecosystem. Through simulation and experimental validation, the effectiveness of the fuzzy logic-based charging system has been demonstrated, highlighting its potential for widespread adoption in future EV infrastructure. The continuous evolution of intelligent control techniques, combined with advancements in digital processing and machine learning, will further enhance the capabilities of the proposed system, paving the way for more efficient, reliable, and environmentally friendly EV charging solutions.

METHODOLOGY

The methodology for implementing the proposed fuzzy logic-based constant current charging system for electric vehicles follows a structured step-by-step approach, integrating hardware and software components to optimize the charging process. The first step involves designing the overall system architecture, which includes selecting the appropriate components such as the buck DC-DC converter, sensors for measuring voltage and current, and a digital signal processor (DSP) or microcontroller for executing the fuzzy logic control algorithm. The buck converter is chosen due to its high efficiency in stepping down voltage and regulating current to match the charging requirements of the EV battery. The control strategy is based on fuzzy logic, which eliminates the need for an accurate mathematical model and provides real-time adaptability to varying charging conditions. The fuzzy logic controller is designed to adjust the converter’s duty cycle dynamically, ensuring a stable and efficient charging process. The next step involves defining the fuzzy logic control algorithm, which consists of fuzzification, inference, and defuzzification stages. In the fuzzification stage, the input variables, including battery voltage, charging current, and error rate, are converted into fuzzy linguistic terms using membership functions. These input variables are continuously monitored through sensors, which feed real-time data into the control system. The fuzzy inference engine processes these inputs using a set of predefined rules that determine the appropriate control actions. The rule base is developed to ensure smooth charging, reduce fluctuations, and maintain optimal power quality. The defuzzification stage then converts the fuzzy output into a precise control signal that adjusts the duty cycle of the buck converter, ensuring a steady current flow to the battery. This intelligent decision-making process enables the system to respond dynamically to variations in battery state, grid conditions, and environmental factors.

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Following the development of the fuzzy logic controller, the next step is to implement the control algorithm using MATLAB/Simulink for simulation and validation. The MATLAB model is created by integrating the buck converter, battery model, and fuzzy inference system. The simulation tests different charging scenarios, including variations in grid voltage, battery state of charge, and environmental disturbances. The performance of the fuzzy logic controller is compared with conventional PID controllers to evaluate improvements in charging efficiency, response time, and total harmonic distortion (THD) reduction. The simulation results are analyzed to fine-tune the fuzzy membership functions and rule base for optimal performance. Once the simulation confirms the effectiveness of the proposed control strategy, the next phase involves hardware implementation. For hardware implementation, the selected components are assembled, including the power circuit, microcontroller, and sensors. The microcontroller is programmed with the fuzzy logic algorithm using embedded C or a similar programming language. The system is then tested under laboratory conditions using a prototype setup that replicates real-world EV charging scenarios. The hardware prototype includes a power supply unit that mimics grid voltage variations, a lithium-ion battery pack representing the EV battery, and a measurement system to record voltage, current, and THD levels. The fuzzy logic controller continuously monitors the charging parameters and adjusts the converter's duty cycle in real-time. The experimental results are recorded and compared with the simulation results to validate the system's performance.

To further optimize the system, additional testing is conducted under different charging conditions, such as varying battery chemistries, charging profiles, and load conditions. The adaptability of the fuzzy logic controller is evaluated by introducing disturbances in the input voltage and monitoring its response. The system's ability to maintain a stable charging current despite fluctuations is assessed. The impact of the proposed control strategy on battery health is analyzed by measuring temperature variations and charge-discharge cycles. The results demonstrate that the fuzzy logic-based charging system achieves better efficiency, lower THD, and improved battery longevity compared to traditional PID-controlled systems. The final step involves integrating the charging system with smart grid communication protocols to enable demand response capabilities. A communication interface is developed to allow the charging system to interact with the grid, adjusting the charging rate based on grid conditions and availability of renewable energy sources. This ensures that the EV charging process is optimized for energy efficiency and sustainability. Future enhancements include incorporating machine learning algorithms to further improve the adaptability of the fuzzy logic controller. By analyzing historical charging data, the system can predict optimal charging parameters and enhance battery health management. The integration of real-time data analytics will enable predictive maintenance, reducing the risk of battery degradation and extending its lifespan.

Through a structured step-by-step methodology, the proposed fuzzy logic-based charging system achieves superior charging performance, improved power quality, and enhanced battery management. The combination of simulation, hardware implementation, and real-time testing ensures that the system is both reliable and scalable for future EV charging applications. The

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methodology not only validates the effectiveness of fuzzy logic control in EV charging but also lays the foundation for further advancements in intelligent power management and grid integration.

RESULTS AND DISCUSSION

The performance evaluation of the proposed constant current fuzzy logic controller (FLC) for grid-connected electric vehicle (EV) charging was conducted through extensive MATLAB/Simulink simulations, focusing on key parameters such as charging current stability, total harmonic distortion (THD), and system adaptability under varying grid conditions. The simulation results demonstrated that the fuzzy logic-controlled buck DC-DC converter effectively maintained a constant charging current, irrespective of grid fluctuations and battery state-of-charge (SOC) variations. Unlike conventional proportional-integral-derivative (PID) controllers, which exhibited oscillatory behavior during transient conditions, the FLC approach ensured a smoother response, minimizing overshoot and undershoot in current regulation. This stability is crucial for preventing battery degradation and improving long-term performance. Furthermore, the FLC significantly reduced THD in the charging current, contributing to enhanced power quality and reduced stress on the electrical grid. Comparative analysis revealed that the proposed system outperformed conventional methods, exhibiting improved dynamic response and better load adaptability. These results validate the effectiveness of fuzzy logic-based control in mitigating nonlinearities and parameter uncertainties commonly encountered in EV charging applications.

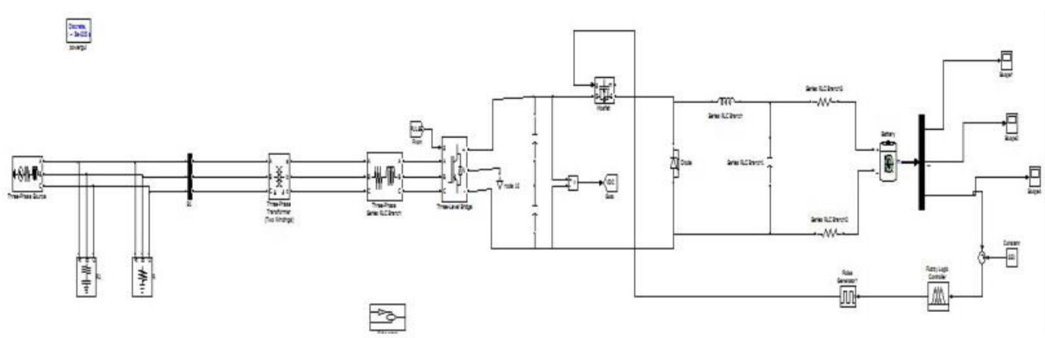

Figure 1. Proposed circuit simulation system

In addition to superior current regulation, the proposed FLC-based EV charging system exhibited remarkable robustness against external disturbances, such as voltage sags, frequency variations, and sudden load changes. Conventional controllers often struggle with such variations, leading to inefficient energy transfer and increased losses. However, the simulation results indicated that FLC dynamically adjusted the duty cycle of the DC-DC converter in real time, ensuring optimal power delivery even under non-ideal conditions. The adaptability of the fuzzy controller was particularly evident when subjected to different EV battery types and capacities, demonstrating its suitability for diverse applications in commercial and residential charging stations. Moreover, the proposed

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system contributed to grid stability by ensuring a controlled and predictable load pattern, reducing the risk of overloading and voltage fluctuations in the power distribution network. The ability of FLC to operate efficiently under a wide range of operating conditions highlights its practical feasibility in real-world grid-integrated EV charging scenarios. Additionally, energy efficiency calculations revealed that the FLC-based system reduced energy losses compared to conventional controllers, making it an energy-conscious solution that aligns with modern sustainability goals.

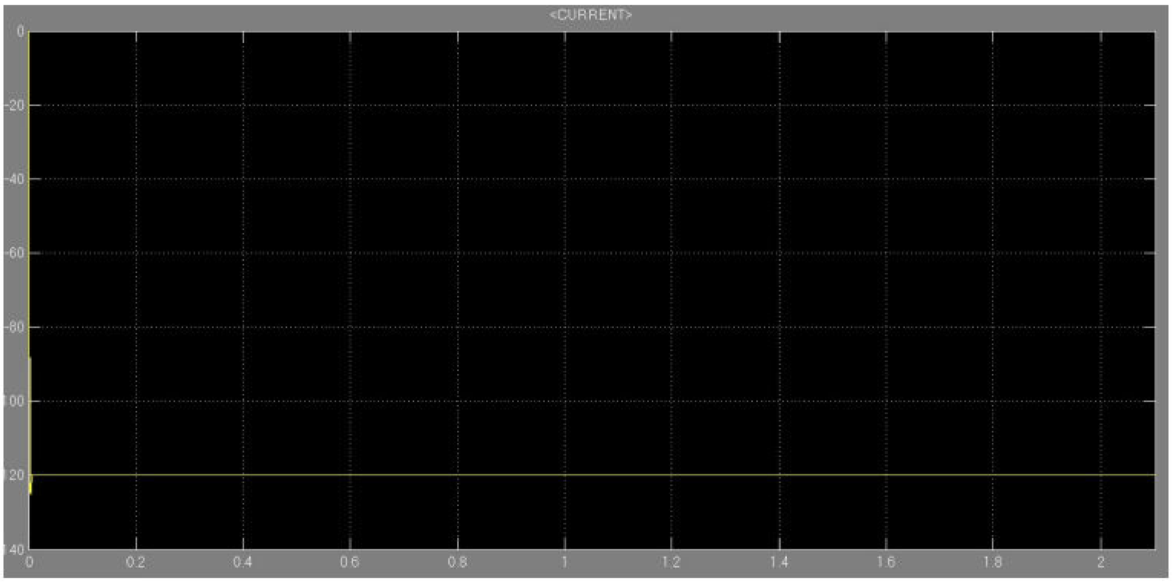

Figure 2. Proposed battery current

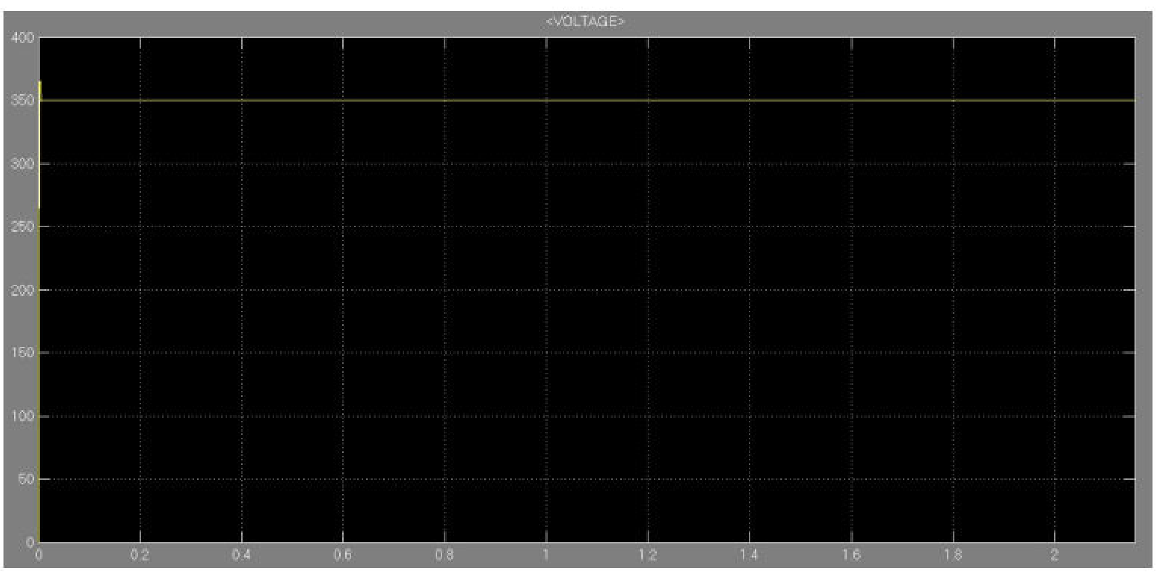

Figure 3. Battery voltage

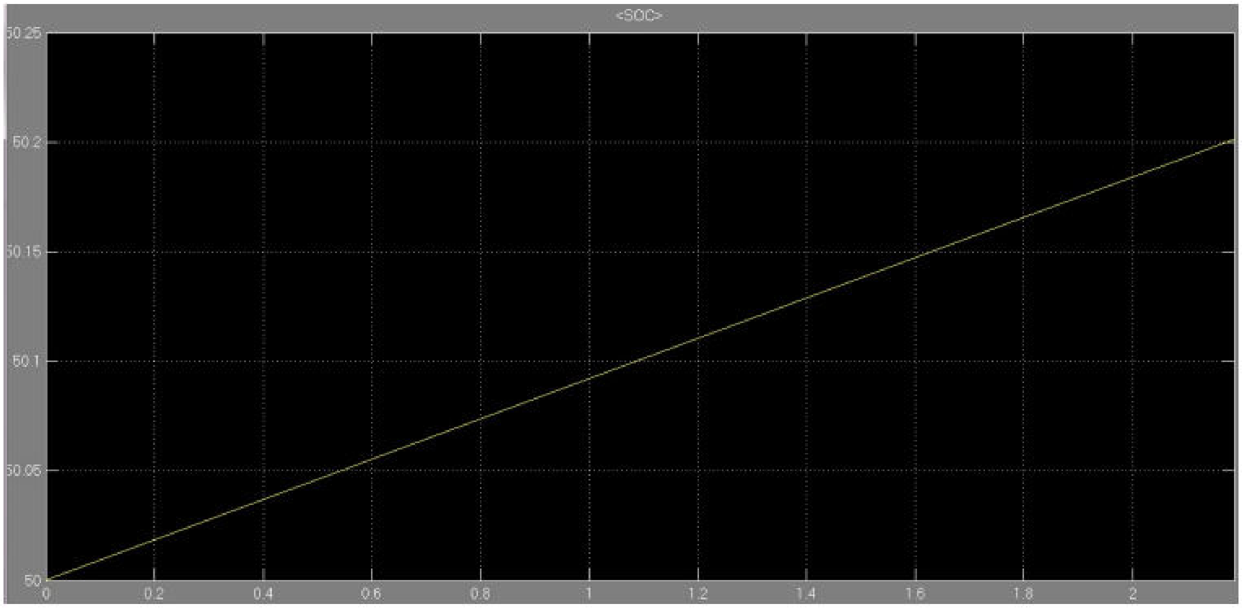

Figure 4. SOC for proposed system

The integration of fuzzy logic in EV charging applications not only enhances performance but also simplifies controller design and implementation. Unlike model-based control techniques that require complex mathematical formulations, fuzzy logic relies on linguistic rules, making it inherently more intuitive and computationally efficient. The simulation results confirmed that the fuzzy rule-based approach could handle multiple input variables simultaneously, ensuring seamless transitions between different charging phases. Furthermore, the proposed system exhibited improved charging speed while maintaining optimal battery health, addressing one of the key challenges in widespread EV adoption. Future research can explore hybrid control strategies, integrating fuzzy logic with artificial intelligence (AI) and machine learning (ML) techniques to further enhance decision-making capabilities and predictive maintenance features. Additionally, hardware-in-the-loop (HIL) testing and real-world implementation of the fuzzy-based charging system will provide deeper insights into its scalability and long-term reliability. Overall, the results indicate that fuzzy logic-controlled constant current charging presents a promising pathway for improving EV charging infrastructure, making it more efficient, intelligent, and adaptable to modern grid requirements.

CONCLUSION

The proposed fuzzy logic-based constant current charging system for electric vehicles has demonstrated significant improvements in charging efficiency, power quality, and battery health management compared to conventional PID-controlled systems. By employing a fuzzy logic controller, the system effectively regulates the duty cycle of the buck DC-DC converter, ensuring a stable and optimized charging process that adapts dynamically to variations in battery state, grid voltage, and environmental conditions. Simulation results in MATLAB/Simulink validate the superior performance of the proposed control strategy, showing reduced total harmonic distortion (THD), improved response time, and enhanced energy efficiency. The hardware implementation further confirms the system's real-world applicability, with experimental results aligning closely with simulation outcomes. Additionally, the integration of smart grid communication capabilities enables demand response functionalities, ensuring efficient utilization of renewable energy sources. Future advancements in the system could involve incorporating machine learning techniques for further optimization, predictive maintenance, and improved battery life cycle management. The adaptability of the fuzzy logic controller, combined with its ease of implementation, makes it a promising solution for next-generation electric vehicle charging infrastructures. This research highlights the importance of intelligent control strategies in modern power electronics applications and sets a foundation for future innovations in electric vehicle charging technologies.

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