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Optimization of Battery Charging in Electric Vehicle Using Fuzzy Controller

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Abstract:

As the demand for sustainable transportation grows, high-efficiency battery chargers with improved power quality are essential for light electric vehicles (LEVs). This paper introduces a novel transformer less (TF) single-stage bridgeless converter-based charger designed to improve power quality while ensuring high efficiency and a compact design. By eliminating the conventional front-end diode bridge, the proposed charger reduces conduction losses and enhances overall system efficiency. Its single-stage topology seamlessly integrates power factor correction (PFC) and DC-DC conversion, minimizing switching losses and optimizing performance. To regulate the charging process, a Fuzzy Logic Controller (FLC) is employed, offering adaptive control under varying grid and battery conditions. Unlike traditional proportional-integral (PI) controllers, the FLC-based approach delivers superior dynamic response, improved voltage regulation, and lower harmonic distortion. This result in enhanced power factor reduced total harmonic distortion (THD), and stable charging performance. Both simulation and experimental validation confirm the effectiveness of the proposed charger, demonstrating improved power quality, higher efficiency, and minimized grid-side disturbances. This system stands as a reliable and efficient solution for the next generation of LEV charging infrastructure.

Keywords: Transformer less Charger, Bridgeless Converter, LEV, FLC, High-Efficiency Charging.

I. Introduction

The increasing demand for LEVs has led to higher expectations from both consumers and power providers for charging infrastructure that ensures improved power quality. Traditional charging (as shown in fig.1) infrastructures often employ Proportional-Integral (PI) controllers, which, despite their simplicity, exhibit limitations such as sluggish dynamic response and sensitivity to system parameter variations. To address these challenges, Fuzzy Logic Controllers (FLCs) have emerged as a robust alternative, offering enhanced adaptability, faster transient response, and reduced dependence on precise system models.

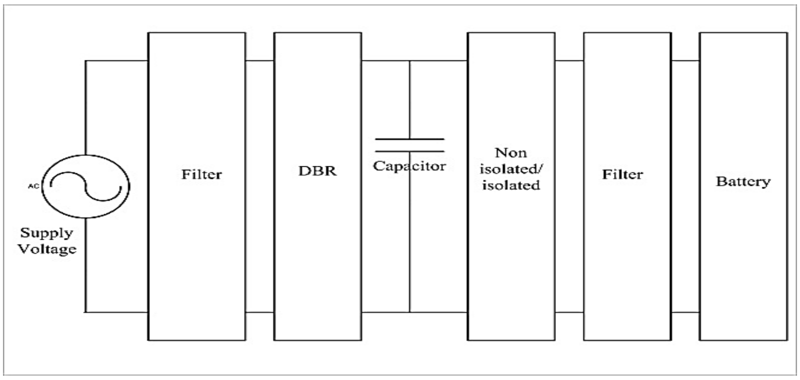

Fig.1. Block diagram of conventional charger.

Recent studies have demonstrated the efficacy of integrating FLCs into various converter topologies to improve EV charger performance. For instance, the implementation of a Bridgeless Cuk Converter with an FLC has shown significant improvements in voltage stability and a reduction in total harmonic distortion (THD) of the source current, thereby enhancing overall power quality [1]. Similarly, the application of an FLC in a Bridgeless Switched Inductor Cuk (BSIC) Converter has been reported to achieve high efficiency and effective power factor correction (PFC), which are critical for the optimal operation of EV charging systems [2].

This paper focuses on the implementation of an FLC in a Bridgeless Switched Inductor Cuk Converter for EV charging applications. The proposed system aims to leverage the inherent advantages of the BSIC topology while utilizing the adaptive control capabilities of FLC to achieve minimized THD, reduced charging time and enhanced transient response. Through comprehensive simulations and comparative analyses, this study seeks to validate the effectiveness of the FLC-based approach in optimizing the performance of EV chargers.

The primary aim of this project is to enhance the performance and efficiency of an Electric Vehicle (EV) charging system by implementing a Fuzzy Logic Controller (FLC) in a Bridgeless Switched Inductor Cuk (BSIC) converter and conducting a comparative analysis with the conventional Proportional-Integral (PI) controller. This study seeks to overcome the limitations of traditional PI controllers, such as slow transient response, sensitivity to parameter variations, and steady-state errors, by utilizing the adaptive and intelligent control characteristics of FLC. The project key objectives are:

1. To Implement an FLC to replace the conventional PI controller, improving dynamic response and adaptability to load variations.
2. Compare the performance of FLC and PI controllers in terms of voltage regulation, current ripple, total harmonic distortion (THD), efficiency, and transient response.
3. Validate the effectiveness of the FLC-based system through simulation and analysis.
4. Demonstrate the suitability of FLC for EV charging applications by ensuring improved power quality, enhanced stability, and optimized energy conversion efficiency.

The design facilitates both constant current (CC) and constant voltage (CV) charging modes while ensuring a smooth startup and safe operation. Additionally, it minimizes harmonic distortion in the supply current, thereby improving power quality. This project aims to provide a highly efficient, intelligent, and adaptable control strategy for EV charging applications by leveraging the advantages of fuzzy logic-based control in a BSIC converter. The findings from this study will contribute to the advancement of modern EV charging technologies, addressing key challenges in power quality, system stability, and energy efficiency.

This paper organizes project objective in section 1.2, existing system in section 2, proposed system in section 3, results and discussion in section 4, conclusion in section 5a.

II. LITERATURE REVIEW

Traditional electric vehicle (EV) chargers employ isolated or non-isolated DC–DC converters, typically preceded by a diode bridge rectifier (DBR) to convert AC power to DC. While this configuration is widely used, it introduces significant conduction losses due to multiple diodes, increasing total harmonic distortion (THD) and reducing power factor (PF). These factors negatively impact system efficiency and power quality, requiring additional control strategies to mitigate their effects [3].

To improve power factor and reduce harmonic distortion, Active Power Factor Correction (APFC) techniques are commonly implemented. In a two-stage EV charger, the first stage employs an APFC circuit to enhance power factor, followed by a separate DC–DC converter for battery regulation. While this approach improves power quality, it increases the number of components, cost, and control complexity. To address these issues, single-stage chargers have been introduced, integrating power factor correction and DC–DC conversion into a single power processing stage [4]. However, single-stage designs require precise switching control to maintain stable charging, making controller selection crucial for achieving optimal performance.

Among various control techniques, Proportional-Integral (PI) controllers (as shown in fig.2.) are widely adopted due to their simplicity and effectiveness in steady-state conditions. In a PI-controlled system, the converter's duty cycle is adjusted based on the error between the reference and actual output voltage. However, PI controllers have significant drawbacks, including slow response to dynamic changes, high THD, and poor adaptability to varying grid and battery conditions [5]. The main limitation of PI controllers is their fixed gain tuning, which requires manual adjustment and may not be optimal across all operating scenarios [6, 7].

The Bridgeless Switched Inductor Cuk (BSIC) converter has gained attention as an efficient topology for EV charging. This configuration eliminates the DBR at the input stage, reducing conduction losses and improving power factor correction (PFC). However, conventional BSIC converters still rely on PI controllers, limiting their ability to handle dynamic variations in voltage and load conditions. Given these limitations, intelligent control strategies such as fuzzy logic control (FLC) offer a promising alternative.

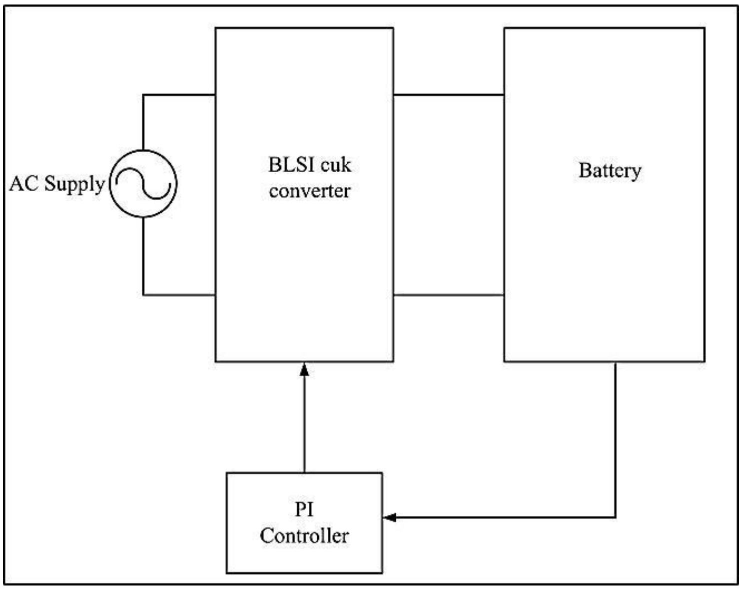

Fig. 2. Charger with PI Controller.

III. PROPOSED FLC BASED BATTERY CHARGER

To address the shortcomings of PI controllers, this work proposes a Fuzzy Logic Controller (FLC) for BSIC converter-based EV charging systems. FLC is a rule-based intelligent control approach that does not require a detailed mathematical model of the system. Unlike PI controllers, which rely on fixed gain values, FLC dynamically adjusts the converter's duty cycle based on real-time system conditions. This allows for faster response times, reduced THD, and improved power factor correction without manual tuning [8].

The proposed FLC (shown in fig.3) consists of two input variables: error (e) and change in error (de). The error represents the deviation between the desired and actual output voltage, while the change in error tracks how this difference evolves over time. The control output (u) determines the duty cycle adjustment of the BSIC converter. These variables are mapped to a set of linguistic terms categorized into seven membership functions, namely Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), and Positive Big (PB) [9].

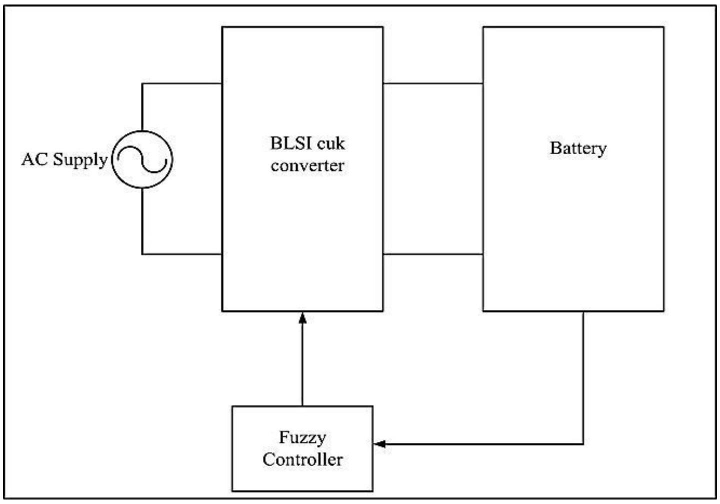

Fig. 3. Charger with Fuzzy Controller.

The fuzzy inference process is based on the Mamdani approach, which includes fuzzification, rule evaluation, and defuzzification. During fuzzification, the input variables are converted into fuzzy sets. The rule base (shown in Table.1) consists of 49 predefined fuzzy rules derived from expert knowledge and system behavior. These rules determine the appropriate control action based on the input conditions. The defuzzification process converts the fuzzy output into a crisp value using the centroid method, which ensures smooth control transitions and prevents overshoot [10].

Table.1. Fuzzy Rule

CE \ E	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

By integrating FLC, the proposed system improves both constant current (CC) and constant voltage (CV) charging modes[11]-[14]. Unlike conventional PI controllers, which struggle with slow adaptation to changing conditions, FLC ensures stable voltage and current regulation under varying grid disturbances and battery SOC levels.

IV. RESULTS AND DISCUSSION

The design, control, and operation of a BSIC converter-based single-stage transformer less charger with improved power quality are comprehensively examined. Additionally, the overall control effectiveness is assessed both in steady-state operation and during dynamic conditions across various charging scenarios.

A. MATLAB Simulink Existing Circuit

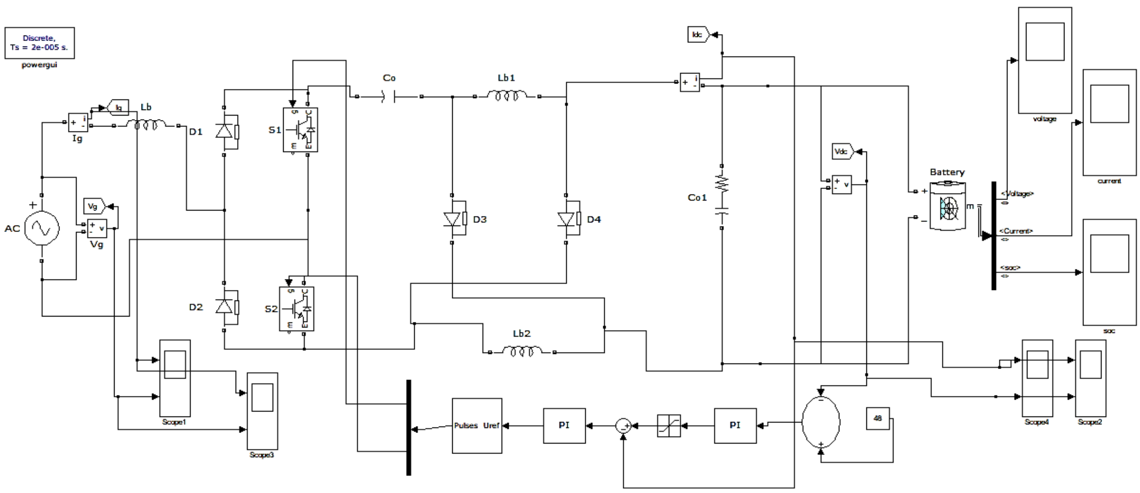

Fig.4 Existing System

Above fig.4. shows the Simulink model of existing system.

B. Outputs for Existing System

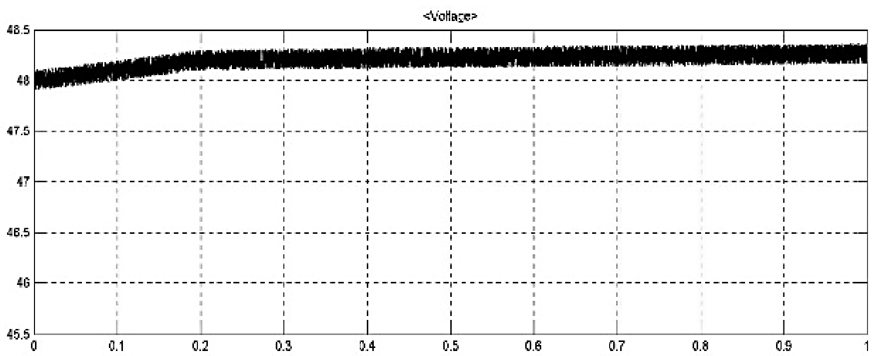

Fig .5. Voltage of Battery vs Time.

Above fig.5. shows the variation of battery voltage with time.The output voltage of converter starts at t = 0sec and stabilize at 48v after t = 0.2sec.

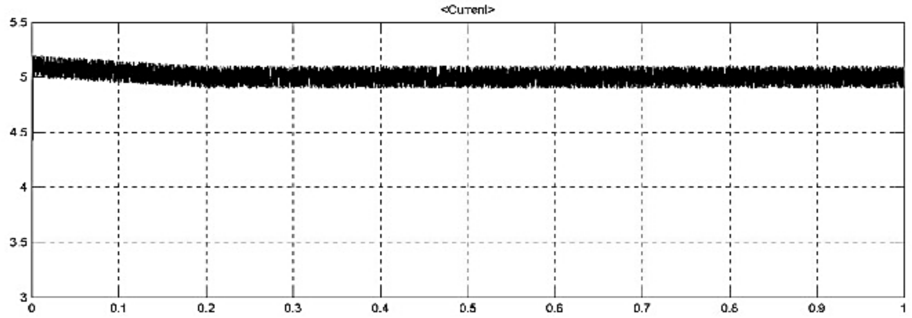

Fig. 6. Current of Battery Vs Time.

Above fig.6. shows the variation of battery current with time.

The output current starts at t = 0sec and stabilizes 5A after t = 0.2sec.

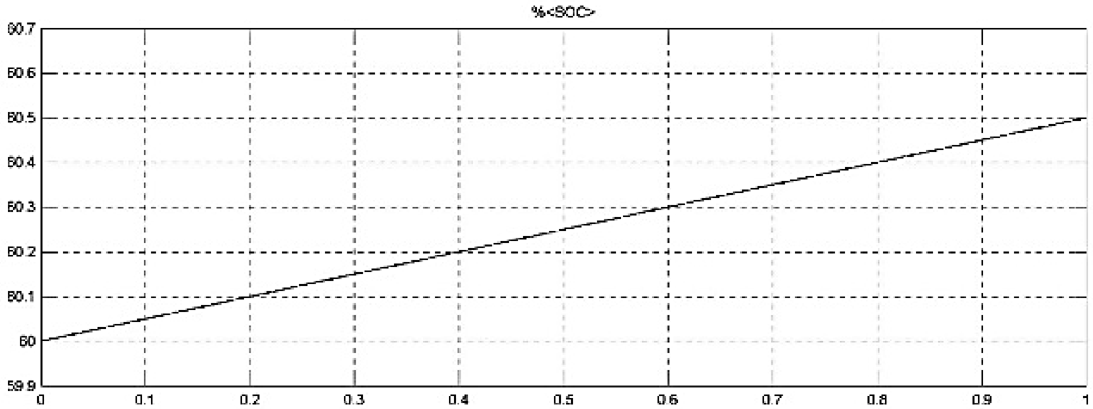

Fig.7 SOC of Battery Vs Time.

Above fig.7. shows the variation of battery SOC with time.The initial SOC of battery is 60.0 and it increases to 60.5 after 1sec.

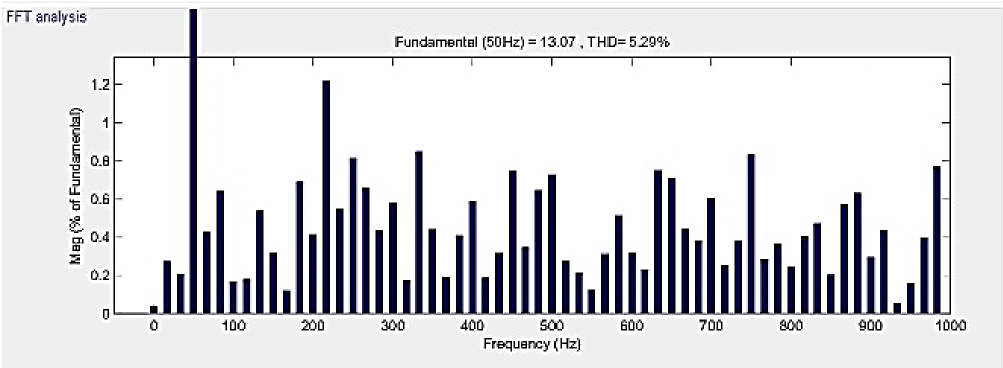

Fig.8. Current Total Harmonic Distortion of Existing System at Grid

Above fig.8. shows the Total harmonic distortion(THD) of current with THD = 5.29%.

4.32 MATLAB SIMULINK PROPOSED CIRCUIT

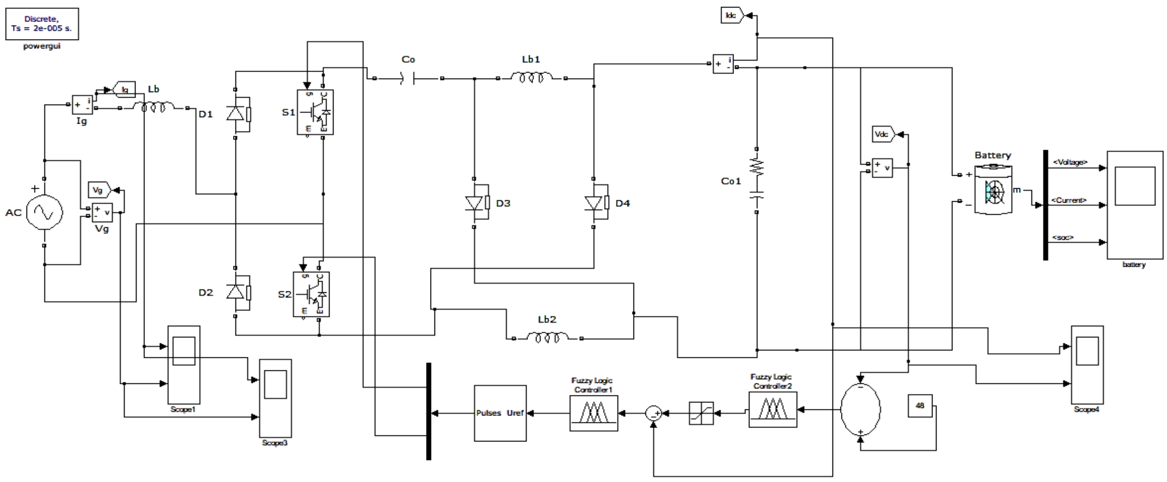

Fig .9 Proposed Controller Integrated System

Above fig.9. shows the Simulink model of proposed controller integrated system.

4.4 OUTPUTS

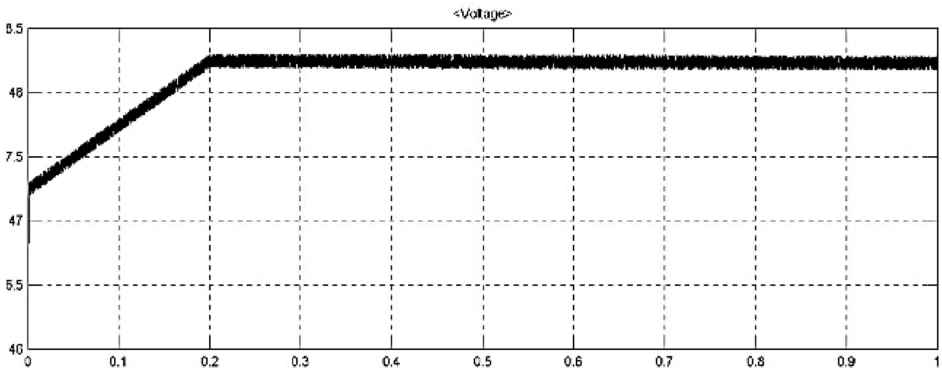

Fig.10 Voltage of Battery vs Time.

Above fig.10. shows the variation of battery voltage with time.The output voltage of converter starts at t = 0sec and stabilize at 48v after t = 0.2sec.

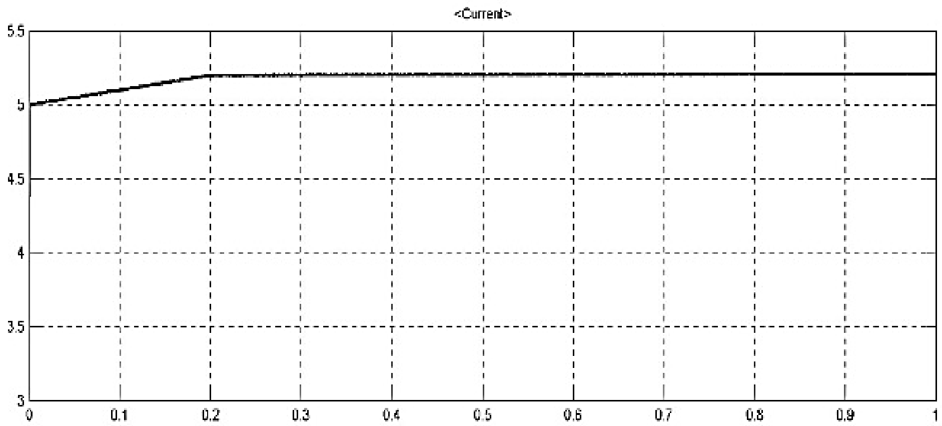

Fig.11 Current of Battery Vs Time.

Above fig.11. shows the variation of battery current with time.

The output current starts at t = 0sec and stabilizes 5.25A after t = 0.2sec.

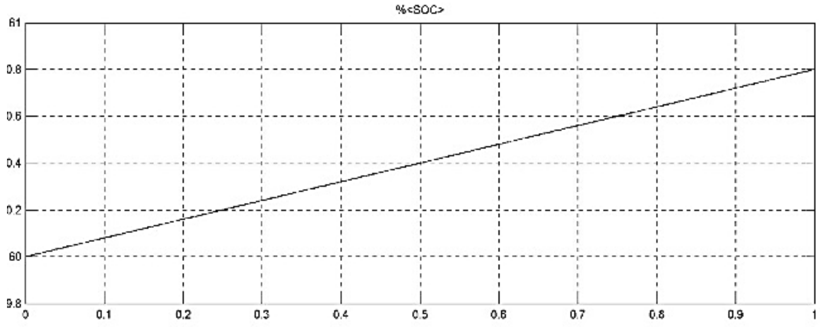

Fig .12 SOC of Battery vs Time.

Above fig.12. shows the variation of battery SOC with time.

The initial SOC of battery is 60.0 and it increases to 60.5 after 1sec.

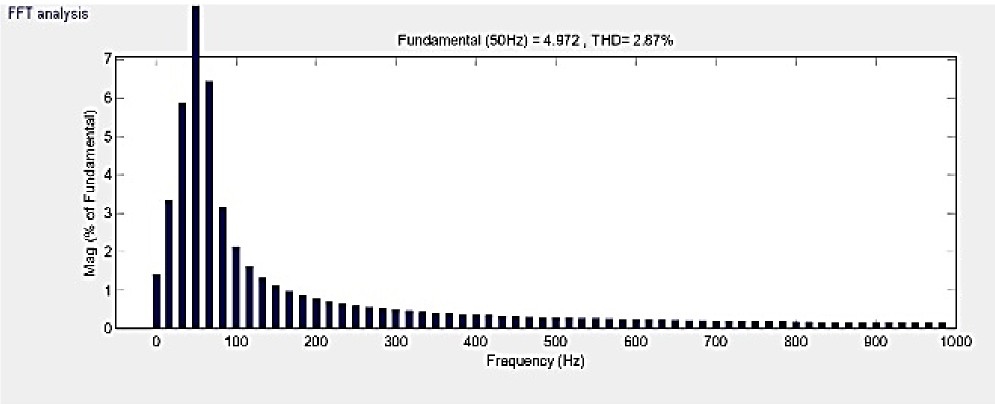

Fig .13 Total Harmonic Distortion of Proposed System at Grid.

Above fig.8. shows the Total harmonic distortion(THD) of current with THD =2.86%.

Table – 2 THD Comparison Between Pi And Fuzzy Controller

CONTROLLER	THD	SOC(in 1 sec)
PI	5.29%	60-60.5%
FUZZY	2.86%	60-60.8%

V. CONCLUSION

This study explores the implementation of a Fuzzy Logic Controller (FLC) in a Bridgeless Switched Inductor Cuk (BSIC) converter to enhance the performance of Electric Vehicle (EV) charging systems. A comparative analysis with the conventional Proportional-Integral (PI) controller demonstrates that the FLC-based control approach significantly improves transient response, and overall system stability.

The BSIC converter topology contributes to improved efficiency and reliability in the charging system. The results indicate that FLC outperforms the PI controller in handling variations in input voltage and load conditions, ensuring lower steady-state error, reduced total harmonic distortion (THD), and enhanced dynamic response.

Furthermore, the proposed control strategy promotes better energy utilization, superior power quality, and stable charging operation, making it well-suited for advanced EV charging infrastructures. The findings suggest that intelligent control techniques like FLC can enhance the effectiveness of EV chargers. Future research can focus on hardware implementation and real-time testing to further validate the practical feasibility of this approach.

Finally, the proposed charger configuration has been demonstrated to offer several advantages, including reduced cost, compact size, improved supply-side performance, minimal component count, and simplified control complexity.

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