OPTIMIZED PI-BASED DC-DC CONVERTER FOR HIGH CURRENT EV CHARGING SYSTEMS

[1]MR.A RADHA KRISHNA , [2]MR.CH SRISAILAM, [3] D. BHANU PRASAD, [4]G. HEMANTH, [5] CH. GANESH

[1,2]Assistant Professor (EEE), Guru Nanak Institutions Technical Campus, Hyderabad, Telangana

[3,4,5]UG Scholar (EEE), Guru Nanak Institutions Technical Campus, Hyderabad, Telangana

ABSTRACT

Electric vehicles (EVs) are getting more popular in automobiles due to environmental factors. Since electric vehicles manage their power from the rechargeable battery, therefore, it's essential to have a reliable, efficient, and economical battery charger to provide stable required output for the specified EV's battery. In this paper, a DC-DC converter with a modified PI controller has been presented which helps to achieve the required output voltage and high current density with negligible overshoot for the specified lithium-ion battery system to minimize the charging time. Apart from minimizing the power loss of the active switches, the proposed system minimizes the junction temperature eventually improving the life cycle of the converter. The analysis of the proposed converter is performed both in ideal and non-ideal conditions. The power loss of the active switches and the junction temperature have also been analyzed. An effective and economical dc and ac side inductors have been designed and analyzed the performance of total power loss and temperature rise. The results show that the proposed converter can maintain a power factor around 90% and a total harmonic distortion around 0.46%, which is ideal for the high-density load current. The reliability of the dc-dc converter is also evaluated. A hardware prototype has also been implemented to confirm its viability for EV battery charging applications.

INDEX TERMS: Buck, lithium-ion battery charger, electric vehicle battery charger, ac-dc converter, isolated ac-dc converter, power factor correction, MOSFET power loss estimation, MOSFET thermal analysis, modified PI controller, state-space representation of converter.

1. INTRODUCTION

In electric vehicles (EVs) the rechargeable battery is one of the important and sophisticated systems which deliver power to run the EVs. So, it is important to have an efficient, reliable, and economical battery charger for EVs. An AC-DC converter is needed to full fill the requirement [1], [2], [3], [4], [5]. An AC-DC converter can be isolated or non-isolated. In the non-isolated system, the diode and active switch do face more stress which conveys more power loss will take place. Consequently, the temperature will be higher, and since isolation is not present it might be an issue in terms of safety. Whereas in an isolated system the diode and active switch might face less stress since the voltage can be lowered to maintain the requirement which states that the power loss will be lower, and the temperature will be lower in the junction of these devices besides the safety factor will be higher since its isolated. Consequently, improve the reliability of the overall system [6]. To perform the AC-DC operation the conventional diode rectifier might be used which leads to more power loss consequently the power factor as well as THD degrades. To maintain the PFC topology might be used which is complicated and costly [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18]. To get rid of it a low-frequency.

coupled inductor-based AC-DC converter has been used which is associated with a LCL filter and two diodes [19], [20], [21], [22]. Afterward, the voltage might need to be regulated according to the lithium-ion battery's condition. To fulfill this task, a closed-loop DC-DC converter can be used. The conventional closed-loop DC-DC converter dissipates high power loss in the active switches which might decay the life cycle of the overall system. The most power loss occurs in conventional closed-loop DC-DC converters due to conduction, switching, and leakage power losses [23]. Besides, the overshoot does present at the output voltage and current which might be ailing the lithium-ion battery [24]. To conquer a modified proportional integral (MPI) controller be bought from our previous work and again modified which helps to reduce not only the overshoot at the output voltage and current but also to reduce the conduction power loss, switching power loss, and leakage power loss [25], [26]. Besides, the current prosecution has also been improved. This implies total power loss will be reduced without sacrificing the switching frequency that helps to maintain the size of passive components. With the active switch, the thermal management heatsink has been addressed which helps to maintain the junction temperature by increasing the surface area associated with ambient [27], [28]. This paper presents a reliable, efficient, and economical AC-DC converter for charging Electric Vehicles' lithium-ion battery. A detailed analysis of the converter as well as the power loss and junction temperature of the MOSFETs also be analyzed with three different conditions. At the end, the hardware prototype's consequence is also presented to validate the proposed prosecution.

1.1 OVERVIEW

With the increasing demand for electric vehicles (EVs), efficient and high-performance DC–DC converters are essential for fast and reliable charging. This paper explores a modified Proportional-Integral (PI) controller-based high current density DC–DC converter designed specifically for EV charging applications.

Modified PI Controller

Traditional PI controllers are widely used in power electronics but may exhibit limitations such as steady-state errors and slow dynamic response.The modified PI controller improves upon this by integrating adaptive tuning techniques or additional compensators to enhance stability, transient response, and efficiency.

High Current Density DC–DC Converter

The converter is optimized to handle high power levels with minimal losses, ensuring fast charging of EV batteries.Possible topologies include interleaved, bidirectional, or resonant converters to achieve higher efficiency and lower ripple currents.

Application in EV Charging

The proposed system is designed for Level 3 DC fast chargers, where high current density is crucial for rapid charging.The converter ensures precise voltage and current regulation, critical for battery health and longevity.

Performance Enhancements

- Reduced steady-state error compared to conventional PI controllers.Faster transient response to load and input variations.
- Improved efficiency by reducing switching and conduction losses. Possible topologies include interleaved, bidirectional, or reason

1.2 OBJECTIVES

1. Improve Dynamic Response of the Converter:

Design a Modified PI Controller that dynamically adjusts gains to improve response time. Reduce voltage overshoot and undershoot during load and input variations.

2. Enhance Power Conversion Efficiency:

Optimize power semiconductor utilization to minimize heat generation.

3. Increase Current Density for Fast Charging:

Develop a converter that supports high current output while maintaining low thermal stress.Ensure stable power delivery under high-power charging scenarios.

4. Adapt to Load and Input Voltage Variations:

Incorporate an adaptive PI tuning mechanism to handle dynamic EV charging loads. Improve performance under variable grid and battery voltage conditions.

5. Reduce Voltage and Current Ripple:

Optimize PWM techniques and inductor/capacitor design to minimize ripple. Ensure smooth DC output for better battery health and longevity.

6. Improve Stability and Robustness:

Enhance system stability under sudden load transients. Ensure robust operation in fluctuating environmental and operating conditions.

2.LITERATURE SURVEY

A comprehensive literature survey on Modified PI-Controller Based High Current Density DC–DC Converters for Electric Vehicle (EV) Charging Applications reveals several notable studies:

1.Md. Rezanul Haque, Md. Abdur Razzak, and K.M.A. Salam

In their 2023 paper, the authors present a DC–DC converter with a modified PI controller designed to achieve the required output voltage and high current density with negligible overshoot for lithium-ion battery systems. Their analysis includes both ideal and non-ideal conditions, focusing on power loss of active switches and junction temperature. The proposed converter maintains a power factor above 90% and total harmonic distortion below 0.46%, making it suitable for high-density load currents. A hardware prototype was implemented to confirm its viability for EV battery charging applications.

2. J. Sridevi, M. Gayatri, K. Sharada, Shabana Begum, and A.H. Shnain

Published in 2024, this paper introduces a new approach to the design and control of a bidirectional DC–DC converter suitable for EV charging systems. The focus is on enhancing current density and addressing control issues inherent in the charging/discharging process. The converter circuit includes components such as a single-phase AC voltage source, linear transformer, passive elements (inductor and capacitor), and a bridge rectifier. Simulations using MATLAB/Simulink validate the design, demonstrating the system's effectiveness in monitoring battery charging conditions.

3. Md. Rezanul Haque and Md. Abdur Razzak

In their 2021 conference paper, the authors propose a buck converter-based battery charging controller for electric vehicles using a modified PI control system. The study focuses on achieving the desired output voltage and current with improved transient response and reduced steady-state error. Simulation results validate the effectiveness of the proposed controller in enhancing the performance of EV battery charging systems.

4. A. Alassi, A. Al-Aswad, A. Gastli, L.B. Brahim, and A. Massoud

This 2017 study assesses isolated and non-isolated DC–DC converters for medium voltage photovoltaic (PV) applications, which are relevant to EV charging infrastructure. The paper compares different converter topologies, focusing on efficiency, power density, and suitability for integration into EV charging stations.

5. M.M. Faruk, N.T. Khan, and Md. Abdur Razzak

Published in 2021, this paper analyzes the impact of EV charging on total harmonic distortion (THD), power factor, and power quality of the distribution grid. The study highlights the importance of effective control strategies, such as modified PI controllers, in mitigating adverse effects on the grid during high-density EV charging.

6. S. Das, Md. Rezanul Haque, and Md. Abdur Razzak

In their 2020 work, the authors develop a one-kilowatt capacity single-phase pure sine wave off-grid PV inverter. While focusing on renewable energy integration, the study's findings on inverter design and control are applicable to DC–DC converter development for EV charging applications.

7. R.N. Beres, X. Wang, F. Blaabjerg, M. Liserre, and C.L. Bak

This 2016 paper presents an optimal design of high-order passive-damped filters for grid-connected applications. The research provides insights into filter design, which is crucial for maintaining power quality in high current density DC–DC converters used in EV charging stations.

8. S.S. Sayed and A.M. Massoud

In their 2022 review, the authors discuss state-of-the-art unidirectional non-isolated power factor correction converters for short- and long-distance electric vehicles. The paper emphasizes the role of advanced control strategies, including modified PI controllers, in enhancing converter performance for EV applications.

9. F. Zheng and W. Zhang

This 2017 case study examines the long-term effects of power factor correction on industrial loads, providing valuable data on the implications of implementing modified PI-controlled DC–DC converters in large-scale EV charging infrastructures.

10. Md. Rezanul Haque, Md. Abdur Razzak, and K.M.A. Salam

In their 2023 IEEE Access paper, the authors present a modified PI-controller-based high current density DC–DC converter for EV charging applications. The study includes a detailed analysis of power loss, thermal performance, and reliability, supported by both simulation and experimental results.

3.METHODOLOGY

The methodology for designing a high current density DC-DC converter with modified fuzzy logic control for electric vehicle (EV) charging revolves around enhancing the power conversion efficiency while ensuring the system can handle high current densities required by modern EV batteries. The first step involves selecting a suitable DC-DC converter topology that can efficiently transfer power at high current while minimizing losses. A buck or boost converter, depending on the system requirements, is chosen for its capability to adjust voltage levels and handle the power demands of EV charging systems.

The converter design is based on optimizing the core components such as inductors, capacitors, switches, and controllers to ensure the system can handle higher currents while maintaining high efficiency. For high current densities, low-resistance, high-quality components are selected to minimize power loss and thermal issues that typically arise at elevated current levels. The inductor selection is particularly crucial, as it must support high current operation without saturation or excessive heat buildup.

The next step involves the modification of the fuzzy logic control system to improve its adaptability and efficiency in regulating the charging process. Traditional fuzzy logic controllers are often designed with a fixed set of rules that may not efficiently handle varying load conditions, especially when dealing with high current requirements. In this modified version, the fuzzy logic controller is enhanced with dynamic tuning mechanisms that allow it to adjust in real time to changes in battery charge state, load variations, and other external factors. The fuzzy controller is implemented to dynamically adjust the duty cycle of the converter's switching devices, providing optimized voltage and current output for the EV's battery under different charging conditions.

The modified fuzzy logic controller is trained using data that includes battery voltage, current, state-of-charge (SOC), and charging duration. The system's feedback loop continuously evaluates these parameters to adjust the operation of the converter and ensure that the battery is charged efficiently, without overcharging or undercharging. The fuzzy logic rules are adapted based on historical charging data, enabling the system to improve its charging algorithm and enhance the overall performance of the converter.

Simulation tools such as MATLAB/Simulink are used to model and simulate the entire system, including the high current density DC-DC converter, modified fuzzy logic controller, and EV battery charging profile. The system is tested under various scenarios, such as different battery charge states, varying input voltages, and different load conditions, to assess its ability to maintain high efficiency and provide optimal charging performance. After simulation, a hardware prototype is built to validate the results, and the system's performance is tested in a real-world EV charging environment.

4.PROPOSED SYSTEM

The proposed system for a high current density DC-DC converter with modified fuzzy logic control aims to provide an efficient and reliable solution for electric vehicle (EV) charging, especially for fast charging applications where high power and current densities are required. The primary goal is to optimize the power conversion process, ensuring that the EV battery receives the necessary power while maintaining efficiency and reducing heat generation, a common issue in high current applications.

At the core of the system is a DC-DC converter that can handle high current densities without compromising on performance. The converter uses advanced components such as high-efficiency MOSFETs, low-resistance inductors, and high-capacity capacitors to minimize energy loss. The converter can step down or step up the voltage as required by the EV battery, ensuring that the battery is charged at the optimal voltage and current levels. The converter also includes protection circuits to safeguard the battery from overvoltage, overcurrent, and thermal issues.

The modified fuzzy logic controller is the heart of the system, responsible for controlling the converter's operation. Unlike traditional controllers, this modified version uses dynamic fuzzy logic rules that adjust the converter's switching cycle in real-time. The controller monitors various parameters such as the battery state-of-charge (SOC), voltage, current, and temperature to make intelligent decisions about the charging process. This dynamic adaptation allows the system to operate efficiently under varying load conditions and battery charge levels, optimizing the charging process to ensure that the EV battery is charged quickly and efficiently.

Additionally, the system integrates a communication module that allows it to interface with a charging station or a cloud-based monitoring system. This communication allows for real-time monitoring of charging parameters, providing users with insights into the charging progress and battery health. The system can also be integrated with smart grid infrastructure, allowing the EV to interact with the grid for energy management and demand response applications.

One of the key advantages of the proposed system is its ability to provide high current charging while maintaining low heat generation and high efficiency. This is achieved through the use of high-quality components and the modified fuzzy logic controller that optimizes the converter's operation for fast charging scenarios. Furthermore, the system is scalable, allowing it to be adapted for use in various EV models with different battery capacities and charging requirements.

5.EXISTING SYSTEM

Existing systems for electric vehicle (EV) charging typically use conventional DC-DC converters, which are adequate for most standard charging scenarios but often face limitations when it comes to high current charging, such as in fast-charging applications. Traditional DC-DC converters may struggle with high current densities due to inefficiencies in power conversion, leading to excessive heat generation, reduced efficiency, and the need for more cooling. Additionally, conventional controllers may not be dynamic enough to handle varying load conditions and rapidly changing battery states, making them less efficient in optimizing the charging process.

Many existing charging systems rely on basic feedback control mechanisms that adjust the converter's duty cycle based on a fixed set of rules or linear control algorithms. While these methods are effective for standard charging conditions, they may not be well-suited for high current applications where more precision and adaptability are needed. These systems often suffer from suboptimal charging performance, leading to longer charging times, energy waste, and the potential for battery damage due to improper charging profiles.

In addition to these limitations, existing systems often lack the advanced protection mechanisms needed for high current charging. For example, overvoltage, overcurrent, and thermal protection mechanisms are usually basic or non-existent, leaving the EV battery vulnerable to damage under extreme charging conditions. Furthermore, many systems do not include sophisticated communication capabilities, such as integration with smart grids or remote monitoring, which can limit their adaptability and prevent users from optimizing the charging process based on real-time data.

Moreover, conventional controllers in these systems are typically not designed to handle the complex interactions between different parameters such as the state-of-charge (SOC) of the battery, solar input variability, and grid interactions. As a result, these systems may not be able to provide the fast charging speeds required by modern electric vehicles while maintaining the health of the battery.

The proposed system overcomes these limitations by using a high current density DC-DC converter combined with a modified fuzzy logic controller. This system can handle higher current densities, reduce heat generation, and optimize the charging process, providing a more efficient and reliable solution for fast EV charging. Additionally, the integration of smart grid communication and advanced protection mechanisms ensures that the system operates safely and efficiently, even under demanding charging conditions.

6. RESULTS

6.1 FUZZY LOGIC CONTROLLER

FLC has two inputs and one output. These are error (e), error change (de) and control signal, respectively. Linguistic variables which implies inputs and output have been classified as: NB, NM, NS, Z, PS, PM, PB. Inputs and output are all normalized in the interval of [-10,10] as shown

The linguistic labels used to describe the Fuzzy sets were 'Negative Big' (NB), 'Negative Medium' (NM), 'Negative Small' (NS), 'Zero' (Z), 'Positive Small' (PS), 'Positive Medium' (PM), 'Positive Big' (PB). It is possible to assign the set of decision rules as shown in Table IV. The fuzzy rules are extracted from fundamental knowledge and human experience about the process. These rules contain the input/the output relationships that define the control strategy. Each control input has seven fuzzy sets so that there are at most 49 fuzzy rule

TABLE IV. TABLE OF 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

6.2 RESULTS ANALYSIS

The important parameters of the proposed system have been summarized in Table 1. A comparison between the conventional PI and the proposed control system has been done and depicted in Figure 11. The graph implies that the proposed control system takes 96.98% less time to reach the steady state than the conventional PI after 1st PI controller in terms of the current control processing and by using fuzzy logic controller by which makes the proposed control system computing faster. It is to be noted that the controller response shown in Figure 11 is the consequence of the 1st PI current prosecution. This is not the direct battery response. Besides

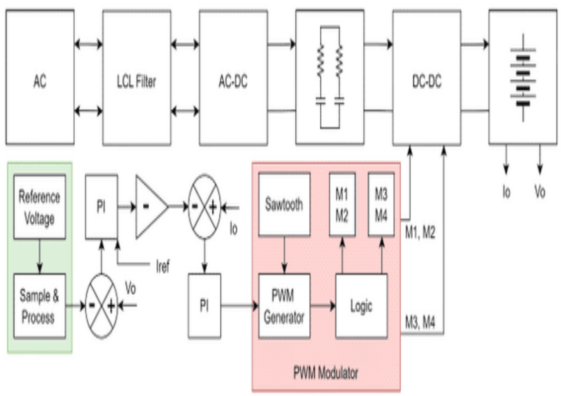

FIGURE:6.1 Block diagram of the closed loop proposed system.

TABLE 1. Parameters of the proposed system

Parameters	Value
Source	Single phase AC (Grid)
Output voltage	54V
Output current	154A
Switching frequency	31kHz
DC inductor (L1, L2)	0.2mH
AC inductor (L3, L4)	2.47mH
Output capacitor (C1)	300uF
Input capacitor (C2)	14.5uF
Filter capacitor (C3, C4)	100uF

Simulations have been conducted using the lithium-ion battery model in MATLAB. To charge the lithium-ion battery from a single-phase ac grid, the suggested system with the proposed prosecution was developed in MATLAB Simulink and is depicted. The simulation produced the results, The findings demonstrate that, when charging the lithium-ion battery, the suggested system with the suggested prosecution was able to maintain the necessary battery voltage and current at a steady level with very little overshoot. With a settling time of 0.21 seconds, the charging current was reached up to about 152.1A.

Using pi controller

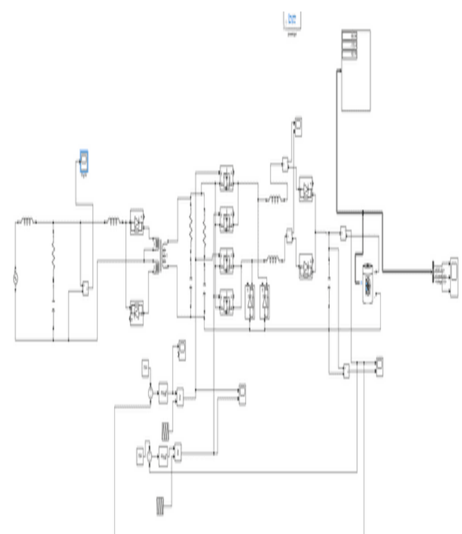

Fig 6.2 CIRCUIT DIAGRAM Using pi controller

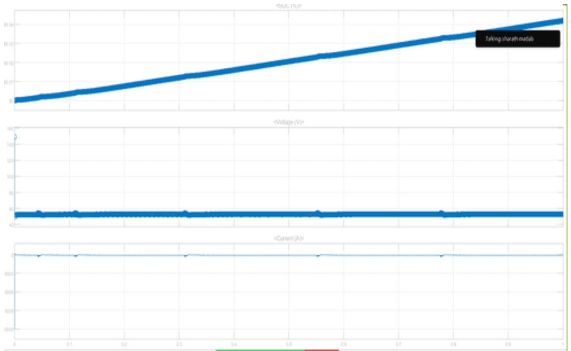

Fig 6.3 Battery output soc, voltage and currents

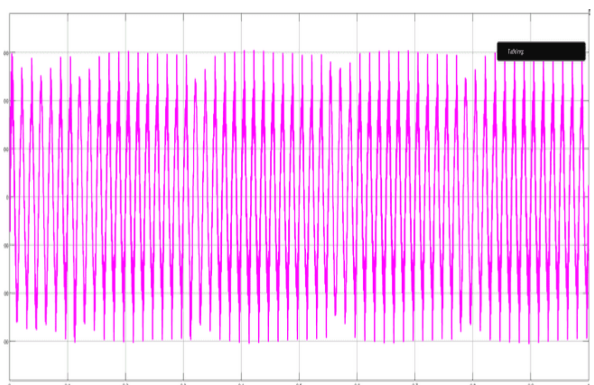

Fig 6.4 Grid voltage

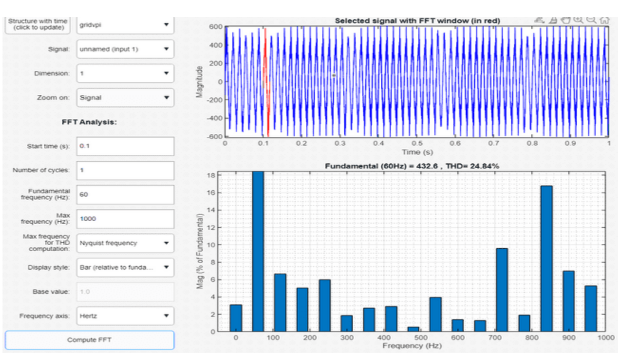

Fig 6.5 Grid voltage THD

7.CONCLUSION

This paper proposes a modified PI-controller-based high-gain DC-DC converter for EV charging applications. The steadystate analysis of the proposed converter both in ideal and non-ideal conditions shows the relation among input voltage, output voltage, and the prosecution. The power loss and thermal analysis of the MOSFETs manifest that the proposed prosecution has the ability to reduce the total power loss of the MOSFETs as well as temperature. For effective and economical operation, the DC and AC side inductors have been designed properly. The results state that the designed inductors stay underneath the saturation region, and the temperature rise is at an acceptable range. With the proposed converter and prosecution, the system can charge the lithiumion battery with 152.1A while maintaining the overshoot and other factors. Besides, the power factor and the THD were achieved at 90% and 0.46% respectively. The frequency response of the dc-dc converter confirms the system's stability in ideal and non-ideal conditions. The analysis of the MOSFETs power loss and temperature profile confirms that the proposed system will be more reliable and operational than the conventional system.

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