Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 2, No.2, February : 2025

OPTIMIZED CHARGING FOR E-BIKES USING VIENNA RECTIFIER AND LLC RESONANCE CONTROLLED BY FUZZY LOGIC

Amal. M. S, Student, Dept. of Electrical and Electronics Engineering, NSS College of Engineering, Palakkad, Kerala, msamal2603@gmail.com
Dr Smitha. B, Professor, Dept. of Electrical and Electronics Engineering, NSS College of Engineering, Palakkad, Kerala, bsmithas@nssce.ac.in

ABSTRACT

This paper presents a two-stage onboard charger (OBC) design that enhances efficiency, power quality, and reliability for electric bike applications. The front-end stage consists of a single-phase Vienna rectifier, which achieves effective power factor correction while minimizing total harmonic distortion. A fuzzy logic controller regulates the rectifier dynamically based on voltage feedback to maintain stable and adaptive control. The back-end stage is designed as an LLC resonant converter which provides galvanic isolation, and the system has efficient regulation of DC output. The control of the converter is implemented through a current-based FLC for optimization of switching frequency, providing better voltage regulation with minimum loss. Incorporating fuzzy logic control in both the stages, it enhances the efficiency of the entire system, decreases THD, and sustains robust performance across different load conditions. The proposed design is verified to be valid through simulation, and it will deliver 500 W of power at an output of 52 V and 10 A with a charging requirement for 48 V e-bike batteries. It can thus be concluded that the proposed OBC architecture provides a high-performance and scalable solution for next-generation e-bike charging systems while adhering to industrial standards on efficiency, reliability, and power quality.

Keywords: E-bike charging, LLC resonant converter, Vienna rectifier, Onboard charger (OBC), Fuzzy logic control

I. Introduction

Electric vehicles (EVs) have emerged as a popular option to help address the negative impacts that traditional fuel powered vehicles pose to the environment, and e-bikes especially stand out as an effective means of getting around in cities because they are economical and eco-friendly. An important part in any EV is the onboard charger (OBC), which is responsible for converting AC from the grid to a regulated DC output that can be used to charge the battery. The effectiveness of an OBC determines the charging time, as well as the quality of the battery's life, the power's quality, and the system's performance. However, traditional charging systems are afflicted by a number of issues such as low power factor, excessive total harmonic distortion (THD), unproductive efficiency, and higher switching losses. A Vienna Rectifier and LLC Resonant Converter controlled by a Fuzzy Logic Controller (FLC) is used to solve the aforementioned issues. This paper proposes an onboard charging system optimized for e-bikes with the above-mentioned technology. The proposed alternative contains two power conversion system stages: a Vienna Rectifier, a Wye connected three switch power factor correction (PFC) stage for the first stage. It achieves reasonable efficiency, low harmonic distortion, and high levels of power quality compliance.

An LLC Resonant Converter, the second stage, offers great efficiency under a range of load circumstances, softswitching capabilities, and less electromagnetic interference (EMI).By modifying the gate pulses of the Vienna Rectifier and the inverter in response to current, voltage, and state of charge (SoC) of the battery in real time, the Fuzzy Logic Controller (FLC) is utilized to improve the system's dynamic reaction.The intelligent control mechanism guarantees optimal power flow, reduces energy losses, and increases charging efficiency.Fuzzy logic offers greater adaptability and robustness than traditional chargers that use on rigid control techniques like PI controllers, particularly in the face of variable load and grid conditions. Additionally, by ensuring galvanic separation between the battery and the grid, an isolation transformer enhances dependability and safety. The suggested system is appropriate for applications requiring lightweight electric mobility because it is built to produce 500W of output power to charge a 48V e-bike battery. The system's performance is verified using a thorough MATLAB/Simulink simulation, which shows increases in power factor, efficiency, and lower THD when compared to traditional rectifier-based chargers. The charger's hardware implementation demonstrates its potential for commercial deployment in next-generation e-bike charging systems and further validates its efficacy in practical applications.

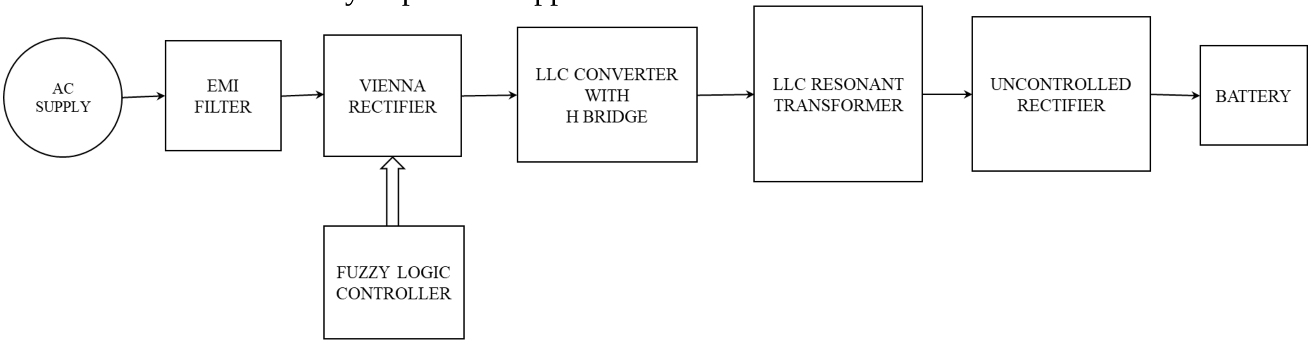


Figure 1: Block diagram of proposed Two-stage battery charger

The flow of proposed two stage battery charger which is controlled by the Fuzzy logic control is shown in the figure 1. Through the integration of an LLC Resonant Converter with intelligent fuzzy logic control and a high-performance Vienna Rectifier, this work advances the development of dependable, efficient, and optimized EV charging solutions, opening the door to improved e-bike performance and sustainable energy use.

II. Literature

Electric vehicle (EV) chargers play a crucial role in the adoption of sustainable transportation. Several studies have explored power electronic converters, specifically Vienna rectifiers and LLC resonant converters, for their efficiency and performance in onboard charging applications. Abdel-Rahman and Infineon Technologies (2012) provided a detailed operation and design methodology for the resonant LLC converter, highlighting its advantages in achieving high efficiency and reduced switching losses [1]. Deng et al. (2013) further developed a design methodology for LLC resonant converters specifically for EV battery chargers, optimizing the efficiency across varying loads [6]. Similarly, Wang et al. (2014) analyzed a full-bridge LLC-based charger optimized for wide battery voltage ranges, making it suitable for diverse EV applications [15]. Vienna rectifiers have also been extensively studied for their role in power factor correction (PFC) and high-efficiency conversion. Vahedi et al. (2015) proposed a single-phase, single-switch Vienna rectifier for EV battery charging, demonstrating its potential for simplified control and high-power density [14]. Thangavelu et al. (2015) modeled and controlled a Vienna rectifier, focusing on its single-phase applications and improved efficiency [13]. More recently, Ali et al. (2021) introduced a soft-switched Vienna rectifier topology for EV chargers, which enhances efficiency and reduces switching losses [2]. Several researchers have explored integrated charging solutions using Vienna rectifiers and LLC resonant converters. Chaurasiya and Singh (2020) developed a home charging system integrating a Vienna-based modified CUK converter with an LLC resonant converter, enhancing efficiency and power quality [4]. Similarly, Pandey and Singh (2020) proposed an EV charger utilizing Vienna rectifier and LLC resonance, emphasizing its superior performance over conventional PFC circuits [8]. B and R (2022) demonstrated an onboard EV charging system incorporating these technologies, providing insights into practical implementation challenges and solutions [3]. Beyond circuit design, control strategies play a crucial role in optimizing charger performance. Prasad et al. (2015) introduced a unidirectional onboard automotive charger utilizing sine charging, showing its impact on lithium-ion battery longevity [11]. Shabarish et al. (2020) explored a fuzzy-based approach for wireless EV charging, highlighting its benefits in enhancing efficiency and adaptability [12]. Finally, practical design considerations and real-world implementations have been studied. Daniel and Chandrakala (2021) presented the design of an isolated onboard plug-in EV charger, focusing on the reliability and safety aspects of the system [5]. Praneeth et al. (2019) proposed a universal onboard battery charger capable of supporting a wide output voltage range, making it a versatile solution for various EV types [9]. The reviewed literature highlights significant advancements in the development of EV onboard chargers, with a focus on high-efficiency power conversion, robust control strategies, and practical design implementations. The integration of Vienna rectifiers with LLC resonant converters has emerged as a promising solution, offering improved power factor correction, efficiency, and adaptability to varying battery conditions. These studies provide a strong foundation for further research in optimizing onboard charging systems for electric vehicles.

III. On-board Battery Charger

Modern power conversion technology, such as a two-level On-Board Charger (OBC), can be used to efficiently and reliably charge EVs. Voltage and damping are introduced during the rectification phase and the DC-DC conversion phase's back end for rectification. This modular approach allows for the greatest outcomes in terms of power factor correction, voltage management, and load compatibility. The front-end Vienna type single-stage and LLC resonance inverter [5], using the eq. ckt of the suggested architecture in Fig. 2, is the basis for this research.

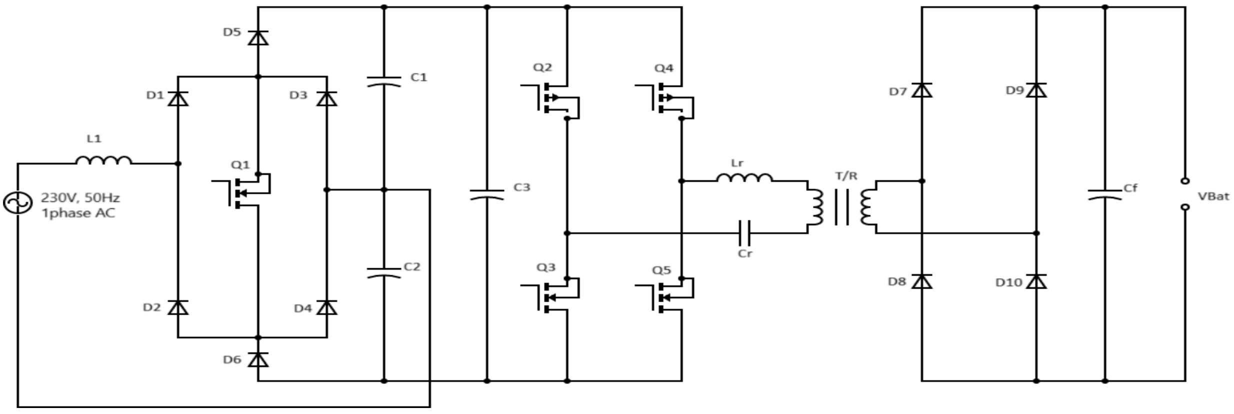


Figure 2: Equivalent Circuit of Proposed methodology

A [14] single-stage Vienna rectifier, which uses a single active electronic switch with six diodes, is intended to serve as an EV battery charger. PFC is advised by the IEC61000-3-2 standard [4]. Thus, the Vienna transformer offers good PFC performance for EV chargers. In the following step, the rectifier's DC output is further processed using a DC-DC resonant converter to meet the voltage and current requirements of the battery. [15] Its gentle switching qualities are what cause this. Excellent performance with a wide load range and galvanic isolation between input and output. For this stage, the LLC resonant converter is hence the suggested option. The full bridge LLC stages can be expanded to higher power levels because to their high-power density and conversion efficiency [15].

In order to offer consistent DC output and effective power factor adjustment under various grid conditions, FLC uses the voltage feedback loop in the front-end Vienna rectifier. To guarantee optimal battery charging, the FLC regulates the LLC resonant converter's output current and voltage based on the current feedback. Additionally, refrain from overcharging and overheating. Unlike conventional PID controllers, FLC manages system uncertainties and nonlinearities through rule-based decision-making, enabling precise control and smooth performance adjustments. This design significantly improves system efficiency, reduces total harmonic distortion (THD), and ensures dependable and good charging for electric bike applications.

3.1 Single-stage Vienna Rectifier

The single-stage single-switch Vienna rectifier [14] is derived from the three-stage Vienna rectifier shown in Figure 3. In order to prevent input current harmonics, power factor correction is utilized. [16] This will help reduce the interference of other devices that are working from the same source. [14] Because of connection path the advantages of this topology are Each component provides half the DC bus voltage at any given time. [14] It should be noted that in each half cycle of the entire period The maximum voltage of Vdc is divided into two equal parts of Vdc/2

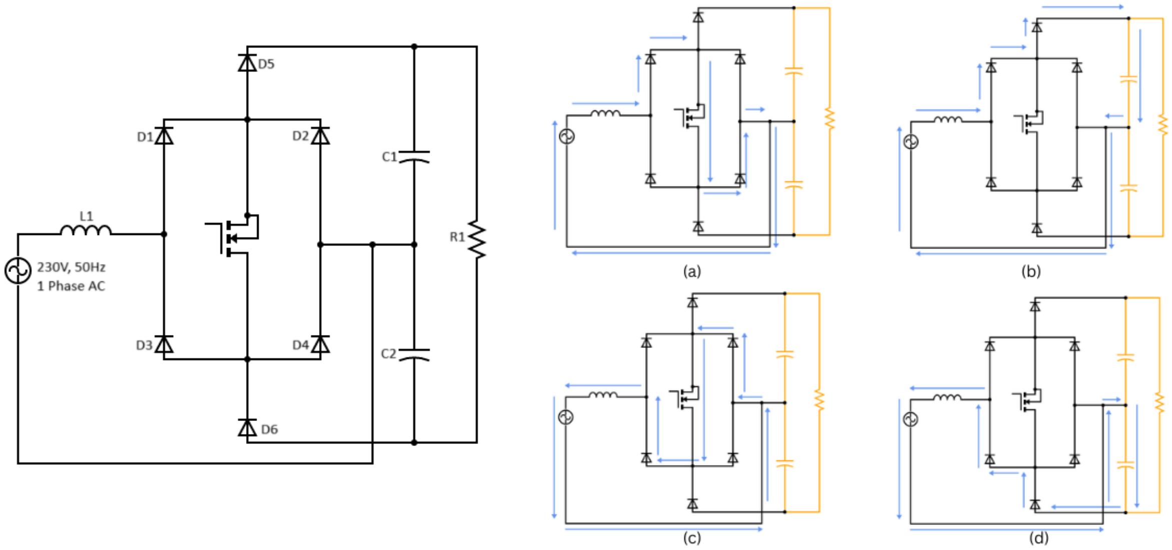


Figure 3: Single-Phase Vienna Rectifier with its Mode of Operation

Single-stage Vienna rectifiers have the intrinsic ability to balance the capacitor voltage without additional control and sensing circuitry [4], across a single AC voltage waveform cycle. There are four components to the power transfer. As shown in Figure 3, [13] When Q1 is turned on during the input power supply's positive half cycle (a), current builds up in the inductor L1 and passes via D1, Q1, and D4 to charge the inductor. concurrently Due to their sufficient size, the output capacitors C1 and C2 provide the load. Thus, it can be said that there won't be any change in the output voltage. [13] In the opposite direction of the input power supply's positive half cycle (b), the energy stored in the inductor is transferred to the output capacitor C1 when Q1 is closed. Until it reaches neutral, the inductor's current passes through Q1, D1, D5, and C1. [13] Additionally, current R1 flows within the load, finds the way to neutral through C2, and releases C2 a little. When Q1 is turned on during [13] the input power supply's (c) negative half cycle, current L1 builds up in the inductor in the opposite direction of mode I and moves from neutral to phase via D2, Q1, and D3. [13] The load is supplied by output capacitors C1 and C2, and during the same negative half cycle of the input power supply (d), when Q1 is closed, the energy stored in the inductor at the output capacitor C2 is transferred, causing the inductor current to diverge from Q1 and flow through C2, D6, and D3 from neutral to phase. Furthermore, a portion of the current passes via load R1, causing C1 to partially discharge [13].

3.2 Resonant Converter-LLC

The suggested topology's H-bridge LLC resonant converter has several desirable characteristics, including high power density, low EMI, and high efficiency. [1]. But the resonant converter design process is more labour intensive and requires more difficult optimization compared to other converters such as PWM. [1] LLC Resonant Converter also enables a soft switching feature. The Current flows in the main switching device only when the voltage is zero, this is an ideal zero voltage switching or ZVS. [1] LLC would operate in a resonant condition. The resonance frequency of the tank circuit is the same as the resonant switching frequency, [1]. The tank circuit's resonant frequency is regulated by the resonant capacitance and resonant inductance. There is only one position at which the LLC converter reaches resonance, and its profit at resonance is one [1]. Although there were certain disadvantages, the LLC will continue to operate effectively with consistency

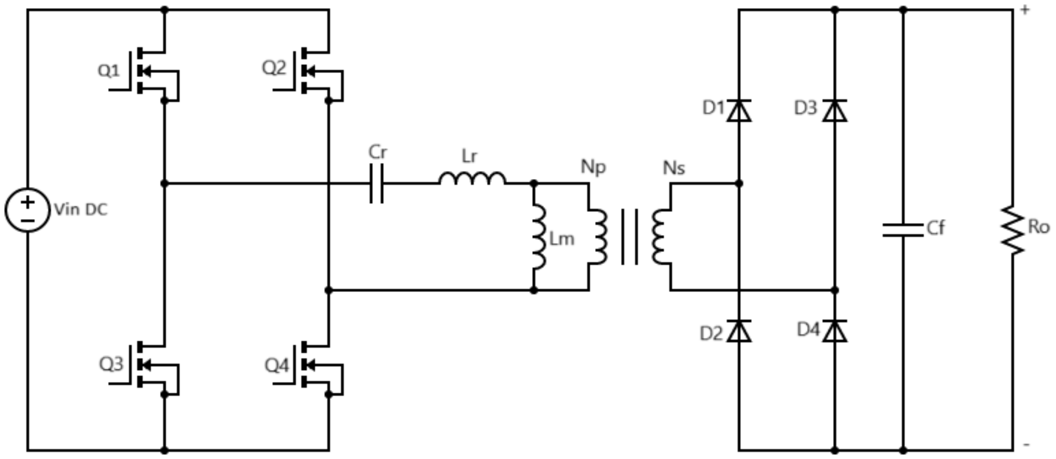


Figure 4: LLC Resonant Converter

As shown in Figure 4, [15] the operation of a H bridge LLC resonant converter has four parts: (a) a DC voltage source with a fully regulated H-bridge converter that acts as a pulse generator like square wave; (b) Resonance tank, (c) Transformer with turns ratio n:1 (d) Full bridge without rectifier control and filter capacitor To put it simply, a [1]transformer and rectifier in the output section scales and rectifies the sinusoidal current that is supplied by the LLC resonant tank, which is excited by a square wave produced by the switching bridge. The output capacitor rectifies the AC current and sends it as a DC voltage that the battery needs to charge. It also serves as a filter. The battery pack is regarded as a resistive load, which is determined by dividing the charging current by the battery voltage [15]. According to [15], the LLC resonant converter also serves as a filter. This removes the input square wave's higher odd harmonics. The peak resonance current has been calculated, as shown in

$$I_{RP} = \frac{2\pi P}{2V_b}$$

With the selected switching frequency of 100KHz, Resonant capacitors are implemented using

$$C_r = \frac{I_{RP}}{2\pi F_s}$$

To obtain the converter voltage [5], the ratio of Lm and Lr is used as a default of 0.3, so the resonant inductance and magnetic inductance can be calculated as;

$$L_r = \frac{1}{(2\pi F_s)^2 C_r}$$

$$L_m = 0.3L_r$$

3.3 Fuzzy Logic Control Implementation

Fuzzy logic controllers help maintain accuracy and reduce poor performance. [12] The input part involves transforming the fuzzy input into a corresponding membership function, such as a trapezoid or Gaussian, the next step calculates the input according to the rules such as centroids, weighted averages, etc. and then, in the third and final step The data is de-fuzzified [12].

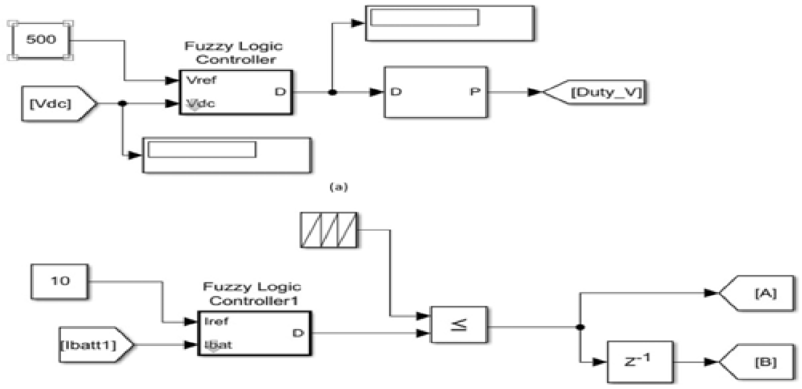


Figure 5: Fuzzy Logic Control Implementation

The fuzzy logic controller used in the OBC charger controls two functions. The switching control of a Vienna rectifier using a voltage providing an Optimized PWM output is shown in Figure 5. Another operation is controlling the H-bridge LLC by sensing the current value to the battery for achieve fast charging and better battery life. Thus, the controller can manage system uncertainties and nonlinearities, allowing for accurate control and seamless performance changes

3.4 Simulation Results

The proposed onboard charger simulation shown in Figure 6 with specifications shown in Table 1 was developed in MATLAB/ Simulink, tested on a 48V lithium-ion battery. The simulation is run for a period of 10 seconds A maximum current of 10A is reached at the output and is shown at an output voltage of 52V on the battery shown in Figure 7 & 8. The Vienna rectifier increases the input voltage to 500V at a PFC of 94.77% which, Works reliably in the current situation

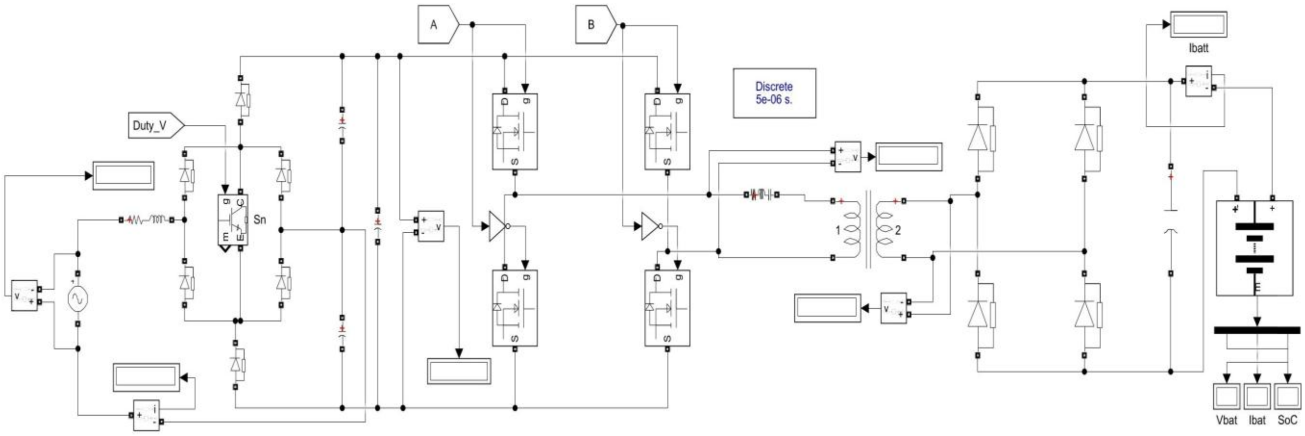


Figure 6: Simulation of Proposed Topology

Quantity	Parameters
Vin	325 V
Vo	50 V
Io	10 A
Efficiency	92
Resonant Capacitor	9.24 nF
Resonant Inductor	274.1 μH
Magnetizing Inductor	1644.6 μH
Filter Capacitor	7000 μF
Switching Frequency	20 kHz
L1	1 mH
DC-Link Capacitor	1500 μF

Table 1: Specifications of Proposed Topology

A maximum current of 10A is reached at the output and is shown at an output voltage of 52V on the battery shown in Figure 7 & 8. The Vienna rectifier increases the input voltage to 500V at a PFC of 94.77% which, Works reliably in the current situation

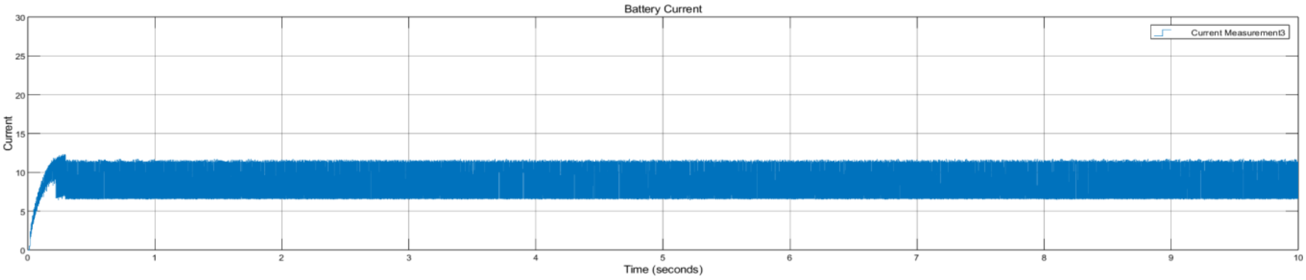


Figure 7: Output Current

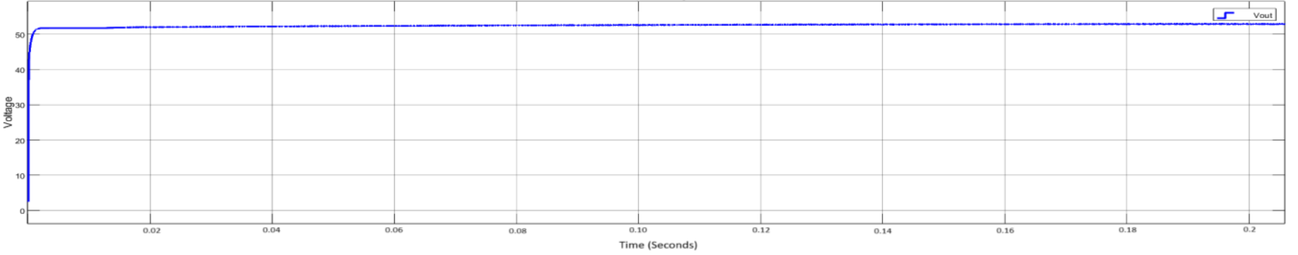
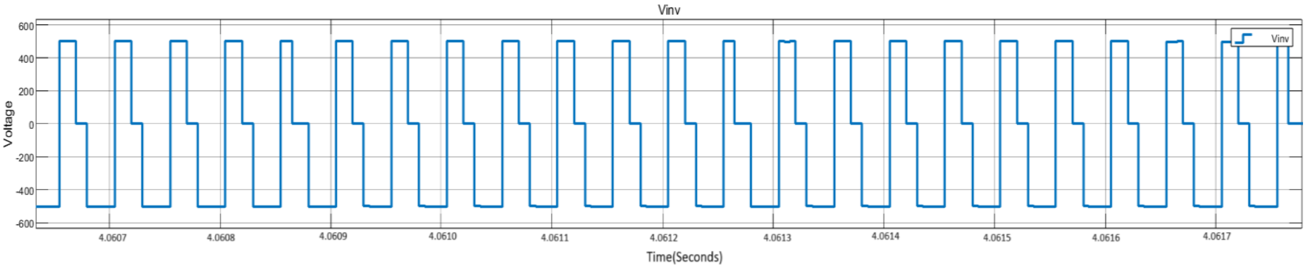


Figure 8: Output Voltage



Figures 9 and 10 show the Vo of the inverter and after the LLC transformer. The rated value of the battery is considered to be 48V and at the initial state of 50% the battery is charged by receiving it from the presented charger.

Figure 9: H-Bridge Inverter Output Voltage

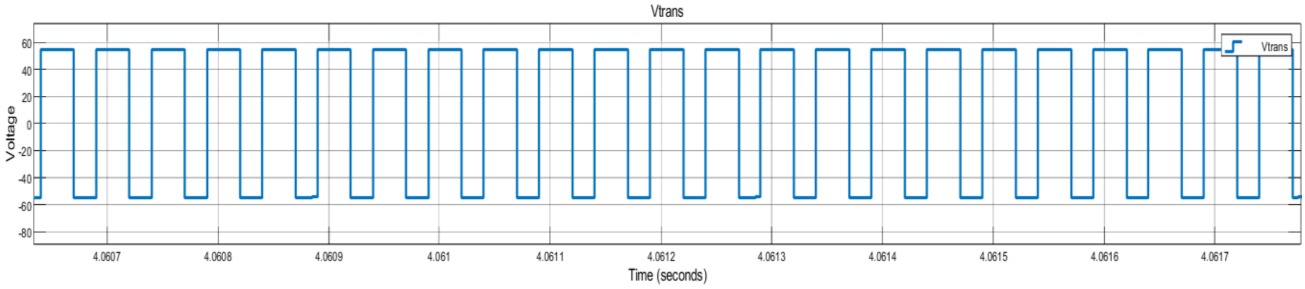


Figure 10: LLC Transformer Output Voltage

A full bridge LLC resonant converter is contacted to the battery which charges as per the requirement using fuzzy logic control. Different parameters of the battery are taken as SOC according to the time shown in Figure 11

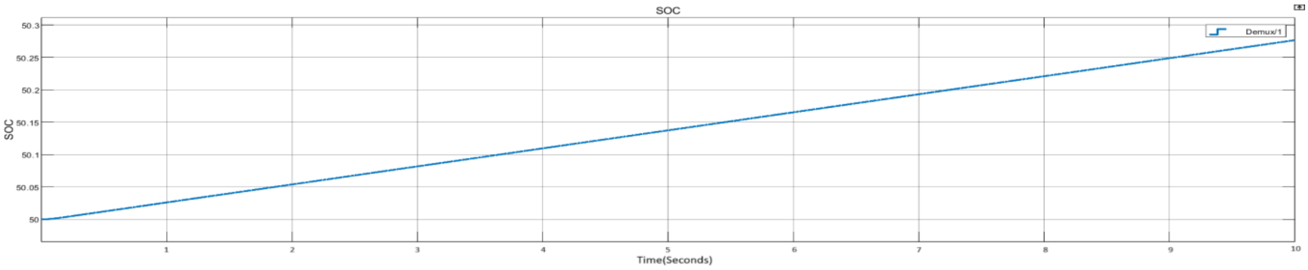


Figure 11: SOC of the Battery

The proposed Onboard battery charger using front-end of Vienna rectifier and back-end of LLC resonant converter charges the battery in optimized way which is reliable using Fuzzy logic control as seen in the above figure. With this charging topology, we can use under low voltage level batteries in the sector of electric vehicle.

IV. Conclusion

In this paper, an optimized charging system for e-bikes using a Vienna Rectifier and an LLC resonant converter controlled by a fuzzy logic controller was proposed and analysed. The system was designed to enhance power factor correction, improve efficiency, and ensure stable charging performance. A simulation model was developed in MATLAB/Simulink to validate the proposed topology. The simulation results demonstrated that the system achieved an output voltage of 50V and a current of 10A, meeting the charging requirements for a 48V e-bike battery. The Vienna Rectifier effectively improved power factor while minimizing harmonics, and the LLC resonant converter enabled soft switching, reducing losses and enhancing overall efficiency. The fuzzy logic controller dynamically adjusted to variations in battery conditions, ensuring optimal power flow and improving battery lifespan. Compared to conventional chargers, the proposed system provided better voltage regulation and current stability. Future work can focus on hardware implementation and experimental validation of the proposed system. Additionally, integrating advanced machine learning techniques could enhance the controller’s adaptability, further optimizing charging efficiency. Expanding the system for higher power applications and bidirectional energy transfer for vehicle-to-grid (V2G) applications can also be explored.

Acknowledgement

The authors acknowledge KSCSTE for the financial support offered under the SARD Scheme for the purchase of laboratory equipment and MATLAB software.

References

[1] Abdel-Rahman, S. & Infineon Technologies North America (IFNA) Corp. (2012), “Resonant LLC Converter: Operation and design”, Retrieved from https://www.infineon.com/dgdl/Application_Note_Resonant+LLC+Converter+Operation+and+Design_Infineon.pdf?fileId=db3a30433a047ba0013a4a60e3be64a1.

[2] Ali, A., Chuanwen, J., Yan, Z., Habib, S. & Khan, M. M. (2021), “An efficient soft-switched Vienna rectifier topology for EV battery chargers”, Energy Reports, Vol.7, 2021, pp. 5059–5073, doi: 10.1016/j.egyr.2021.08.105.

[3] B, A. S. R. & R, S. M. (2022), “On-Board EV Charging with Vienna Rectifier and LLC Resonant Converter”, IEEE 18th India Council International Conference (INDICON), 2021, pp. 1–6, doi: 10.1109/indicon56171.2022.10039848.

[4] Chaurasiya, S. & Singh, B. (2020), “A home charging system for EVs using Vienna-based modified CUK Converter and LLC Resonant Converter”, International Conference on Power, Instrumentation, Control and Computing (PICC), 2020, pp. 1–6, doi: 10.1109/picc51425.2020.9362441.

[5] Daniel, A. S. & Chandrakala, K. R. M. V. (2021), “Design of an isolated onboard plug-in electric vehicle charger”, International Conference on Electrical Energy Systems (ICEES), 7th ed., Vol. 147–149, 2021, doi: 10.1109/icees51510.2021.9383717.

[6] Deng, N. J., Li, N. S., Hu, N. S., Mi, C. C. & Ruiqing, N. MA (2013), “Design Methodology of LLC Resonant Converters for electric vehicle battery chargers”, IEEE Transactions on Vehicular Technology, Vol.63, No.4, 2013, pp. 1581–1592, doi: 10.1109/tvt.2013.2287379.

[7] "Design and Development of Smart Battery Charger for EVs using Single Phase Vienna Rectifier" (2021), International Journal of Engineering Research in Electronics and Communication Engineering, Vol.8, 2021.

[8] Pandey, R. & Singh, B. (2020), “An electric vehicle charger based on Vienna Rectifier and Resonant LLC converter”, IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), 2020, pp. 1–6, doi: 10.1109/pedes49360.2020.9379886.

[9] Praneeth, A. V. J. S., Vincent, D. & Williamson, S. S. (2019), “A Universal On-board Battery Charger with Wide Output Voltage Range for Electric Transportation”, IEEE Energy Conversion Congress and Exposition (ECCE), 2019, pp. 1159–1165, doi: 10.1109/ecce.2019.8912749.

[10] Praneeth, A. V. J. S. & Williamson, S. S. (2019), “A wide input and output voltage range battery charger using Buck-Boost Power Factor Correction Converter”, IEEE Applied Power Electronics Conference and Exposition (APEC), 2019, pp. 2974–2979, doi: 10.1109/apec.2019.8721797.

[11] Prasad, R., Namuduri, C. & Kollmeyer, P. (2015), “Onboard unidirectional automotive G2V battery charger using sine charging and its effect on li-ion batteries”, IEEE Energy Conversion Congress and Exposition (ECCE), 2015, pp. 6299–6305, doi: 10.1109/ecce.2015.7310543.

[12] Shabarish, P. R., Krishna, R. P., Prasanth, B., Deepa, K., Manitha, P. & Sailaja, V. (2020), “Fuzzy-based Approach to Enhance the Wireless Charging System in Electric Vehicles”, International Conference on Electronics, Communication and Aerospace Technology (ICECA), 2020, pp. 176–181, doi: 10.1109/iceca49313.2020.9297505.

[13] Thangavelu, T., Shanmugam, P. & Raj, K. (2015), “Modelling and control of Vienna Rectifier: A single-phase approach”, IET Power Electronics, Vol.8, No.12, 2015, pp. 2471–2482, doi: 10.1049/iet-pel.2014.0503.

[14] Vahedi, H., Labbe, P. & Al-Haddad, K. (2015), “Single-Phase Single-Switch Vienna Rectifier as electric vehicle PFC battery charger”, IEEE Vehicle Power and Propulsion Conference (VPPC), 2015, pp. 1–6, doi: 10.1109/vppc.2015.7353019.

[15] Wang, N. H., Dusmez, S. & Khaligh, A. (2014), “Design and analysis of a Full-Bridge LLC-Based PEV charger optimized for wide battery voltage range”, IEEE Transactions on Vehicular Technology, Vol.63, No.4, 2014, pp. 1603–1613, doi: 10.1109/tvt.2013.2288772.

[16] Winnefred Poul Luke Kingkam Durai (2020), “Design of On-board charger for Electric Vehicle”, International Journal of Engineering Research and Applications, Vol.7, 2020, pp. 16–23, doi: 10.9790/9622-1007041623.