ISSN (Online) 2394-6849

International Journal of Engineering Research in Electronics and Communication Engineering (IJERECE)

Vol 8, Issue 8, August 2021

Design and Development of Smart Battery Charger for EVs using Single Phase Vienna Rectifier

[1] Aadesh Aslekar, [2] Atharv Belsare, [3] Sudhanshu Baraskar, [4] Dr. Anagha Kunte

[1][2][3][4] Marathwada Mitra Mandal's College of Engineering, Pune, Maharashtra, India

***Abstract*---With advancement in technologies, it is suggested that electricity is the most suitable energy carrier for transportation. For this to happen we need powerful battery charging stations. In this project we have proposed a level-2 on-board plug-in battery charger which operates in fast charging mode (up to 4-6hrs), and will notify the charging status to the user, over the Wi-Fi. This paper presents design and implementation of a Single-Phase Vienna rectifier as Power Factor Correction circuit to improve the overall efficiency of the charger. Smart features include monitoring the cells in the battery to make sure that they function properly and notify the user of the issue, if any, in the battery pack. It also indicates possible failures that may occur in the battery pack. Different types of batteries can be charged as per the required voltage and current levels to ensure longevity of battery life. The implemented charger can work at 180-250VAC and can supply up to 20 Amperes of current, depending on battery charging specifications.**

***Index Terms*—E-Rickshaw, Power Factor Correction, Single Phase Vienna Rectifier, Smart Charger**

I. INTRODUCTION

Recently, there has been a growing interest in eco-friendly electric vehicle (EV) systems, as a result of the depletion of fossil-fuels, and so as to scale back greenhouse emissions. With the development of EV systems, the demand for related infrastructure has also increased. In particular, designing of chargers for EV systems remains the most important infrastructure-related issue. An EV charger consists of two parts, one to deliver energy from the AC grid to the DC link, and another to deliver energy from the DC link to the battery. When building an AC to DC conversion system, two different circuits are frequently considered: an inverter, which is capable of AC-DC and DC-AC conversion, and a Vienna rectifier, which is capable of AC-DC conversion. As EV chargers must have a fast-charging capability and high efficiency, the Vienna rectifier, which has a simple construction and high efficiency, is usually used because the pulse-width modulation (PWM) converter in this device, to control the grid side current.

Many design methodologies are proposed for this type of converter within the past decades. Exact analysis of LLC resonant converters ensures accuracy but can't be easily accustomed to get a handy design procedure because of the complexity of the model. The methods that use first harmonic approximation (FHA) analysis, are much simpler to handle. The FHA method provides accurate results at operating points below and above the resonant tank's resonance frequency. Therefore, it is been widely utilized in constant output voltage applications where the LLC converter is intended to resonate at nominal condition. Designing a wide-output-range LLC resonant converter supported FHA is investigated in, and therefore the expanded range is especially designed in frequencies above the resonant frequency. However, zero-current switching (ZCS) for output rectifier diodes is lost in this region. The FHA is still valid but less accurate; therefore, it is useful for qualitative analysis but not for optimal design procedure.

These approaches can give quite good design results but involve utilizing sophisticated calculation tools.

Fig. 1 shows the various blocks that constitute the proposed charger system.

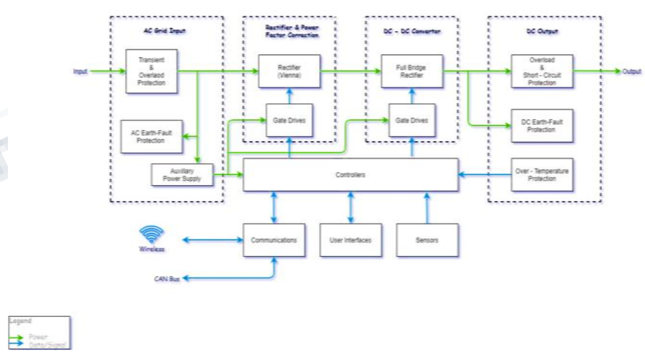

Figure 1. Block diagram of proposed system

II. VIENNA PFC RECTIFIER TOPOLOGY

Various Power Factor Correction (PFC) topologies are used to get the power factor ratio as high as possible. Some of the most widely used topologies are bridgeless-boost PFC, dual-boost semi-bridgeless PFC, etc.

The Vienna rectifier discussed in this paper is derived from three-phase Vienna rectifier which is analogous in

IFERP
connecting engineers... developing research

ISSN (Online) 2394-6849

International Journal of Engineering Research in Electronics and Communication Engineering (IJERECE)

Vol 8, Issue 8, August 2021

structure of a T-type inverter. However, the outer switches are replaced by diodes in this device, D_p and D_n, as indicated in Figure 2, which prevents energy from flowing from DC to AC. Furthermore, due of the simpler structure of this design and the usage of fewer switching devices, we consider a single-phase architecture for use in an EV's on-board charger (OBC). For normal operation of Vienna Rectifier, the "important rule", defined as the sign of the voltage should be equal to the sign of current, should be satisfied. Failure to meet this criterion will degrade the current quality and lead to increase in total harmonic distortion.

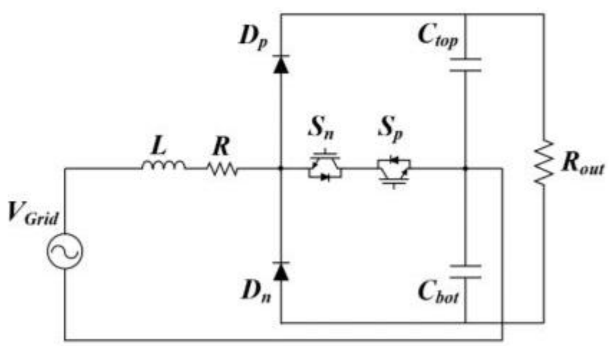

Figure 2: The proposed Single-phase boost PFC Vienna Rectifier.

Conventionally Vienna rectifiers use Proportional-Integrator (PI) controller for controlling the line current in the loop. This controller is good for regulating the DC and not AC components due to their dynamic response is slow for AC components. As the line current frequency increases the system power decreases, and line current distortion dominates.

In addition to large errors and the slow dynamic response of the PI controller, another reason for current distortion is a difference between the sensed current and the average current caused by discontinuous current mode (DCM) operation around the input voltage's zero crossing point. The phase difference between the input voltage and the line current also increases around this neutral region. Thus, to reduce the response error and the problems associated with the DCM, a controller that has a fast dynamic response and can control the power factor (PF) to unity is necessary.

The predictive control method was studied to make the controller with faster dynamics. The predictive control is designed with the system model. Generally, in this method, the current is predicted by the past state data. The optimal duty cycle is resultant of using this predicted current method. Hence, the controller is possible to get the faster dynamics than the PI control method. As mentioned above, in order to construe the optimal duty cycle, the current prediction is one of the important procedures. The inductance model and simple mathematical method is used for calculating the predicted current.

III. VIENNA RECTIFIER CONTROL

A circuit diagram of the proposed single-phase Vienna rectifier is shown in Figure 2. To the grid side, input filter of this topology consists inductor, L. The resistor, R, signifies the resistive component in the inductor. As stated above, the topology of this device is similar to that of a single-phase T-type inverter, with the outer switches of the inverter having been replaced by the diodes D_p and D_n in the rectifier. The rectifier topology includes two inner switches, a top switch, S_p, which only operates when the top capacitor, C_{top}, is charging, and a bottom switch, Sn, which only operates while the bottom capacitor, C_{bot}, is charging. Fig. 3(a) shows the equivalent circuit and the current path of a single-phase Vienna rectifier when the top switch is in operation. Figure 3(b) shows the equivalent circuit and the current path of a single-phase Vienna rectifier when the bottom switch is in operation. Figures 3(a) and 3(b) are further subdivided into different modes. Mode 1 and Mode 2 are operational when the grid is supplied with positive voltage and Mode 3 and Mode 4 operate when the grid is supplied with negative voltage. When Mode 1 is in operation, both switches, Sp and Sn, are turned off. The current flows through the top diode, Dp, and charges Ctop. In Mode 2, Sp is turned on and the current flows through this switch and the anti-parallel diode of Sn.

The closed current path consists of the switching device and the neutral point of the DC link to the grid. The current path in Mode 3 is same as Mode 2. However, the direction of current flow is reversed during mode. In Mode 4, Sn is turned off and current flow from the DC link to the grid side is in the same direction as in Mode 3. In this mode, the current path includes the bottom diode.

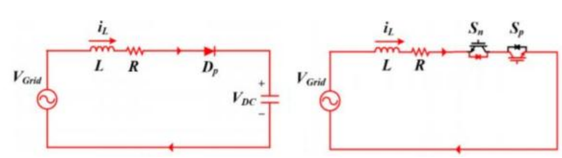

Figure 3 (a): Equivalent Circuit of the rectifier with top `switch in operation (a)Mode 1 (b)Mode 2

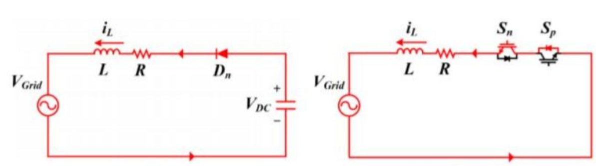

Figure 3 (b): Equivalent Circuit of the rectifier with bottom switch in operation. (a)Mode 3 (b)Mode 4

ISSN (Online) 2394-6849

International Journal of Engineering Research in Electronics and Communication Engineering (IJERECE)

Vol 8, Issue 8, August 2021

IV. DESIGN OF FULL BRIDGE RESONANT CONVERTER

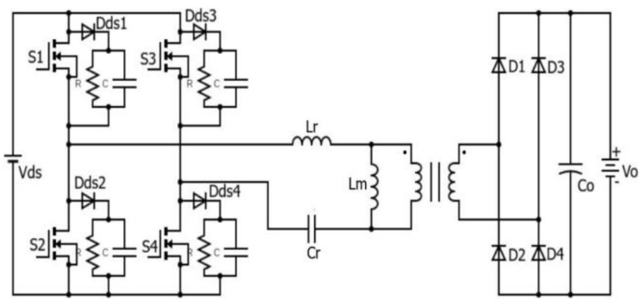

Figure 4. Proposed Design of LLC Resonant Circuit with Full Bridge rectifier

The configuration of the full-bridge resonant converter is shown in Fig. 4, which comprises of a switching network, the resonant tank, the output rectifier. The switching network consists of MOSFETs, S1 – S4, which are operated as switches to obtain a square wave. The square wave is applied to the resonant tank consisting of two inductors namely, magnetizing inductance L_m and leakage inductance L_r, and a capacitor C_r as shown.

The resonant tank is designed in such a way that it will limit all higher order harmonics and only pass fundamental sinusoidal harmonics of the square wave through the circuit. The output capacitor, Co, filters the rectified AC current and provides DC voltage which is then supplied to the load.

Table 1. Design Specification for the LLC convertor

Parameter	Designator	Value
Input Voltage	V_{dc}	400V
Output Power	P_o	1200W
Switching Frequency	F_s	75 – 120kHz
Primary Resonant Frequency	F_r	100kHz

V. OPERATION PRINCIPLE

This section offers an overview of LLC converter and its respective waveforms in resonant mode.

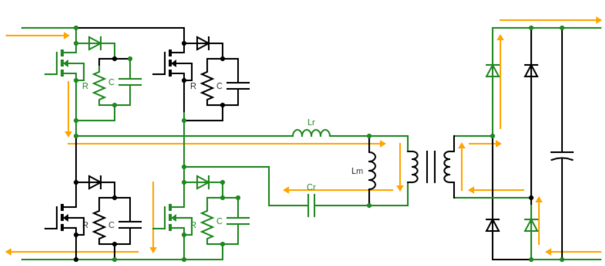

Figure 5(a)

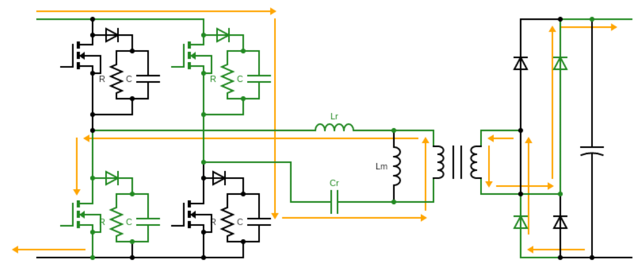

Figure 5(b)

Power delivery operation occurs twice during a switching cycle –

1. When the resonant tank is energized with a positive voltage, the current starts to resonate in the positive direction during the first half of the switching cycle, the equivalent circuit of this mode is shown in Figure 5(a).
2. When the resonant tank is energized with negative voltage, the current starts to resonates in the negative direction during the second half of the switching cycle, the equivalent circuit of this mode is shown in Figure 5(b).

Each half of the switching cycle comprises of an entire power delivery operation where the resonant half cycle is completed during the switching half cycle. The resonant inductor current I_{Lr} approaches the magnetizing current I_{Lm} by the end of the switching half cycle, and the rectifier current becomes zero. The resonant tank has a gain of unity and provides the optimal operation and efficiency; thus, the transformer turns ratio is set so that the converter runs at nominal input and output voltages.

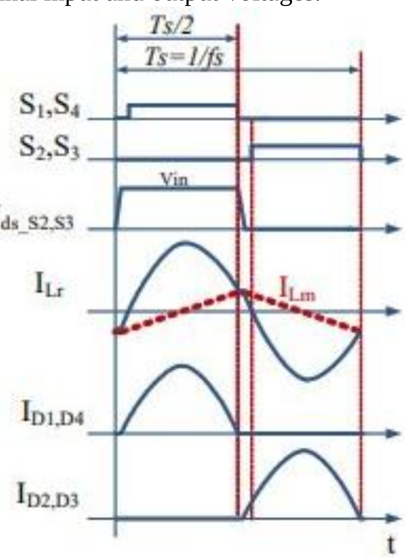

Figure 6. Expected waveforms of the proposed converter

ISSN (Online) 2394-6849

International Journal of Engineering Research in Electronics and Communication Engineering (IJERECE)

Vol 8, Issue 8, August 2021

Table 2. List of Components used

Component	Symbol	Parameter
MOSFET	S1 ~ S4	SIHF35N60EF-GE3 (600V/32A)
Rectifier Diodes	D1 ~ D4	FFSH4065A (650V/40A)

VI. SIMULATION RESULTS

The following design is implemented for LLC resonant convertor with the specification of Po=1.2kW, Vin=400V, Vo=58V as shown in Fig. 7, The input to the convertor is the output from Vienna rectifier. Integrated transformer is used for isolation and a resonant capacitor (Cr) is connected in series with the transformer primary. The schematic of the LLC convertor is modelled such that it maintains an output voltage of 58V as shown in fig., while the maximum power being 1200W.

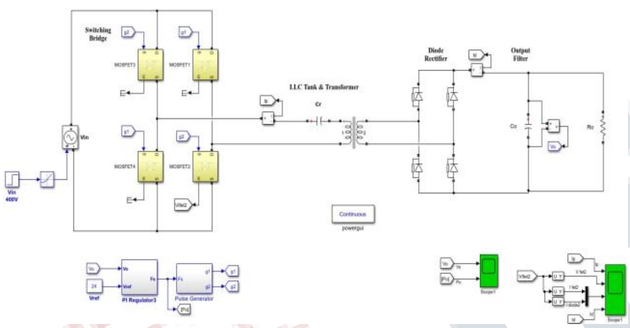

Figure 7. Schematic of Modelled Resonant LLC Converter

Figure 8. Simulation Result of Output Voltage

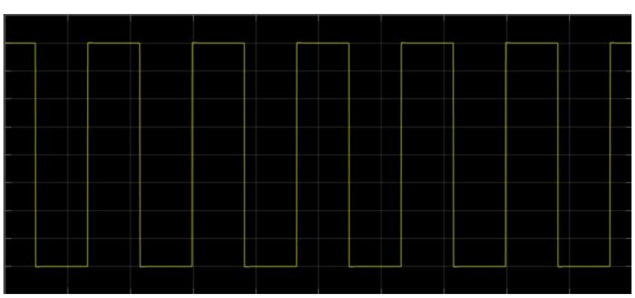

Figure 9. Voltage across the switch

The output voltage of the proposed convertor for the input voltage of 400V and the duty cycle ratio of 50% is 58V.

Figure 10. Simulation of input current

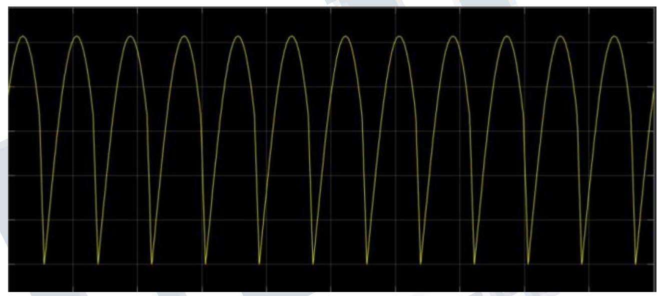

Figure 11. Simulation of output current

VII. SMART FEATURES

A smart device is defined as a context-aware electronic device capable of performing computing autonomously and being able to connect to other devices wirelessly for sending data. Smart features such as WIFI, CAN communication is provided in the designed system so that one can effortlessly connect to the charger to get various data on other devices that support these connection facilities.

The data user can access includes current battery charging status, estimated time to fully charge the battery, notification after the battery has been fully charged, logs of battery charging cycles for estimation of battery life or for studying the battery degradation and giving an estimate when the battery needs to be replaced.

VIII. CONCLUSION

According to the design proposed in the report we come to a conclusion that we are able to efficiently charge a battery, whether Lithium ion or Lead Acid, keep a track of the charging cycles of the battery, notify the user of the battery parameters over WIFI and also use the logs to determine the battery degradation and reduce or prevent further degradation, thus increasing battery life. The Vienna Rectifier topology provides an efficiency of ~98% which gives us better performance at high current and voltages. All of this is achieved by the plug-in charger proposed without any external infrastructure.

IX. ACKNOWLEDGEMENTS

The authors would like to gratefully acknowledge Mr. Vivek Aranke and Mr. Vinay Deshpande, Sunay Enterprises, the sponsor, for the technical guidance and sharing the lab equipment.

REFERENCES

[1] Kim, J.-H.; Lee, I.-O.; "Moon, G.-W. Integrated Dual Full-Bridge Converter with Current-Doubler Rectifier for EV Charger". IEEE Trans. Power Electron. 2016

[2] Yang, S.H.; Park, J.-H.; Lee, K.-B. "Current Quality Improvement for a Vienna Rectifier with High-Switching Frequency." Trans. Korean Inst. Power Electron. 2017

[3] Kim, D.-H.; Kim, M.-J.; Lee, B.-K. "An Integrated Battery Charger with High Power Density and Efficiency for Electric Vehicles. IEEE Trans." Power Electron. 2017

[4] X. Zhang and C. Mi, "Vehicle Power Management: Modeling, Control and Optimization." Berlin, Germany: Springer-Verlag, 2011.

[5] "Electric Vehicle OBC System Design and Simulation Using Power Modules", ON Semiconductor Application Note, AN−6982 Rev. 1.0.1, November 26th 2014.

[6] "Power Electronics: Converters Applications and Design, Media Enhanced", Robbins Mohan, Undeland.

[7] "Power Electronics- Devices, Circuits and Applications", Muhammad H. Rashid.

[8] "Design Guidelines for RCD Snubber of Flyback Converters", FAIRCHILD.

[9] "Review Paper on Electric Vehicle Charging and Battery Management System", ICCIP.

[10] "Design Methodology of LLC Resonant Converters for Electric Vehicle Battery Chargers", IEEE Transactions on vehicular Technology.

[11] "Single-Phase Single-Switch Vienna Rectifier as Electric Vehicle PFC Battery Charger", EEE Vehicle Power and Propulsion Conference (VPPC).

[12] "Taking charge of electric vehicles – both in the vehicle and on the grid", Texas Instruments.

[13] "Improving Line Current Distortion in Single-Phase Vienna Rectifiers Using Model-Based Predictive Control", Yong-Dae Kwon, Jin-Hyuk Park and Kyo-Beum Lee.

[14] "Power Factor Correction design for On-Board Chargers in

[15] Electric Vehicles", Application Report, Texas Instruments.