Performance Evaluation of the Highly Efficient Vienna Rectifier Configuration in PISIM for Rapid Charging of Electric Cars

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Abstract

The future of cleaner and more energy-efficient transportation electrification is being shaped by the increase in the number of electric cars being utilized by customers. High-efficiency charging stations are essential to the economic viability of electric cars (EVs). This paper covers the effective converter architecture for charging stations as well as the design and assessment of various current converter topologies. The efficacy and dependability of the overall harmonic distortion, component count, power factor, output power, and evaluation of these converters' designs are discussed, examined, and contrasted. The Vienna rectifier is the most ideal converter architecture for high-power DC fast-charging infrastructure because to its low output voltage ripple, high efficiency, low current ripple, and high power density, according to the research. The work primarily focuses on several Vienna rectifier topologies on Level-3 DC fast-charging stations, which reduce CO2 emissions at these locations and help to meet the climate action targets of the Sustainable Development Goals. This work discusses the components of a proposed DC-DC converter topology. The selected topology, including its many stages of operation and workings, will be thoroughly elucidated.

Keywords: DC- DC CONVERTER; ELECTRIC VEHICLES; CHARGING STATIONS; VIENNA RECTIFIER.

1. INTRODUCTION

Fast charger integration in electric vehicles (EVs) is hampered by the high cost of the electrical parts required for energy conversion, which drives up the price of EVs. The high cost of the EV's power electronics limits the speed at which EVs can be charged using on-board chargers; thus, the vehicle's charger capacity must be increased. High DC power off-board chargers are used to facilitate fast EV charging. Interestingly, each off-board charger's AC/DC power conversion is carried out by separate inverters, necessitating more converter power to guarantee quick vehicle charging. Designing durable and effective EV charging systems at charging stations has been made possible by the insights gained from a variety of research. Thus, it is important to investigate the idea of public spaces with high-power off-board chargers that serve as charging stations. These would provide EVs with similar functionality to gas stations by providing direct current to EV batteries so they may be quickly charged. Two options—AC and DC—emerge when thinking about charging station layouts that depend on a grid connection. Whereas the latter sets up a single AC/DC stage to offer a common DC bus service for system loads, the former uses the secondary side of a step-down transformer as a common AC bus, with each load connected to the bus via separate AC/DC stages. An input filter consisting of an inductor (L) and resistor (R) that represent resistive parts within the inductor is used in a single-phase Vienna rectifier architecture. The converter that is being discussed here is similar to a single-phase T-type inverter, except instead of outside switches, the rectifier's diodes are used. An internal switch in these rectifier topologies only turns on when the top capacitor is being charged. Because of their lower switching frequency, circuits with fewer switches have lower Total Harmonic Distortion (THD) in line currents, which improves power factor at the source side. This converter, also known as a split capacitor, is unique in that it places two capacitors at the output side to reduce the voltage stress on power semiconductor switches.

1. Simulation in PISIM

For single-phase EV charging stations, the Vienna Rectifier is simulated using PSIM modeling software in all three topologies. In topology-01, electrical switches are comprised of six diodes per phase and one power MOSFET. Topology-03 has only two diodes and two controlled switches, whereas Topology-02 utilizes four diodes per phase and two power MOSFETs. The recommended rectifier circuit is ideal for electric vehicle charging station converters as it has fewer components and a higher output DC voltage level. The output voltage level will be covered in more depth in the results section.

1.1. Topology-1

The input current is made sinusoidal in this design by using the power factor correction controller to adjust the output voltage to a constant value [9]. Nevertheless, this topology's six diodes and single semiconducting switch lower the system's efficiency. One of the most notable benefits of this connection is the ability to achieve low voltage stress on each component, which at each interval lowers the overall DC bus voltage by half [10,11]. The average and RMS current ratings of the semiconductor have been computed using analytical approximations. These converters can boost the DC output voltage and enhance the input side's power quality by utilizing the inductor that is already there.

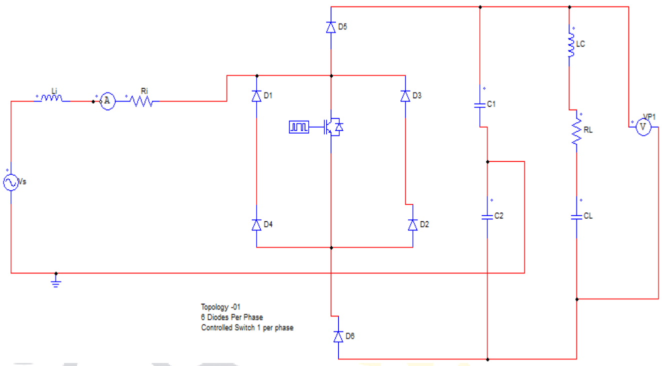

Figure 4 (a) Simulation Circuit for Topology- 1

1.1. Topology 2 :

The MOSFET current is split between two MOSFETs in Topology 2, but the freewheeling diode currents I_{D2} and I_{D4} and the capacitor ripple current I_C stay the same as in Topology 1. Two capacitors are linked in parallel to decrease switch losses and lessen the voltage stress on the switches [12].

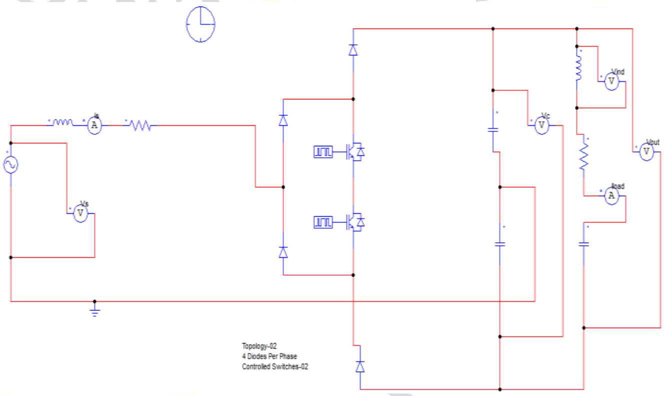

Figure 4 (b) Simulation Circuit for Topology- 2

1.1. Topology 3

Third Topology There are no redundancy states in Topology 1 or Topology 2 to continually balance the capacitor's voltage. The primary disadvantage of the aforementioned topologies is that they cause a large amount of voltage ripple at the DC output. By employing two switches that are linked in anti-parallel to the neutral, Topology 2 reduces voltage ripple. The freewheeling diode current in Topology 3 is the same as in the previous topologies. The switch differs from Topology 1 in that it consists of two MOSFETs instead of one, which lessens the voltage stress on the switches. It also features a circuit with just two diodes, which lowers diode losses. The device's cost is decreased and its efficiency is increased as a result of this design's decreased diode losses and decreased switch rating. The switches in this architecture are coupled in a MOSFET back-to-back configuration [13, 14, 15]. MOSFET S1 and the S2 diode conduct in the positive half of the cycle, while MOSFET S2 and the S1 diode conduct in the negative half.

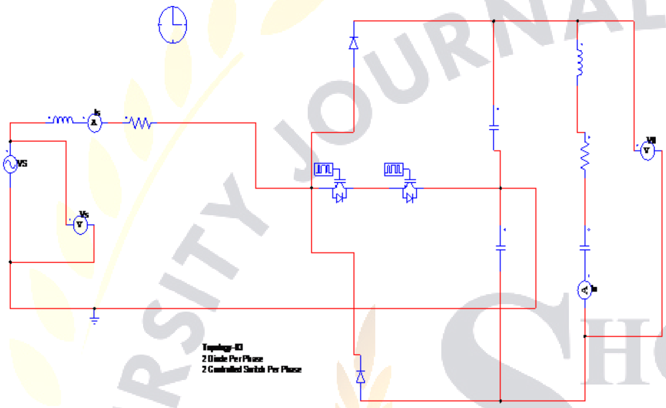

Figure 4 (c) Simulation Circuit for Topology- 3

Table-1 Simulation Parameters for the Proposed DC-DC Converter

Parameters	No. of controlled switches per phase	No. of diodes per phase Input current THD	No. of diodes per phase Input current THD	P fa
Topology -1, V.R	1	6	5	[illegible]
Topology-2, V.R	2	4	20	[illegible]
Topology-3, V.R	2	2	5	[illegible]

2. Results & Discussion

Table 2 lists the quantity, kind, and number of diodes for each topology. It is noted that Topology 3 has a relatively small number of components accessible.

Table -2: Device count of various topologies

Converter topology	Reference	Mode of operation	Phase current THD (%)	Efficiency (%)	Power density (kW/ dm3)
Unidirectional Boost converter	[11]	Boost	30	63.5	2.6
SWISS Rectifier	[15]	Buck	5	99.3	4
Matrix converter	[18]	Buck-Boost	20	98	4
Vienna Rectifier	Proposed	Boost	5	98	12

We examine the three Vienna rectifier topologies at 50 kHz. Topology 3, as seen in Figs. 5.1 to 5.3, is more efficient than Topology 2 and Topology 3 between input voltages of 200 V and 600 V. Switching losses will rise over 200 V because Topology 1 has more switches than it does. Therefore, Topology 3 is more efficient than Topology 1 and more efficient than other topologies for a wide range of input voltage. It should be mentioned that Topology 3 has fewer switches than the other two topologies. As a result, Topology 3 has extremely low losses, which increases efficiency.

2.1. Input Current Characteristics

For three topologies, it is observed that the input current waveform is almost sinusoidal. In Fig. 5, the input current is shown. The sinusoidal waveform of input current varies somewhat in each of the three topologies due to small shifts in the harmonics. Topology 3 exhibits a sinusoidal input current, indicating unity power factor at the input power source, in contrast to the other two topologies.

THD Spectrum of Input Current It is observed that Topology 1's input current THD percentage of 8% falls short of the IEEE requirement of 5%. Topology 2's higher number of switches results in lower input current harmonics (0.55%) than Topology 1, which satisfies IEEE requirements. As a result, Topology 2 experiences greater losses and the circuit's efficiency declines. Topology 3's percentage input current THD is less than 5%, at 0.35%, meeting IEEE requirements. The research clearly shows that, out of the three topologies, Topology 3 performs better than Topologies 1 and 2.

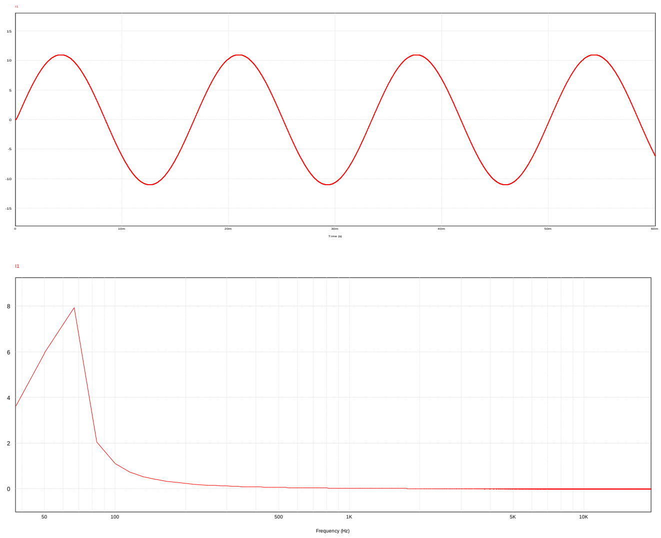

Figure 5 Waveform (a) Input Current, (b) THD of Topology -01

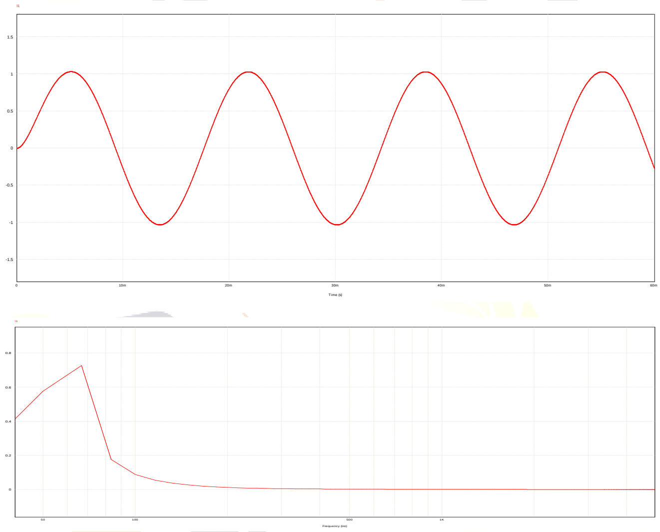

Figure 6- Waveform (a) Input Current, (b) THD of Topology -02

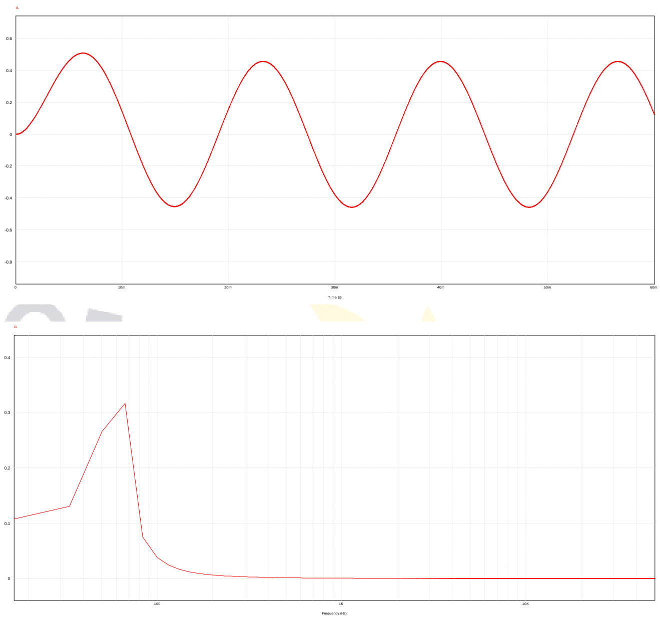

Figure 7- Waveform (a) Input Current, (b) THD of Topology -03

2.2. Output Voltage of Vienna Rectifier Topologies

In every topology, the DC output voltage is nearly constant. Tables 8 through 10 provide the output DC voltage for each of the three topologies. Assessments of Vienna Rectifier Topologies' Performance In comparison to other topologies, it is evident that Topology 3 offers superior performance in terms of THD value. The quantity of diodes and controlled switches in the converters is what causes harmonics to be introduced. Compared to Topology 2 and Topology 3, Topology 1 contains more semiconductor switches, which causes greater losses and lowers

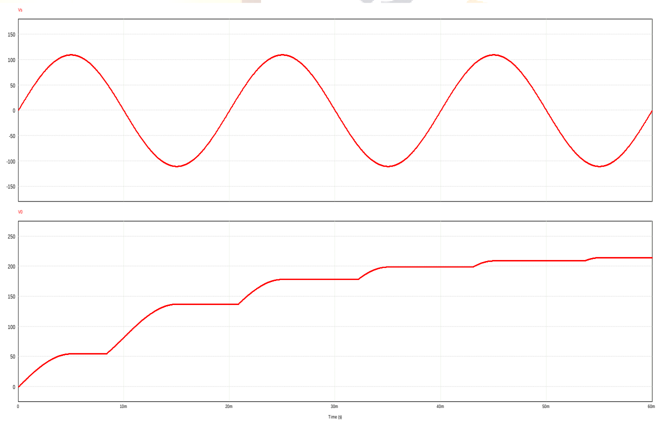

Figure 8- Waveform (a) Input Voltage, (b) Output Voltage Topology -01

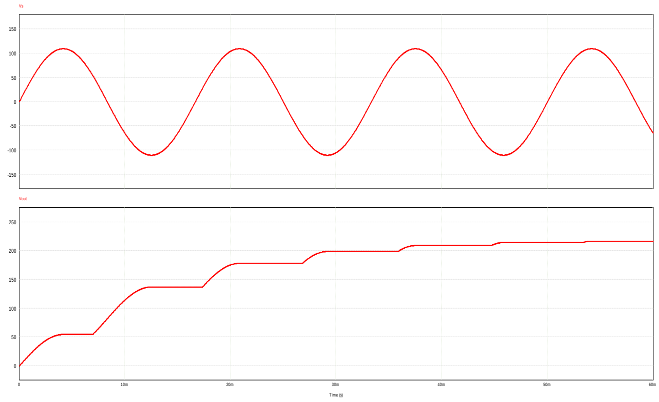

Figure 9- Waveform (a) Input Voltage, (b) Output Voltage Topology -02

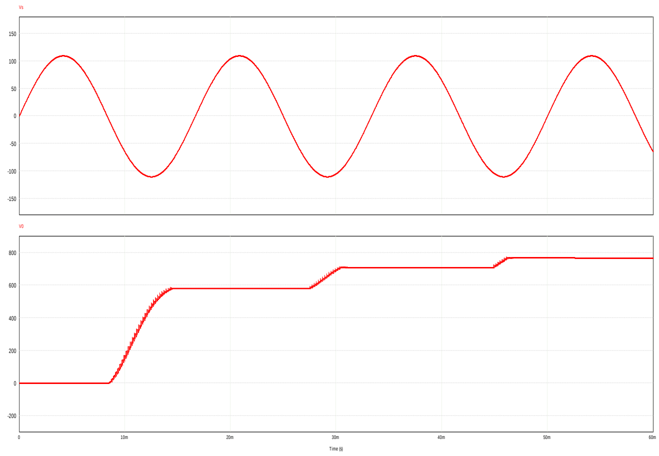

Figure 10- Waveform (a) Input Voltage, (b) Output Voltage Topology -03

The system's effectiveness Topology 3 features fewer diodes than Topology 2, although having the same amount of controlled switches. As a result, the input current harmonics in Topology 1 grew to greater than 5%, which has an impact on the source's power quality. With the input current's THD decreased in Topology 3, the power factor has increased to unity. It raises the system's efficiency and lowers the circuit's losses.

3. Conclusion:

A comparative analysis of the efficiency of several Vienna rectifier topologies has been conducted. Three Vienna rectifier topologies were analyzed, and it was found that, when compared to the other topologies, Topology 3 used the fewest semiconductor switches. The most similar efficiency values are seen in Topologies 1 and 3, with Topology 3 operating at a greater efficiency level over 600 V. Three topologies are simulated and their performance is examined in terms of power factor, THD, total loss and efficiency, and the number of active and passive devices. We find that the Topology 3 converter is the best option for electric car charging stations. It is characterized by low complexity, high efficiency, high power density design, low input current THD, and lower power consumption.

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