Modeling of Vienna rectifier with PFC controller for electric vehicle charging stations

Cite as: AIP Conference Proceedings **2137**, 030003 (2019); https://doi.org/10.1063/1.5120996
Published Online: 07 August 2019

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Modeling of Vienna Rectifier with PFC Controller for Electric Vehicle Charging Stations

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Abstract. Battery Electric Vehicles (BEVs) are a promising technology that can be replaced with ICE driven cars to reduce global warming effects. In 2030 the number of BEVs will rise to 18% compared to ICE vehicles. Recently, the charging stations are the bottlenecks to increase the BEVs. When the BEVs connected to the charging stations, the quality of the power is reduced and failed to meet IEEE standards. In this paper, the Vienna rectifier with a power factor correction (PFC) controller is proposed. The Vienna rectifier is the favourite choice for the high power applications for its merits such as less number of switches, simple structure, high power density, and it can able to realize the unity power factor and total harmonic distortion to less than 5%. The Vienna rectifier is controlled with a PFC controller to minimize the power quality issues such as power factor and total harmonic distortion. The simulation of Vienna rectifier with PFC controller is done by using MATLAB/Simulink, and the quality of the power is analyzed and compared. The effectiveness of the Vienna rectifier is verified by using MATLAB/Simulink.

Keywords: Electric vehicles, Charging stations, Vienna Rectifier, Total harmonic distortion, Power factor

INTRODUCTION

According to the survey results produced by the United Nations Environmental Program (UNEP) [1-2], the harmful gasses from transported vehicles are the third largest sources for CO_2 emission as shown Fig. 1. Since the increase in awareness of environmental issues, manufacturers have devised a means of powering up a vehicle using alternative forms of energy instead of using the more commonly used, fossil fuels. Recently, the electricity is the most popular means of powering up a vehicle which is widely used. These vehicles are universally known as Battery Electric Vehicles (BEVs). Nowadays, the number of BEVs on the road is very low compared to the fuel driven vehicles because it is providing low carbon emission into the atmosphere. The percentage of electric vehicles in the global during 2015-2016 is 1%. The percentage of BEVs are expected to be increased by 18% in 2030[3]. It is evident that the number of BEVs will be gradually increased in the future is shown in Fig. 2.

In recent years. The number of battery electric vehicles on the road is gradually increased due to the greenhouse effect. Due to the increase in BEVs, the demand for charging the batteries are also increased. The charging stations are classified as slow charging, accelerated recharge, and DC fast charging. All three charging stations are having a different level of voltage ratings. By using AC to DC converters at the charging stations, the harmonics are introduced into the grid. The batteries can be rechargeable from the grid by using different types of sockets. To charge the batteries, different types of charging stations are available in the market. They are classified into three types, such as 120V charging, 240V charging, and DC fast charging [4-5].

Proceedings of the International Engineering Research Conference - 12th EURECA 2019
AIP Conf. Proc. 2137, 030003-1–030003-7; https://doi.org/10.1063/1.5120996
Published by AIP Publishing. 978-0-7354-1880-6/$30.00

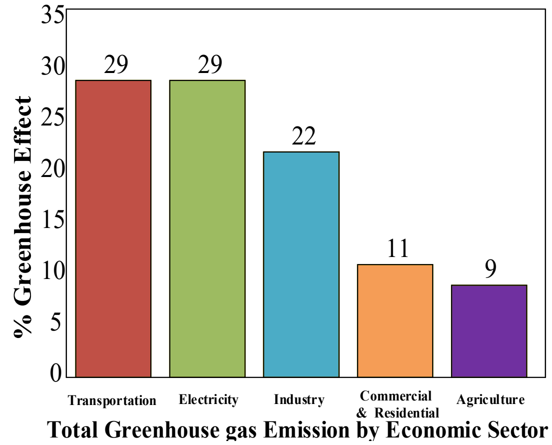


FIGURE 1. Total Greenhouse gas emission by the economic sector [1-2]

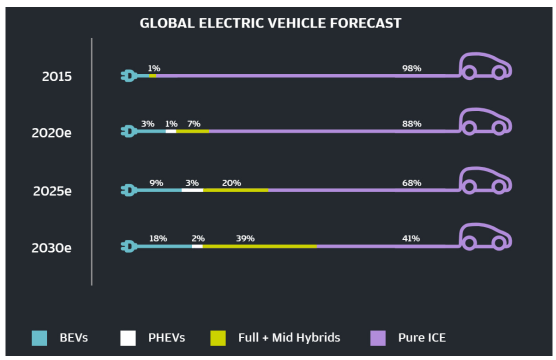


FIGURE 2. Future Growth in BEVs [3]

CIRCUIT MODEL AND ANALYSIS

The single phase Vienna rectifier composed of 1 boost inductor, two fast rectifier diodes, and two bidirectional semiconductor switches with DC split capacitors at the output side. The DC split capacitors are used to reduce the voltage stress across the semiconductor switches. The power factor, total harmonic distortion, capacitor voltage, and output voltage are controlled by the control of power semiconductor switches. Fig. 3(a) shows the structure of the Vienna configurations. The switch diagram of the Vienna model consists of six fast rectifier diodes and one semiconductor switch, as shown in Fig. 3(b). The voltage source circuit, which is used to find the voltages and currents in each phase, as shown in Fig. 3(c).

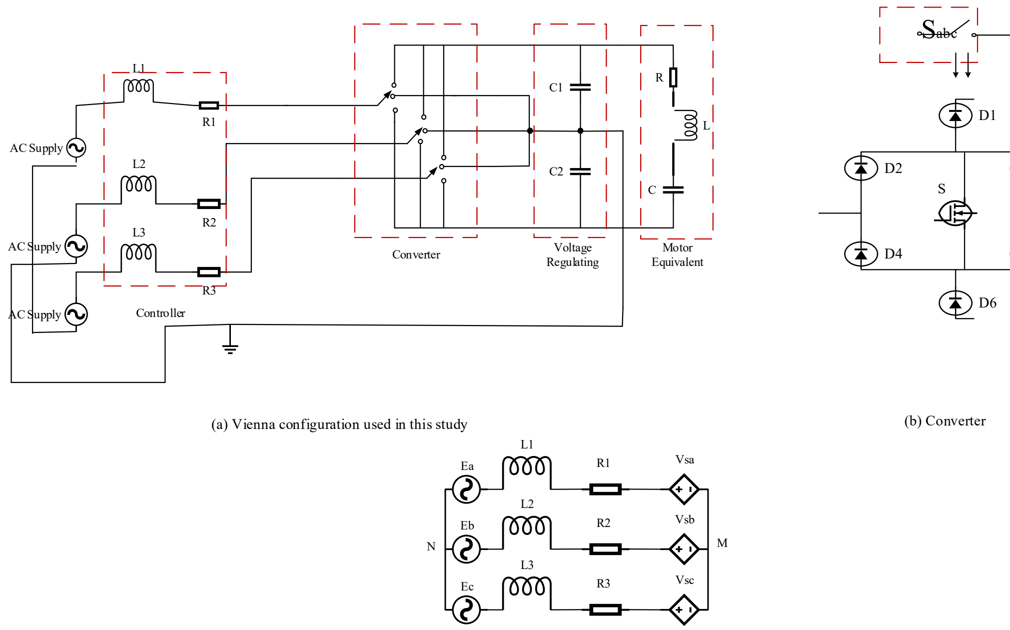
The mathematical model of the Vienna rectifier is developed to facilitate the design of three-phase Vienna rectifier. All the power switching devices are assumed to be ideal for the model [6-8].

According to Fig. 3(c), the loop voltage is listed as in Eq. (1) – Eq. (3) :

$$E_a = L_1 \frac{di_a}{dt} + RI_a + V_{sa} + V_{MN} \tag{1}$$

$$E_b = L_2 \frac{di_b}{dt} + RI_b + V_{sb} + V_{MN} \tag{2}$$

$$E_c = L_3 \frac{di_c}{dt} + RI_c + V_{sc} + V_{MN} \tag{3}$$



(a) Vienna configuration used in this study

(b) Converter

(c) Equivalent Circuit Model

FIGURE 3. Configuration of the proposed converter-controller

For the case of three-phase symmetry is obtained as in Eq. (4) – Eq. (6):

$$E_a + E_b + E_c = 0 \tag{4}$$

$$i_a + i_b + i_c = 0 \tag{5}$$

$$V_{MN} = -\frac{V_{sa}+V_{sb}+V_{sc}}{3} \tag{6}$$

S_{ij}(i=a, b, c, j= p, o, n) is the switching function. When the switch is conducting, the value is 1, and 0 for breaking time. It can be expressed as in Eq. (7) – Eq. (9):

$$V_{sa} = S_{ap}V_{C1} - S_{an}V_{C2} \tag{7}$$

$$V_{sb} = S_{bp}V_{C1} - S_{bn}V_{C2} \tag{8}$$

$$V_{sc} = S_{cp}V_{C1} - S_{cn}V_{C2} \tag{9}$$

The voltage loop equation can be expressed as in Eq. (10) – Eq. (12):

$$L_1\frac{di_a}{dt} = E_a - Ri_a - \left(\frac{2S_{ap}-2S_{bp}-2S_{cp}}{3}\right)V_{C1} - \left(\frac{-2S_{an}+2S_{bn}+2S_{cn}}{3}\right)V_{C2} \tag{10}$$

$$L_2\frac{di_b}{dt} = E_b - Ri_b - \left(\frac{2S_{ap}-2S_{bp}-2S_{cp}}{3}\right)V_{C1} - \left(\frac{-2S_{an}+2S_{bn}+2S_{cn}}{3}\right)V_{C2} \tag{11}$$

$$L_3\frac{di_c}{dt} = E_c - Ri_c - \left(\frac{2S_{ap}-2S_{bp}-2S_{cp}}{3}\right)V_{C1} - \left(\frac{-2S_{an}+2S_{bn}+2S_{cn}}{3}\right)V_{C2} \tag{12}$$

The analysis is performed for determining the three-phase Vienna rectifier output.

MODELING AND ANALYSIS OF THE PROPOSED CONVERTER

The methodology of the modeling of Vienna Rectifier is shown in Fig. 4. The evaluations of the system are based on determining total harmonic distortion, the power factor of the input supply of the converter. In this proposed controller, as in Fig.5, the PFC controller consists of three PI controller to improve the power quality issues. The first PI controller s used to regulate the DC output voltage across the load. The second PI controller is used to improve the quality of the input current. The third PI controller is used to regulate the capacitor voltage. In Vienna Rectifier, the power factor correction controller is used to control the output voltage to a constant value and to make the input current sinusoidal to maintain the unity power factor at the input supply. However, this Topology has only one semi-conducting switch, six diodes reducing the efficiency of the system. Due to this connection, one most outstanding merit of this converter is low voltage stress on each component that will reduce half of the total DC bus voltage at each interval. The simulation is done with RLE load, which is equivalent to the motor load. The simulation of Vienna Rectifier is shown in Fig. 6.

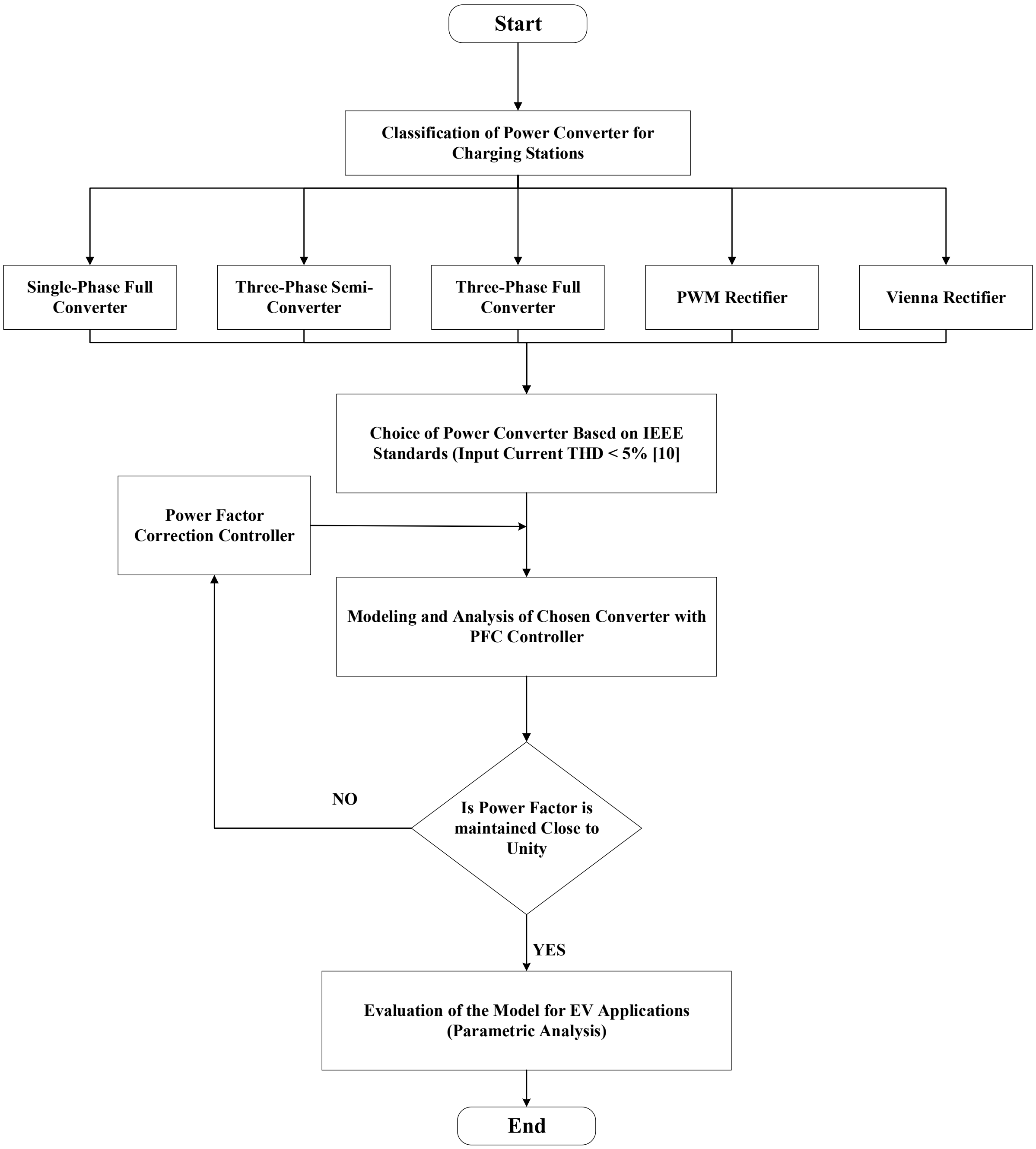


FIGURE 4. Methodology of modeling of Vienna Rectifier with PFC Controller

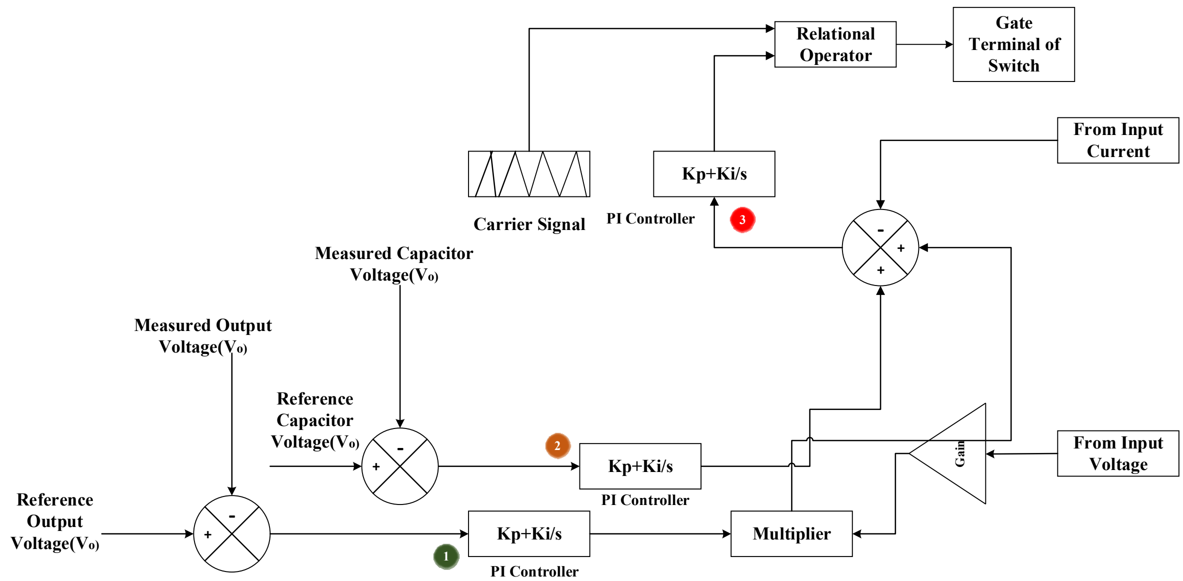


FIGURE 5. PFC Controller for Vienna Rectifier

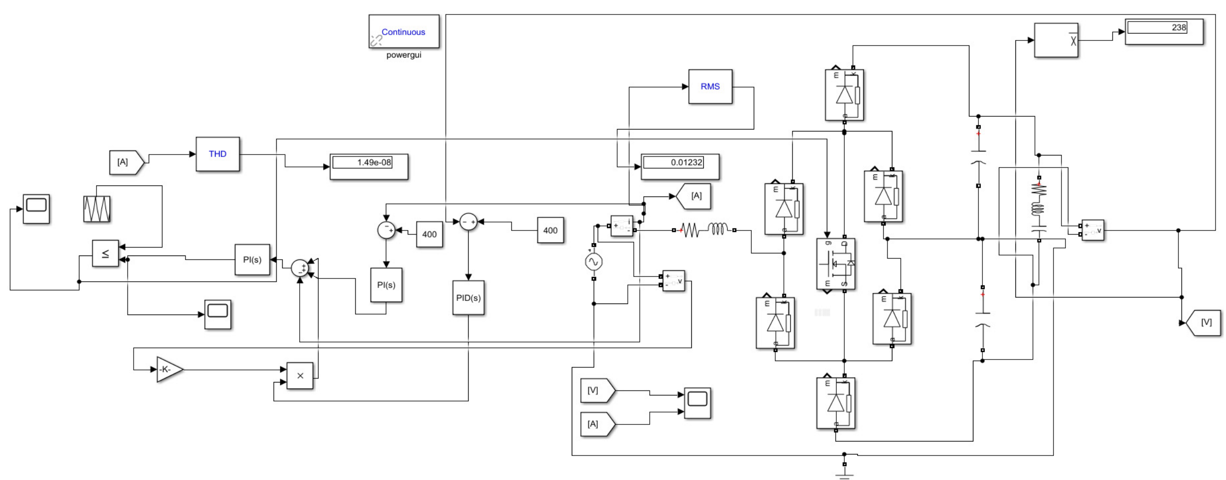
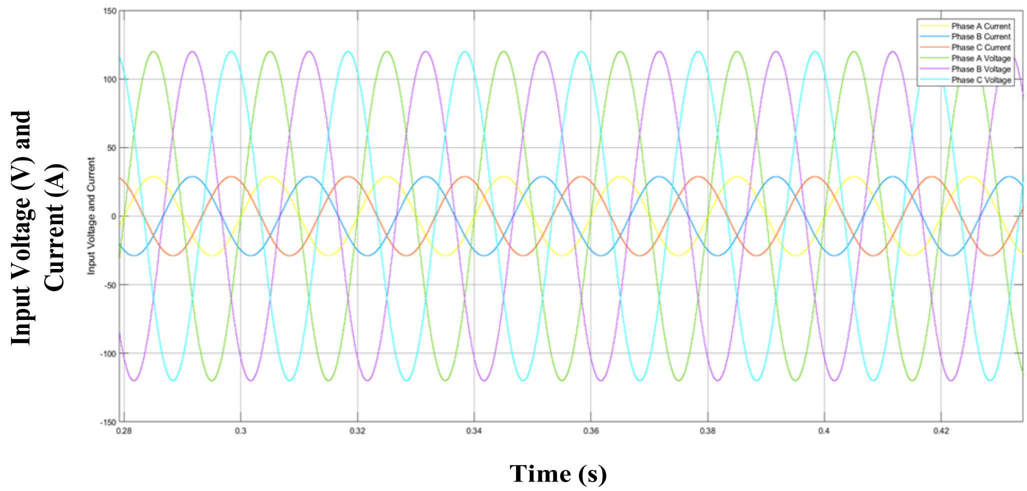


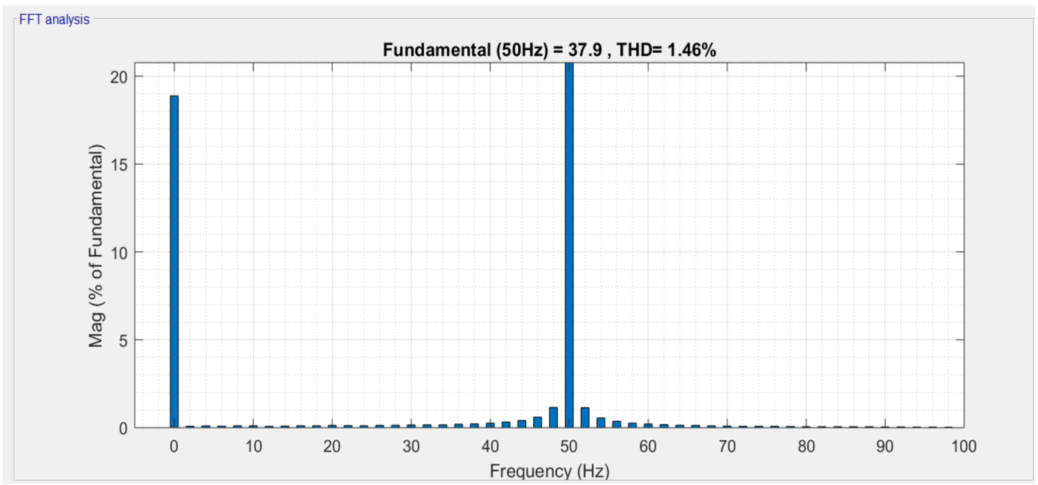
FIGURE 6. Proposed Converter modeled using MATLAB/SIMULINK Tool

RESULTS AND DISCUSSION

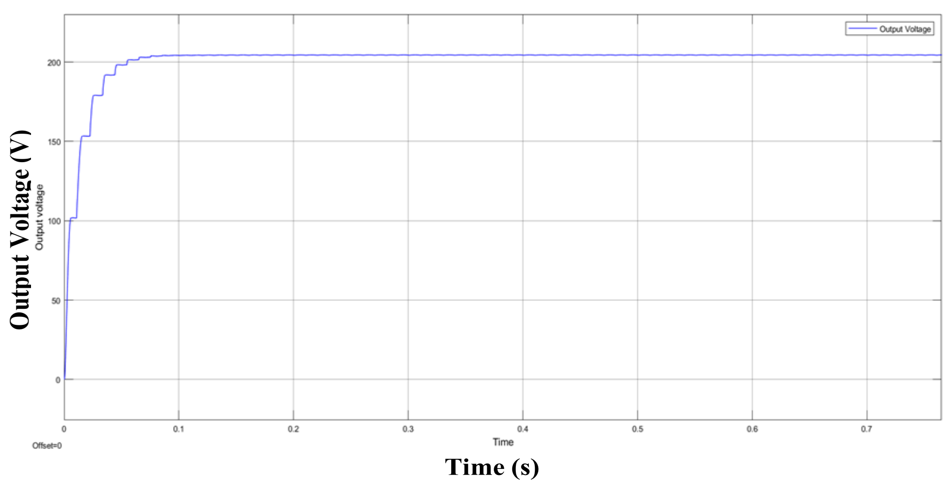
It is noted that the input waveform for the Vienna Rectifier is almost sinusoidal, which is Input voltage and current are in phase. It shows that the input power factor is to be maintained unity, which gives the better performance of the charging stations and reduces the losses in the system. It increases the efficiency of the system. The input voltage and current are in phase with each other, and it is shown in Fig. 7(a). It is noted that the percentage Input current THD for the Vienna Rectifier is 1.46, which is less than 5%, and it is meeting the IEEE standards[9-11]. It evident that, due to the less THD, the losses in the system is reduced and the efficiency of the system increased. The % Input current THD for the three topologies are shown in Fig. 7(b). The DC output voltage is almost constant in Vienna Rectifier. It is evident that the rising time of the system is less in Vienna Rectifier, and it quickly reaches the constant DC value. Due to this, the performance of the battery in the electric vehicle is improved. The output DC voltage for Vienna Rectifier is shown in Fig. 7(c).



(a). Characteristics of input current and voltage vs time



(b). FFT Analysis of Input Current



(c). Output Voltage vs time

FIGURE 7. Results from the modeling of the machine

CONCLUSION

In this paper, three types of charging stations were discussed, and the performance of the Vienna Rectifier is simulated and analyzed in terms of power factor and THD using MATLAB/Simulink software. The proposed converter is having improved power factor in the ac mains and reduced input current THD. The Vienna Rectifier is more admirable power converter in terms of efficiency, THD, and power factor for the electric vehicle charging stations. It can be concluded that Vienna Rectifier is the most suitable converter for the electric vehicle charging stations and it is benchmarked for less complexity, high efficiency, high power density design, less input current THD, and improved power factor.

ACKNOWLEDGEMENT

This work is supported by Taylor's University under its TAYLOR'S RESEARCH SCHOLARSHIP programme through grant TUFR/2017/001/01.

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