

Comparative Study of Switching Technique for Vienna Rectifier at 50 kW-350kW

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ABSTRACT

This research presents a comparison of switch control techniques for the Vienna Rectifier between Pulse width modulation (PWM) and Space Vector Pulse Width Modulation (SVPWM) for electric vehicle charging systems with power ratings between 50–350 kW. Focusing on studying the impact on power quality from the supply side, including of Total Harmonic Distortion (THD) and Power Factor (PF). The system simulation was conducted on the MATLAB/Simulink platform, with the design of a PI controller to generate control signals for the circuit switch, particularly in the case of PWM techniques. The experimental results show that the output voltage remains constant at 800 V, and the harmonic distortion of the input current can be maintained below 5%, which complies with the IEEE 519-2022 standard. Additionally, stability tests of the system were conducted under sudden load changes by varying the load power at 50 kW, 100 kW, 250 kW, and 350 kW, respectively. The test results show that the output voltage remains stable at 800 V with THD values of 4.794%, 2.4%, 1.0%, and 0.7065%, respectively. Compared with the SVPWM technique, the PWM technique has a lower THD for the input current, and the output voltage ripple signal is smaller when the power level exceeds 250 kW, reflecting better system performance under a wide range of load conditions. Additionally, the PWM technique uses fewer resources for system control.

Keywords: Vienna Rectifier, Model-based design, Total harmonic distortion (THD), Pulse width modulation (PWM) method, Processor-in-the-Loop (PIL)

1. INTRODUCTION

As the adoption of electric vehicles increases, DC fast charging stations have become essential for users seeking to charge their vehicle batteries in the shortest time possible [1]-[2]. To achieve this, charging stations must supply high power to charge batteries as quickly as possible [3]-[4]. Currently, charging stations on the

market provide power ranging from 50 kW to 250 kW [5]-[6], with examples such as the Nissan Leaf (50 kW) and the Tesla Model 3 (250 kW). However, the high power required for rapid charging can lead to reduced battery lifespan and increased harmonic distortion in the power supply. Historically, EV charging stations utilized simple bridge-type power converters. While these offered moderate efficiency in generating output voltage and power, they were less effective at minimizing harmonics on the supply side. Recent advancements have significantly improved charging station converters through the integration of Vienna rectifier circuits. These circuits provide high output power and voltage and offer superior reduction of supply-side harmonics.

This research aims to enhance the efficiency of a three-phase electric vehicle charging station by reducing input current harmonics and extending battery lifespan. This will ultimately lead to improved overall charging performance. In this study, we compare the control techniques for a Vienna rectifier using the proposed PWM technique [22]-[24] against the SVPWM technique [7]-[8], [25]. The comparison is conducted using MATLAB Simulink, employing identical design parameters to evaluate system performance. Performance will be assessed based on the Total Harmonic Distortion (THD) of the supply current and the system's Power Factor.

To evaluate the design's performance and confirm its suitability for real-world application, the researchers utilized the Processor-in-the-Loop (PIL) method [18]-[21]. This method involved integrating a C2000 microcontroller (TI Delfino F2833x) within a MATLAB Simulink simulation. This approach successfully validated the operation of the designed model and demonstrated its potential for implementation with actual hardware.

2. RELATED THEORIES

2.1 Vienna Rectifier Topology

The output DC voltage is maintained constant by the Vienna rectifier, a three-level AC-DC converter. Additionally, the input power factor is modified, and harmonics are eliminated. As a result, total harmonic distortion (THD) is reduced [8]. The schematic diagram of the circuit is as follows: Figure 1 shows the three-phase supply, three input filter inductors, six power diodes, and three bidirectional switches on each phase. The final part is the DC bus capacitor, which reduces ripples and helps to keep the bus voltage constant.

In designing the parameters for the Vienna rectifier circuit, equations (1)-(2) are used to determine the ca-

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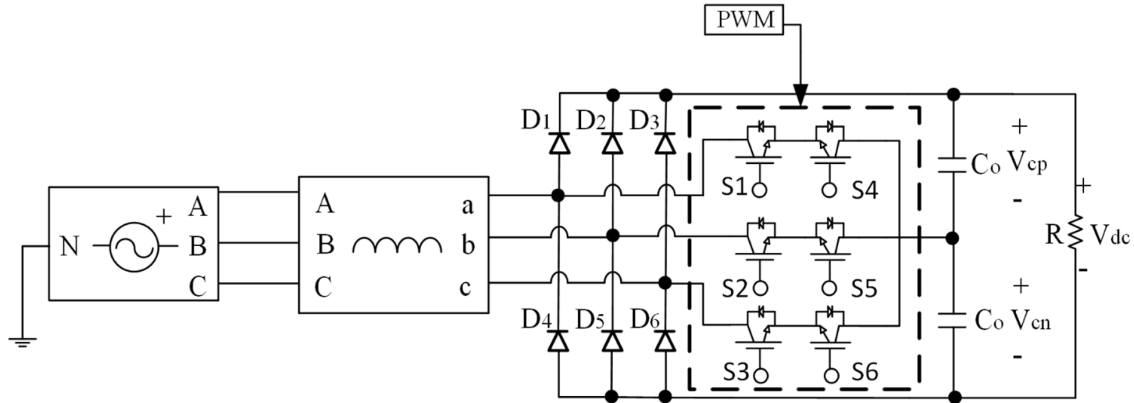


Fig. 1: 3-phase Vienna rectifier model.

Table 1: Calculation Parameters of The Vienna Rectifier for A 50 kW System.

Parameters	Value
L-L rms grid to voltage (V_{abc})	380 V
Output current (I_o)	62.51 A
Bus capacitor (C_o)	1,335 μ F
Input filter inductance (L_s)	23.8 μ H
Input current THD	4.794%

capacitance and inductance values. The design parameters are specified as follows: AC voltage power supply of 380 V, switching frequency of the Vienna rectifier circuit (f_{sw}) at 20 kHz, output DC bus voltage (V_{dc}) at 800 V, maximum ripple current in the inductor (Δi_{ppmax}) at 210 A, bus voltage ripple (ΔV_{dc}) at 40 V, grid frequency (f_s) at 50 Hz, and rated system power (P_{ac}) at 50 kW. The calculated parameter values based on this design are presented in Table 1.

$$L_s = \frac{\left(\frac{V_{dc}}{2}\right)}{4f_{sw}\Delta i_{pmax}} \quad (1)$$

$$C_o = \frac{1}{3} \frac{P_{ac}}{4f_s (V_{dc}^2 - (V_{dc} - \Delta V_{dc})^2)} \quad (2)$$

2.2 Modeling and Control of the Vienna Rectifier for PWM Technique

In this study, the current on the q-axis is set to zero, eliminating reactive power and improving the power factor close to 1. As a result, as shown in Equation (3), the power factor becomes 1. Figure 2 illustrates the control architecture of the Vienna rectifier circuit.

$$PF = \frac{P}{\sqrt{P^2 + Q^2}}; P = v_d i_d + v_q i_q, Q = v_q i_d - v_d i_q \quad (3)$$

From Figure 2, the parameters for the PI controller are designed in four parts as follows:

1. The d-axis current control loop

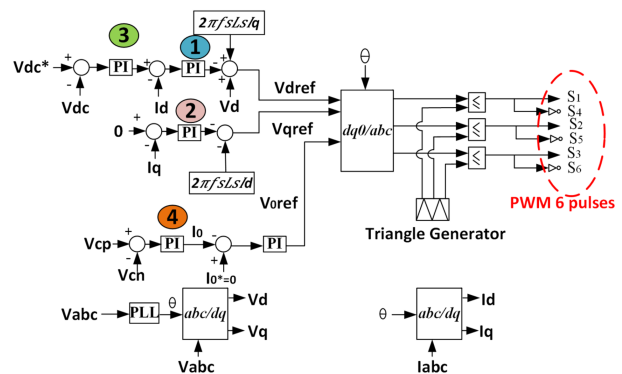


Fig. 2: Design of PI controller for generating PWM signal.

2. The q-axis current control loop
3. The outer DC voltage loop
4. The capacitor voltage balance loop

Before designing any part of the PI controller, the modulation index— which controls the switching modulation— must first be determined. The design parameters include the magnitudes of the input and output voltages. The modulation index can be calculated using Equation (4) [9].

$$M = \frac{|V|}{\left(\frac{V_{dc}}{2}\right)} = \frac{\sqrt{\frac{3}{2}}\sqrt{2} \cdot 220}{\left(\frac{800}{2}\right)} = 0.95 \quad (4)$$

The switching technique from [20]-[21] is applied as demonstrated in equations (5)-(7) to determine the proper values of the parameters k_p and k_i in each of the four control sections since the variable d'_{dq0} must be discovered in the design of the PI controller.

$$d_{k(a,b,c)} = (1 - d'_k) \times \text{sgn}(i_s, k); k = a, b, c \quad (5)$$

$$\text{sgn}(x) = \begin{cases} -1; x < 0 \\ 0; x = 0 \\ 1; x > 0 \end{cases} \quad (6)$$

$$[d'_{dg0}] = [k] [d'_{abc}] \quad (7)$$

The Park transformations are used to design the switch control by converting the switch control from the abc-axis to the dq0 reference axis, as shown in equation (8). The equation for designing the control operation of the indicator switch is shown in equation (9).

$$\begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin(\omega t) & \sin(\omega t - \frac{2\pi}{3}) & \sin(\omega t + \frac{2\pi}{3}) \\ \cos(\omega t) & \cos(\omega t - \frac{2\pi}{3}) & \cos(\omega t + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \cdot \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (8)$$

$$\begin{bmatrix} d_a \\ d_b \\ d_c \end{bmatrix} = \frac{1}{2} \begin{bmatrix} 1 + M \cos(\omega t + \varphi) \\ 1 + M \cos(\omega t + \frac{2\pi}{3} + \varphi) \\ 1 + M \cos(\omega t - \frac{2\pi}{3} + \varphi) \end{bmatrix}$$

$$\begin{bmatrix} d_d \\ d_q \\ d_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta_{pcc} + \varphi_1) & \cos(\theta_{pcc} - \frac{2\pi}{3} + \varphi_1) & \cos(\theta_{pcc} + \frac{2\pi}{3} + \varphi_1) \\ -\sin(\theta_{pcc} + \varphi_1) & -\sin(\theta_{pcc} - \frac{2\pi}{3} + \varphi_1) & -\sin(\theta_{pcc} + \frac{2\pi}{3} + \varphi_1) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \cdot \begin{bmatrix} 1 + M \cos(\omega t + \varphi) \\ 1 + M \cos(\omega t + \frac{2\pi}{3} + \varphi) \\ 1 + M \cos(\omega t - \frac{2\pi}{3} + \varphi) \end{bmatrix} = \frac{1}{2} \begin{bmatrix} \sqrt{\frac{3}{2}} \cdot M \\ 0 \\ \sqrt{3} \end{bmatrix} \quad (9)$$

The design equations from (10) to (13), in each section, serve as the foundation for the equations used to construct the PI controller of the system [8].

$$\frac{di_d}{dt} = \frac{1}{L_s} \left(V_d + 2\pi f_s L_s I_q + r_s I_q - \frac{V_{dc}}{2} d'_d \right) \quad (10)$$

$$\frac{di_q}{dt} = \frac{1}{L_s} \left(V_q - 2\pi f_s L_s I_d - r_s I_d - \frac{V_{dc}}{2} d'_q \right) \quad (11)$$

$$\begin{aligned} \frac{dV_{dc}}{dt} &= \frac{1}{C_o} \left(\frac{3}{2} (d'_d I_d + d'_q I_q) \right. \\ &\quad \left. - \frac{V_{dc}}{2r_c} - \frac{2\Delta V_C}{\pi V_{dc}} d'_0 I_d - d'_q I_o \right) \end{aligned} \quad (12)$$

$$\begin{aligned} \frac{dV_C}{dt} &= \frac{1}{C_o} \left(-\frac{3}{2} \frac{\Delta V_C}{V_{dc}} (d'_d I_d + d'_q I_q) \right. \\ &\quad \left. - \frac{V_{dc}}{2r_c} - \frac{2}{\pi} d'_0 I_d \right) \end{aligned} \quad (13)$$

2.2.1 Design Parameters for the D-axis Current Control Loop

Apply the Laplace transform to (10) and obtain as in (14).

$$sL_s I_d = V_d + 2\pi f_s L_s I_q + r_s I_q - \frac{V_{dref}}{2} \quad (14)$$

From (14) obtain the equation for the plant system equation (G) as it shows in (15).

$$G = \frac{1}{sL_s} \quad (15)$$

Next, determine the transfer function by figuring out the equation for the plant system, which will yield the relationship shown below:

$k_p = 2\delta\omega_n L_s$ and $k_i = \omega_{ni}^2 L_s$
where $\delta = 0.7$, $\omega_{ni} = 2\pi \times 2500 \text{ rad/s}$, $L_s = 2.381 \times 10^{-5} \text{ H}$.

After designing the PI controller of the d-axis current control loop, the difference signal obtained by comparing the reference current on the d-axis (I_d^*) will be compared with the current on the d-axis (I_d). The current on the d-axis is obtained by taking the three-phase current (I_{abc}) through Parks transformation to get the current on the dq0-axis (I_{dq0}) as an input signal to the PI controller of the d-axis current control loop.

The output signal is combined with the d-axis voltage signal (V_d) obtained by applying the three-phase input voltage signal (V_{abc}) through Park transformation and the signal obtained by selecting pling ($2\pi f_s L_s I_q$). From the combination of these signals, the resulting output is a reference voltage signal on the d-axis (V_{dref}).

2.2.2 Design Parameters for the Q-Axis Current Control Loop

Apply the Laplace transform to (11) and obtain as in (16).

$$sL_s I_q = V_q - 2\pi f_s L_s I_d - r_s I_d - \frac{V_{dref}}{2} \quad (16)$$

From (16), obtain the equation for the plant system equation (G) as it shown in (17).

$$G = \frac{1}{sL_s} \quad (17)$$

The plant system equations are the same as the d-axis current control loop design. Therefore, the k_p and k_i values will be the same.

The q-axis current control loop is designed similarly to the PI controller design of the d-axis, with the difference signal obtained by comparing the reference current on the q-axis set to equal zero ($I_q^* = 0$) and compared with the current on the q-axis (I_q). The signal obtained from the comparison is combined with the voltage signal on the q-axis (V_q) and the signal obtained from the coupling ($2\pi f_s L_s I_d$). The output will be a reference voltage signal on the q-axis (V_{qref}).

2.2.3 Design Parameters for the Outer DC Voltage Loop

Apply the Laplace transform to (12) and obtain as in (18).

$$sV_{dc} C_o = \frac{3}{2} (d'_d I_d + d'_q I_q) - \frac{V_{dc}}{2r_c} - \frac{2\Delta V_C}{\pi V_{dc}} d'_0 I_d - d'_q I_o \quad (18)$$

From (18), the plant system equation (G) will be obtained as in (19).

$$G = \frac{\frac{3}{2} d'_d - \left(\frac{2\Delta V_C}{\pi} \right) \cdot V_{dc} \cdot d'_0}{sC_o + \frac{1}{2r_c} + \left(\frac{2\Delta V_C}{\pi} \right) \cdot d'_0 \cdot I_d} \quad (19)$$

After obtaining the plant system equation as in (19), it can be used to find the relationship of k_p and k_i as follows:

$$k_p = \frac{2\delta\omega_{nv} \cdot 8C_o}{3\sqrt{3}M} \text{ and } k_i = \frac{\omega_{nv}^2 \cdot 8C_o}{3\sqrt{3}M}$$

$$\omega_{nv} = 2\pi 50 \text{ rad/s}$$

The outer DC voltage loop used to control DC output voltage has an input DC reference voltage of 800V which is compared to the DC output voltage generated by the rectifier. This difference fed into the PI controller of the outer DC voltage loop. The output signal is the reference current on the d-axis (I_d) that will be used as the input signal of the PI Controller of the d-axis current control loop mentioned earlier.

2.2.4 Design Parameters for Capacitor Voltage Balance Loop

Apply the Laplace transform to (13) and obtain as in (20).

$$sV_C C_o = -\frac{3}{2} \frac{2\Delta V_C}{V_{dc}} (d'_d I_d + d'_q I_q) - \frac{V_{dc}}{2r_c} - \frac{2}{\pi} d'_0 I_d \quad (20)$$

From (20), the plant system equation (G) will be obtained as in (21).

$$G = \frac{2V_{dc}}{2sV_{dc}C_o + 3d'_0 I_d} \quad (21)$$

After obtaining the plant system equation as in (21), it can be used to find the relationship of k_p and k_i as follows:

$$k_p = \frac{2\delta\omega_{nv}(8C_o\pi V_{dc} - 3\sqrt{3}\pi\Delta V_C M C_o - 8\sqrt{3}C_o V_{dc})}{8\pi V_{dc}}$$

and

$$k_i = \frac{\omega_{nv}^2(8C_o\pi V_{dc} - 3\sqrt{3}\pi\Delta V_C M C_o - 8\sqrt{3}C_o V_{dc})}{8\pi V_{dc}}$$

In the design of the PI controller for the capacitor voltage balance loop, it is used to regulate the DC bus voltage, ensuring a balanced voltage between the upper capacitor (C_p) and the lower capacitor (C_n). By using the voltage difference between the upper (V_{cp}) and lower (V_{cn}) capacitors as input to the PI controller, the output is a current signal on the 0-axis (I_0). This signal is then compared with the reference current signal on the 0-axis. Since the three-phase power supply is balanced, the reference current on the 0-axis is zero ($I_0^* = 0$). The signal passing through the PI controller is then fed into another PI controller, where it is converted into a reference voltage signal on the 0-axis (V_{0ref}).

After designing all four parts of the PI controller, the output signals— V_{dref} , V_{qref} , and V_{0ref} —were processed through inverse Park transformation to convert them back into a three-phase reference voltage signal ($V_{abc,ref}$). This reference signal was then compared with a carrier signal, which is a triangular wave with an amplitude of 1V and a frequency of 20 kHz. By comparing it with the carrier signal, six pulse-width modulation (PWM) signals— S_1 to S_6 —were generated. These six PWM signals are used to control the operation of the six

Table 2: Summary Table of PI Controller Design Parameters.

PI Control Loop	Parameter	
	K_p	K_i
Current Loop (d-axis)	0.5236	5874.88
Current Loop (q-axis)	0.5236	5874.88
The outer DC voltage loop	0.9515	213.533
The capacitor voltage balance loop	0.263	59.116

switches (S_1 - S_6) in the Vienna rectifier circuit, as shown in Figure 1. The parameters of the four PI controllers are listed in Table 2.

2.3 Comparison with Reference Circuits Using the SVPWM Technique

In controlling the operation of the Vienna Rectifier circuit, the widely used technique is SVPWM [7]-[8], [25] because it can efficiently control voltage and current, reduce energy loss, and improve the quality of electrical power. In this article, a reference circuit using the SVPWM technique [8] was chosen for performance comparison because it has output voltage levels and power levels similar to the designed system. By using the same parameters and controller design to compare the performance between PWM and SVPWM techniques.

The steps of SVPWM control can be summarized as follows:

1. Input signal measurement: Measure the voltage and current of the three-phase system, such as V_{abc} and I_{abc} , as well as the DC-link voltage for use in feedback control.
2. Coordinate transformation: Convert current or voltage from the abc coordinate system to the alpha-beta coordinate system using Clarke Transformation to enable efficient vector analysis and control.
3. Creating the Reference Vector: Calculate the desired reference pressure to be controlled, which generally comes from the output of the PI controller that controls the desired current or voltage. This vector will represent the direction and magnitude of the pressure in vector form.
4. Finding the position of the vector in the sector (Sector Identification): Consider the position of the reference pressure vector in the two-dimensional plane $\alpha\beta$ to determine which of the 6 sectors it belongs to.
5. Calculating switch-on duration.
6. Generating PWM signals for switches.

The details of the SVPWM design for controlling the operation of the switches in the Vienna rectifier circuit are described in reference [8].

3. RESULTS AND PERFORMANCE EVALUATION

To evaluate the designed electric vehicle charging system, the stability of the controller was tested using MATLAB Simulink. The tests in this study were divided into two parts: (1) Testing the efficiency and stability of

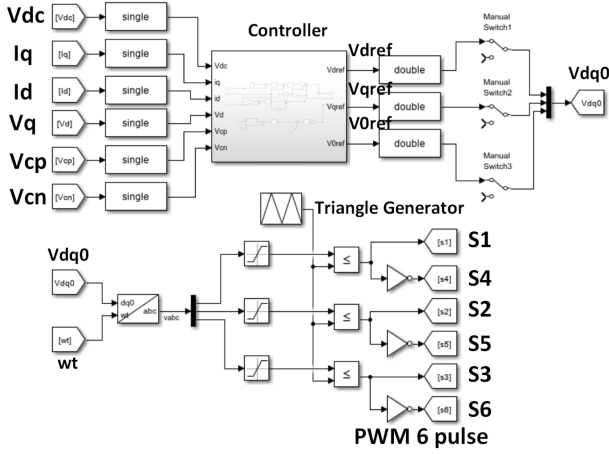


Fig. 3: Simulation model of Vienna rectifier in MATLAB Simulink program.

the controller in MATLAB Simulink with a rated power load of 50 kW, and (2) Testing the performance of the charging system on TI Delfino F2833x board. TI Delfino F2833x board was used to assess the performance of the controller, which was designed using the Processor-in-the-Loop (PIL) method. In this study, a simulation test was conducted under sudden load changes to evaluate system stability in maintaining output voltage, output current, and total harmonic distortion (%THD). The test involved sudden power increases to 50 kW, 100 kW, 250 kW and 350 kW. The test results from the simulation were analysed and compared with those obtained from TI Delfino F2833x board to assess the system's stability and determine whether it can be effectively implemented in real hardware.

3.1 Simulation Results

In the performance test of the designed charging system, a 50 kW test load was used to evaluate the stability of the controller using MATLAB Simulink. The model of the designed PWM of Vienna rectifier circuit is shown in Figure 3 and Figure 4. The test aimed to maintain a constant output voltage of 800 V, ensure output current stability, and keep the total harmonic distortion (%THD) of the input current below 5%, in compliance with the IEEE 519-2022 standard. The test results are presented in Figure 5 to Figure 9.

Figure 5 to Figure 9 show the simulation results of the designed charging circuit. In Figure 5, during the initial phase of operation, the system gradually stabilized, and the output voltage increased until it reached a constant value of 800 V. Figure 6 illustrates that the output current remained constant at 62.51 A. Regarding the input current from the power supply, improvements were observed in the Vienna rectifier design, with an input current of 120 A. Additionally, the %THD value of the input current initially fluctuated but eventually stabilized at 4.794%.

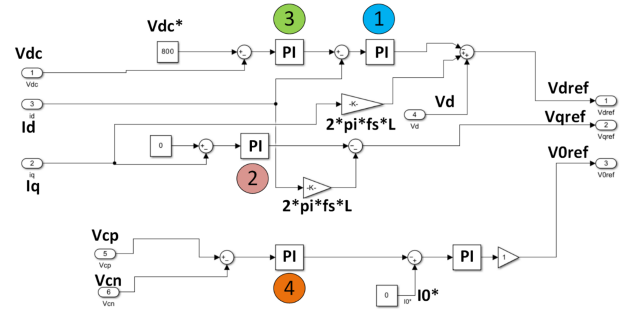


Fig. 4: PI Controller design block.

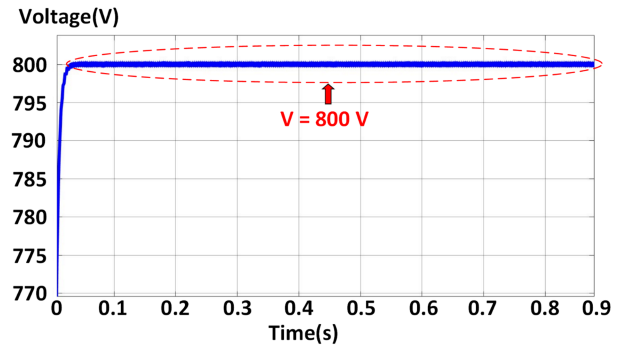


Fig. 5: Output voltage was obtained from the Vienna rectifier.

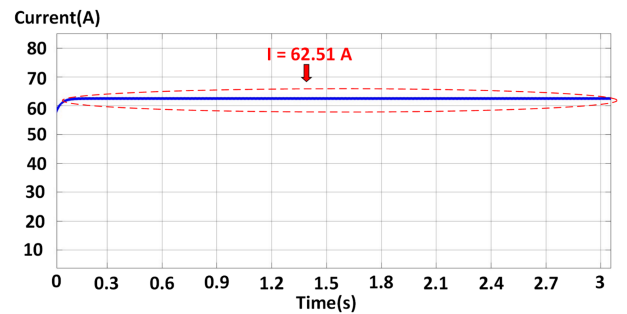


Fig. 6: DC output current.

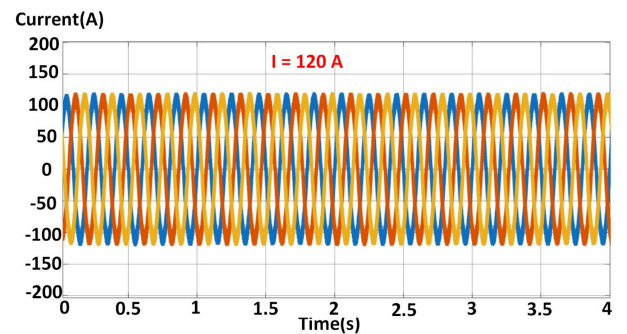


Fig. 7: The input current of a three-phase power supply.

3.2 PIL Performance Evaluation

To evaluate whether the designed charging system can operate with real hardware, TI Delfino F2833x board was used as a testing device. The four designed

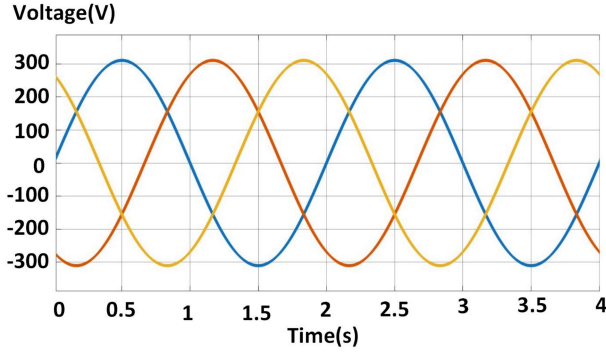


Fig. 8: The input voltage of a three-phase power supply.

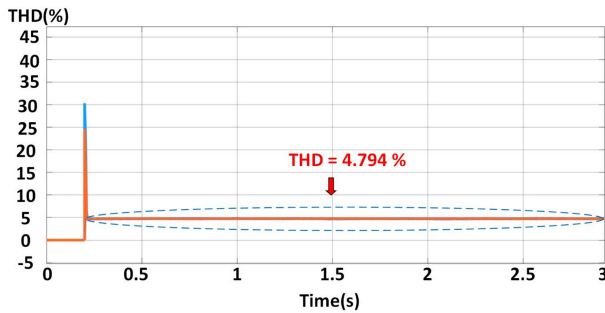


Fig. 9: Total harmonic distortion value (THD) of the current from the electrical grid supply.

controllers were converted into Processor-in-the-Loop (PIL) command blocks for testing in MATLAB Simulink. The testing procedure is illustrated in Figure 10(a) using PWM technique and Figure 10(b) using SVPWM technique. The test simulates sudden load changes to assess system stability. Specifically, the load power is suddenly increased to 50 kW, 100 kW, 250 kW and 350 kW. The test results include measurements of output voltage, output current, and the total harmonic distortion (%THD) of the input current.

3.2.1 Comparison of control systems between the designed PWM technique and the SVPWM technique

The comparison of the control systems between the designed PWM technique and the SVPWM technique will use a testing method involving sudden changes in electrical load from levels of 50kW, 100kW, 250kW, and 350kW. Based on the following important parameters: output voltage, output current, %THD of the input current, and Power Factor. In the test, divide the period of power increase of the load into 4 steps as follows:

- Step 1. Duration: 0-1 s, 50 kW test load.
- Step 2. Duration: 1-2 s, add test load to 100 kW.
- Step 3. Duration: 2-3 s, add test load to 250 kW.
- Step 4. Duration: 3-4 s, add test load to 350 kW.

The results of the analysis of output voltage, output current, harmonic values on the power supply side, and power factor to evaluate the performance of the designed electric vehicle charger, as shown in Figures 11-14.

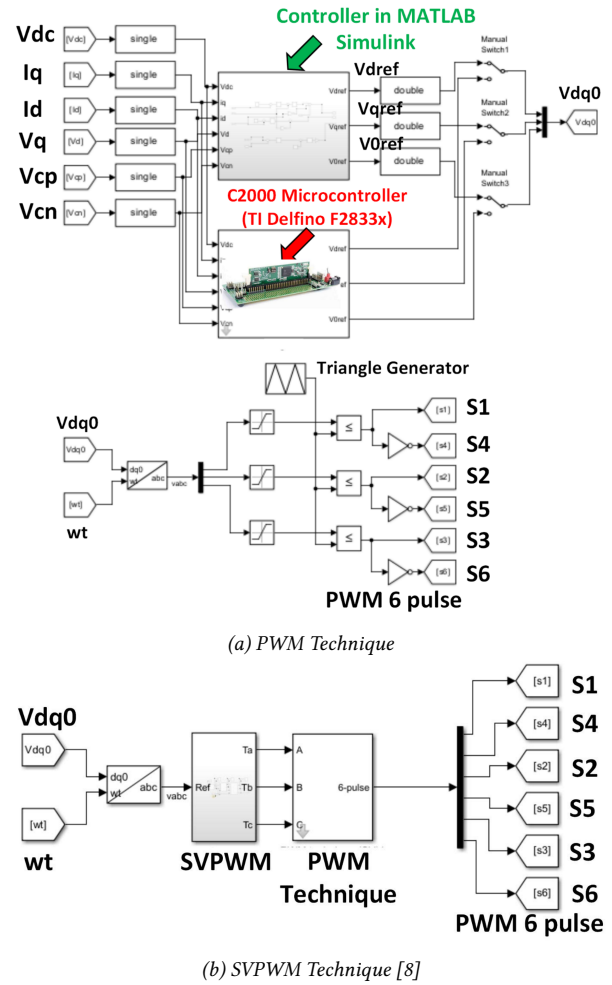
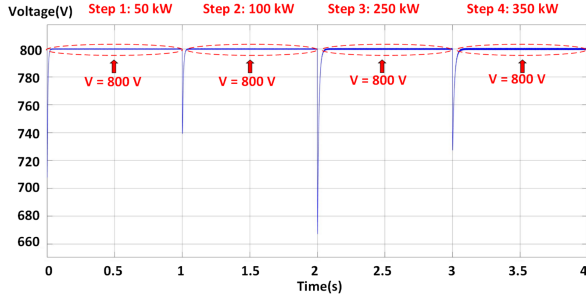


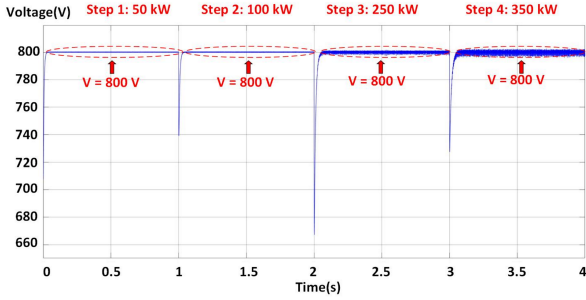
Fig. 10: The model presented along with TI Delfino F2833x board.

From Figure 11, the output voltage in case of a sudden increase the load can be seen as starting with step 1 using a fixed voltage load of 50 kW. The output from the controller is designed to provide an output voltage of 800 V. Step 2 adjusts the load to 100 kW while changing the load. The voltage drops to about 60 V, but the designed controller can keep the output voltage level at 800 V as usual and Step 3 increases the load to 250 kW, The voltage drops to about 120 V, but after a few seconds, the system can stabilize the output voltage level at 800 V. Step 4 increases the load to 350 kW, the system can stabilize the output voltage level at 800 V. From the results of the step load increase tests from 50 kW, 100 kW, 250 kW, and up to 350 kW, despite the increased load, the controllers designed using PWM and SVPWM techniques were able to maintain the output voltage level at 800 V consistently and steadily throughout the testing period, and the power factor during the test period is close to 1 as shown in Figure 14(a) and Figure 14(b) respectively.

From Figure 12, the stepwise increase in load from 50kW, 100kW, 250kW, and 350kW shows that the current in each stage increases when adjusting the power in the first step. The constant power load is 50kW. In the case

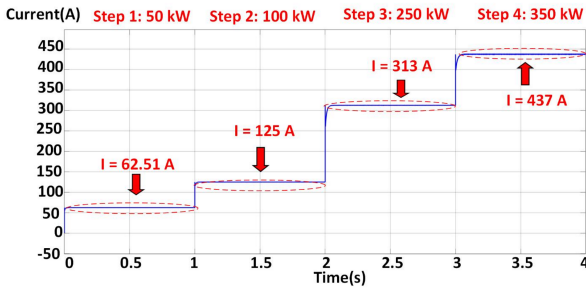


(a) PWM Technique

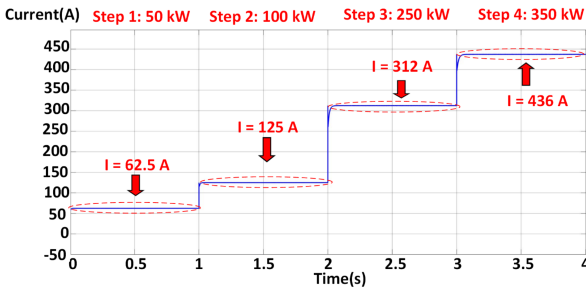


(b) SVPWM Technique [8]

Fig. 11: Output voltage of a sudden increase in the test load.



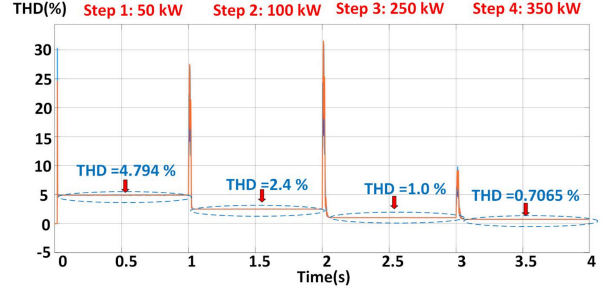
(a) PWM Technique



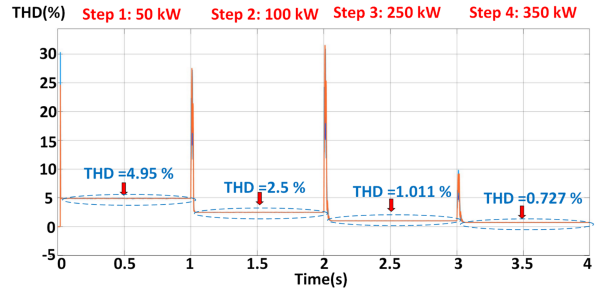
(b) SVPWM Technique [8]

Fig. 12: Output current of a sudden increase in test load.

of using PWM switch technique and SVPWM switch technique, the output current is 62.51 A and 62.5 A, respectively. In the second step, the power is 100kW, and the output current is 125 A for the PWM technique and 125 A for the SVPWM technique. When the power is 250 kW, the output current is 313 A for the PWM technique and 312 A for the SVPWM technique. Finally, in the fourth stage, the power is at 350kW, with an output current of 437 A for the PWM technique and 436 A for

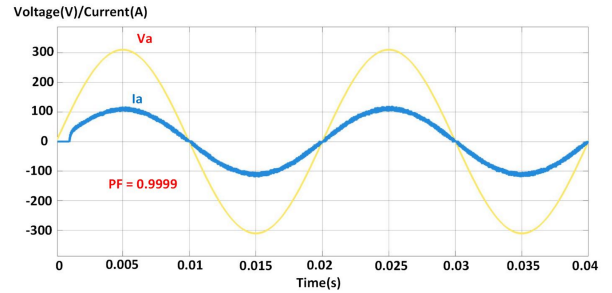


(a) PWM Technique

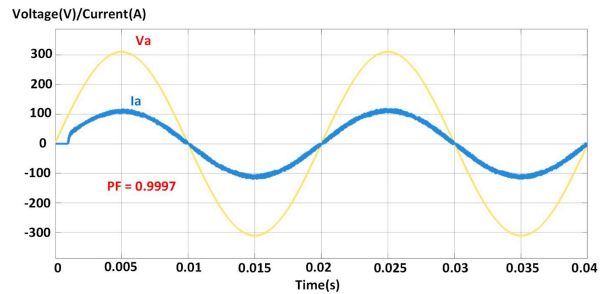


(b) SVPWM Technique [8]

Fig. 13: Harmonic value in the input current in case of a sudden increase in test load.



(a) PWM Technique



(b) SVPWM Technique [8]

Fig. 14: Power Factor.

the SVPWM technique. Each power level tested at 50 kW, 100 kW, 250 kW, and 350 kW yields a %THD of the power supply current equal to 4.794%, 2.4%, 1.0%, and 0.7065% respectively for the PWM technique, and a %THD of the power supply current equal to 4.95%, 2.5%, 1.011%, and 0.727% respectively for the SVPWM technique, as shown in Figure 13(a) and Figure 13(b) respectively.

From Figure 14, it is shown that the voltage and current from the power supply have the same phase

Table 3: Comparison of the performance between PWM technique and SVPWM technique.

Performance Index	Switching Technique	
	PWM	SVPWM
V_{dc} (V)	800	800
% THD I_{in}	0.7065	0.727
Power Factor	0.9999	0.9997

angle. The calculation of the power factor found that the proposed PWM technique yields a slightly higher power factor than the SVPWM technique. Both techniques can provide a power factor close to 1.

4. CONCLUSION

This article compares the performance of Vienna rectifier controllers using PWM and SVPWM techniques. The study evaluates their effectiveness in improving the power factor and reducing the Total Harmonic Distortion (THD) of the input current for a 50 kW–350 kW electric vehicle battery charging system. The results of using the proposed PWM technique and the SVPWM technique show that both methods can generate a stable output voltage level of 800 volts throughout the tested electrical load range for use in fast electric vehicle charging systems. As a result of designing the Vienna rectifier control circuit using the method of controlling the current on the q-axis to be equal to zero, in order to make the power factor as close to 1 as possible according to the electrical triangle theory. In the control section, four PI Controllers were designed to generate reference signals from the controllers, which will be used to create PWM signals suitable for controlling the operation of the switches in the Vienna rectifier circuit, so that the system can produce the designed output voltage level.

In the sudden load adjustment test, the results showed that the controllers designed using PWM and SVPWM techniques could maintain an output voltage of 800 V. Additionally, the system's performance was improved by enhancing the power factor to be as close to 1 as possible and reducing the %THD of the input current, as shown in Figures 13 and 14. This ensures that the proposed electric vehicle charging system experiences minimal losses in the electrical system. Furthermore, the test results from the TI Delfino F2833x board in MATLAB Simulink matched the results of the well-designed system, confirming its efficiency. Therefore, it can be concluded that the proposed electric vehicle charging system can be effectively implemented on real hardware.

From Table 3, the comparison of the performance of PWM and SVPWM techniques shows that both techniques can control the DC voltage at the same level and similar power factors. By the SVPWM technique, the THD value of the current from the power supply is slightly higher than the PWM technique, but this value still remains below the standard threshold of 5%,

which is considered acceptable and suitable for use in power systems. As a result, both presented techniques are well-suited for electric vehicle fast charging systems. Notably, the PWM technique is more resource-efficient and involves a less complex control system design.

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