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# Voltage Oriented Controller Based Vienna Rectifier for Electric Vehicle Charging Stations

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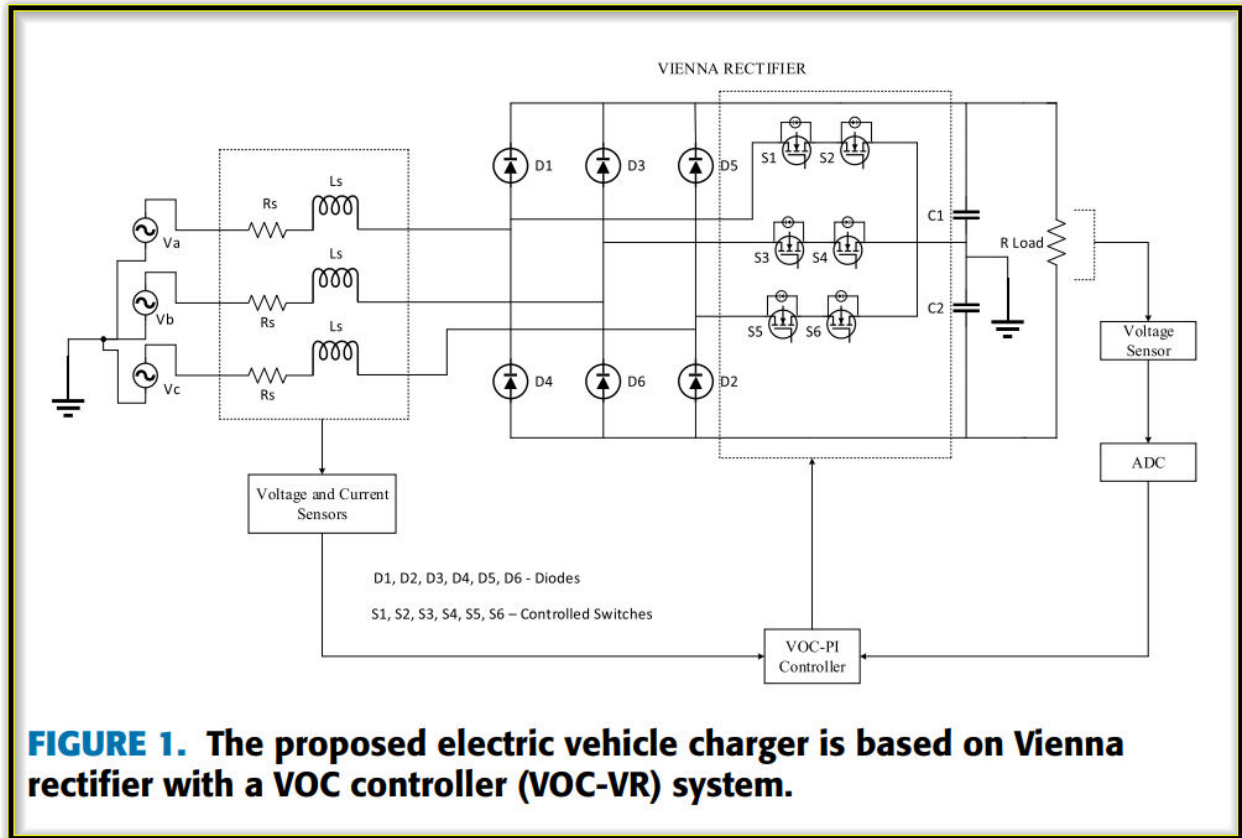
**ABSTRACT:** The Vienna rectifiers have gained popularity in recent years for AC to DC power conversion for many industrial applications such as welding power supplies, data centers, telecommunication power sources, aircraft systems, and electric vehicle charging stations. The advantages of this converter are low total harmonic distortion (THD), high power density, and high efficiency. Due to the inherent current control loop in the voltage-oriented control strategy proposed in this paper, good steady-state performance and fast transient response can be ensured. The proposed voltage-oriented control of the Vienna rectifier with a PI controller (VOC-VR) has been simulated using MATLAB/Simulink. The simulations indicate that the input current THD of the proposed VOC-VR system was below 3.27% for 650V and 90A output, which is less than 5% to satisfy the IEEE-519 standard. Experimental results from a scaled-down prototype showed that the THD remains below 5% for a wide range of input voltage, output voltage, and loading conditions (up to 2 kW). The results prove that the proposed rectifier system can be applied for high power applications such as DC fast-charging stations and welding power sources.

**KEYWORDS:** High power applications, power factor, total harmonic distortion, Vienna rectifier, voltage-oriented controller.

## I. INTRODUCTION

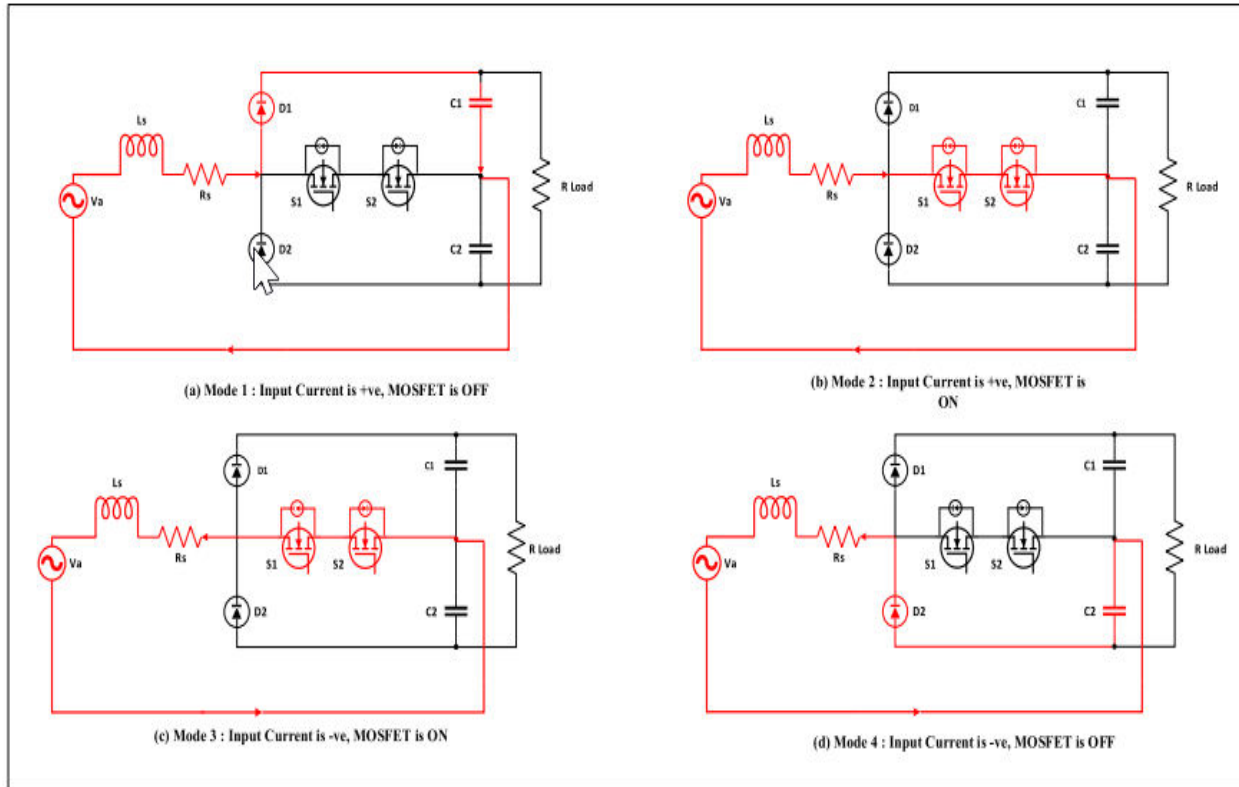
The alternating current to direct current converters used in this system. These are controlled direct current output voltage is used.[1,2,3] As these are used as a front-end converter for various used e.g., EV's chargers[4,5], communication purposes appliances[6,7], welding purposes[8], data center[9], and motor drives[10]. The electrical vehicle recharge stn[11] and welding stn requires high power[12], this indicates voltage rating and current rating should be high that the voltage and current required for other applications[13-17]. The working of one direction rectifier known as Vienna rectifier is used[18]. This converter is well known for its topological structure advantages such as high efficiency, high power to weight ratio, low total harmonic distortion in the line current, unity power factor at the grid, and the small size of the filter compared to conventional three-phase rectifiers[19-22]. The Vienna rectifier is ideal for high power applications owing to the high power to weight ratio, high efficiency, and low voltage stress[23,24].The basic controller used in a power converter is a proportional-integral (PI) controller[25]. However, it is challenging to achieve an accurate linear mathematical model of the system required for the PI controller[26]. Moreover, the PI controller often struggles to work satisfactorily under parameter variations, non linearity, and load disturbances. The different control methods are used in AC to DC converters for high power applications such as welding power sources and electric vehicle charging stations. The most popular power controllers for EV charging stations are power factor correction controllers (PFC), direct power controller (DPC), voltage-oriented controller (VOC), and their combination DPC-SVM[27-30]. Voltage oriented controller is commonly used as a power controller for power factor correction in active front-end converters[31].

The simulations indicate that the  $i/p$  THD of the proposed VOC-VR system was below which is less than 5% to satisfy the IEEE-519 standard. Experimental results from a scaled-down prototype showed that the THD remains below 5% for a wide range of input voltage, output voltage, and loading conditions (up to 2 kW). The results prove that the proposed rectifier system can be applied for high power applications such as DC fast-charging stations and welding power sources[32].



## II. WORKING PRINCIPAL OF PROPOSED SYSTEM

The Vienna rectifier topology includes six active semiconductor switches, either MOSFET or IGBT, and six diodes. The three-phase three-level Vienna rectifier topology is shown in Fig. 1. The voltage stress on each diode and semiconductor switches is  $V_{dc}/2$ . Three inductors on the input AC side and two capacitors are parallelly connected on the DC side. The neutral point of the grid is associated with the neutral point of the DC link. The operation of the three-level Vienna rectifier for the current path of one leg at each mode. The remaining two legs perform the same operation with a  $120^\circ$  phase difference. as shown in Fig. 2(c). As shown in following Fig. The proposed system operates in three modes viz., mode1, mode2 and mode 3 & mode 4 as explained in this section[33].



Mode: 1

Working in mode 1, when a Volt is a +ve for half cycle and controlled switches (IGBTs/MOSFETs) are OFF, the diode  $D_1$  conducts. During this time, the current flows through  $V_a-L_s-R_s-D_1-C_1$ .

Mode: 2

Working in mode 2 operation, when switches  $S_1$  &  $S_2$  ON I.e controller conducts the current flows through  $V_a-L_s-R_s-S_1-S_2$ . In occasion the reference voltage is +ve half cycle with controlled switches is ON,

Mode:3

Mode 3 working operations, when a refvolt is -ve half cycle with switches are ON, switches  $S_1, S_2$  conducts and the current flows through such a way as like  $v_{S1-S2-Rs-Ls-Va}$ .

Mode:4

In mode 4 operation, when a reference voltage is negative half cycle with controlled switches are OFF, the current flows through  $C_2-D_2-Rs-Ls-Va$ .

### III. DESIGN OF THE PROPOSED VOC-VR SYSTEM

#### 3.1 Circuit Configuration:-

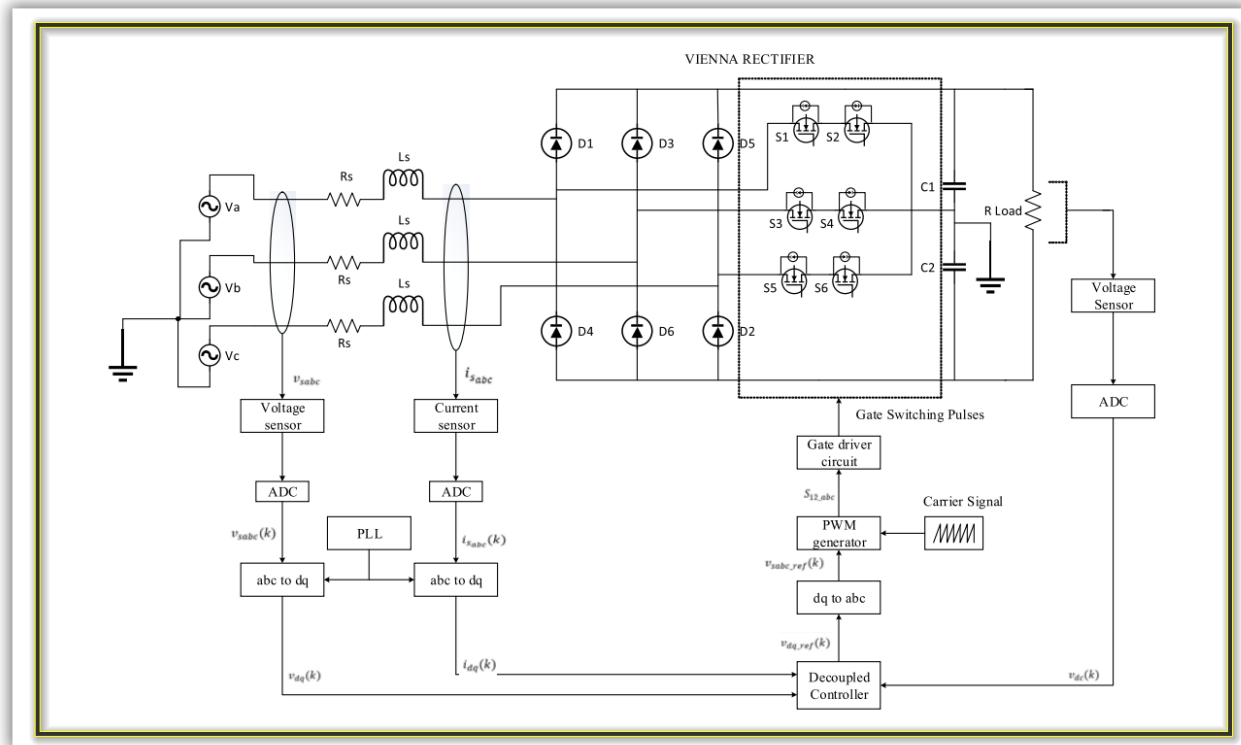


Fig.2 Overall Circuit

The 3-ph,3-level Vienna rectifier, which is controlled by the VOC-VR algorithm. The intended system includes a 3-phase alternating current, a Vienna rectifier controlled by a DC link capacitor and with the help of the VOC algorithm. Feedback voltage obtained from the electrical vehicle load-side battery is generated using current and voltage controllers and which then forms the closed-loop operations. The two main functions: (1) DC output voltage regulation to a predetermined value, and (2) the regulation of the total input harmonic distortion and maintaining in phase with the voltage to provide unity power factor. The controlled circuit diagram of the proposed VOC-VR system is shown in Fig. 3 below. The de-coupler controller is the key feature of the proposed VOC control algorithm, as shown in Fig. 6. The DC link voltage control method controls the active current component  $i_d$  which aims to achieve an active power flow balance in the systems while the reactive current component  $i_q$  is controlled to 0 to provide a unity power factor at the input side. The characteristics of two PI current controllers and PI voltage controllers are given in equation (1)-equation[34].

For the voltage control loop, the PI controller is tuned by using a DC link capacitor as the following :

$$K_{p3} \geq C_{dc1} \xi \omega \text{ and } K_{i3} \geq C_{dc1} \xi \omega / 2 \quad (1)$$

where damping factor  $\xi$  is equal to 0.707 and  $\omega$  is angular frequency. Using initial values, tuning and modifications are made, which strengthens the proposed charging technique.

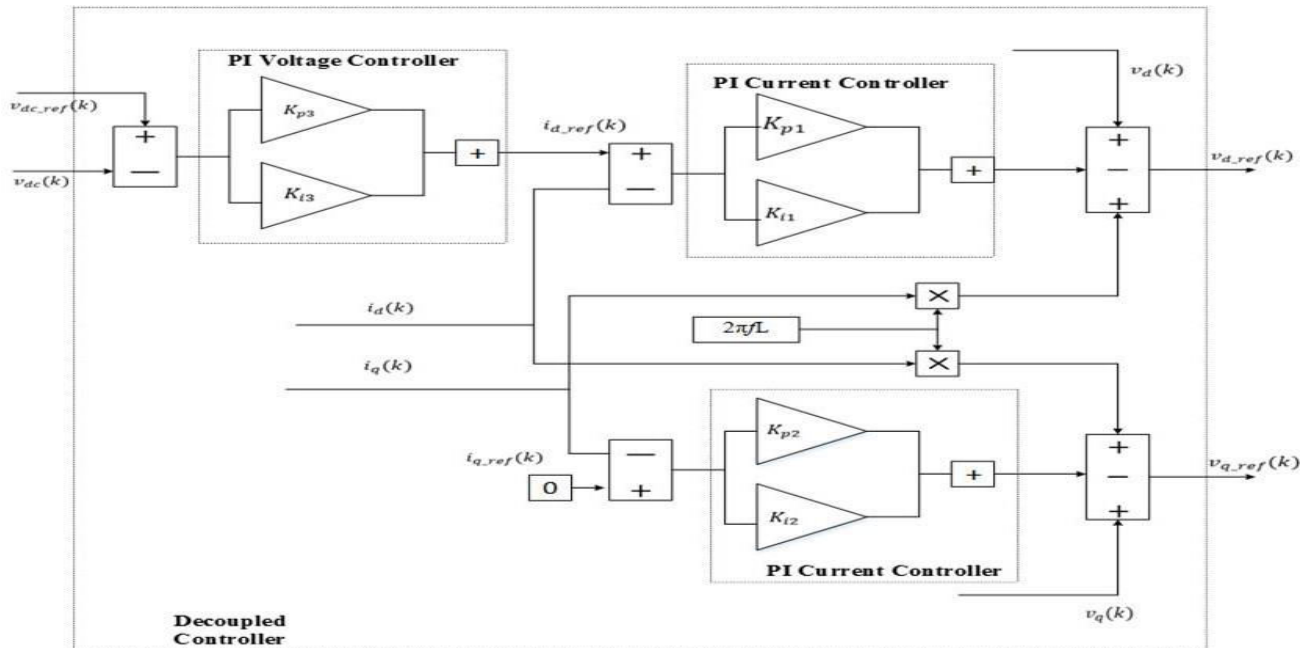


Fig.3The control circuit of the decoupled controller for the VOC technique.

### 3.2 VOLTAGE ORIENTED CONTROLLER:-

VOLTAGE ORIENTED CONTROLLER The operation of AC to DC power converters strongly depends on the implemented control structure. The operation of a voltage-oriented controller is based on dual vector current controllers (DVCC). Voltage-oriented control is used to mitigate the following problem: • Output DC voltage ripples • Total harmonics distortion in the input current • Input power factor at the grid side The voltage-oriented controller consists of a voltage controller and a current controller. The current control algorithm has two independent current controllers, which will work in the positive and negative synchronous reference frames (SRF). The positive SRF is used to control the positive current component, which rotates in a clockwise direction, whereas the negative SRF is used to control the negative current component, which rotates in the opposite direction. Since the currents occur as DC values in their frame in SRF, a tracking controller does not need to be built. Due to this advantage, the PI controller is adequate to solve the problems above. The root of VOC approach is the field-oriented controller (FOC) for induction motors, which offers fast and dynamic responses using current controller loops. The VOC technique used for power electronic converters has been widely known in its theoretical aspects. The pulse width modulation approach is added to the control system to improve the features of the VOC system. The minimization of interference (disturbance) can be done by using the VOC technique. By applying hysteresis Pulse Width Modulation (PWM) technique, the system performance has improved.

## IV. SIMULATION STUDIES AND RESULTS

The performance of the proposed controller for high-power applications that require 600V/100A DC output is evaluated. The proposed system are summarized in Table 3.

Parameter	Symbol	Unit	Value
Resistor Load	$R_{load}$	$\Omega$	20
Input inductance	$L_f$	mH	5
Grid frequency	$f$	Hz	50
Switching frequency	$f_s$	kHz	12
Input resistance	$R_f$	$\Omega$	5
Source voltage (AC- RMS)	$V_{in}$	V	440
Output voltage	$V_{dc}$	V	600
Current controller	$K_{p1}$ and $K_{p2}$	-	67
Current controller	$K_{i1}$ and $K_{i2}$	-	$1.7 \times 10^4$
Voltage controller	$K_{p3}$	-	0.00027
Voltage controller	$K_{i3}$	-	0.017

TABLE1.Specification of a VOC based vienna rectifier (VOC-VR).

The VOC-VR experimented first on software based I.e in simulated in MATLAB S, The results obtained are shown in Fig. 7 and Fig. 8. as below The current waveforms which are nothing but input wave forms are shown in Fig. 7. The i/p harmonics for VR without a voltage over controller and with a voltage over controller are shown in Fig. 8 (a) and (b), respectively. From Fig. 7 and Fig. 8,

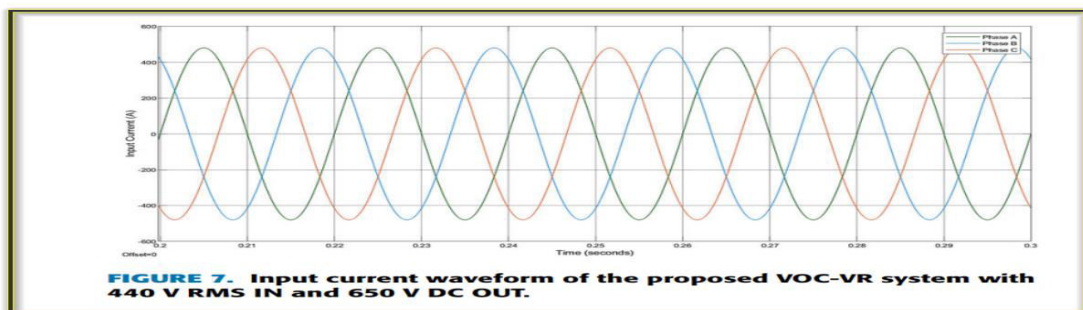
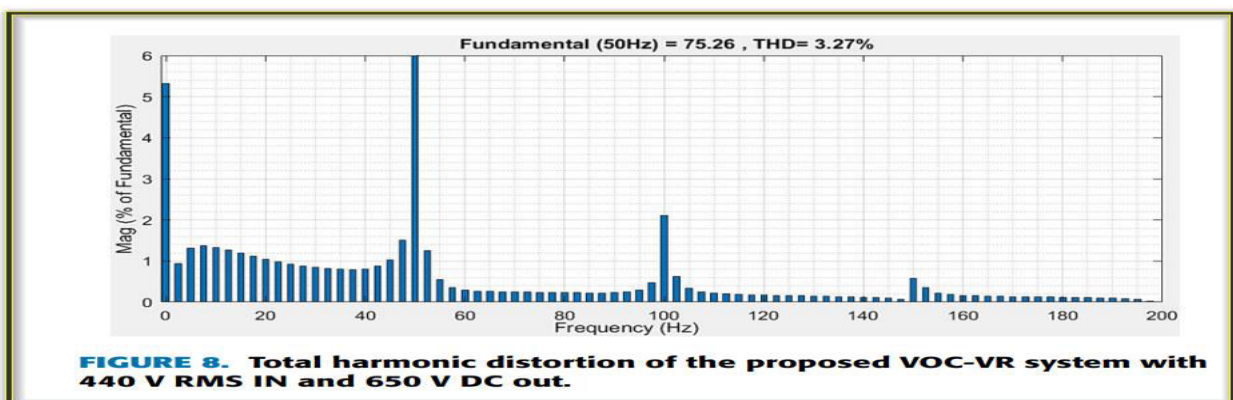
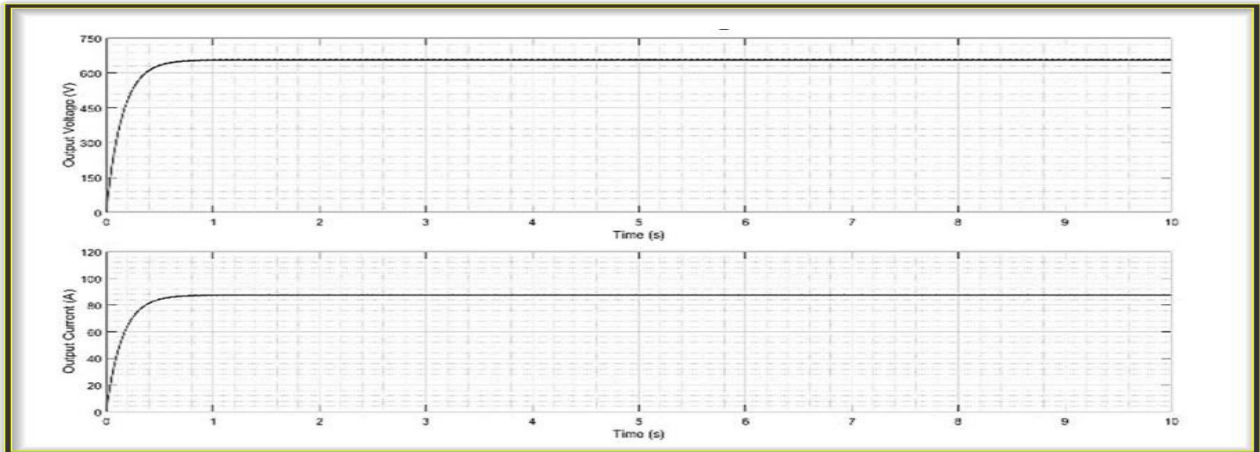


Fig.7 i/p current wave



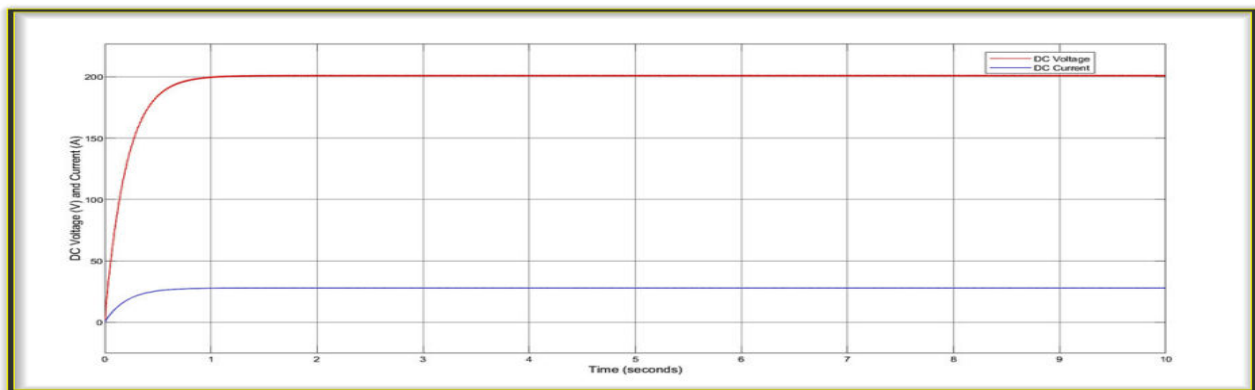
it observed that the technique ensures total harmonics distortions of the i/p current is less than 3.27%, and the system run on the unity power factor at the source side. Therefore, the proposed VOC-VR system has been proven to be

applicable for high power applications with reduced total harmonic distortion to the connected grid. In a previous work, Vienna Rectifier with the PFC controller ensured an input current THD of 1.46%.



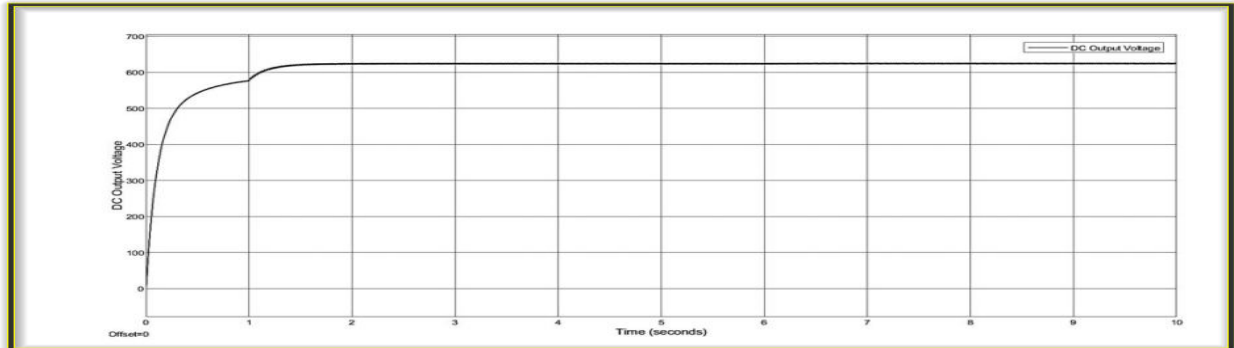
**FIGURE 9. DC output voltage and output current of the Vienna rectifier with VOC controller with 350 V AC RMS input and 650 V DC output voltage.**

Fig 9. shows that the proposed system can maintain the DC output voltage at an optimal level of 650V. The results from this system also show that DC current has been maintained approximately at 90A, which can be used for EV fast charging and welding applications. By scaling down the proposed system and optimizing PI parameters in the VOC controller.

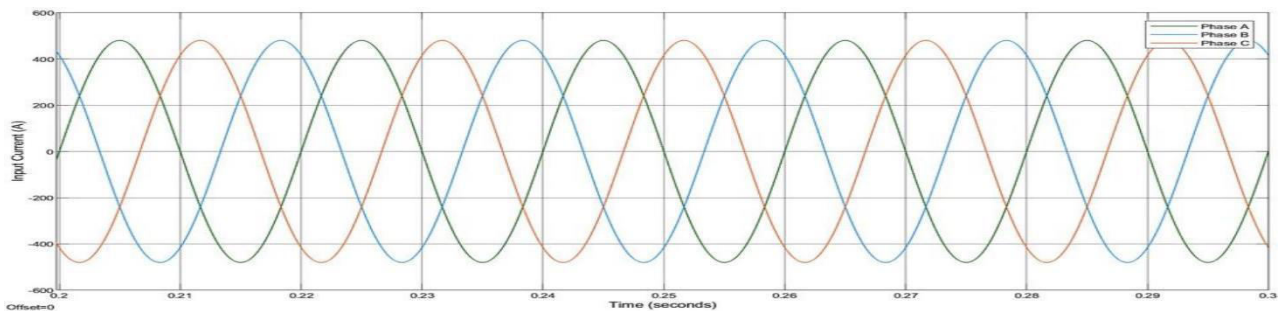


**FIGURE 10. DC output voltage and output current of the Vienna rectifier with VOC controller with 350 V AC RMS input and 220 V DC output voltage for slow charging stations.**





**FIGURE 11. DC output voltage for the transient condition during the load variations.**



**Fig.12** Input current waveform of the proposed VOC-VR system with 440 V RMS IN and 650 V DC OUT.

### V. EXPERIMENTAL RESULTS

The VOC-VR Tested and intentions behind this test so that to ensure the constant DC voltage at low input current THD. Table shows the experimental results of the Vienna rectifier with a VOC controller for the input voltage of 208 V AC RMS and output voltage of 600 V DC. The tests were carried out for different load conditions. The DC output voltage is shown in table describes the experimental results of the Vienna rectifier with a VOC controller for the input voltage of 350 V AC RMS with 700 V DC output voltage. The test results are carried out with different load conditions. Harmonics in the experimental input current for 350 V AC RMS and 700 V DC output, it can be observed that the odd harmonics in the input current have been eliminated, which will reduce the size of the filtering components. This again proves that the efficiency of the overall system has been improved with the VOC controller.

$V_{bus}$ (V) (AC – RMS)	$V_{out}$ (V)	$P_{in}$ (W)	$I_{out}$ (A)	$P_{out}$ (W)	Efficiency	THD %	PF
300.5	598.5	74	0.117	70.069	0.946	23.20%	0.8623
300	598.35	124.4	0.2	119.16	0.962	17%	0.9203
299.8	598.57	245.1	0.4	239.58	0.977	8.09%	0.9775
299	598.26	481.3	0.788	471.78	0.980	3%	0.997
299.6	598.47	623.2	1.027	612.98	0.981	2.54%	0.995
299.4	598.36	858.6	1.416	841.85	0.980	1.71%	0.994
299.1	598.15	1001.8	1.632	980.46	0.978	1.52%	0.997
299.82	599.8	1150.2	1.878	1125.5	0.978	1.22%	0.998
298.8	598.68	1399.6	2.278	1364.6	0.974	0.96%	0.999

TABLE 2. Test Outputs with 208 VAC, 600 V DC output voltage,

### VI. CONCLUSION

In this paper presentation, a Vienna rectifier based on a voltage-oriented controller (VOC-VR) has been discussed and tested and simulated by MATLAB software targeting high-power uses such as DC-fast chargers for electric vehicles.

The controller for Vienna rectifier expresses on combining voltage-oriented controllers with the PWM technique. this design, the reactive and unstable active currents are counteracted by the input and output filters and Voltage Oriented Controller (VOC) with Vienna rectifier. The proposed design also confirms a sinusoidal current at the input side with low ripples and distortions. The factor is maintained at unity, and THD of the input current is kept less than 5 %, which meets the IEEE-519 standard.

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