ANFIS CONTROLLED BASED VIENNA RECTIFIER FOR ELECTRIC VEHICLE CHARGING STATIONS

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ABSTRACT

In this project, ANFIS controller based Vienna rectifier for Electric Vehicle Charging Stations is presented. 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 ANFIS controller (VOC-VR) has been simulated using MATLAB/Simulink software.

Key Words: Front-end converters, high power applications, power factor, total harmonic distortion, Vienna rectifier, voltage oriented controller.

I INTRODUCTION

AC to DC converters with regulated DC output voltage is used as front-end converters for different applications such as electric vehicle chargers, telecommunication applications, welding power sources, data center, and motor drives [1], [2]. The power required for EV charging stations and welding power sources is high, which means that the voltage and current rating at the power converters must be higher than the voltage and current required for other applications such as motor traction [3], [4]. The unidirectional boost rectifier known as Vienna rectifier is used as a front-end converter [5]. 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 com- pared to conventional three-phase rectifiers [6]. The Vienna rectifier is ideal for high power applications owing to the high power to weight ratio, high efficiency, and low voltage stress [7], [8].

In recent years, the core of the power electronics systems is the controller unit, which has been subjected to intensive research. The basic controller used in a power converter is a proportional-integral (PI) controller. However, it is challenging to achieve an accurate linear mathematical model of the system required for the PI controller [9]. Moreover, the PI controller often struggles to work satisfactorily under parameter variations, nonlinearity, and load disturbances [10].

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) [11], direct power controller (DPC) [12], voltage-oriented controller (VOC) [13], Voltage-oriented controller based Vienna rectifier (VOC-VR) with ANFIS controller and their combination DPC-SVM [14]. Voltage oriented controller is commonly used as a power controller for power factor correction in active front-end converters.

A novel design of EV charging system consisting of voltage oriented controller with a Vienna rectifier with ANFIS controller (VOC-VR) is proposed for high power applications. The proposed system is a hybrid control structure consisting of voltage-oriented controller with ANFIS controller for the Vienna rectifier, which is used for EV charging stations. Prior designs of AC/DC converters for high power applications employed a hybrid controller using conventional three-phase controlled rectifiers,

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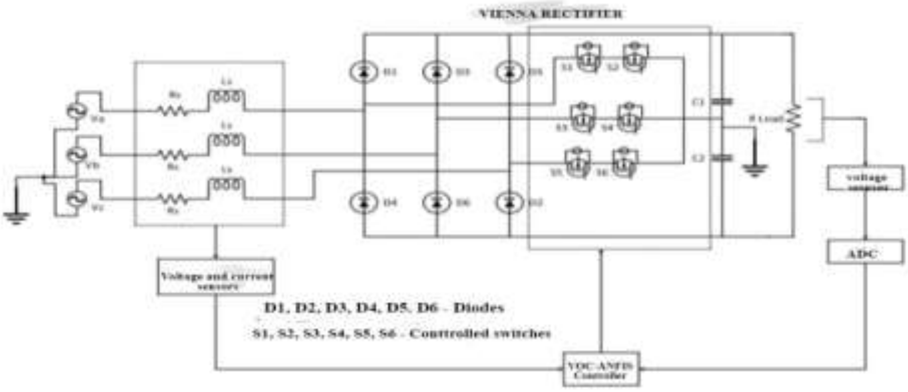

FIGURE 1. The proposed electric vehicle charger is based on Vienna rectifier with a VOC controller (VOC-VR) system.

which requires input and output filters with high rating to mitigate the input current THD [13], [14]. This led to reduced efficiency and power density of the system. To address this issue, a novel design of integrating Vienna rectifier with a VOC and ANFIS controller for high power applications is proposed. THD is reduced to less than 5%, which satisfies the IEEE-519 standard. The proposed novel design outperforms existing AC/DC power converters for high power applications by significantly reducing the input current THD and increasing the power density. Using Vienna rectifier, transient stability is improved, and for an output voltage of 650 V/ 90 A, the THD is reduced to less than 5%, which satisfies the IEEE-519 standard.

The proposed novel design outperforms existing AC/DC power converters for high power applications by significantly reducing the input current THD and increasing the power density.

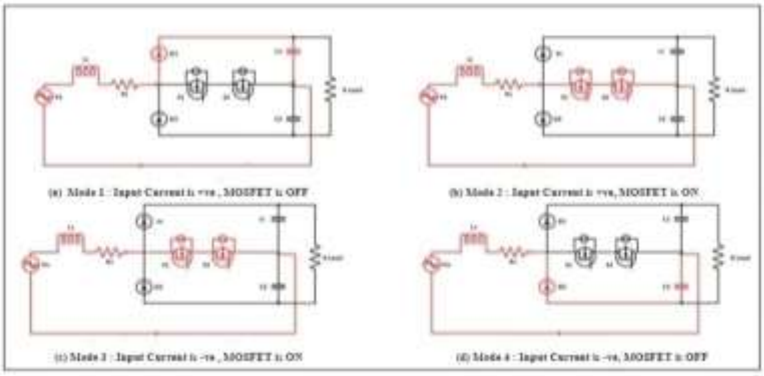

FIGURE 2. Four modes of operation of Vienna rectifier topology

II VIENNA RECTIFIER

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 Vdc/2. Three inductors on the input AC side and two capacitors are parallely connected on the DC side. The neutral point of the grid is associated with the neutral point of the DC link. Fig. 2 shows 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◦ phase difference.

In mode 1, when a reference voltage is a positive half cycle and controlled switches (IGBTs/MOSFETs) are OFF, the diode D1 conducts. During this time, the current flows through Va-

Ls-Rs-D1-C1 as shown in Fig. 2(a). In mode 2 operation, when a reference voltage is positive half cycle with a 120◦ phase difference. In mode 1, when a reference voltage is a positive half cycle and controlled switches (IGBTs/MOSFETs) are OFF, the diode D1 conducts. During this time, the current flows through Va-Ls-Rs-D1-C1 as shown in Fig. 2(a). In mode 2 operation, when a reference voltage is positive half cycle with controlled switches are ON, switches S1S2 conducts and current flows through Va-Ls-Rs-S1-S2 as shown in Fig. 2(b). In mode 3 operations, when a reference voltage is negative half cycle with controlled switches are ON, switches S1S2 conducts and the current flows through S1-S2-Rs-Ls-Va as shown in Fig. 2(c). In mode 4 operation, when a reference voltage is negative half cycle with controlled switches are OFF, the current flows through C2-D2-Rs-Ls-Va as shown in Fig. 2(d).

Vienna Rectifier is applicable for high power applications such as welding power sources, wind energy conversion systems, electric vehicle charging stations, and telecommunication power sources. Different power controllers have been used in Vienna Rectifier for high power applications, such as vector controller, SVPWM controller, predictive controller, and dead-beat controller. The different types of intelligent controllers have been combined with conventional controllers to improve the stability of the system, which increases the complexity of the system. The proposed system consists of Voltage Oriented Controller for Vienna Rectifier with ANFIS controller (VOC-VR). The proposed system reduces the harmonics in the input source current, improves the power factor at the grid side, and improves the stability of the system.

III 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 ANFIS 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. The variable switching frequency of the power converters raises the stress in power switching, resulting in large input and output filters.

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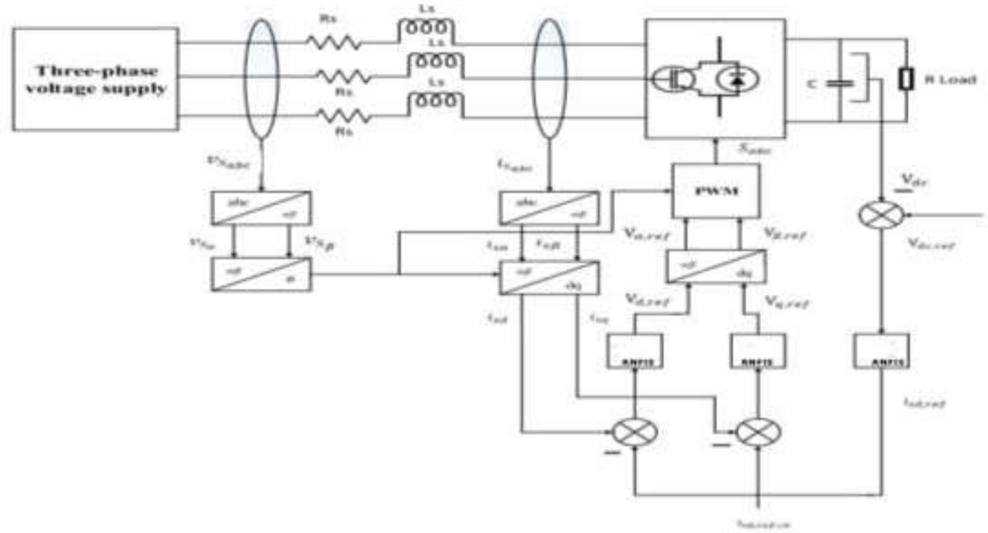

FIGURE 3. The control structure of voltage-oriented controller with PWM technique

The proposed approach applies the VOC technology for regulating the charging mechanism with reduced current harmonics in the grid, as shown in Fig. 3. The voltage oriented controller primarily works in the two-phase αβ0 and dq0 domains where Clark and Park transformation matrices are implemented, as shown in equations (1) and (2), respectively.

$$\begin{bmatrix} Vs\alpha \\ Vs\beta \\ V0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} Vsa \\ Vsb \\ Vsc \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} Vd \\ Vq \end{bmatrix} = \begin{bmatrix} \sin\theta & \cos\theta \\ -\cos\theta & \sin\theta \end{bmatrix} \begin{bmatrix} Vs\alpha \\ Vs\beta \end{bmatrix} \quad (2)$$

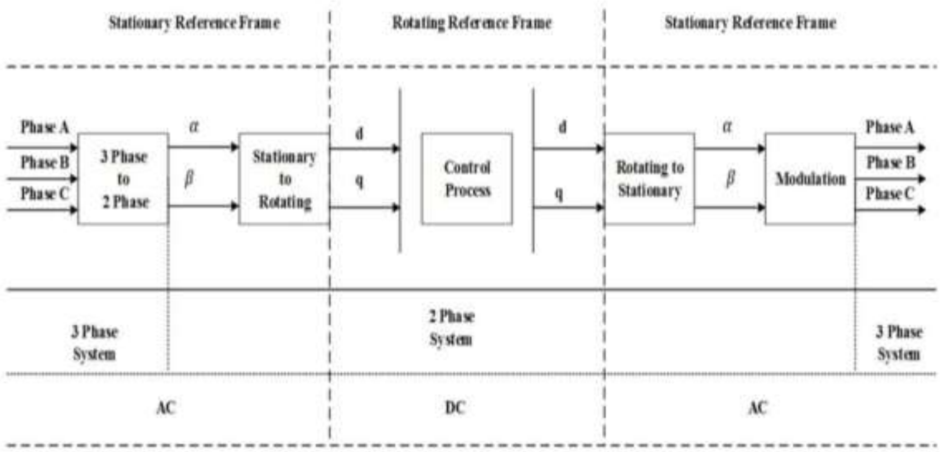

FIGURE 4. Overall domain transformation sequences involved in the voltage-oriented controller technique.

where, Vsa, Vsb, Vsc are the three-phase source voltages in the ABC domain, Vsα, Vsβ, V0, Vd, Vq are the source voltages in the αβ0 and dq0 domains, and θ is the operating phase of the power system. A similar transformation approach is applied to convert the three-phase source current iSabc as shown in Fig. 3. AC side control variables become the DC signals by modifying the transformation technique. The ANFIS controllers easily eliminate steady-state errors according to the following approaches [13]:

$$Vd,ref = \text{Kp}\ (iSd,ref - iSd) + Ki(iSd,ref - iSd)dt \quad (3)$$
$$Vq,ref = \text{Kp}\ (iSq,ref - iSq) + Ki(iSq,ref - iSq)dt \quad (4)$$

Kp and Ki = ANFIS controller gains
iSd and iSq = input current in the dq0 domain,
iSd,ref and iSq,ref = reference signals for iSd and iSq

By applying an inverse park transformation, the operation of the Vienna rectifier has been controlled, as shown in Eq. (5); after obtaining the reference voltage Vd,ref and Vq,ref which is used to derive the gate switching pulses Sabc. The VOC operation involving the overall domain transformation process is summarized in Fig. 4.

$$\begin{bmatrix} \frac{V\alpha,ref}{V\beta,ref} \end{bmatrix} = \begin{bmatrix} \sin\theta & -\cos\theta \\ \cos\theta & \sin\theta \end{bmatrix} \begin{bmatrix} Vd,ref \\ Vq,ref \end{bmatrix} \quad (5)$$

The transformation consists of Park's transformations and Clarke's transformation. Clarke's transformation is used to convert the three-phase quantities (phases A, B, C) into the two-phase stationary quantities (α and β). The Park's transformation converts stationary two-phase (α and β) into the rotating reference frame (d and q). Similarly, using the inverse park's transformation technique, the rotating reference frame (d and q) has been converted into a stationary reference frame (α and β). Furthermore, the Stationary Reference frame is converted into a three-phase AC system using inverse Clarke's transformation technique.

IV Adaptive Neural based Fuzzy Inference System

Adaptive Neural Fuzzy Inference System (ANFIS) is Fuzzy Sugeno model put in the framework to facilitate learning and adaption procedure. Basic architecture of ANFIS that has two inputs x and y and one output f. This model can be selected based on the fuzzy rules framed by either using the subtractive clustering technique or the grid partitioning technique with each input having three membership functions and Similarly, the 25 rules which are obtained from the clustering or grid partition based method are updated by neural network which uses back propagation learning method with gradient descent algorithm.

FIGURE 5. Output Variable

Table.1: variable selection process for a four input initial model

Error/change in error	NB	N	Z	P	PB
NB	PB	PB	P	Z	Z
N	P	P	Z	Z	Z
Z	Z	Z	Z	Z	Z

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P	Z	Z	Z	N	N
PB	N	N	N	NB	NB

Where N = Negative
P = Positive
Z = Zero
PB = Positive Big
NB =Negative Big

V METHODOLOGY:

The proposed Vienna rectifier with VOC controller (VOC-VR) is a three-phase three-level rectifier, which is controlled by the voltage-oriented controller algorithm. The proposed system includes a three-phase AC system, a Vienna rectifier controlled by a VOC algorithm, and a DC link capacitor. Feedback voltage from the EV's load-side battery is generated using current and voltage controllers for the closed-loop operations. The VOC controller performs 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 proposed VOC-VR system is shown in Fig. 5.

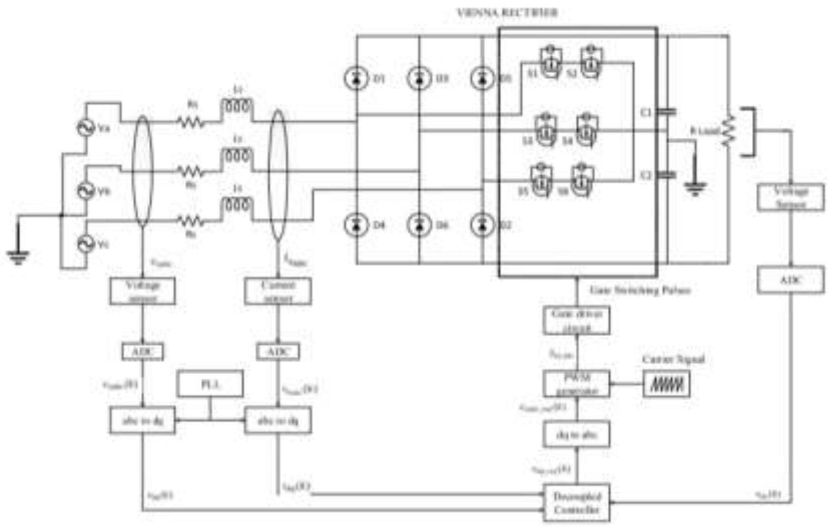

FIGURE 6. Overall Circuit Configuration of the proposed VOC-VR system

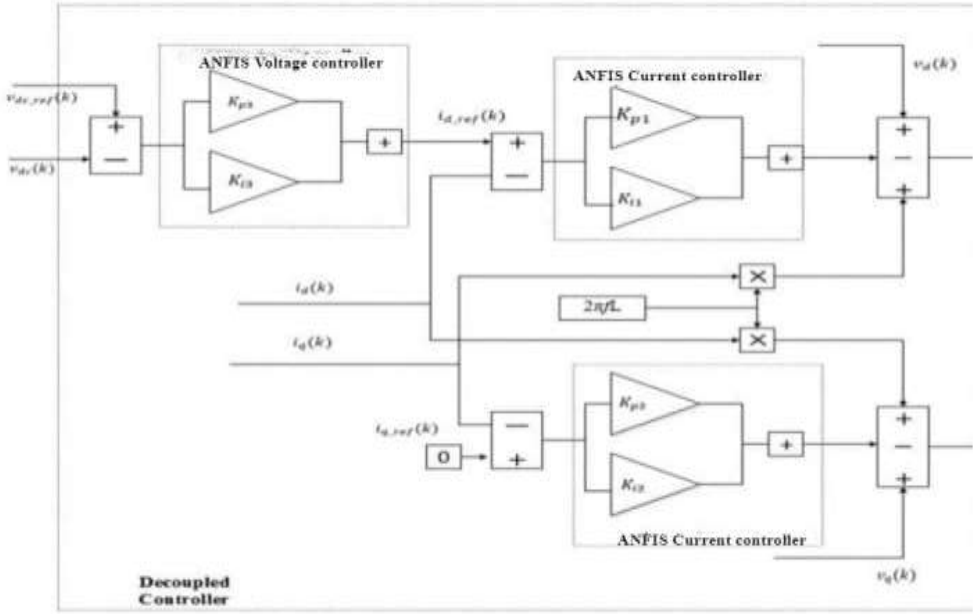

FIGURE 7. The control circuit of the decoupled controller for the voltage-oriented controller technique.

The de-coupler controller is the key feature of the proposed VOC control algorithm, as shown in Fig. 6. Three ANFIS controllers were used in the proposed control circuit. The first ANFIS controller is a current controller that controls the internal loop of id current component. This controller is used to estimate the reference voltage signal vd_ref by minimizing the error between id with id_ref . Second ANFIS controller is also called a PI current controller, which reduces iq current component to 0 by managing the inner loop of iq a current component which is used to estimate the voltage reference voltage signal vq_ref . Third ANFIS controller is a voltage controller, which is used to manage the output loop of DC-link voltage Vdc. This controller is used to estimate reference current signal id_ref by comparing measured Vdc with its pre-determined reference voltage vd_ref . The voltage-oriented controller must transform input from three-phase current and decouple into active id and reactive iq components, respectively. Regulating the decoupled active and the reactive components minimizes errors between required reference and calculated values of the active and reactive components. The DC link voltage control method controls the active current component id which aims to achieve an active power flow balance in the systems while the reactive current component iq is controlled to 0 to provide a unity power factor at the input side. The characteristics of two ANFIS current controllers and ANFIS voltage controllers are given in equation (6)-equation (8) [13] .

$$Vd_{ref} = V_d + 2\pi f L_s i_q - (Kp1(id_{ref} - i_d) + \mathrm{Ki1}\int (id_{ref} - i_d)dt) \quad (6)$$

$$Vq_{ref} = V_q - 2\pi f L_s i_d - (Kp2(0 - i_q) + \mathrm{Ki2}\int (0 - i_q)dt) \quad (7)$$

$$id_{ref} = Kp3(Vdc_{ref} - V_{dc}) + \mathrm{Ki3}\int (Vdc_{ref} - V_{dc})dt) \quad (8)$$

Kp1, Ki1Kp2, Ki2Kp3, Ki3 = gain values ANFIS current controller Ls = source inductance.
The switching frequency for the current control loop will be larger than the bandwidth αi,

$$\alpha_i < 2\pi \frac{f_s}{10} \quad (9)$$

$$K_{p1} = K_{p2} = \alpha_i L_s \quad (10)$$

$$K_{i1} = K_{i2} = \alpha_i R_s \quad (11)$$

where, αi (rad/s) = current controller bandwidth. For the voltage control loop, the ANFIS controller is tuned by using a DC link capacitor as the following:

$$K_{p3} \geq C_{dc1}\xi\omega \text{ and } K_{i3} \geq C_{dc1}\xi\omega/2 \qquad (11)$$

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

VI SIMULATION RESULTS

This section presents the simulation results of a VOC-based Vienna rectifier circuit. The performance of the proposed controller for high-power applications that require 600V/100A DC output is evaluated. Vienna rectifier with VOC controller has been simulated in MATLAB Simulink, and results are shown in Fig. 7 and Fig. 8. The input-current waveforms are shown in Fig. 7. The input-current harmonics for Vienna rectifier without a VOC controller and with a VOC controller are shown in Fig. 8 (a) and (b), respectively. From Fig. 7 and Fig. 8, it can be seen that the proposed control technique ensures THD of the input current is less than 2.10%, and the system maintains 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.

However, the output voltage of the PFC controller with the Vienna rectifier was around 200V, which cannot be used for high power applications such as DC fast chargers for electric vehicles and welding power sources. Hence, voltage-oriented controller with the PWM method for Vienna rectifier gives better performance than the previous work.

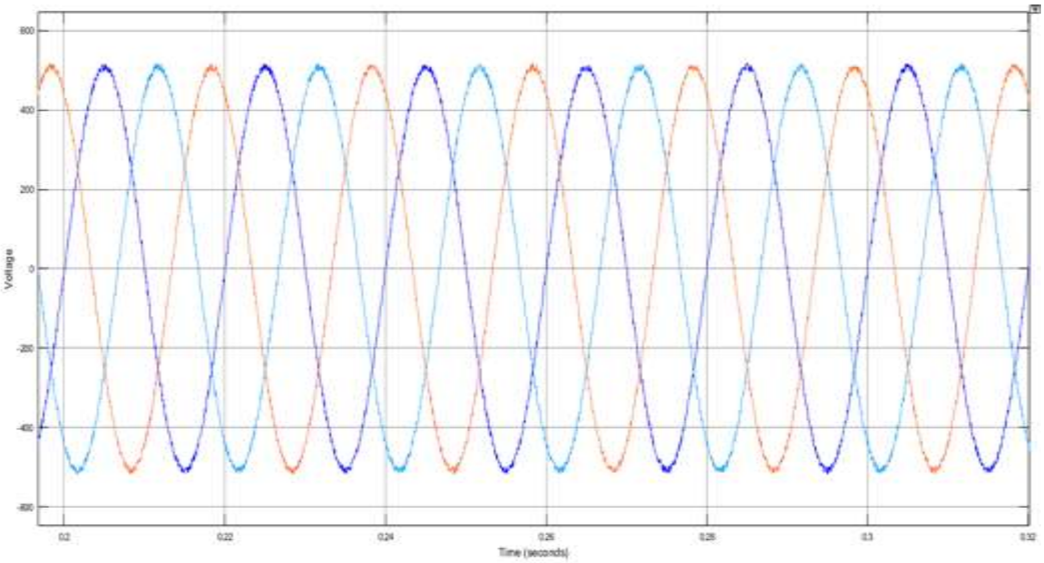

Figure 8: Input current waveform of the proposed VOC-VR system with 440 V RMS

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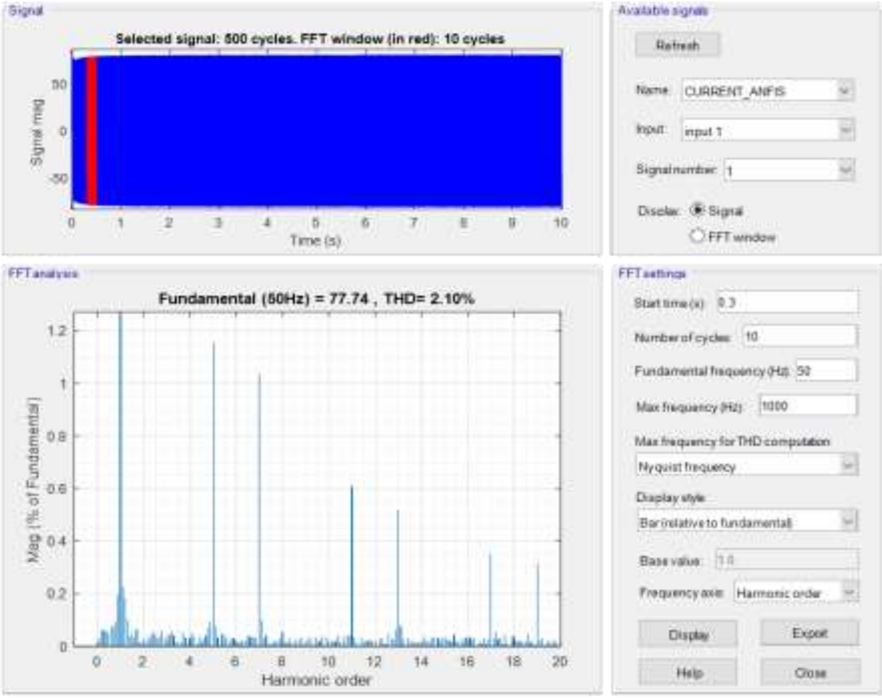

Figure 9: Total harmonic distortion of the proposed VOC-VR system with 440 V RMS

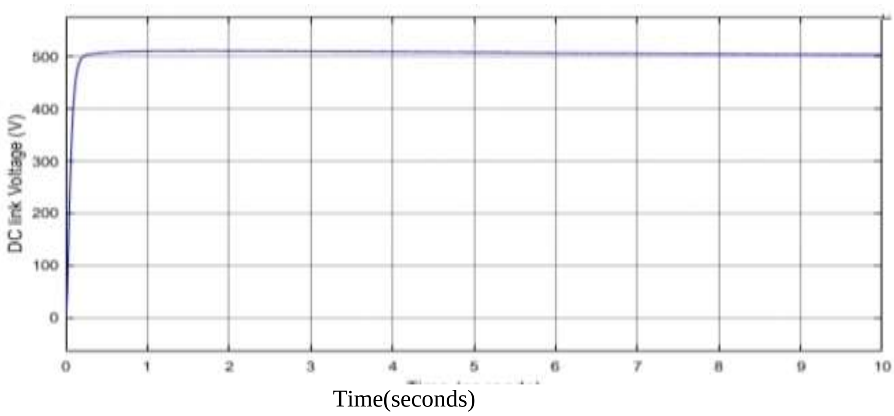

Figure 10: DC output voltage of the Vienna rectifier with VOC controller with 350 V AC RMS input

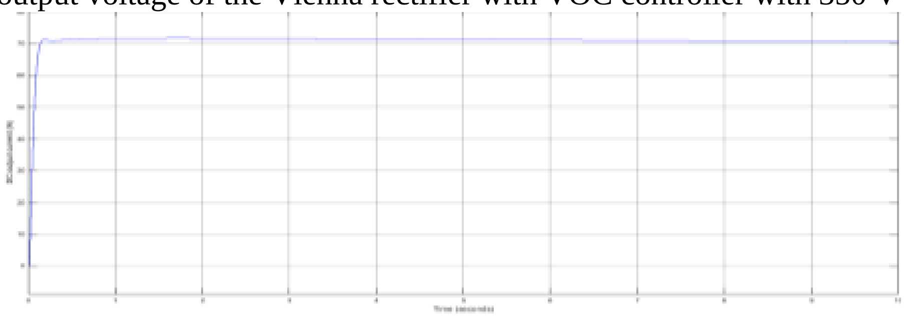

Figure 11: DC output current of the Vienna rectifier with VOC controller with 350 V AC RMS input

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 [13]. By scaling down the proposed system and optimizing ANFIS parameters in the VOC controller, the rectifier can be used for slow charging scenarios (250 V/40 A output) as shown in Fig. 9 whereas, the Vienna rectifier with PFC controller can maintain the DC voltage up to 200 V with 16.5 A. As a consequence, the Vienna rectifier with a PFC controller can only be used for slow charging applications (Level 1 charging). The transient analysis has been performed by studying the system performance in the case of an instantaneous increase in the load by a factor of 2. The DC output voltage during the transient condition is shown in Fig. 10.

VII CONCLUSION

A Three-level Vienna rectifier based on a ANFIS controller has been designed and simulated. Using MATLAB Simulink software targeting high power applications such as DC-fast chargers for electric vehicles. This focuses on combining voltage-oriented controllers with the PWM method. The reactive and unstable active currents are counteracted by the input and output filters and ANFIS with Vienna rectifier. The proposed design also guarantees a sinusoidal current at the input side with minimum ripples and distortions. The systems power factor is maintained at unity, and total harmonic distortion of the input current is kept less than 5 %, which meets the IEEE-519 standard. The benefit of the proposed controller over conventional PFC controller has been demonstrated by simulations and experimental results. Low THD, good power factor, and smaller filtering requirements make the voltage-oriented controller-based Vienna rectifier an ideal candidate in electric vehicle charging stations.

VIII REFERENCES

[1] F. Nejabatkhah, Y. W. Li, and H. Tian, ''Power quality control of smart hybrid AC/DC microgrids: An overview,'' IEEE Access, vol. 7, pp. 52295–52318, 2019.
[2] P. Arboleya, G. Diaz, and M. Coto, ''Unified AC/DC power flow for traction systems: A new concept,''IEEE Trans. Veh. Technol., vol. 61, no. 6, pp. 2421–2430, Jul. 2012.
[3] W. Su, H. Eichi, W. Zeng, and M.-Y. Chow, ''A survey on the electrification of transportation in a smart grid environment,'' IEEE Trans. Ind. Informat., vol. 8, no. 1, pp. 1–10, Feb. 2012.
[4] I. Pavić, T. Capuder, and I. Kuzle, ''Value of flexible electric vehicles in providing spinning reserve services,'' Appl. Energy, vol. 157, pp. 60–74, Nov. 2015.
[5] L. Hang, H. Zhang, S. Liu, X. Xie, C. Zhao, and S. Liu, ''A novel control strategy based on natural frame for Vienna-type rectifier under light unbalanced-grid conditions,'' IEEE Trans. Ind. Electron., vol. 62, no. 3, pp. 1353–1362, Mar. 2015.
[6] J.-S. Lee and K.-B. Lee, ''Carrier-based discontinuous PWM method for Vienna rectifiers,'' IEEE Trans. Power Electron., vol. 30, no. 6, pp. 2896–2900, Jun. 2015.
[7] A. Ali, M. Mansoor Khan, J. Yuning, Y. Ali, M. T. Faiz, and J. Chuanwen, ''ZVS/ZCS Vienna rectifier topology for high power applications,'' IET Power Electron., vol. 12, no. 5, pp. 1285–1294, May 2019.
[8] G. Rajendran, C. A. Vaithilingam, K. Naidu, and K. S. P. Oruganti, ''Energy-efficient converters for electric vehicle charging stations,'' Social Netw. Appl. Sci., vol. 2, no. 4, pp. 1–15, Apr. 2020.
[9] Y.-Y. Hong and M.-J. Liu, ''Optimized interval type-II fuzzy controllerbased STATCOM for voltage regulation in power systems with photovoltaic farm,'' IEEE Access, vol. 6, pp. 78731–78739, 2018.
[10] K. Y. Ahmed, N. Z. Bin Yahaya, V. S. Asirvadam, N. Saad, R. Kannan, and O. Ibrahim, ''Development of power electronic distribution transformer based on adaptive PI controller,'' IEEE Access, vol. 6, pp. 44970–44980, 2018.
[11] S. Narula, B. Singh, and G. Bhuvaneswari, ''Power factor corrected welding power supply using modified zeta converter,'' IEEE J. Emerg. Sel. Topics Power Electron., vol. 4, no. 2, pp. 617–625, Jun. 2016.
[12] S. Vazquez, J. A. Sanchez, J. M. Carrasco, J. I. Leon, and E. Galvan, ''A model-based direct

power control for three-phase power converters,'' IEEE Trans. Ind. Electron., vol. 55, no. 4, pp. 1647–1657, Apr. 2008.
[13] A. S. Al-Ogaili, I. B. Aris, R. Verayiah, A. Ramasamy, M. Marsadek, N. A. Rahmat, Y. Hoon, A. Aljanad, and A. N. Al-Masri, ''A three-level universal electric vehicle charger based on voltage-oriented control and pulse-width modulation,'' Energies, vol. 12, no. 12, p. 2375, Jun. 2019.
[14] M. Malinowski, M. Jasinski, and M. P. Kazmierkowski, ''Simple direct power control of three-phase PWM rectifier using space-vector modulation (DPC-SVM),'' IEEE Trans. Ind. Electron., vol. 51, no. 2, pp. 447–454, Apr. 2004.

