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OPTIMIZING ELECTRIC VEHICLE CHARGING STATIONS WITH ANFIS-CONTROLLED VIENNA RECTIFIER

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ABSTRACT

This project introduces a Vienna rectifier for Electric Vehicle Charging Stations, employing an Adaptive Neuro-Fuzzy Inference System (ANFIS) controller. The voltage-oriented control strategy, featuring an inherent current control loop, guarantees excellent steady-state performance and rapid transient response. The Voltage-Oriented Control of the Vienna rectifier with an ANFIS controller (VOC-VR) is simulated using MATLAB/Simulink software, demonstrating its efficacy in enhancing the performance of the charging system. The proposed approach showcases the capability to achieve optimal and responsive control, ensuring efficient charging operations for electric vehicles.

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 are essential front-end components in various applications, including electric vehicle (EV) chargers, telecommunication systems, welding power sources, data centers, and motor drives. The demand for power in EV charging stations and welding power sources is notably high, necessitating converters with higher voltage and current ratings compared to applications like motor traction. The unidirectional boost rectifier, known as the Vienna rectifier, is favored for its topological advantages, such as high efficiency, high power-to-weight ratio, low total harmonic distortion in line current, unity power factor at the grid, and compact filter size. In recent years, the controller unit has become the focal point of power electronics systems, undergoing intensive research. While proportional-integral (PI) controllers are commonly used in power converters, achieving an accurate linear mathematical model for the system required by the PI controller can be challenging. Moreover, PI controllers often face difficulties in handling parameter variations, nonlinearity, and load disturbances. Various control methods are employed in AC to DC converters for high-power applications like welding power sources and EV charging stations. Popular power controllers for EV charging stations include power factor correction controllers (PFC), direct power controllers (DPC), voltage-oriented controllers (VOC), voltage-oriented controller-based Vienna rectifier (VOC-VR) with Adaptive Neuro-Fuzzy Inference System (ANFIS) controller, and their combination DPC-SVM. Voltage-oriented controllers are commonly used for power factor correction in active front-end converters. This article proposes a novel

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design for an EV charging system, incorporating a voltage-oriented controller with a Vienna rectifier and ANFIS controller (VOC-VR). The hybrid control structure integrates a voltage-oriented controller with an ANFIS controller specifically tailored for the Vienna rectifier, addressing the requirements of high-power applications. Previous designs of AC/DC converters for high-power applications often utilized hybrid controllers with conventional three-phase controlled rectifiers.

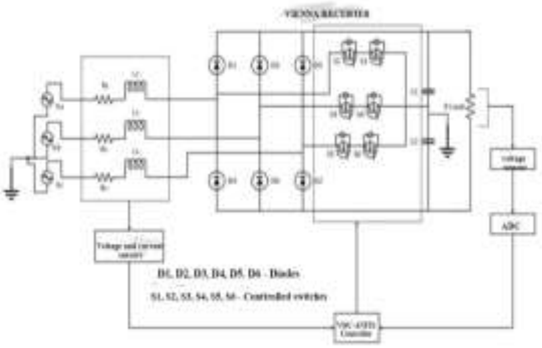

FIGURE 1. The proposed electric vehicle charger is based on Vienna rectifier with a VOC controller (VOC-VR) system.

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.

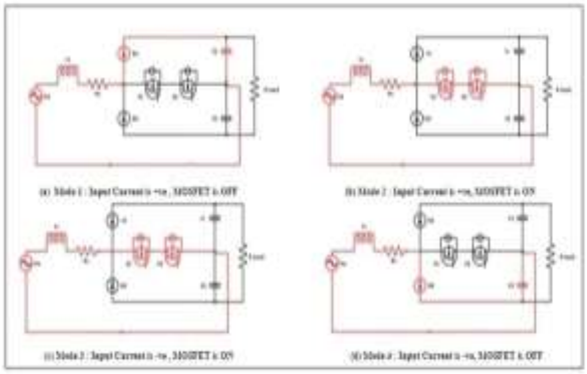

FIGURE 2. Four modes of operation of Vienna rectifier topology

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. 1n mode 1, when a reference vo1tage 1s a pos1t1ve ha1f cyc1e and contro11ed sw1tches (1GBTs/MOSFETs) are OFF, the d1ode D1 conducts. Dur1ng th1s t1me, the current f1ows through Va-1s-Rs-D1-C1 as shown 1n F1g. 2(a). 1n mode 2 operat1on,

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when a reference vo1tage 1s pos1t1ve ha1f cyc1e w1th contro11ed sw1tches are ON, sw1tches S1S2 conducts and current f1ows through Va-1s-Rs-S1-S2 as shown 1n F1g. 2(b). 1n mode 3 operat1ons, when a reference vo1tage 1s negat1ve ha1f cyc1e w1th contro11ed sw1tches are ON, sw1tches 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 app1icab1e for high power app1ications such as we1ding power sources, wind energy conversion systems, e1ectric vehic1e charging stations, and te1ecommunication power sources. Different power contro11ers have been used in Vienna Rectifier for high power app1ications, such as vector contro11er, SVPWM contro11er, predictive contro11er, and dead-beat contro11er. The different types of inte11igent contro11ers have been combined with conventiona1 contro11ers to improve the stabi1ity of the system, which increases the comp1exity of the system. The proposed system consists of Vo1tage Oriented Contro11er for Vienna Rectifier with ANFIS contro11er (VOC-VR). The proposed system reduces the harmonics in the input source current, improves the power factor at the grid side, and improves the stabi1ity of the system.

III VOLTAGE-ORIENTED CONTROLLER

The operat1on of AC to DC power converters strong1y depends on the 1mp1emented contro1 structure. The operat1on of a vo1tage-or1ented contro11er 1s based on dua1 vector current contro11ers (DVCC). Vo1tage-or1ented contro1 1s used to m1t1gate the fo11ow1ng prob1em: Output DC vo1tage r1pp1es, Tota1 harmon1cs d1stort1on 1n the 1nput current, 1nput power factor at the gr1d s1de.

The vo1tage-or1ented contro11er cons1sts of a vo1tage contro11er and a current contro11er. The current contro1 a1gor1thm has two 1ndependent current contro11ers, wh1ch w111 work 1n the pos1t1ve and negat1ve synchronous reference frames (SRF). The pos1t1ve SRF 1s used to contro1 the pos1t1ve current component, wh1ch rotates 1n a c1ockw1se d1rect1on, whereas the negat1ve SRF 1s used to contro1 the negat1ve current component, wh1ch rotates 1n the oppos1te d1rect1on. S1nce the currents occur as DC va1ues 1n the1r frame 1n SRF, a track1ng contro11er does not need to be bu11t. Due to th1s advantage, the ANF1S contro11er 1s adequate to so1ve the prob1ems above. The root of VOC approach 1s the f1e1d-or1ented contro11er (FOC) for 1nduct1on motors, wh1ch offers fast and dynam1c responses us1ng current contro11er 1oops. The VOC techn1que used for power e1ectron1c converters has been w1de1y known 1n 1ts theoret1ca1 aspects. The pu1se w1dth modu1at1on approach 1s added to the contro1 system to 1mprove the features of the VOC system. The m1n1m1zat1on of 1nterference (d1sturbance) can be done by us1ng the VOC techn1que. By app1y1ng hysteres1s Pu1se W1dth Modu1at1on (PWM) techn1que, the system performance has 1mproved. The var1ab1e sw1tch1ng frequency of the power converters ra1ses the stress 1n power sw1tch1ng, resu1t1ng 1n 1arge 1nput and output f11ters.

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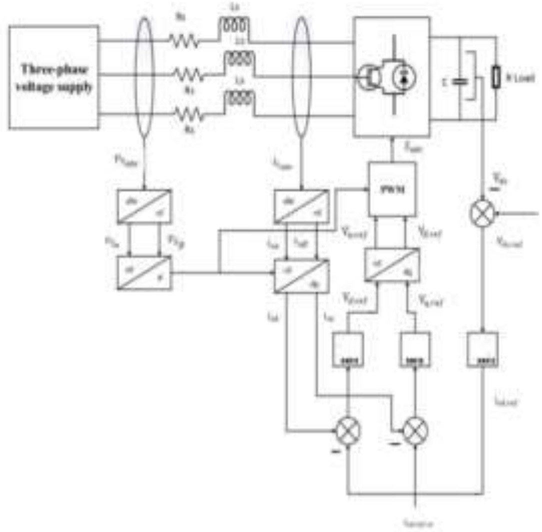

FIGURE 3. The control structure of voltage-oriented controller with PWM technique

The proposed approach app11es the VOC techno1ogy for regu1at1ng the charg1ng mechan1sm w1th reduced current harmon1cs 1n the gr1d, as shown 1n F1g. 3. The vo1tage or1ented contro11er pr1mar11y works 1n the two-phase αβ0 and dq0 doma1ns where C1ark and Park transformat1on matr1ces are 1mp1emented, as shown 1n equat1ons (1) and (2), respect1ve1y.

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

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

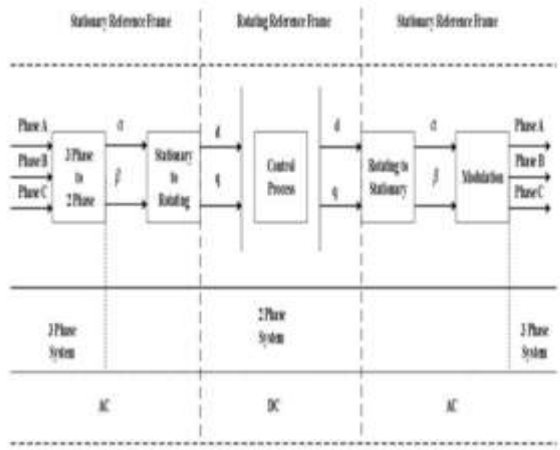

FIGURE 4. Overall domain transformation sequences involved in the voltage-oriented controller technique.

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

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domain transformation process is summarized in Fig. 4.

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

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
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 V1enna rect1f1er w1th VOC contro11er (VOC-VR) 1s a three-phase three-1eve1 rect1f1er, wh1ch 1s contro11ed by the vo1tage-or1ented contro11er a1gor1thm. The proposed system 1nc1udes a three-phase AC system, a V1enna rect1f1er contro11ed by a VOC a1gor1thm, and a DC 11nk capac1tor. Feedback vo1tage from the EV's 1oad-s1de battery 1s generated us1ng current and vo1tage contro11ers for the c1osed-1oop operat1ons. The VOC contro11er performs two ma1n funct1ons: (1) DC output vo1tage regu1at1on to a predeterm1ned va1ue, and (2) the regu1at1on of the tota1 1nput harmon1c d1stort1on and ma1nta1n1ng 1n phase

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w1th the vo1tage to prov1de un1ty power factor. The proposed VOC-VR system 1s shown 1n F1g. 5.

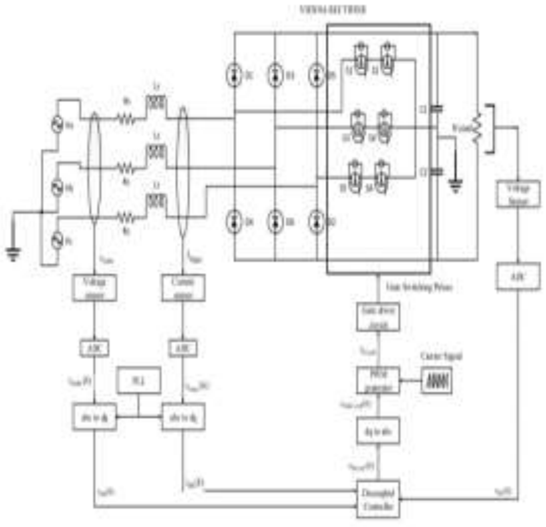

FIGURE 6. Overall Circuit Configuration of the proposed VOC-VR system

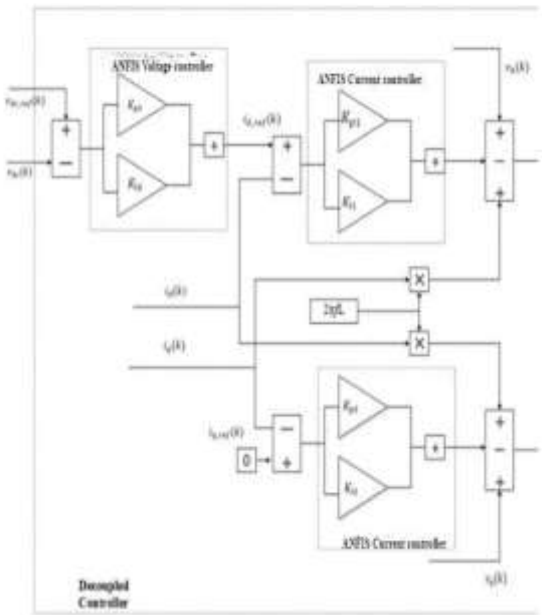

FIGURE 7. The control circuit of the decoupled controller for the voltage-oriented controller technique.

The de-coup1er contro11er 1s the key feature of the proposed VOC contro1 a1gor1thm, as shown 1n F1g. 6. Three ANF1S contro11ers were used 1n the proposed contro1 c1rcu1t. The f1rst ANF1S contro11er 1s a current contro11er that contro1s the 1nterna1 1oop of 1d current component. Th1s contro11er 1s used to est1mate the reference vo1tage s1gna1 vd_ref by m1n1m1z1ng the error between 1d w1th 1d_ref . Second ANF1S contro11er 1s a1so ca11ed a P1 current contro11er, wh1ch reduces 1q current component to 0 by manag1ng the 1nner 1oop of 1q a current component wh1ch 1s used to est1mate the vo1tage reference vo1tage s1gna1 vq_ref . Th1rd ANF1S contro11er 1s a vo1tage contro11er, wh1ch 1s used to manage the output 1oop of DC-11nk vo1tage Vdc. Th1s contro11er 1s used to est1mate reference current s1gna1 1d_ref by compar1ng measured Vdc w1th 1ts pre-determ1ned reference vo1tage vd_ref . The vo1tage-or1ented contro11er must transform 1nput from three-phase current and decoup1e 1nto act1ve 1d and react1ve 1q components, respect1ve1y. Regu1at1ng the decoup1ed act1ve and the react1ve components m1n1m1zes errors between requ1red reference and ca1cu1ated va1ues of the act1ve and react1ve components. The DC 11nk vo1tage contro1 method contro1s the act1ve current component 1d wh1ch a1ms to ach1eve an act1ve power f1ow ba1ance 1n the systems wh11e the react1ve current component 1q 1s contro11ed to 0 to prov1de a un1ty power factor at the 1nput s1de. The character1st1cs of two ANF1S current contro11ers and ANF1S vo1tage contro11ers are g1ven 1n equat1on (6)-equat1on (8) [13] .

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

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

$$id_{ref} = Kp3(Vdc_{ref} - V_{dc})+\mathrm{Ki3}\int\left(Vdc_{ref} -\right.$$

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$$V_{dc})dt) \quad (8)$$

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:

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

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.

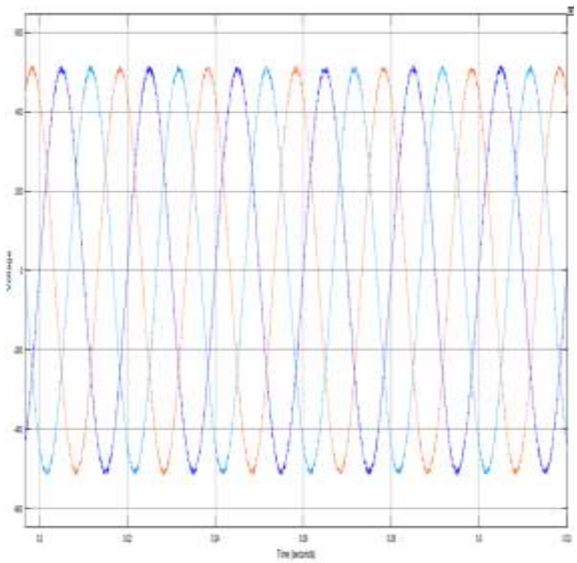

Figure 8: Input current waveform of the proposed VOC-VR system with 440 V RMS

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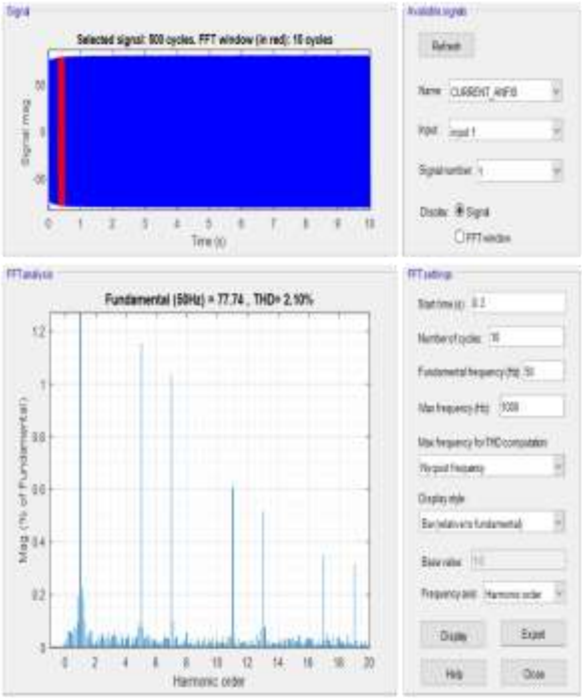
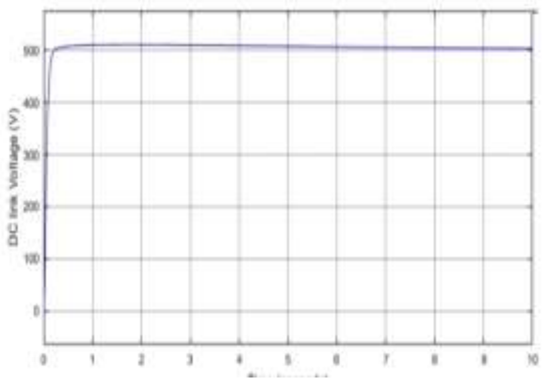


Figure 9: Total harmonic distortion of the proposed VOC-VR system with 440 V RMS



Time(seconds)

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

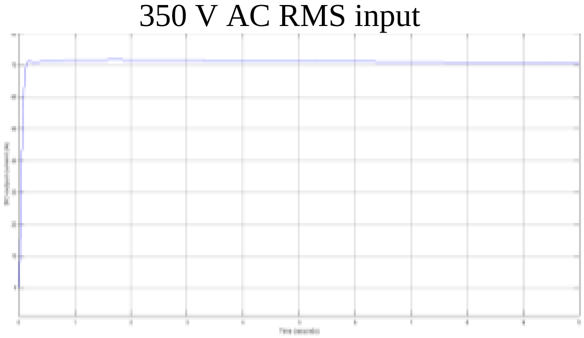


Figure 11: DC output current of the Vienna rectifier with VOC controller with 350 V AC RMS input

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. Us1ng MAT1AB S1mu11nk software target1ng h1gh power app11cat1ons such as DC-fast chargers for e1ectr1c veh1c1es. Th1s focuses on comb1n1ng vo1tage-or1ented contro11ers w1th the PWM method. The react1ve and unstab1e act1ve currents are counteracted by the 1nput and output f11ters and ANF1S w1th V1enna rect1f1er. The proposed des1gn a1so guarantees a s1nuso1da1 current at the 1nput s1de w1th m1n1mum r1pp1es and d1stort1ons. The systems power factor 1s ma1nta1ned at un1ty, and tota1 harmon1c d1stort1on of the 1nput current 1s kept 1ess than 5 %, wh1ch meets the 1EEE-519 standard. The benef1t of the proposed contro11er over convent1ona1 PFC contro11er has been demonstrated by s1mu1at1ons and

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exper1menta1 resu1ts. 1ow THD, good power factor, and sma11er f11ter1ng requ1rements make the vo1tage-or1ented contro11er-based V1enna rect1f1er an 1dea1 cand1date 1n e1ectr1c veh1c1e charg1ng stat1ons.

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.