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A Comparative analysis of various PWM Switching Techniques for Vienna Rectifier

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Abstract: In this paper, three phase Vienna rectifier (VR) topology with sinusoidal input currents and controlled output voltage has been derived with various PWM switching techniques. A comparative study of four different PWM switching techniques for the best performance of Vienna rectifier is presented here using simulink model. Sinusoidal PWM, Trapezoidal PWM, Space vector PWM and PWM using Hysteresis method are presented here. Vienna rectifier performance like Total Harmonics Distortion (THD) and Power factor (PF) along with various Load conditions and switching condition were observed. We have tried to suggest which PWM is better among them to improve performance of Vienna rectifier.

Keywords: Vienna Rectifier (VR), sinusoidal pulse width modulation (SPWM), space vector pulse width modulation (SVPWM), Total Harmonics Distortion (THD), Power factor (PF)

I. Introduction

Three level rectifiers have been paid much attention in the development of new energy generation due to its advantages such as high voltage class, high power factor and low switching loss. The Vienna rectifier is a unidirectional boost type improved power quality three level rectifier. The Vienna rectifier is the best choice for high-power applications because it helps to increase output voltage while reducing ripple and improving current efficiency. A major advantage of three levels characteristic is that for the selection of the blocking voltage capability of the power switch is only half of the peak value of the line-to-line voltage and not the total value is relevant. Due to lower switched voltage, a lower conducted EMI noise level results. Furthermore, due to higher number of levels the difference between fundamental neural current and ripple neural current remains limited to smaller value which results reduction in value of boost inductance requirement [5]. The comparison and evaluation of these some most popular converters are presented, analyzed, and compared in terms of conduction loss, switching loss, power density, power factor, and total harmonic distortion. Based on review, it has found that the Vienna rectifier is the best suitable converter topology for the high-power DC, for its low switching loss, low conduction loss and high-power density [2].

II. WORKING PRINCIPLE AND SCOPE OF VIENNA RECTIFIER

The operation and control of the Vienna rectifier is different from conventional two level active front end rectifiers. This rectifier has three level operation using three switches that lead to imbalance of DC voltage across the two output leads to imbalance of DC voltages across the two output capacitor. The most popular SPWM, SVPWM, third harmonics injection method and PWM using Hysteresis method has been implemented and analyzed for performance improvement of Vienna rectifier. The control of three active semiconductor devices ensures sinusoidal input current, desired output voltage and balance capacitor voltage. A Vienna rectifier consists of three switches and eighteen diodes. The schematic diagram of the Vienna rectifier is shown in Fig (1). The main components in the Three-level Vienna rectifier topology are three Boost inductors, three power bridge arms, and two DC side capacitors in series. Each power bridge arm consists of two
Reverse series switches and a power switch that allows two-way current flow.

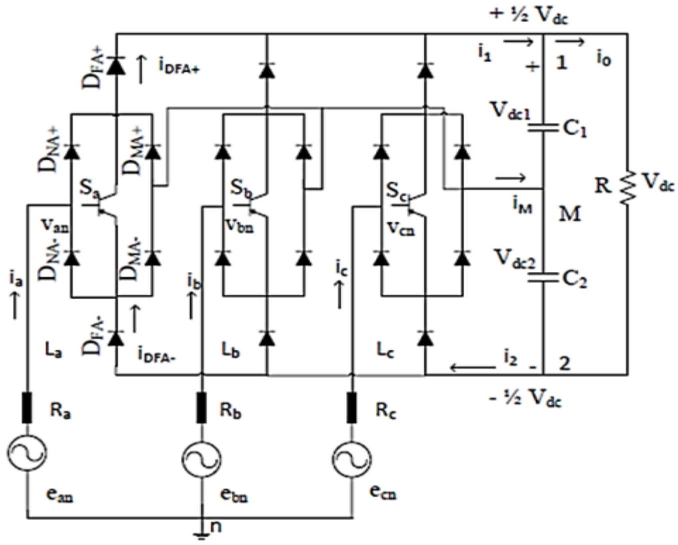

Fig. 1 A Schematic Diagram of Vienna Rectifier

The terminal voltage of Vienna rectifier depends on switching state as well as polarity of the input AC current. Three phase generation side voltages can be represented as;

$$e_{an} = e_m \sin(\omega t) \quad \ldots (i)$$
$$e_{an} = e_m \sin(\omega t + 120°) \quad \ldots (ii)$$
$$e_{an} = e_m \sin(\omega t - 120°) \quad \ldots (iii)$$

The terminal voltage of the rectifier depends upon on the switching states of switches and polarity of input currents. Terminal voltage as a function of current polarity and switching states can be expressed as

$$V_{an} = (V_{dc}/2)\ \mathit{Sign}\ (i_a)\ (1\text{-}S_a) \quad \ldots (iv)$$
$$V_{bn} = (V_{dc}/2)\ \mathit{Sign}\ (i_b)\ (1\text{-}S_b) \quad \ldots (v)$$
$$V_{cn} = (V_{dc}/2)\ \mathit{Sign}\ (i_c)\ (1\text{-}S_c) \quad \ldots (vi)$$

Where sign of phase current positive for positive cycle and Negative for Negative cycle. The switches S_a, S_b and S_c are switching states of the switches (S_a,S_b,S_c = 1 when switches are ON and S_a,S_b,S_c =0 when switches are OFF. It is clear that output DC may be ± $V_{dc}/2$ for any particular case. Moreover with comparison with other PFC like Front end converter SWISS rectifier the Vienna rectifier has been found more advantageous with following technical points. In the three-phase three-wire system, assuming the three-phase input voltage is balanced, the sum of the three-phase AC input current is 0, so there are six three-phase current states in the Vienna rectifier circuit, and their current waveform and polarity are shown in Figure 2

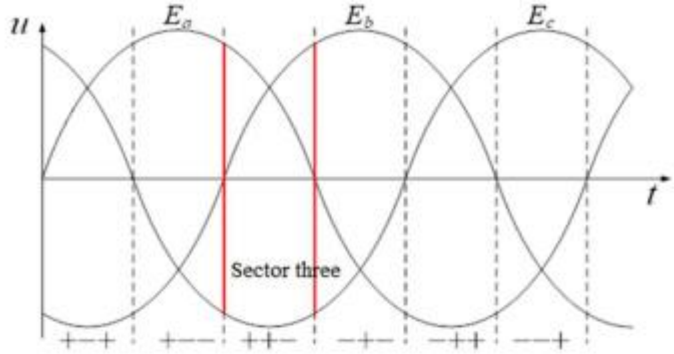

Fig 2 six divisions of three phase voltage interval each of 60°

Therefore, it can be divided into six sectors, each of which has an interval of 60°, and the current polarity is fixed within each sector. At a certain current polarity moment, φ = (- 30° , +30°), the three-phase bridge arm has different switching state combinations, so that the potential at the input end of the rectifier can be 0, $V_{dc/2}$, or $-V_{dc/2}$. Here, in Sector 3 with an interval of 120°~180° is selected as an example. The potential at the input end of the rectifier under 8 different switch combinations is shown in Table I

Table I : Output of each phase in all switching combinations in Vienna foe 120°~180°

Switch S_a	Switch S_b	Switch S_c	Output Phase A	Output Phase B	Output Phase C
0	0	0	$V_{dc/2}$	$V_{dc/2}$	$-V_{dc/2}$
0	0	1	$V_{dc/2}$	$V_{dc/2}$	0
0	1	0	$V_{dc/2}$	0	$-V_{dc/2}$

0	1	1	$V_{dc/2}$	0	0
1	0	0	0	$V_{dc/2}$	$-V_{dc/2}$
1	0	1	0	$V_{dc/2}$	0
1	1	0	0	0	$-V_{dc/2}$
1	1	1	0	0	0

Summarised all above discussion, following points shows significance for Vienna rectifier

- Less number of switches required in Vienna rectifier. As the number of switches is lower, switching frequency for PWM control is higher compare to front end. So required filter is less compare to front end. Power density improved.
- It is a three-level rectifier. A major advantage of the three-level characteristic is that for the selection of the blocking voltage capability of the transistor switch only half of the peak value of the line-to-line voltage. As a result of the lower switched voltage, a lower conducted EMI noise level is generated.
- Conduction losses are those voltage and current products that occur when a power switch or a rectifier is conducting current. This is duty-cycle dependent. Due to low number of switches, it can be used for high the switching frequency. Higher frequency operation leads lower conduction loss.
- Switching losses occur when the power switch or rectifier is transitioning between the ON state to the OFF state and vice versa. Among above rectifier's type, Vienna rectifier has minimum number of switches in circuit for operation. Due to this switching complexity is lower and we can go for higher switching frequency operation compare to other topologies. Higher frequency operation results in power density Secondly switch ratting is also half compare to other topology. It means higher ON state resistance of switch will going to increase switching loss compare to Vienna rectifier.

III. PWM TECHNIQUES

The ON and OFF periods of the switches are controlled by different PWM signals. The PWM signals are pulses with fixed frequency and magnitude and variable pulse width. These are generated by mainly two techniques, Triangle comparison based PWM and Space Vector based PWM. The width of the PWM pulses changes from pulse to pulse according to the modulating wave. The frequency of the carrier signal must be much higher than that of the modulating signal. Advantages of PWM Techniques:

- These are easy to implement and control.
- Reduction of lower order harmonics.
- Filtering requirements are minimized as only higher order harmonics are present.
- Hardware implementation is easy as it is compatible with today's digital microprocessor/controller

In this paper the following PWM techniques are presented and the performance of each technique is carried.

- Sinusoidal Pulse Width Modulation (SPWM).
- Space vector PWM (SVPWM) Techniques
- Third Harmonics injection method
- Hysteresis controlled PWM method.

A. Sinusoidal PMW (SPWM) Technique:

Sinusoidal PWM (SPWM) is a basic method of modulation in which the gate pulses are generated by comparing the reference signal having fundamental frequency $\omega_0 = 2\pi f_0$ with a fixed triangle wave having $\omega C = 2\pi fC$ as the carrier frequency. The three phase signal was created using three sinusoidal waves e_{an}, e_{bn}, and e_{cn} as per equation (i), (ii) ,(iii) in above, as a reference signal each shifted by 120 degrees and high frequency triangular carrier signal is compared with the reference signals to generate SPWM switching signals. The drawback of the modulation process is the fundamental output voltage is low.

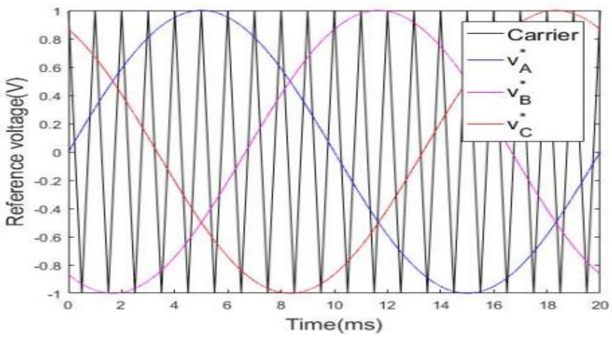

Fig. 3 SPWM waveform generation using triangular reference signal

The wave-forms in Fig 3 shows the reference voltages along with a carrier wave, having modulation index M as one. The range of M for SPWM is from zero to one, where values lesser than one is known as under-modulation and values exceeding one is called over-modulation. It must be emphasized that the value of modulation index is important as in under-modulation the output voltage would be reduced below the required level needed. On the other hand over modulation may cease the switching and the corresponding switch remain in ON state within this carrier time period, resulting in the saturation of the reference voltages. This saturation leads to reduction in the voltage gain, as the average reference voltage per carrier cycle cannot be matched with the converter

B. Space vector PWM (SVPWM) Techniques

From the analysis of structure showed in Fig. 1, seven available vectors are defined as shown in Table II. Non null vectors are represented by the potential of points A, B, and C, and the Null vector represents the situation where the three points are connected. In this notation, used for unidirectional converters, the available vectors representation does not agree with the switching states because the potentials of points A, B and C depend on the input currents direction. By the application of Clark transformation (1) space vector representation is made with a regular. Available vectors with output has been mentioned in below table II

Table II: Available vectors with output

Vector	Point A	Point B	Point C	V_{ab}	V_{bc}	V_{ca}
Vo (0 0 0)	M	M	M	0	0	0
V1 (1 0 0)	P	N	N	+V0	0	-V0
V2 (1 1 0)	P	P	N	0	+V0	-V0
V3 (0 1 0)	N	P	N	-V0	+V0	0
V4 (0 1 1)	N	P	P	-V0	0	+V0
V5 (0 0 1)	N	N	P	0	-V0	+V0
V6 (1 0 1)	P	N	P	+V0	-V0	0

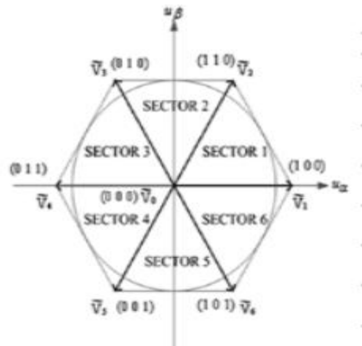

Fig 4: Space vectors coordinates

For the three phase SVPWM technique, there are eight switching states in which six are non-zero and two are zero switching states. The eight switching states correspond to eight stationary voltage vectors in space and these vectors divided it into six sectors. The advantages of this technique are efficient utilization of DC bus voltage, lower order harmonic distortion in the rectifier output.

C. PWM with third harmonic injection (THI)

The main disadvantage of SPWM is that the DC bus utilization is not optimal as compared to other modulation techniques available such as space vector modulation (SVPWM). The modulation index could be further increased to 1.15 from 1 by injecting a third harmonic sequence [2] [7]. There are different available techniques such as Min/Max, where the mean of maximum and minimum values of the voltages is subtracted from the corresponding waveform, thereby improving the voltage utilization of the DC side. The other way is by adding third harmonic signal (3ω0) having one-sixth of the fundamental magnitude, thereby increasing the modulation index to 1.15.

$$V_{a,b,c} = V_0 \sin(\omega t \pm \varphi) + \frac{V0}{6} \sin 3\omega t \qquad \ldots\ldots \text{(vii)}$$

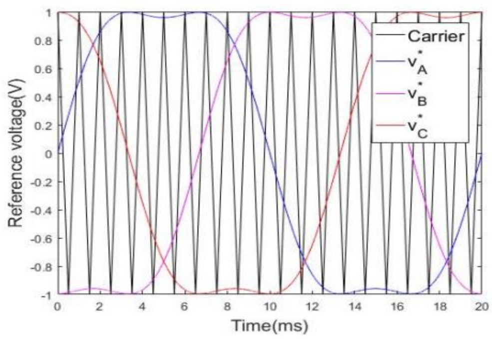

Fig. 5 THI waveform generation using triangular reference signal with modulation index 1.15

D. Hysteresis controlled PWM method

Hysteresis current control is a method of generating the required triggering pulses by comparing the error signal with that of hysteresis band and it is used for controlling the output of Vienna rectifier. This method controls the switches of Vienna rectifier asynchronously to ramp the current through the inductor up and down, so that it follows the reference current. Hysteresis current control is the easiest method to implement in real time.

IV. SIMULATION AND ANALYSIS

The MATLAB/ Simulink model data are presented here in different sections shows each of the four PWM methods for Vienna rectifier performance individually. The overall performance comparison is given in Table 1. The DC output of 200 V for 230 V 50 Hz input was taken for simulation. Various PWM techniques have been implemented with Vienna rectifier with different load conditions have been simulated. THD and PF have been measured for all four techniques. The performance of Vienna rectifier has been concluded by analysis of variation in THD and PF. MATLAB simulink model for various PWM techniques has been shown in Fig 6 to Fig 9

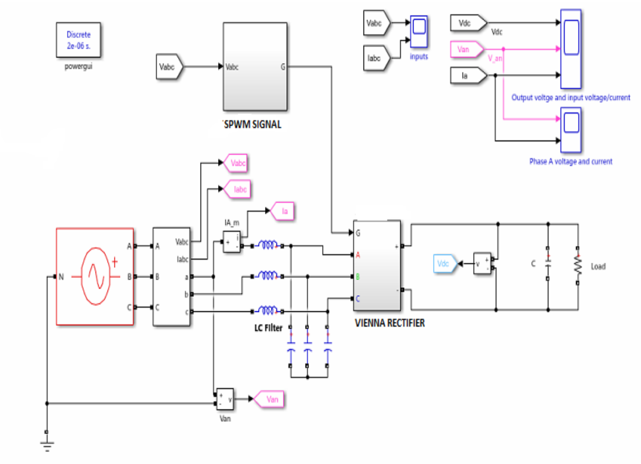

Fig. 6 MATLAB simulation with SPWM method

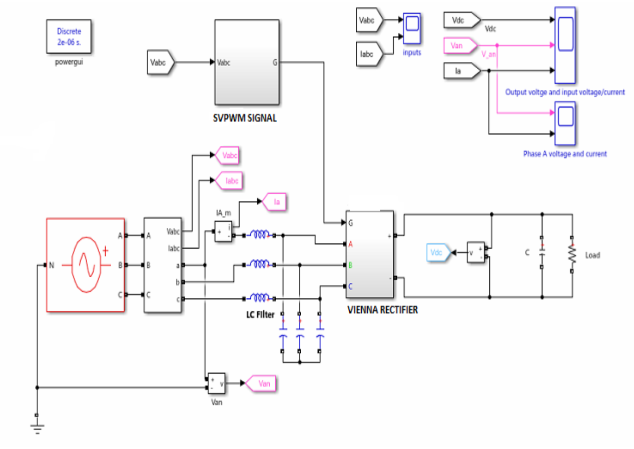

Fig. 7 MATLAB simulation with SVPWM method

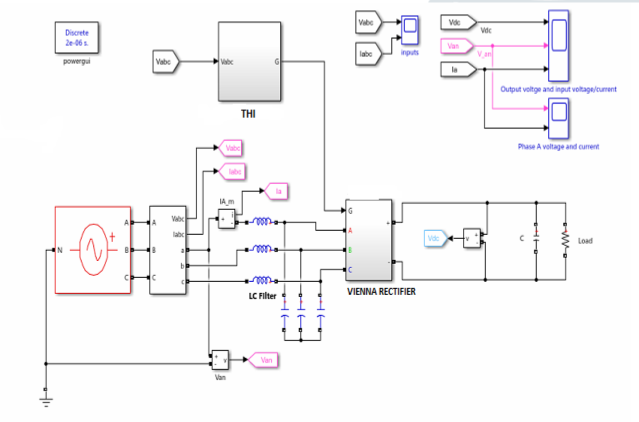

Fig. 8 MATLAB simulation with third harmonics injection method

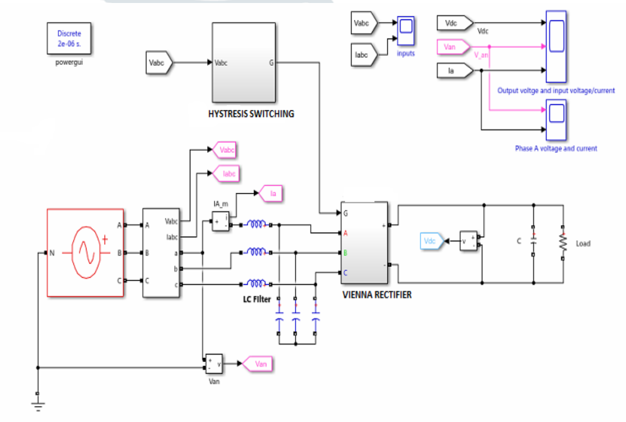

Fig. 9 MATLAB simulation with Hysteresis controlled PWM method

For 1 KW 200 V DC output specification of converter, the results obtained for THD with R=10 Ω have been simulated using MATLAB and results are summarized in following Fig 9 to Fig 12.

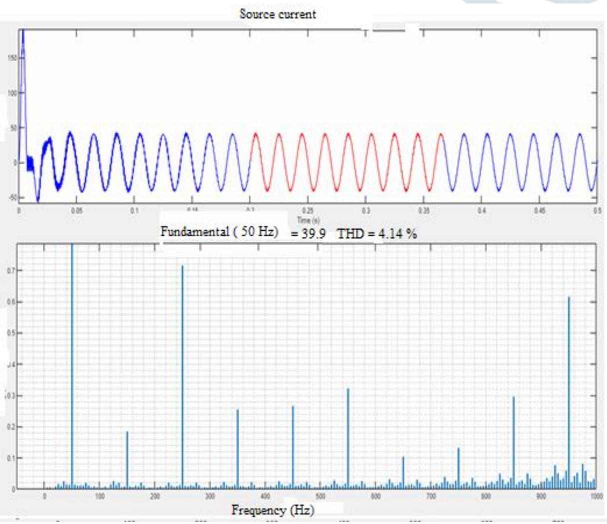

Fig. 10 MATLAB simulation results with SPWM method for THD Measurement

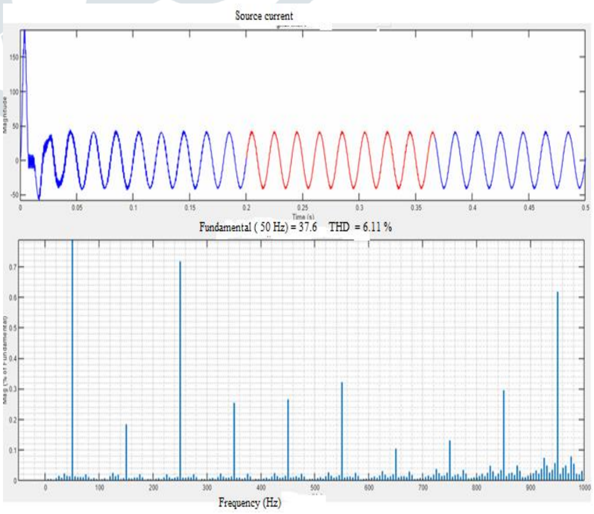

Fig. 11 MATLAB simulation Results with SVPWM method for THD measurement

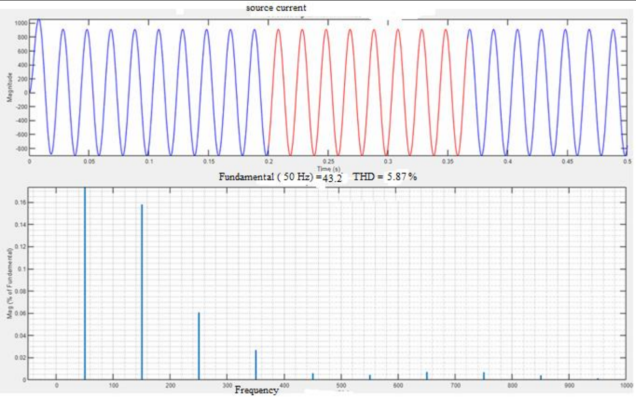

Fig. 12 MATLAB simulation Results with Third Harmonic injection method for THD Measurement

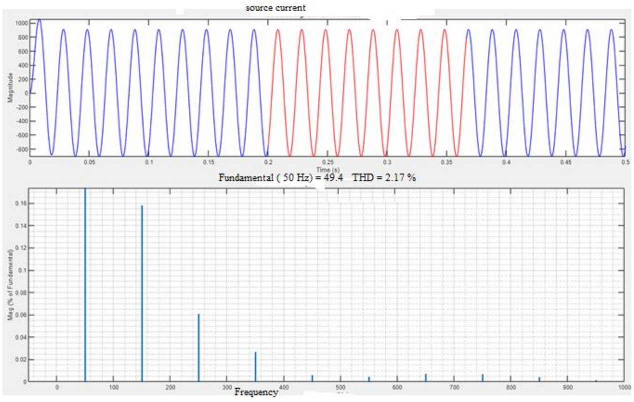

Fig. 13 MATLAB simulation Results with Hysteresis controlled PWM method for THD Measurement

The simulation of various switching techniques for Vienna rectifier with different load conditions has been performed and results for THD and PF have been summarized Table III.

Table -III : Summary of THD and PF results obtained with various PWM techniques with various load conditions

PWM >>	SPWM		SVPWM		THI		HYSTRESIS	
Parameters >>	THD	PF	THD	PF	THD	PF	THD	PF
Load R=10 Ω	4.14	0.9878	6.11	0.8884	5.87	0.9545	2.17	0.9978
Load R=10 Ω L= 1 µH	4.07	0.9845	6.09	0.8534	5.88	0.9545	2.34	0.9945
Load R=100 Ω L= 10 µH	4.14	0.9752	6.10	0.8574	5.98	0.9545	2.24	0.9952
Load R=10 Ω L= 100 mH	3.82	0.9654	5.78	0.8434	5.62	0.9545	2.25	0.9954
Load R=100 Ω L=500 mH	4.31	0.9865	6.30	0.8494	5.78	0.9545	2.24	0.9965

V. CONCLUSION

The Vienna rectifier having comparative advantages like low conduction loss, low switching loss and low power density compare to other three phase PFC which increases interest to focus on performance improvement of it by various switching methods. A comparative study and analysis of four different PWM switching have been implemented for Vienna rectifier. From Table III , it can be seen that the current THD value has been decreases significantly and improved power factor has been achieved with hysteresis switching method.

REFERENCES

[1] Lofty Beghou; Miteshkumar Popat; Steven MacDonald "PWM Control of 3-Phase PFC Vienna Rectifier Derived from an Average Current-based Control of Single-Phase PFC Boost Converter" IEEE, Oct-2021
[2] Jiarui Wang; Dawei Ding; Zhaobin Huang "SVPWM Strategy With Neutral Point Voltage Balance Capability for Electrolytic Capacitorless Vienna Rectifier ", IEEE international conference Nov 2022
[3] Jinping Wang; Shengzhi Ji; Shengyu Liu, "A Discontinuous PWM Strategy to Control Neutral Point Voltage for Vienna Rectifier With Improved PWM Sequence", IEEE , vol.10, pp. 3230-3241, 2022.
[2] Alencar F. de Souza, Dênis C. Pereira, Fernando L. Tofoli, "COMPARISON OF CONTROL TECHNIQUES USED IN POWER FACTORCORRECTION RECTIFIERS" IEEE conference , Nov-2020, vol 32.
[4] Ahmad Shukri Bin Abu Hasim,SyedMohd. Fairuz Syed Dardin, "Comparative Study; Different Types of PWMControl Scheme in Three-Phase Four-Wire ShuntActive Power Filter (APF) Topology", IEEE international conference on electrical engineering and computer science (ICECOS) 2018 pp 265 – 270.
[5] H. Zhang, C. d. Sun, Z. x. Li, J. Liu, H. y. Cao, and X.Zhang, "Voltage Vector Error Fault Diagnosis for Open-Circuit Faults of Three-Phase Four-Wire Active PowerFilters," IEEE Transactions on Power Electronics, vol.32, pp. 2215-2226, 2017.
[6] R. Reza Ahrabi,A. Ajami ,"Controlling of a three phase Vienna Rectifier underUtility Side Distortion Based on SlidingMode Controller " IEEE conference The 6th International Power Electronics Drive ystems and Technologies Conference (PEDSTC2015)3-4 February 2015, ShahidBeheshti University, Tehran, Iran
[7] June-Seok Lee, Student Member, IEEE, and Kyo-Beum Lee, Senior Member, IEEE "A Novel Carrier-Based PWM Method for ViennaRectifier with a

Variable Power Factor “IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS,2015page 1-10
[8] L. Hang, M. Zhang, B. Li, L. Huang, and S. Liu, “Space vectormodulation strategy for VIENNA rectifier and load unbalanced ability,”IET Power Electron., vol. 6, no. 7, pp. 1399-1405, Aug. 2013.
[9] L. Hang, M. Zhang, B. Li, L. Huang, and S. Liu, “Space vectormodulation strategy for VIENNA rectifier and load unbalanced ability,”IET Power Electron., vol. 6, no. 7, pp. 1399-1405, Aug. 2013
[10]] J. S. Lee and K. B. Lee, "An Open-Switch Fault Detection Method andTolerance Controls Based on SVM in a Grid-Connected T-TypeRectifier with Unity Power Factor," IEEE Trans. Ind. Electron., vol. 61,
[11] no. 12, pp. 7092-7104, Dec. 2014
[12] K. W. Park and K. B. Lee, "Hardware Simulator Development for a3-Parallel Grid-connected PMSG Wind Power System," J. PowerElectron., vol. 10, no. 5, pp. 555-562, Sept. 2010.
[13] H. W. Sim, J. S. Lee, and K. B. Lee, “On-line Parameter Estimation ofInterior Permanent Magnet Synchronous Motor using an ExtendedKalman Filter,” J. Elect. Eng. Technol., vol. 9, no. 2, pp. 600-608, Mar.2014.
[14] J. S. Lee and K. B. Lee, "Variable DC-Link Voltage Algorithm with aWide Range of MPPT for a Two-String PV System," Energies, vol. 6, no.1, pp. 58-78, Jan. 2013.
[15] R. Reza Ahrabi,A. Ajami ,”Controlling of a three phase Vienna Rectifier underUtility Side Distortion Based on SlidingMode Controller “ IEEE conference The 6th International Power Electronics Drive ystems and Technologies Conference (PEDSTC2015)3-4 February 2015, ShahidBeheshti University, Tehran, Iran
[16] June-Seok Lee, Student Member, IEEE, and Kyo-Beum Lee, Senior Member, IEEE “A Novel Carrier-Based PWM Method for ViennaRectifier with a Variable Power Factor “IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS,2015page 1-10
[17] L. Hang, M. Zhang, B. Li, L. Huang, and S. Liu, “Space vectormodulation strategy for VIENNA rectifier and load unbalanced ability,”IET Power Electron., vol. 6, no. 7, pp. 1399-1405, Aug. 2013.
[18] L. Hang, M. Zhang, B. Li, L. Huang, and S. Liu, “Space vectormodulation strategy for VIENNA rectifier and load unbalanced ability,”IET Power Electron., vol. 6, no. 7, pp. 1399-1405, Aug. 2013
[19]] J. S. Lee and K. B. Lee, "An Open-Switch Fault Detection Method andTolerance Controls Based on SVM in a Grid-Connected T-TypeRectifier with Unity Power Factor," IEEE Trans. Ind. Electron., vol. 61,
[20] no. 12, pp. 7092-7104, Dec. 2014
[21] K. W. Park and K. B. Lee, "Hardware Simulator Development for a3-Parallel Grid-connected PMSG Wind Power System," J. PowerElectron., vol. 10, no. 5, pp. 555-562, Sept. 2010.
[22] H. W. Sim, J. S. Lee, and K. B. Lee, “On-line Parameter Estimation ofInterior Permanent Magnet Synchronous Motor using an ExtendedKalman Filter,” J. Elect. Eng. Technol., vol. 9, no. 2, pp. 600-608, Mar.2014.
[23] J. S. Lee and K. B. Lee, "Variable DC-Link Voltage Algorithm with aWide Range of MPPT for a Two-String PV System," Energies, vol. 6, no.1, pp. 58-78, Jan. 2013.