Journal of Nano- and Electronic Physics
Vol. 17 No 5, 05024(5pp) (2025)

Журнал нано- та електронної фізики
Том 17 № 5, 05024(5cc) (2025)

REGULAR ARTICLE

Implementation of Three Phase Vienna Rectifier for DC Load Applications Using Multicarrier Pulse Width Modulation

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(Received 28 August 2025; revised manuscript received 15 October 2025; published online 30 October 2025)

The three-phase Vienna rectifier is a high-performance power conversion topology widely used in industrial and commercial applications due to its superior efficiency, power factor correction (PFC) capabilities, and reduced harmonic distortion. This paper presents the implementation of a three-phase Vienna rectifier tailored for DC load applications, utilizing Multicarrier Pulse Width Modulation (MCPWM) to achieve enhanced control and performance. The proposed system focuses on optimizing the operation of the Vienna rectifier through the strategic deployment of MCPWM, enabling precise switching control for effective power factor correction and reduced Total Harmonic Distortion (THD) in the input current. The design methodology, circuit configuration, and modulation strategy are discussed in detail, with a focus on achieving stable output DC voltage, low switching losses, and improved overall system efficiency. Simulation results validate the effectiveness of the proposed MCPWM-based Vienna rectifier in handling variable DC loads while maintaining high efficiency and power quality. The implementation offers a scalable and robust solution for applications in renewable energy systems, electric vehicle chargers, and industrial power supplies, providing a pathway for further exploration and development in advanced rectifier technologies.

Keywords: Three phase Vienna rectifier, Multicarrier Pulse Width Modulation, Total harmonic distortion, Power factor correction.

DOI: 10.21272/jnep.17(5).05024 PACS number: 84.30.Jc

1. INTRODUCTION

The increasing demand for energy-efficient and reliable power conversion systems has propelled advancements in rectifier technologies [1]. Among these, the three-phase Vienna rectifier has emerged as a promising topology due to its superior performance in power factor correction (PFC), reduced harmonic distortion, and high efficiency. Designed primarily for AC to DC conversion, the Vienna rectifier finds applications in renewable energy systems, electric vehicle (EV) charging stations, industrial power supplies, and telecommunications [2]. Its three-level configuration enables efficient power conversion while ensuring compliance with stringent power quality standards, making it a preferred choice for modern power electronic systems [3].

The Vienna rectifier is characterized by its ability to operate with reduced switching losses, lower component stress, and high-power density [4, 5]. The use of advanced modulation techniques, such as Multicarrier Pulse Width Modulation (MCPWM), further enhances its performance by providing precise control over switching devices. This ensures minimal Total Harmonic Distortion (THD) in the input current and stable DC output voltage, even under dynamic load conditions [6].

Over the years, extensive research has been conducted on the development and optimization of rectifier topologies, with particular emphasis on achieving high efficiency and power quality. This section reviews the key contributions in the field of Vienna rectifiers and the application of modulation techniques to improve their performance [7].

The Vienna rectifier, introduced by Johann W. Kolar in the 1990s, represents a milestone in three-phase PFC topologies. It features a three-level structure that minimizes voltage stress on semiconductor devices, enabling the use of lower-rated components [8]. Early studies highlighted the rectifier's potential for reducing THD in the input current while achieving near-unity power factor. Subsequent advancements focused on enhancing its efficiency and expanding its applicability to higher power ranges [9].

The rectifier's capability to operate with a high-power factor and low THD under varying load conditions. These findings paved the way for further exploration of control strategies and modulation techniques to improve its performance [10]. The modulation strategy plays a crucial role in determining the performance of Vienna rectifiers. Conventional Pulse Width Modulation (PWM) techniques, though effective, often result in higher switching losses and limited harmonic suppression [11]. To address these challenges, researchers have proposed advanced modulation schemes,

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Cite this article as: Palanisamy R et al., *J. Nano- Electron. Phys.* 17 No 5, 05024 (2025) https://doi.org/10.21272/jnep.17(5).05024

such as Space Vector Modulation (SVM) and Multicarrier Pulse Width Modulation (MCPWM) [12].

MCPWM has gained attention for its ability to provide enhanced harmonic suppression and precise control over switching transitions [13]. The use of MCPWM in three-phase rectifiers demonstrates significant improvements in THD reduction and system efficiency [14]. The optimized carrier signals and switching sequences, further improving the rectifier's performance. The Vienna rectifier's ability to deliver stable DC output with high efficiency makes it ideal for a variety of applications [15]. In renewable energy systems, it serves as an essential interface for integrating photovoltaic (PV) arrays and wind turbines with DC microgrids. Similarly, in EV charging stations, the rectifier's PFC capability ensures compliance with power quality standards while minimizing energy losses. Use of Vienna rectifiers in industrial power supplies, highlighting their ability to maintain stable operation under dynamic load conditions. More recently, investigated the application of MCPWM-based Vienna rectifiers in high-power data centers, emphasizing their scalability and robustness [16].

This paper focuses on the implementation of a three-phase Vienna rectifier using MCPWM for DC load applications. The proposed approach is designed to optimize efficiency, reliability, and power quality, making it suitable for a wide range of high-performance applications. Future research is expected to explore the combination of MCPWM with AI-based control strategies to further enhance the rectifier's performance. Additionally, the development of compact and cost-effective designs will be critical for expanding the adoption of Vienna rectifiers in emerging applications.

2. THREE PHASE VIENNA RECTIFIER

The Vienna Rectifier is a high-efficiency, three-phase, three-level power factor correction (PFC) rectifier. It was developed to address the need for compact and efficient AC-to-DC conversion systems with low harmonic distortion and high-power quality. Named after its origin at Vienna University of Technology, this rectifier topology is widely used in applications like industrial drives, renewable energy systems, and electric vehicle chargers. The key features are achieves reduced voltage stress on components and minimizes harmonic distortion, ensures nearly sinusoidal input currents and unity power factor. And minimal switching losses due to reduced switching frequency.

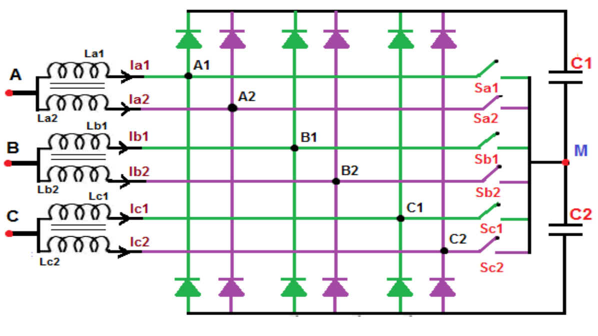

Fig. 1 – Power circuit of three phase Vienna rectifier

The Vienna Rectifier operates as a unidirectional three-level rectifier, converting three-phase AC input to a regulated DC output. Its topology typically includes a three-phase full-bridge rectifier at the input, switching devices are IGBTs that are used for modulation, achieves three voltage levels using clamping diodes, Input inductors and DC-link capacitors for current smoothing and energy storage. The working stages includes AC input currents are filtered by inductors to shape them into nearly sinusoidal waveforms and reduce electromagnetic interference (EMI). The input AC voltage is rectified by the diode bridge, and the output is modulated using the switching devices to regulate the DC-link voltage and control the input current shape. The clamping diodes balance the voltage across the DC-link capacitors, creating three voltage levels: positive, negative, and zero. This reduces voltage stress and enables better current shaping. By controlling the switching of the power devices, the rectifier ensures the input current is in phase with the input voltage, achieving high power factor and low total harmonic distortion (THD). The output of the Vienna Rectifier is a regulated DC voltage suitable for downstream applications like DC buses or battery charging systems.

The advantages of Vienna Rectifier include high efficiency with reduced conduction and switching losses, low harmonic distortion with meets stringent power quality standards like IEEE 519, compact design with fewer components compared to other three-level topologies, high power density with suitable for applications with limited space. It widely used three-phase AC-to-DC conversion topology designed for high efficiency and excellent power quality. It addresses the challenges of modern power electronics systems, such as meeting stringent harmonic distortion standards and achieving high power factor while operating at medium to high power levels. The Vienna Rectifier is now recognized as one of the most reliable and effective solutions for applications requiring regulated DC output from three-phase AC input.

3. MULTICARRIER PULSE WIDTH MODULATION

Multicarrier Pulse Width Modulation (MCPWM) is a widely used technique in power electronics for generating gating signals in various power converters. It involves the use of multiple carrier signals to compare with a reference signal, enabling the creation of multiple switching levels in the output waveform. This technique is critical in applications requiring high-power, low-harmonic distortion, and improved voltage control. MCPWM is especially useful in multilevel inverters, which are designed to generate stepped waveforms that closely approximate sinusoidal output, improving power quality and reducing stress on electrical components.

It includes carrier signals with multiple triangular or sawtooth waveforms that are used as carrier signals. The number of carriers depends on the levels of the power converter. And reference signal with typically a sinusoidal or desired waveform used to compare against the carriers. Comparison Process with each carrier signal is compared with the reference signal. When the reference signal exceeds a carrier signal, a gating signal is generated for the corresponding switch in the inverter. Switching and output levels with the generated gating signals control the switching devices in the inverter.

This results in an output waveform with multiple voltage levels, reducing harmonic content and closely approximating a sinusoidal waveform.

The output voltage of proposed system based on the applied input voltage and modulation index, which is defined as,

a. $V_{sin} < 0$ and $V_{sin} > V_{tag1}$ ⟶ S1 switched ON
b. $V_{sin} > 0$ and $V_{sin} < V_{tag2}$ ⟶ S2 switched ON
c. $V_{sin} > V_{tag4}$ ⟶ S4 switched ON and
$V_{sin} < V_{tag4}$ ⟶ S3 switched ON
d. $V_{sin} > V_{tag5}$ ⟶ S5 switched ON and
$V_{sin} < V_{tag4}$ ⟶ S6 switched ON
e. $V_{sin} > V_{tag6}$ ⟶ S7 switched ON
f. $V_{sin} > V_{tag3}$ ⟶ S8 switched ON

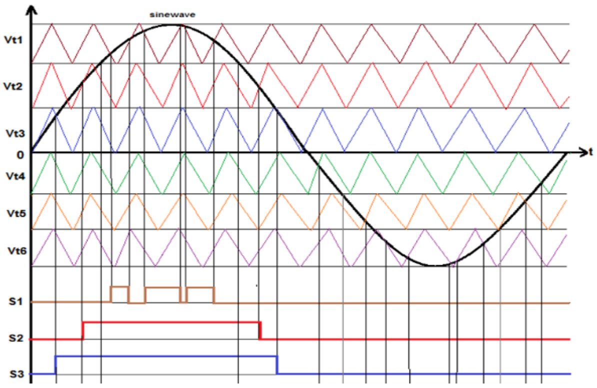

Fig. 2 – Representation of Multicarrier Pulse Width Modulation

4. SIMULATION RESULTS AND DISCUSSIONS

The implementation of a three-phase Vienna Rectifier for DC load applications using Multicarrier Pulse Width Modulation (MCPWM) involves designing a system in MATLAB Simulink with key components such as a three-phase AC source, diode bridge with clamping diodes, switching devices, DC-link capacitors, and a resistive or DC motor load. MCPWM is used to generate gating signals for the switches by comparing multiple carrier signals with a sinusoidal reference, enabling multilevel voltage control. The control system includes a PI controller for DC-link voltage regulation and a current control loop to ensure sinusoidal input currents and unity power factor. The simulation should focus on key metrics such as stable DC output voltage with minimal ripple, low total harmonic distortion (THD) in input currents, and high conversion efficiency. The results should demonstrate sinusoidal input waveforms, steady DC output under varying load conditions, and efficient switching transitions. FFT analysis can validate the power quality improvements, and the rectifier's robust performance under load changes confirms its suitability for high-power DC applications like renewable energy systems, industrial drives, and electric vehicle chargers.

The Switching pulses generation using multicarrier PWM shown in fig.3. DC Output voltage of Vienna rectifier is shown in fig.4, which is 580 V. The Voltage across the capacitors VC1 and VC2 is 290.5 and 289.5 respectively, which is shown in fig.5. Voltage across the power switches is shown in fig.6, which varies up to 290 V. The voltage across the inductor is shown in 7. The PI tuned voltage for pulse generation is shown in fig.8. The current through the DC load is shown fig.9, which is shown in fig.9. The current through three phase ac voltage is shown in fig.10.

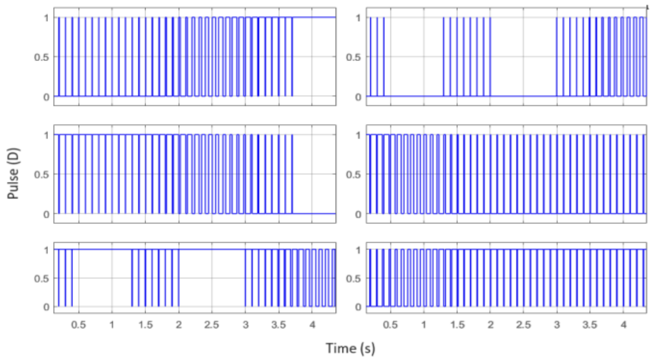

Fig. 3 – Switching pulses generation using multicarrier PWM

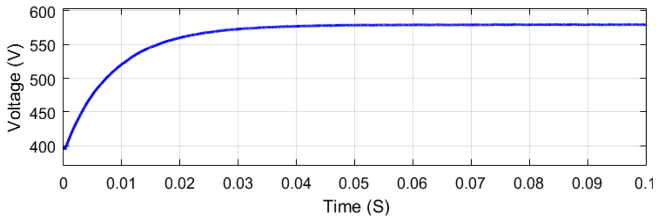

Fig. 4 – DC Output voltage of Vienna rectifier

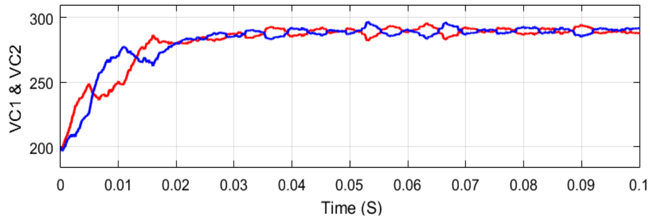

Fig. 5 – Voltage across the capacitors VC1 and VC2

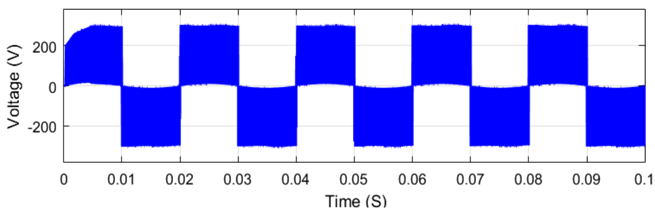

Fig. 6 – Voltage across the power switches

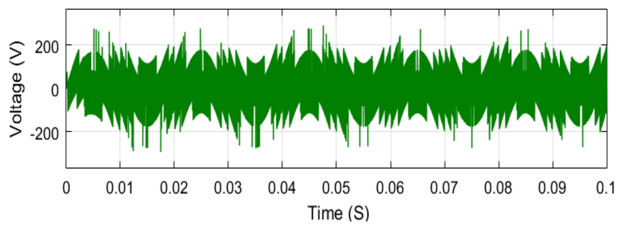

Fig. 7 – Voltage across the inductor L1

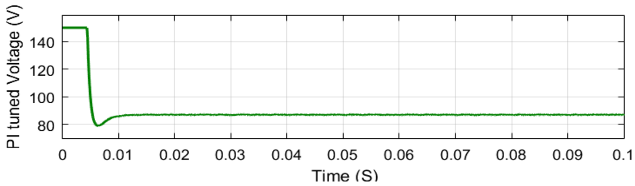

Fig. 8 – PI tuned voltage for pulse generation

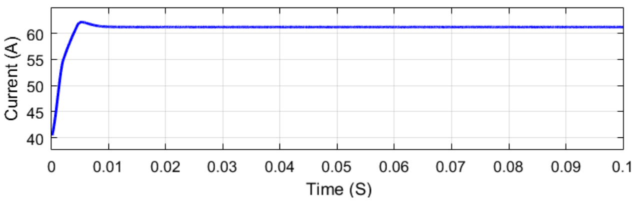

Fig. 9 – Current through the DC load

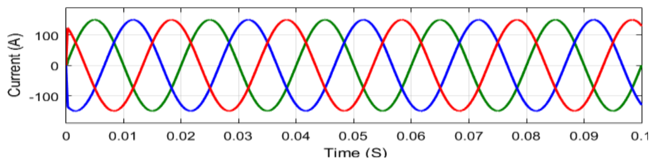

Fig. 10 – Current through three phase ac voltage

5. CONCLUSION

The implementation of the three-phase Vienna Rectifier using Multicarrier Pulse Width Modulation (MCPWM) for DC load applications provides a highly efficient and effective solution for AC to DC conversion. The system achieves improved power quality with reduced harmonic distortion, ensuring sinusoidal input currents and a regulated DC output voltage with minimal ripple. The use of MCPWM enhances the multilevel voltage control, leading to smoother switching transitions and higher efficiency. The simulation results validate the rectifier's stable performance under varying load conditions and its compliance with power quality standards, making it suitable for applications such as industrial drives, renewable energy systems, and electric vehicle chargers. The Vienna Rectifier, with MCPWM, proves to be a reliable and scalable solution for high-power DC applications, offering both efficiency and robustness in practical scenarios.

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Реалізація трифазного Віденського випрямляча для застосувань постійного навантаження з використанням багатоканальної широтно-імпульсної модуляції

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Трифазний віденський випрямляч – це високопродуктивна топологія перетворення енергії, яка широко використовується в промислових та комерційних застосуваннях завдяки своїй високій ефективності, можливостям корекції коефіцієнта потужності (PFC) та зниженим гармонійним спотворенням. У цій статті представлено реалізацію трифазного віденського випрямляча, адаптованого для застосувань постійного навантаження, з використанням багатоканальної широтно-імпульсної модуляції (MCPWM) для досягнення покращеного керування та продуктивності. Запропонована система зосереджена на оптимізації роботи віденського випрямляча шляхом стратегічного розгортання MCPWM, що забезпечує точне керування комутацією для ефективної корекції коефіцієнта потужності та зниження загального гармонійного спотворення (THD) у вхідному струмі. Детально обговорюються методологія проектування, конфігурація схеми та стратегія модуляції, з акцентом на досягнення стабільної вихідної напруги постійного струму, низьких втрат на комутацію та покращення загальної ефективності системи. Результати моделювання підтверджують ефективність запропонованого віденського випрямляча на основі MCPWM у обробці змінних навантажень постійного струму, зберігаючи при цьому високу ефективність та якість електроенергії. Реалізація пропонує масштабоване та надійне рішення для застосувань у системах відновлюваної енергії, зарядних пристроях для електромобілів та промислових джерелах живлення, що забезпечує шлях для подальшого дослідження та розвитку передових технологій випрямлячів.

Ключові слова: Трифазний віденський випрямляч, Широтно-імпульсна модуляція, Повне гармонійне спотворення, Корекція коефіцієнта потужності.