Comprehensive Analysis of Vienna Rectifiers for Renewable Resources

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Abstract. The issue of energy has emerged as a significant subject of concern in contemporary discourse. The significance of the advancement of novel energy sources is progressively growing. Relevant strategies should aid in the advancement of power electronics. The rectifier is a commonly used electronic component that finds application in many circuits involving electronic equipment. Its primary function is to convert alternating current into direct current, which is then supplied to the load. The Vienna rectifier is a widely used rectifier that has garnered significant attention and scrutiny from professionals in the field of power electronics on a global scale. This article begins by illustrating the use of power electronics technology, specifically focusing on the charging pile circuit. It proceeds to discuss the classification and current research status of rectifiers. Subsequently, the article provides an overview of the circuit layout and operational principles of the Vienna rectifier circuit. This section provides an overview of the approaches and features used to optimize the operating performance of Vienna rectifiers in four key areas: current control, voltage control, neutral point voltage balance management, and harmonic stability control. This research will ultimately provide a forecast about the future development trend of Vienna rectifiers, together with a comprehensive overview of all improvement attempts.

Keywords: Vienna rectifier, topological structure, circuit principle, basic control.

1. Introduction

In contemporary times, the global discourse has increasingly focused on the issues of energy scarcity and environmental preservation. To address the challenges posed by the depletion of fossil fuels and ecological degradation, there is an ongoing effort by humans to explore and create alternative energy sources that can cater to future and unanticipated energy demands [1]. To realize the strategic objectives outlined in 2020, which aim to achieve carbon peaking by 2030 and carbon neutrality by 2060, China has initiated the process of industrial transformation and upgrading of existing sectors, with a particular focus on new energy sources [2].

At present, new electrical engineering technologies represented by power electronics technology play an irreplaceable role in the production of various fields of society. In light of the emerging new energy revolution, an increasing number of industrial sectors are necessitating the incorporation of power electronics technology in electrical components. This integration aims to achieve many objectives, including the reduction of industrial prices, the facilitation of industrial upgrading, and the enhancement of production efficiency and convenience [3]. The use and implementation of power electronics technology have been seen in several domains. The power system serves as an illustrative case for examining power transmission technologies, namely the use of power electronics. In particular, two prominent technologies in this domain are flexible AC transmission technology (FACTS) and high voltage direct current transmission technology (HVDC). Furthermore, power electronics technology may increase the working efficiency of circuits used in agricultural production, home appliances, power distribution systems, and so on, and the circuit system can operate for an extended period of time [3, 4].

The rectifier has an unbreakable connection to the ongoing development of power electronics technology. The research issue of enhancing the functionalities and performance of power electronic components has been a subject of considerable attention since beginning of the first batch of these components. The rectifier's primary function of converting alternating current to direct current makes

it commonly utilized. The primary function of the rectifier is to convert alternating current towards direct current, rendering it extensively used.

The rectification circuit module of the new energy charging pile consists of an AC/DC rectifier and a DC/DC converter, as can be seen in Figure 1. In this circuit diagram, the rectifier converts the AC input from the AC grid to DC, and the converter linked in series with the rectifier filters and conducts additional processes before converting it to the DC needed by the new energy vehicle. Meanwhile, the converter must employ a rear-stage half-bridge three-level LLC circuit resonant converter to stabilize the resonant waveform and guarantee the DC current in the circuit is stable [5,6].

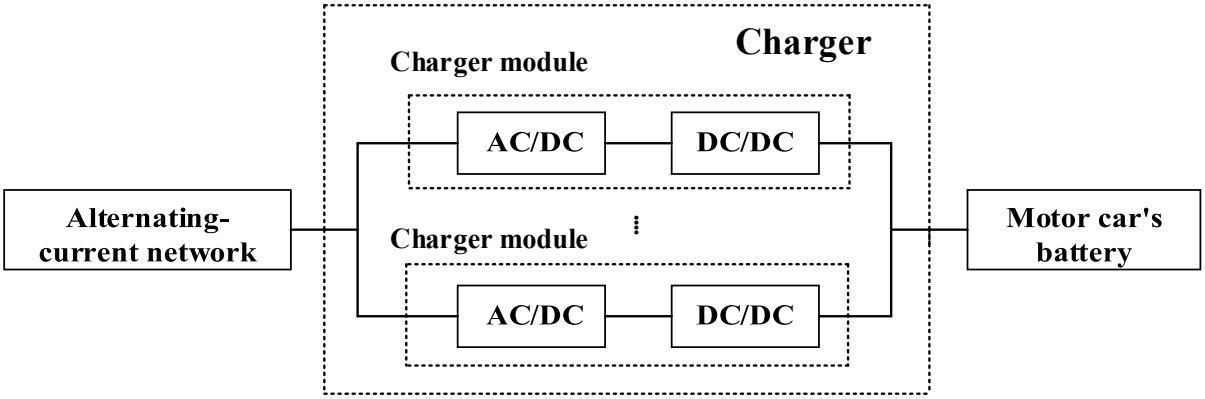


Fig. 1 Circuit diagram of charging piles [6].

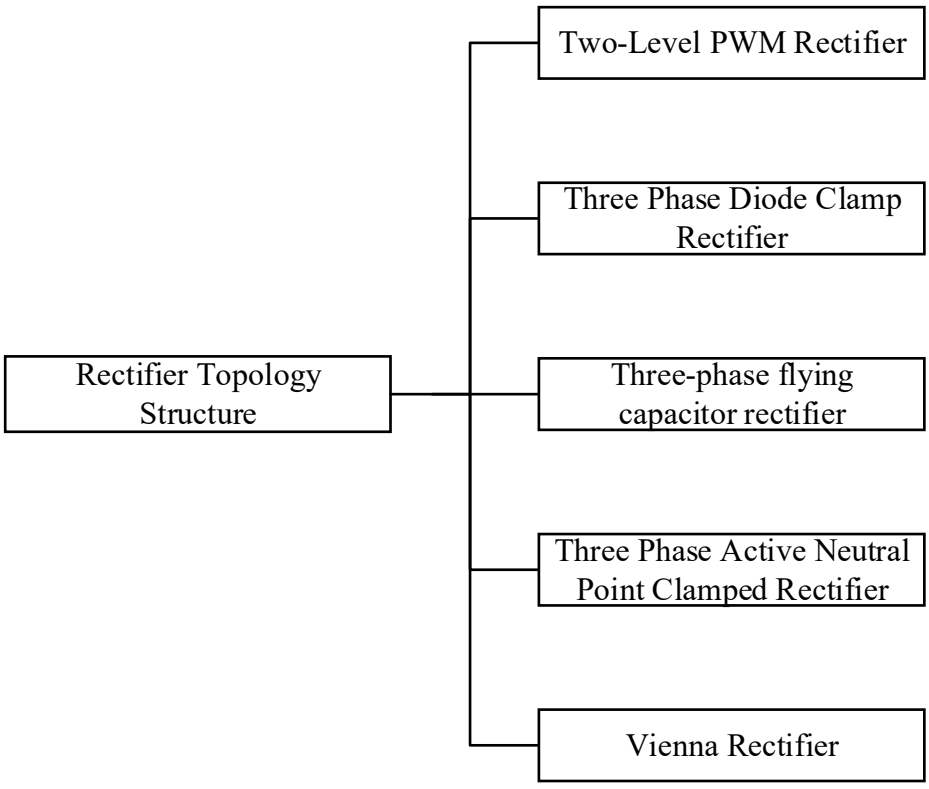


Fig. 2 Classifications of rectifiers (Photo/Picture credit: Original).

Figure 2 illustrates the categorization of rectifiers based on their circuit design and topology. Basically, the rectifier's topology may be loosely classified into five kinds. The three-phase two-level PWM rectifier, being a conventional rectifier, is capable of meeting the fundamental circuit requirements. Nevertheless, the rectifier was eventually replaced by other rectifiers due to the cost escalation resulting from an excessive number of fully-controlled switching tube components and the challenge of establishing a suitable dead time to prevent damage caused by high withstand voltage [6]. In the enhanced configuration of the three-phase three-level rectifier, it can be observed that although the maximum voltage of the three-phase diode-clamped rectifier is reduced by half

compared to the two-level rectifier, the circuit cost remains elevated and an issue of imbalanced midway voltage persists. Subsequently, researchers expressed a desire to use capacitors in lieu of diodes for the purpose of constructing three-phase flying capacitor rectifiers, or alternatively, to utilize more extensively-controlled switches for the building of three-phase active neutral-point clamped rectifiers. However, the issue of expensive expenses remained unresolved. The Vienna rectifier, which was introduced in 1994, has played a pivotal role in the advancement of rectifier technology. The rectifiers have been commonly used due to their straightforward circuit layout and the advantageous feature of not requiring consideration of dead zone voltage issues. This has resulted in a notable reduction in rectifier costs and a substantial enhancement in work efficiency [6].

The present paper will first provide the circuit idea and topology of the Vienna rectifier. Subsequently, a comprehensive examination of the relevant literature pertaining to the enhancement of operational efficiency in Vienna rectifiers is undertaken, including four key aspects: current regulation, direct current voltage regulation, neutral point voltage equilibrium, and harmonic stability regulation. In conclusion, this article provides a concise assessment and articulates the anticipated advancements in rectifier-related technology.

2. Fundamentals of Vienna Rectifier

The Vienna rectifier is made up of three input filter inductors (L_a, L_b, and L_c), three pairs of power bridge arms, and two sets of output capacitors (C_1, C_2). Each set of power bridge arms consists of two rectifier diodes and two switch tubes, which are linked in series with the same source with a reverse position. Among these are grid side voltages (e_a, e_b, and e_c), grid side input currents (i_a, i_b, and i_c), grid side resistance (R), DC side load (R_L), L_a=L_b=L_c, and C_1=C_2[7-8]. Figure 3 demonstrates the topological structure:

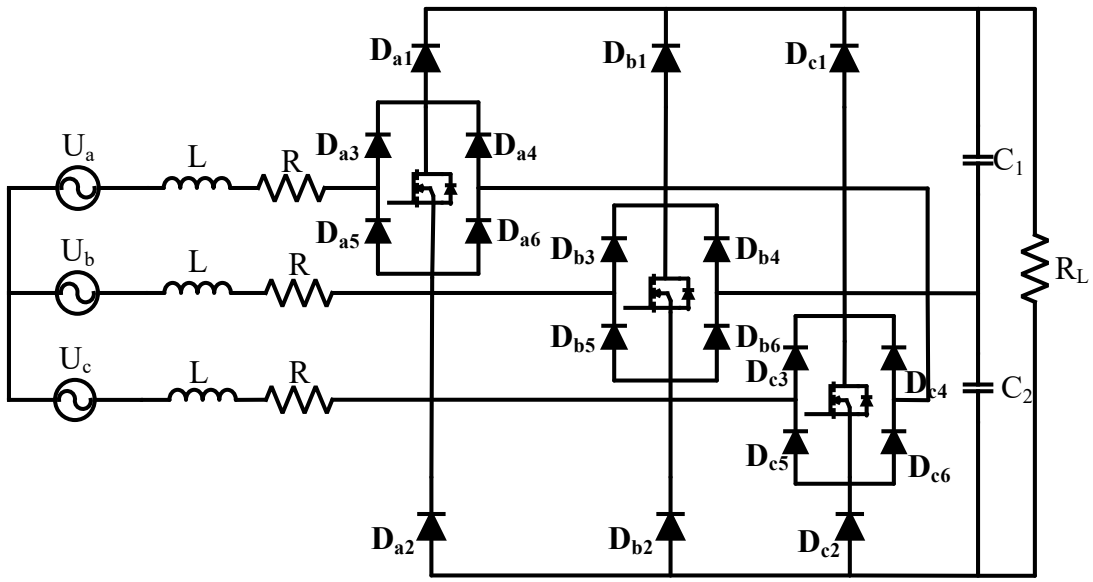


Fig. 3 Topology of Vienna rectifier [7].

2.1. Operation Principle of Vienna rectifier

The functioning strategy of the Vienna rectifier is depending on the input current polarity and the state of the switch tube, as discerned from the circuit structures. The single-phase Vienna rectifier circuit, which serves as an example in the context of single-phase power circuits, contains four distinct current operating modes, as clearly shown in Figure 4.

When the switch tube is activated and the current input is in the positive direction, the state shown in Figure 4(a) will manifest. Conversely, when the switch tube is activated and the current input is in the negative direction, the condition depicted in Figure 4(b) will manifest.

When the switch tube is deactivated and the current input is oriented positively, the condition shown in Figure 4(c) will manifest. Conversely, when the switch tube is deactivated and the current input is oriented negatively, the state depicted in Figure 4(d) will manifest.

The functioning condition of the three-phase Vienna rectifier circuit may be inferred from the working principle of the single-phase Vienna rectifier circuit. The Vienna rectifier has a topological configuration with three pairs of power bridge arms. Consequently, the rectifier circuit, in conjunction with the state of the switching tube, may generate a total of eight distinct switching states. Furthermore, the direction of current flow varies across each of these states [7-8].

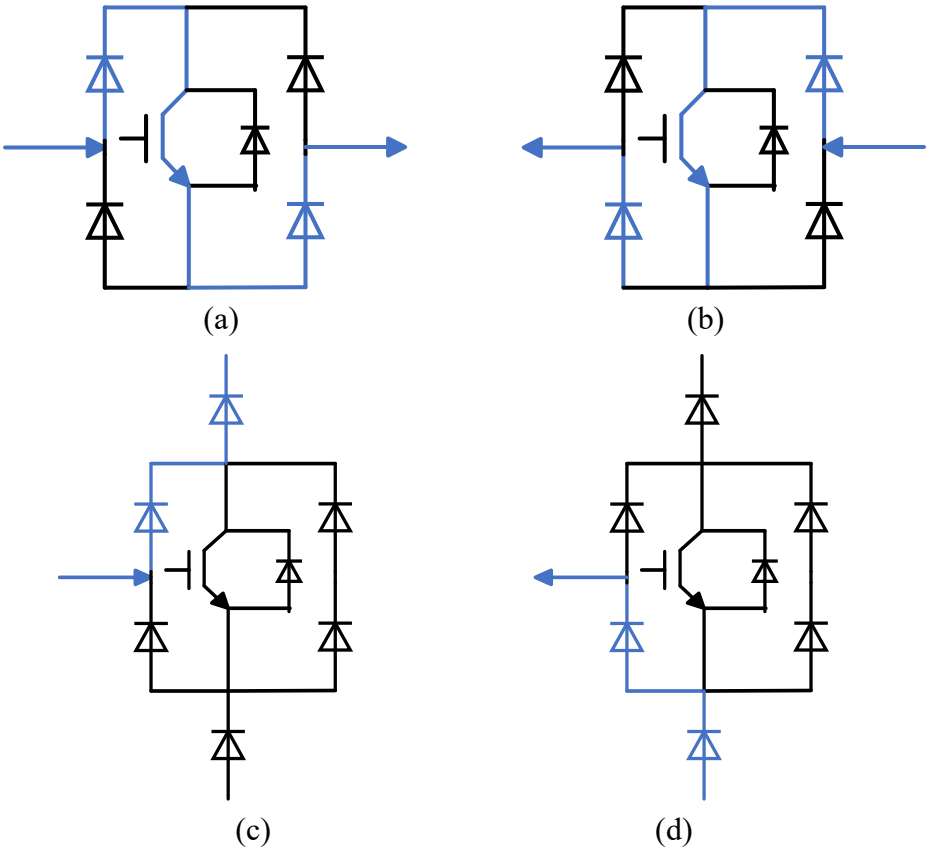


Fig. 4 Current working state of Vienna rectifier topology [8]. (a) The current is positive when the switch is on. (b) The current is negative when the switch is on. (c) The current is positive when the switch is off. (d) The current is negative when the switch is off.

2.2. Mathematical Model of Vienna Rectifier

Upon conducting an examination of the operational mechanism of the Vienna rectifier circuit, it has been found that the three distinct topological configurations of the Vienna rectifier circuit display three possible states, namely -Udc/2, 0, and +Udc/2. According to the article [8], it has been observed that these three possible states may be categorized into three distinct switch function groups. The article [8] utilized the fundamental principles of circuit operation to apply the Kirchhoff's Current Law (KCL) to the capacitor module and the Kirchhoff's Voltage Law (KVL) to the inductance module. By incorporating the three potential state functions, the authors derived the mathematical model of the Vienna rectifier. Subsequently, they employed the Clark equal-amplitude value transformation and Park transformation to obtain homogeneous models.

The mathematical model of Vienna rectifier is expressed as [8],

$$\begin{cases} L_a\dfrac{di_a}{dt}=e_a-Ri_a-[S_{ap}-\dfrac{1}{3}(S_{ap}+S_{bp}+S_{cp})-S_{an}+\dfrac{1}{3}(S_{an}+S_{bn}+S_{cn})]\dfrac{U_{dc}}{2} \\ L_b\dfrac{di_b}{dt}=e_b-Ri_b-[S_{bp}-\dfrac{1}{3}(S_{ap}+S_{bp}+S_{cp})-S_{an}+\dfrac{1}{3}(S_{an}+S_{bn}+S_{cn})]\dfrac{U_{dc}}{2} \\ L_c\dfrac{di_c}{dt}=e_c-Ri_c-[S_{cp}-\dfrac{1}{3}(S_{ap}+S_{bp}+S_{cp})-S_{an}+\dfrac{1}{3}(S_{an}+S_{bn}+S_{cn})]\dfrac{U_{dc}}{2} \\ C_1\dfrac{dU_{dc1}}{dt}=-\dfrac{U_{dc}}{R_L}+S_{ap}i_a+S_{bp}i_b+S_{cp}i_c \\ C_2\dfrac{dU_{dc2}}{dt}=-\dfrac{U_{dc}}{R_L}-(S_{ap}i_a+S_{bp}i_b+S_{cp}i_c) \end{cases} \tag{1}$$

The potential state is referred to S_k (where k might take the values of a, b, or c), and the switching potential S_k is defined by three switching functions: S_{kp}, S_{k0}, and S_{kn}.

Mathematical model obtained by Clark's equal-magnitude transformation:

$$\begin{cases} L\dfrac{di_\alpha}{dt}=e_\alpha-Ri_\alpha-(S_{\alpha p}-S_{\alpha n})\dfrac{U_{dc}}{2} \\ L\dfrac{di_\beta}{dt}=e_\beta-Ri_\beta-(S_{\beta p}-S_{\beta n})\dfrac{U_{dc}}{2} \\ C_1\dfrac{dU_{dc1}}{dt}=-\dfrac{U_{dc}}{R_L}+S_{\alpha p}i_\alpha+S_{\beta p}i_\beta \\ C_2\dfrac{dU_{dc2}}{dt}=-\dfrac{U_{dc}}{R_L}-(S_{\alpha n}i_\alpha+S_{\beta n}i_\beta) \end{cases} \tag{2}$$

Following the application of the Clark transformation, the voltage on the grid side is represented as e_α and e_β, while the input current is denoted as i_α and i_β.

The mathematical model obtained by the park transformation:

$$\begin{cases} L\dfrac{di_d}{dt}=e_d-Ri_d+\omega Li_q-(S_{dp}-S_{dn})\dfrac{U_{dc}}{2} \\ L\dfrac{di_q}{dt}=e_q-Ri_q-\omega Li_d-(S_{qp}-S_{qn})\dfrac{U_{dc}}{2} \\ C_1\dfrac{dU_{dc1}}{dt}=-\dfrac{U_{dc}}{R_L}+S_{dp}i_d+S_{qp}i_q \\ C_2\dfrac{dU_{dc2}}{dt}=-\dfrac{U_{dc}}{R_L}-(S_{dn}i_d+S_{qn}i_q) \end{cases} \tag{3}$$

Similarly, after the application of the park transformation, the KVL (Kirchhoff's Voltage Law) inductance equation may be used to determine the voltage induced by jωL. Simultaneously, the voltage and current notations are updated to utilize the subscripts d and q.

2.3. Basic Control for Vienna Rectifier

The Vienna rectifier receives three-phase voltage and three-phase current from the power grid and carries out fundamental control operations on the circuit. The output of the voltage outer loop serves as the reference value for the current inner loop, which subsequently controls the amplitude of the input current. To perform power factor adjustment, this amplitude is in phase with the input voltage [7]. Figure 5 depicts the control block diagram depicted in Reference [7]. The control block diagram illustrates that the grid-side three-phase voltage and current inputs acquire a phase angle through phase-locking. Following the implementation of the double-loop decoupling method, the park

transformation is applied to obtain the desired voltage vector. Ultimately, the SVPWM control technique is employed to generate three PWM drives, enabling the fundamental control of the Vienna rectifier system. The block diagram consists of three AC voltage sources, denoted as e_{abc}, which represent the topology. The input current is represented by i_{abc}, while the currents after park transformation are i_q and i_d. Similarly, the voltages after park transformation are ed and eq. The voltages subscripted as ref indicate voltage reference values, while dc refers to the DC output. The converted output voltage, denoted as V_{gs}, represents the voltage that has been transformed or modified.

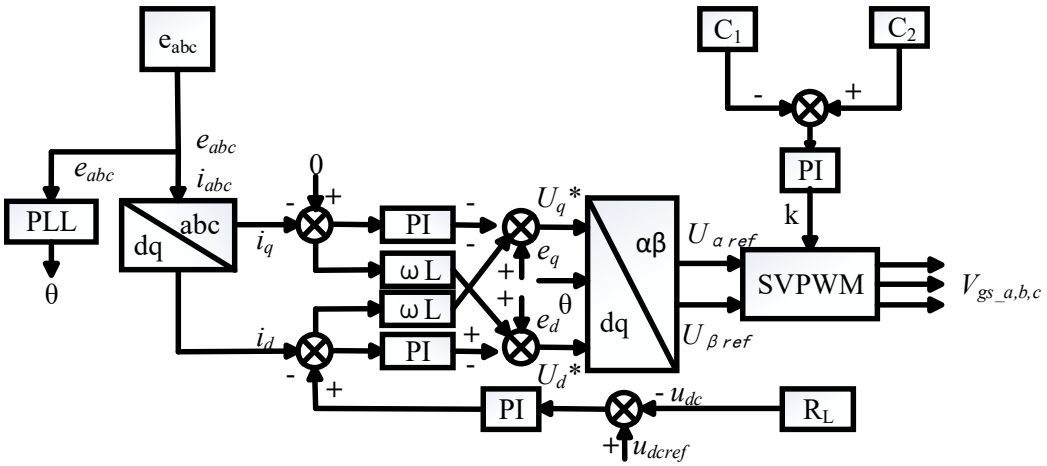


Fig. 5 Basic control scheme of Vienna rectifier [7].

3. Advanced Control Strategy for Vienna Rectifier

Despite the inherent simplicity of the circuit configuration of the Vienna rectifier, the practical implementation of this rectifier gives rise to a variety of challenges. The investigation and improvement of difficulties related to stabilizing the output of current and voltage, the instability of the midway voltage in relation to the circuit's condition, and the harmonic pollution induced by the rectifier on the grid current are all areas of concern [9]. Numerous scientists have put forward ways for enhancing the performance of the Vienna rectifier circuit in order to address these issues.

3.1. Current Control

The fundamental regulation of the Vienna rectifier is inherently linked to the current. Therefore, ensuring a smooth current output in the rectifier circuit is crucial for maintaining stable power quality, achieving high power output, and ensuring the circuit's waveform stability [9].

3.1.1 PI controller-based control strategy for current decoupling

According to the research [9], the current control strategy mentioned is widely recognized as one of the prevailing approaches in current control strategies. It has been extensively used across several domains and is considered to have reached a level of technological advancement. The voltage and current of the Vienna rectifier components may be appropriately converted to regulate the active component and reactive power, therefore enabling the attainment of unity power factor operation. Nevertheless, this technique is plagued by issues like as extensive computational requirements and subpar dynamic responsiveness.

3.1.2 Current control strategy based on PR controllers

According to the research [9], it has been observed that the use of proportional resonance technology in the PR controller enables the tracking of sinusoidal quantities without discrimination. However, a notable issue arises in the form of unstable resonance waveforms. Given these circumstances, it is essential to continue examining the concept of harmonic stability regulation. The prospective expenses associated with the implementation of this technique result in an elevated circuit design cost.

3.1.3 Traditional hysteresis current control strategy

The conventional hysteresis control strategy in circuit control is characterized by its simplicity, low cost, strong robustness, and satisfactory performance even under sudden load changes. However, it is worth noting that the filter waveform may become unstable due to frequency instability, leading to a decline in the quality of the circuit's output effect [9].

3.1.4 Model prediction strategy

The use of model predictive control in Vienna rectifier systems enables the efficient identification of optimum strategies for addressing actual issues. Consequently, this control method has a broad scope of applicability. However, it is important to note that the successful implementation of this approach necessitates adherence to stringent restrictions regarding switching frequency sampling [9].

In addition to the mentioned four prevalent ways for enhancing current control, some academics have put forward novel approaches. A model-free predictive current control (MFPCC) approach based on space vector modulation (SVM) was used in the literature [10]. This approach is distinguished by the fact that it is independent of the rectifier model and system characteristics. It outperforms the usual current control method in terms of robustness and steady-state dynamic performance. However, whether or not this method can be implemented again remains to be seen. Literature [11] use a negative-sequence current adjustment coefficient k to change the current static operating range to assure circuit quality under unbalanced power grid conditions, however this technique still suffers from current distortion and waveform resonance. The above-mentioned improvement solutions are summarized and compared in Table 1.

Table 1 Comparison of current control methods

Strategy Introduction	Advantages	Disadvantages
PI Controller-Based Control Strategy for Current Decoupling	A wide variety of applications, as well as established technology	Extensive computation, low dynamic reaction
Current control strategy based on PR controllers	Undifferentiated tracking should be enabled	High cost, unstable harmonic wave
Traditional hysteresis current control strategy	Control is simple, the cost is minimal, and the robustness is high	Waveform of an unstable filter
Model Prediction Strategy	Rapid operation, excellent range	High Frequency Requirements
Modeless Predictive Current Control (MFPCC) based on spatial vector modulation (SVM)	Do not rely on the system parameters of the corridor model. Stable dynamic performance is good.	Additional Testing is Required for the Circuit Effect
Introducing the k adjusting current negative current adjustment coefficient	Current range adjustable Circuit work more stable	A problem of current distortion

3.2. DC Voltage Control

The Vienna corrugator is classified as an AC/DC connection, therefore emphasizing the significance of the input and stability of the DC voltage in the first segment of the circuit [9]. The problem of ensuring steady input of AC voltage has garnered significant attention among researchers engaged in the study of voltage regulation. This study will explore its qualities from the following angles, and Table 2 will offer a comparative overview.

Table 2 Comparison of voltage control methods

Strategy Introduction	Characteristics
Voltage control strategy based on PI controllers	Heavily affected by circuit components
Structural control strategy for sliding shift	It is not impacted by external systems and is hence resilient.
Adaptive voltage in-circuit slider control using RBF neural networks	The circuit can be adapted to close, reduce the friction, strong resistance to interference
Voltage Infrared Control Strategy Using a Single Neural PID Controller	Solve nonlinear problems. Strong stability, easy operation

3.2.1 Voltage control strategy based on PI controllers

The use of conventional PI controllers may serve as effective methods for both current control and voltage control strategies. However, it is important to note that when a component undergoes a mutation, the circuit parameters are impacted, necessitating a certain level of optimization in many areas to guarantee circuit stability [9].

3.2.2 Structural control strategy for sliding shift

Based on existing research, it is evident that the use of the sliding mold transformation structure has emerged as a prevalent approach for voltage management. This strategy is applicable in both balanced and unbalanced grid conditions, as it enables the maintenance of steady voltage output and enhances operational efficiency. According to paper [9], it may be inferred that the parameters and external environment variables present in the sliding state exhibit robustness and do not have a significant impact on the system. The proposed approach outlined in the paper [12] presents a method for managing the proportional point-smooth and harmonic vibration in direct power management. This control mechanism might potentially experience voltage-related inhibition, and the strategy aims to address this issue to ensure the stability of the Vienna perpendicular and stable circuitry. The proposed technique in paper [13] presents an adaptive voltage slider control approach that utilizes the radial basis function (RBF) neural network. The integration of the neural network with the slider control technique efficiently facilitates the adaptive behavior of the circuit towards external voltage systems. This integration leads to a reduction in the amplitude of shaking, enhancement of dynamic static performance, and improved resistance to interference.

3.2.3 Voltage infrared control strategy using a single neural PID controller

The dynamic performance of traditional PID controllers is often suboptimal, as they struggle to effectively respond to changing conditions. However, the adaptive adjustment capability of a single neuron presents a promising solution for circuit voltage management, enabling the system to effectively address a wide range of nonlinear challenges. According to reference [9], this control method enhances the stability and operability of the output voltage on the DC side.

Table 3 Comparison of middle-point voltage balance control methods

Strategy Introduction	Advantages	Disadvantages
SVPWM modulated medium point voltage balancing technique	Easy to implement, increased voltage utilization	Large calculations, poor control accuracy, more harmonic waves
Changing the methods of positive and negative small vector action time control	Simple approach, powerful control	The circuit is not fully controlled when the system is larger
Control approach for medium point voltage stagnation balance	Simple method of implementation and robust	Presence Blind Zone

3.3. Vienna Central Point Voltage Balance Control Strategy

The Vienna integrator primarily operates as a three-phase circuit. During the charging phase of the double-voltage capacitor, the current at the midpoint of the current flowing through the DC side capacitor exhibits variation. Consequently, the voltage generated by the two capacitors is unequal. Excessive voltage imbalance may lead to a deterioration in circuit performance and potential damage to the component [9]. Hence, in the analysis of the equilibrium state, it is necessary to include circuitry that encompasses the regulation of the voltage midpoint for achieving balance. In contemporary times, the management of medium voltage equilibrium strategy is mostly governed by software. To facilitate a comparative analysis, Table 3 will enumerate a range of prevalent medium-voltage equilibrium control techniques.

3.3.1 SVPWM modulated medium point voltage balancing technique

The essay proposes a way for effectively managing the variations of the middle-point voltage by manipulating the current flowing through the neutral wire using a combination of vector actions [14]. This approach enhances the usage of voltage, but at the cost of increased computational requirements. The existing essay [15] enhances the conventional space vector pulse width modulation (SVPWM) technique by incorporating the input side three-phase current polarity. This is achieved by dividing the conventional sector into multiple regions based on the determination of the new sector and applying a negative small vector adjustment factor to counteract the vector effect in the input. Consequently, this approach achieves a balanced medium-point output.

3.3.2 Changing the methods of positive and negative small vector action time control

The essay [9] provides a comprehensive overview of the straightforward and effective functioning of the conventional positive-negative vector time control. However, it fails to address the issue of middle-point voltage imbalance in its entirety. Although some improvements have been made, achieving an ideal state remains elusive, and the actual loss cannot be disregarded, thereby preventing the assurance of complete voltage balance. Additionally, it might potentially result in a decrease in circuit efficiency.

3.3.3 Control approach for medium point voltage stagnation balance

The principle governing the control of circuit voltage is analogous to the principle governing current voltage control. It involves the adjustment of vector angles to align with the direction of deviation following circuit current deviation. This control method is characterized by its ease of operation and robustness. However, it exhibits limited effectiveness in low power factor conditions and possesses certain blind areas within its operational range [9].

3.4. Vienna harmonic wave stability control Analysis

The effective mitigation of harmonic wave effects on the circuit is crucial for achieving harmonic wave control. This paper aims to provide an examination of the approaches used in the regulation of partial harmonic stability, while also presenting a comparison of their respective benefits and drawbacks.

3.4.1 Vienna Rectifier Harmonic Vibration Suppression Strategy (HRSS-VR)

The closed-circle input harmonic wave resistance of the integrator was recreated using the Vienna double-circuit method, which is based on the dq coordinate frame. Additionally, HRSS-VR enhancement techniques and software simulation verification were presented [16]. Significant attention is given to the observation that prior to the implementation of HRSS-VR, the PCC point voltage and current harmonic fluctuation in the Vienna reinforcer network exhibited considerable magnitudes, thereby significantly compromising the quality of their respective electrical energy. Conversely, following the integration of HRSS-VR, the issue of harmonic voltage amplification at the PCC point and current distortion within the Vienna rectifiers network were effectively mitigated.

Moreover, the waveform exhibited resistance characteristics and demonstrated a notable inhibitory effect, thereby ensuring the stability of the circuitry.

3.4.2 Other methods of harmonic wave control

Other response techniques, in addition to the HRSS-VR suppression approach outlined above, have been suggested by certain academics. The subject matter being discussed is literature, as indicated by the citation [17]. The management of the sliding fluctuation structure is facilitated by establishing a voltage ring based on the mathematical model of the Vienna rectangle. Additionally, a current inner ring with multi-PR control is constructed, taking into account the non-alignment qualities of the rectangle on the αβ coordinate system. The Multi-PR module system exhibits enhanced resilience, improved capacity for modifying current mutations, and the ability to effectively suppress high harmonic waves, resulting in reduced distortion of the current harmonic wavelength. The present text refers to a specific source, identified as Documentation [18]. The enhancement of DPWM modulation technology may be achieved by implementing methods that address low-harmonic wave operation and current distortions. These strategies are based on the use of LCL filters and classic DPWM modelling approaches, as well as the incorporation of three-layer voltage injection. Technological advancements have the potential to address the issues of middle-point voltage balancing and zero-point deformation, hence facilitating the effective functioning of low harmonic waves. The comparison of the three techniques is shown in Table 4.

Table 4 Summary of Vienna rectifier harmonic wave control improvement

Harmony Wave Suppression Control Strategy	Characteristics
Vienna Rectifier Harmonic Vibration Suppression Strategy (HRSS-VR)	The circuit's voltage amplification and current distortion are improved, It is more stable.
Sliding Multi PR Module Control Strategy	Strong rubber, good mutation adjustment ability, suppressing high harmonic waves to prevent distortion
Strategy for improvement of three-layer voltage injection DPWM modulation technology	Ensure harmonic wave stability, solve current balance and zero point deformation problems

4. Outlook

Future improvements to the performance of Vienna rectifiers continue to be a popular topic of research, as the current electrical electronics technology system offers only a limited number of circuit enhancements for Vienna rectifiers. The present condition of the harmonic wave formed by the voltage input is not yet optimal and lacks stability. To address this issue, two potential approaches may be considered: operating the circuit in closed-circuit mode or introducing additional materials to mitigate the development of circuit exposure current, hence enhancing the stability of the circuit waveform. Moreover, the use of semiconductor components inside the Vienna integrator allows for their integration with Sic and other crystal materials, resulting in the generation of a heightened level of stability in the direct current (DC) state. Consequently, this leads to a notable enhancement in work efficiency. If the circuit improvement plan achieves a significant advancement from these perspectives, it is anticipated that the Vienna integrator circuit will experience cost reduction and an increased scope of applications. This, in turn, would facilitate the prompt implementation of China's new energy policy.

5. Summary

After conducting a comprehensive examination of the research and practical implementation of the Vienna integrator, it has been determined that the integrator circuitry used in Vienna represents a significant improvement in performance, particularly in terms of topology and intersection point. The performance of the Wiener integrator may be enhanced by the use of several control techniques, such as current and DC voltage control, middle-point balance point voltage control, and harmonic wave

stabilization control. The integration of the AC/DC-DC/DC circuit state with the LLC harmonic inverter enhances stability and contributes to the increased efficiency of the new energy charging station.

References

[1] Y. Zhu, H. Wen, Q. Bu, X. Wang, Y. Hu and G. Chen. An Improved Photovoltaic Power Reserve Control with Rapid Real-Time Available Power Estimation and Drift Avoidance. IEEE Transactions on Industrial Electronics, 2023, 70(11): 11287-11298.

[2] Wei Chang, Bin Liu, Yueyan Zhu. Trends in the automotive sector in accordance with the double-carbon target. Auto Review, 2022, 12(07): 158-160.

[3] Yunjuan Mao. Application of contemporary electrical and electronic technology and related investigation into its evolution. Technology Innovation and Application, 2022, 12(07): 158-160.

[4] Tao Yang. A review of the current status of electrical system electrical electronics technology. Technology Wind, 2020(05): 196.

[5] Yongchao Zhao. Research on Electric Vehicle Charging Pile Converter and Its Control Strategy Responding to Grid Frequency Modulation. Hunan University of Technology, 2021.

[6] Zilong Xiong. Design of High-Power Charging for Electric Vehicles based on Vienna Rectifier. Shandong University, 2022.

[7] Tianhang Fan. Development of VIENNA Rectifier with AC/DC Input Compatible. Nanjing University of Aeronautics and Astronautics, 2021.

[8] Shouzhong Lei. Research on DC Charging Pile System of Electric Vehicle Based on VIENNA Rectifier. Anhui Polytechnic University, 2022.

[9] Yaai Chen, Zixuan Li, Jinghua Zhou, et al. Summary of Control Strategies for VIENNA Rectifier. Electric Drive, 2021, 51(09): 3-10.

[10] Yongchang Zhang, Qiyan Qu, Haitao Yang. Model Free Predictive Current Control of Vienna Rectifier Based on Space Vector Modulation. Transactions of China Electrotechnical Society, 2022, 37(21): 5541-5547.

[11] Zhaocheng Shi. Research on Current Control Strategy of Three-phase VIENNA Rectifier in Wide-range-Unbalanced Grid Conditions. Nanjing University of Science and Technology, 2021.

[12] Yunhong Zhou, Aimin Zhang, Hang Zhang, et al. A Resonance Sliding Mode Control Strategy for Vienna Rectifier under Unbalanced Voltage Conditions. Journal of Xi'an Jiaotong University, 2020, 54(04): 76-84.

[13] Xuhong Yang, Yang Chen, Wei Jia, et al. Vienna rectifier with voltage outer loop sliding mode control based on an RBF neural network. Power System Protection and Control, 2022 ,50(18): 103-115.

[14] Deyang Zhang, Wenjing Chang, Haihong Huang. VIENNA Rectifier Midpoint Potential Fluctuation Principle and Balance Method. Low Voltage Apparatus, 2021(12): 47-51.

[15] Dangshu Wang, Yaqiang Yang, Jiaan Yi, et al. Improved SVPWM Strategy for VIENNA Rectifier with Midpoint Balance. Journal of Guangxi Normal University (Natural Science Edition), 2023, 41(01): 67-75.

[16] Yuchao Yuan. STRATEGY OF VIENNA RECTIFIERHARMONIC RESONANCE SUPPRESSION. Yanshan University, 2022.

[17] Wenjie Zhu, Cong Ren, Ying Xu, et al. Current Harmonic Suppression of Vienna Rectifier Based on Sliding Mode Control. Electric Engineering, 2022(11): 36-39.

[18] Boxue Zhang. Research on Modulation and Control Strategy of Vienna Rectifier. Shandong University, 2023.