Application of Half-Uncontrolled 3-Phase Rectifier Circuit for Wave Analysis

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Abstract

The study investigates the application of a half-uncontrolled 3-phase rectifier circuit for wave analysis. This circuit functions as a device to convert alternating current (AC) into direct current (DC) electricity using a half-wave approach. In this method, only one cycle of the AC signal is allowed to flow, while the other cycles are blocked through the diode's operational characteristics. The main component of the rectifier circuit, whether full-wave or half-wave, is the diode configured in forward bias. The diode's functionality ensures that electric current flows in one direction to the load and back to the transformer, blocking current in the opposite direction. Consequently, a positive wave is produced by suppressing the negative half-wave. Simulations reveal that the output voltage of the uncontrolled rectifier cannot be regulated, as it depends solely on the inherent properties of the circuit design. This limitation underscores the fundamental behavior of half-wave rectifiers, which utilize the diode's ability to pass current selectively to achieve rectification. The analysis highlights the circuit's simplicity and effectiveness in producing a positive DC output from a 3-phase AC input, making it suitable for applications where minimal wave shaping is required. This research contributes to a deeper understanding of the working principles of 3-phase rectifier circuits and provides insights into their application in electrical systems. Future studies could focus on optimizing such circuits for higher efficiency and exploring their integration with controlled rectification systems.

Keywords: Rectifier, 3phase, half wave

1. Introduction

In today's modern era, where electricity plays a crucial role in daily life, the need for reliable electrical systems has grown significantly. In general, households require an electricity supply of 220V at a frequency of 50Hz, which is typically provided by utility companies like PLN (Nugraha et al., 2022). However, most electronic devices used in households operate on direct current (DC) rather than alternating current (AC) (Agna, Yuniza, & Nugraha, 2022). This discrepancy necessitates the conversion of AC into DC to meet the specific operational requirements of various electronic devices.

To address this need, rectifier circuits have been developed and are commonly used to perform this conversion. A rectifier is a vital electronic device that transforms AC into DC, facilitating the use of AC power sources for DC-based devices (Nugraha et al., 2023). Specifically, the half-uncontrolled 3-phase rectifier circuit is designed to convert three-phase AC electricity into DC electricity in a half-wave form (As'ad, Yuniza, & Nugraha, 2022). This process ensures that only one half-cycle of the AC waveform is utilized, while the other half is blocked by the circuit. This blocking is achieved by employing the unique properties of diode components.

The half-wave rectification process is characterized by its simplicity and functionality. The diode, a primary component in both full-wave and half-wave rectifiers, is arranged in a forward-biased configuration (Nugraha & Eviningsih, 2022). This allows the diode to conduct electric current in one direction transmitting current from the load back to the transformer during the positive cycle while inhibiting the reverse flow of current during the negative cycle (Paluga et al., 2024). Consequently, only the positive portion of the AC waveform is passed through, and the output voltage is unregulated, hence classified as uncontrolled.

The application and significance of rectifier circuits have evolved over time, particularly in engineering fields where the development of efficient power supply systems is critical. As a result, rectifier circuits are not only used to power household electronics but have also become essential components in industrial systems, renewable energy applications, and other engineering domains. This research focuses on the "Application of Half-Uncontrolled 3-Phase Rectifier Circuit for Wave Analysis," exploring its operational principles, performance characteristics, and potential improvements.

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2. Material and methods

2.1. Diodes

Diodes are among the simplest yet most essential electronic components, constructed from two types of semiconductors: n-type and p-type (Mu'in et al., 2023). These semiconductors exhibit a unique property they allow current to flow in only one direction. This characteristic makes diodes fundamental in rectification applications, as they enable the conversion of alternating current (AC) into direct current (DC) (Pangestu et al., 2024). By configuring diodes appropriately, it is possible to produce a higher output power in the DC circuit. For applications requiring rectification with power levels exceeding 15 kW, a three-phase rectifier system is typically employed due to its efficiency and capability to handle high power loads.

In the context of wave rectifier circuits, alternating current (AC) is transformed into direct current (DC) as it passes through the rectification process. Electrical signals used in electronic systems are often in AC form, represented by various waveforms (Kurniawan et al., 2023). Among these, the sinusoidal waveform serves as the most fundamental shape due to its widespread occurrence in power systems and its mathematical simplicity. According to Fourier's theorem, nearly all complex waveforms can be expressed as a combination of sinusoidal components, forming a Fourier series (Dermawan et al., 2023). This principle underscores the importance of sinusoidal waveforms in analyzing and processing AC signals in rectifier systems.

The three-phase rectifier system stands out in engineering applications due to its ability to deliver a smoother DC output with reduced ripple voltage compared to single-phase systems (Xu, 2023). This advantage is particularly crucial in industrial and engineering applications where stable and high-quality DC power is required (Hao et al., 2023). The interaction of diode configurations and sinusoidal input waveforms plays a pivotal role in determining the efficiency, stability, and output quality of the rectification process.

2.2. Uncontrolled 3-phase rectifier

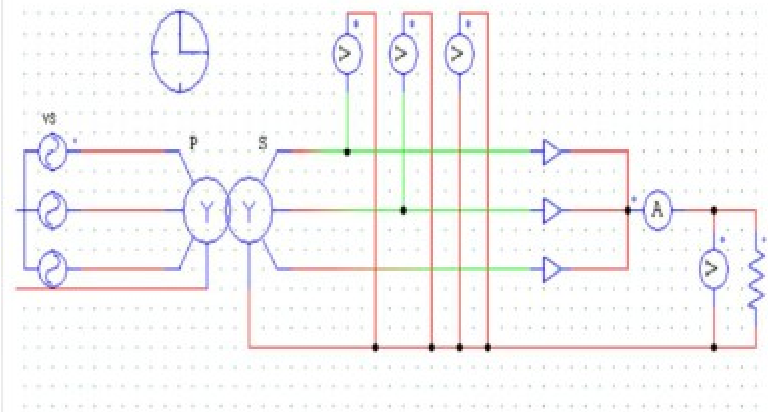

Figure 1. circuit of 3-phase uncontrolled half-wave rectifier

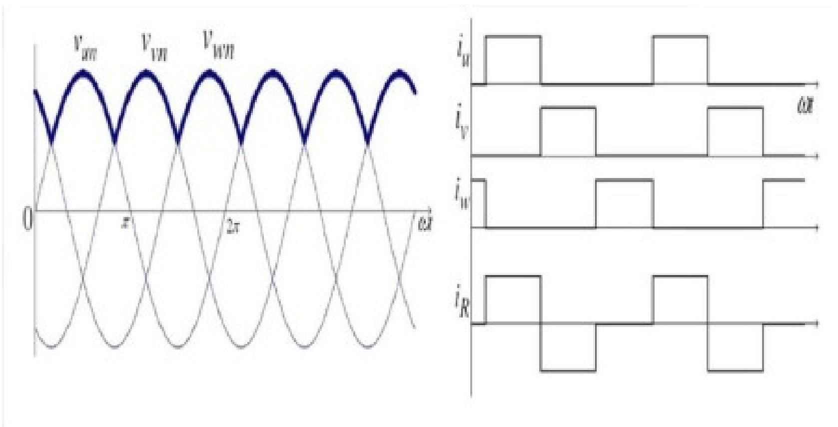

Figure 2. output half wave

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Figure 1.1 illustrates a simplified schematic of an uncontrolled 3-phase rectifier circuit designed using three diodes. This circuit is modeled and analyzed through simulation in the PSIM software application. The figure incorporates a three-phase voltage source derived from a transformer and a resistive load, forming the fundamental configuration for demonstrating rectification principles in three-phase systems.

Figure 1.2 displays the output waveform obtained from the uncontrolled 3-phase rectifier circuit under the same conditions—using a three-phase transformer voltage source and three diodes. The waveform represents the rectification process, showcasing how the circuit converts alternating current (AC) into direct current (DC) with distinctive characteristics shaped by the diode operation.

In the uncontrolled 3-phase rectifier circuit, the process begins with the R-phase waveform, which is rectified into a positive half-cycle (Petrović, 2023). During this phase, current flows through Diode 1 (D1), delivering power to the load before returning to the transformer. Each diode in the circuit becomes conductive only when a positive voltage is applied across its terminals, thereby blocking any negative half-cycle of the waveform (Dhanawade & Sangale, 2024). Consequently, the output for this phase is a unidirectional positive waveform.

Subsequently, a positive S-phase waveform is generated. Current flows through Diode 2 (D2), energizing the load, and similarly returns to the transformer. The negative portion of the S-phase waveform is blocked, resulting in another positive waveform. This process repeats for all phases, with each diode conducting sequentially as its corresponding phase voltage turns positive. The cumulative effect is a rectified output waveform composed entirely of positive half-cycles, characteristic of a half-wave rectification in a three-phase system.

2.3. Rectifier circuit

A rectifier is an electrical device used to convert alternating current (AC) into direct current (DC), a process fundamental in various applications across electrical engineering and power electronics (Mamo, 2024). In particular, the uncontrolled 3-phase half-wave rectifier serves as a vital component for converting three-phase AC power into a unidirectional DC output (Zhou et al., 2023). This circuit operates by allowing current to flow only during one half of the AC cycle while blocking the opposite half, a feature made possible by the selective conduction of diodes (Zheng et al., 2023).

In the case of the half-wave rectifier, the current is allowed to flow during one positive half-cycle of the AC waveform. During the other half-cycle, the current is blocked, and no current flows. This process effectively converts the AC waveform into a series of half-waves of DC, albeit with some ripple and fluctuations. The magnitude of the output voltage in this uncontrolled configuration is determined by the peak AC voltage applied to the rectifier but cannot be controlled.

In an uncontrolled 3-phase half-wave rectifier, the three-phase AC power is rectified into three separate, positive half-cycles that combine to produce a less smooth but functional DC output (Weihe et al., 2024). However, due to the nature of the circuit's design and lack of regulation, the output voltage is inherently unstable and fluctuates according to the input AC signal characteristics. The absence of a control mechanism in this type of rectifier makes it suitable for specific applications where the stability of the output voltage is not critical, but the simplicity and efficiency of the conversion process are of paramount importance.

One of the primary advantages of a 3-phase rectifier circuit, compared to a single-phase rectifier system, is its ability to deliver higher output power (Hao et al., 2023). This is due to the fact that a 3-phase system utilizes three distinct AC power sources, resulting in a more continuous and stable output compared to the periodic nature of a single-phase system. As a result, the 3-phase rectifier system is often preferred for high-power applications. For instance, in industrial and commercial settings where power requirements exceed 15 kW, a 3-phase rectifier system is typically employed due to its superior efficiency, enhanced power capacity, and ability to handle higher loads without significant voltage fluctuations.

The increased output power and stability of the 3-phase system make it a more reliable choice for applications that demand consistent and uninterrupted DC power (Menzi et al., 2023). These characteristics are particularly valuable in sectors such as manufacturing, telecommunications, and electric transportation systems, where large-scale power conversion is critical.

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2.4. Methods

The research methodology employed in the preparation of this paper is an experimental research approach. Experimental research is a method that aims to test the effect of one variable on another, or to examine the causal relationships between variables. Essentially, this method involves the collection of data through experimentation, observation, and the systematic recording of results. Once the data is gathered, it is analyzed to derive conclusions that can contribute to the existing body of knowledge, and ultimately, assist in generating reports or papers. In the context of this research, the experimental method is used to investigate the behavior and performance of a half-uncontrolled 3-phase rectifier circuit, specifically in relation to its impact on the output waveforms.

To gather the necessary data for this study, simulations were conducted using PSIM software, which is widely recognized in the field of electrical and electronic engineering. PSIM (Power Simulation) is a powerful tool designed specifically for simulating electronic circuits. Developed by Powersim Inc., PSIM provides an intuitive and comprehensive platform for circuit analysis, enabling researchers and engineers to model complex circuits, simulate their behavior, and evaluate performance before physical implementation. This capability is especially crucial in power electronics research, where simulations offer a cost-effective way to explore various circuit configurations and predict their real-world behavior.

In this study, PSIM was utilized to simulate the behavior of a half-uncontrolled 3-phase rectifier circuit. By inputting various parameters and adjusting circuit configurations within the software, a series of simulations were conducted to observe the effect of different factors on the output waveform. The primary focus was to analyze the shape and quality of the rectified output, assess the rectifier's efficiency, and explore how the circuit interacts with the load under different operating conditions. This method allows for a detailed and accurate analysis of circuit performance without the need for physical prototypes, saving both time and resources.

Furthermore, using simulation tools such as PSIM aligns with the recommendations of both reviewers and editors, as it provides a controlled and reproducible environment to test hypotheses and validate theoretical models. Simulations serve as a foundation for further experimental validation, enabling researchers to refine their approach before real-world implementation. Additionally, employing PSIM ensures that the research findings are grounded in robust computational analysis, which is a crucial aspect of modern engineering research. The insights gained through these simulations contribute significantly to understanding the practical applications of the half-uncontrolled 3-phase rectifier circuit, supporting the paper's broader aim of improving wave analysis techniques in electrical power systems.

3. Results and discussion

3.1. Result

In this practical investigation, we explore the functionality and applications of a wave rectifier circuit. A rectifier is an essential electronic component used to convert alternating current (AC) into direct current (DC), which is crucial for the operation of various electrical devices that require DC power. Rectifiers achieve this by utilizing diodes, which allow current to flow in only one direction, effectively transforming the AC waveform into a unidirectional DC waveform. The half-wave rectifier, particularly the 3-phase half-uncontrolled rectifier, is a fundamental circuit used in industrial applications to convert AC to DC with relatively simple configurations. This conversion process is pivotal in areas such as power supplies, industrial control systems, and renewable energy systems, where DC is required for efficient operation.

During the simulation of the half-uncontrolled 3-phase rectifier circuit, various parameters such as voltage and current were measured across the diodes in the circuit. These measurements were carefully recorded and analyzed to observe the performance and behavior of the rectifier under different operating conditions. The results were compiled into a comprehensive data set, which is presented in the table below. These data points provide insight into how the rectifier operates, particularly in terms of the output DC voltage and current characteristics as affected by the AC input waveform. The data collected also help evaluate the rectifier's efficiency and the accuracy of the theoretical models, which are crucial for the validation of the circuit's design.

The practical application of the wave rectifier circuit is important for a deeper understanding of power electronics, especially in the context of its use in high-power applications. By observing the simulation results, it is evident that the 3-phase rectifier circuit offers distinct advantages over single-phase systems, including improved output power and better smoothing of the DC output. Furthermore, the study of current and voltage measurements in the context of the rectifier provides a clear understanding of how diodes control the flow of current and shape the output waveform. This also highlights the practical considerations that must be taken into account when designing rectifier circuits for real-world applications.

Table 1. 3 phase half wave rectifier

No	Vin	Vd1	Vd2	Vd3	Id1	Id2	Id3	Vo (R)	Vo (R&L)		
									R	L	RL
1	6	6,7	6,73	6,75	6,03	6,1	5,7	4,19	3,8	0,69	4,27
2	9	12,1	12,07	12,10	11	11,02	10,63	7,63	6,9	1	7,61
3	12	12,25	12,13	12,12	14,6	13,8	13,8	10	9,15	1,4	10,5

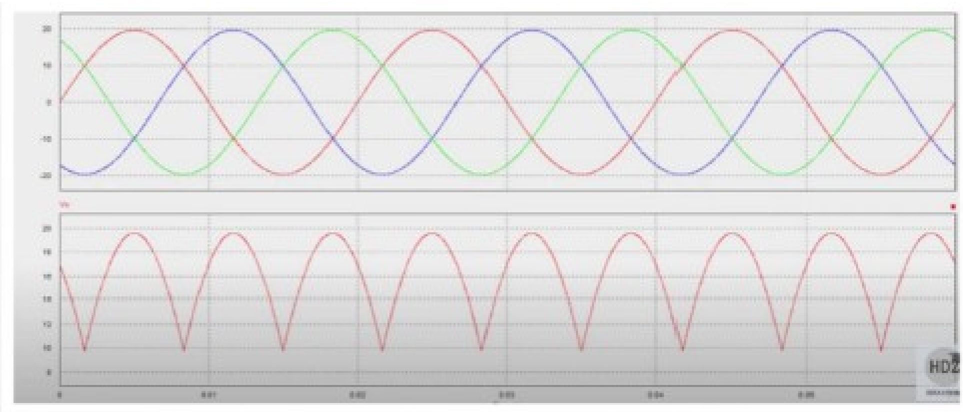

Figure 3. The results of running a sinusoidal wave

Figure 3 is illustrates the behavior of a 3-phase rectifier circuit. The upper part of the image shows three sinusoidal waveforms in blue, green, and red, representing the three-phase alternating current (AC) input (phases R, S, and T). These waves are identical in frequency but are offset by 120 degrees in phase from each other, which is characteristic of a 3-phase AC system. This section depicts the input AC waves that feed into the rectifier.

The lower part of the image shows the output waveform of the 3-phase rectifier, which is a half-wave rectified signal. The red waveform represents the rectified output, where only the positive half of the AC cycle is allowed to pass through the circuit, while the negative half is blocked. This is the result of the diode's function in the rectifier, which only permits current to flow in one direction, creating a pulsed direct current (DC) output.

Overall, the image demonstrates how a 3-phase AC input is processed through a half-wave rectifier circuit to produce a DC output with the negative half-cycle of the input AC blocked.

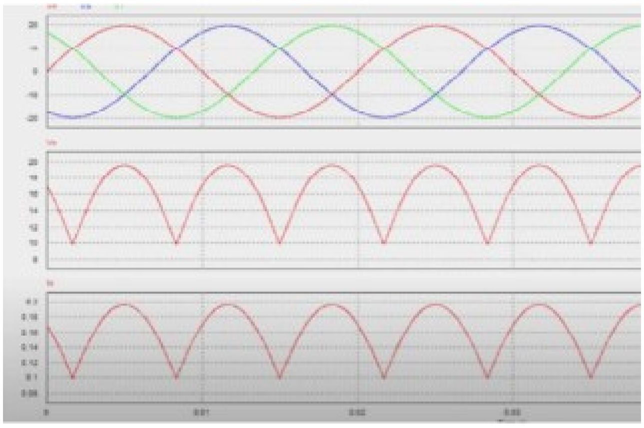

Figure 4. The results waveform

This image illustrates the operation of a 3-phase rectifier circuit. The top section shows the three-phase AC input, represented by sinusoidal waveforms in blue, green, and red, which are offset by 120 degrees from each other, characteristic of a 3-phase AC system. In the middle section, the output voltage is shown after being processed by the rectifier, which performs half-wave rectification. Here, only the positive half of each AC cycle passes through, while the negative half is blocked, resulting in a series of pulses in the output voltage waveform, depicted in red. Finally, the bottom section displays the output current, which follows the same pattern as the voltage, with current flowing during the positive half-cycle of the AC input and being blocked during the negative half-cycle. This demonstrates how the rectifier converts the 3-phase AC input into a pulsating direct current (DC) output, with the negative portions of the AC input removed.

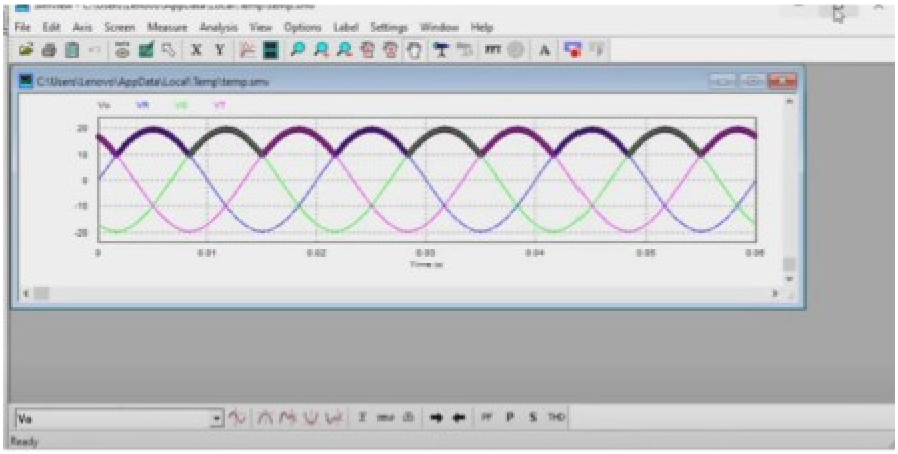

Figure 5. The results of running a half-wave sinusoidal wave

Figure 5 illustrates the output voltage waveform of a 3-phase uncontrolled half-wave rectifier circuit. A half-wave rectifier is a key electronic device that converts alternating current (AC) into direct current (DC). The 3-phase half-wave rectifier specifically converts the AC input from three phases into DC, utilizing the unique characteristics of diodes to allow current to flow in a single direction. The term "half-wave" refers to the fact that only one half of the AC waveform is allowed to pass through the rectifier circuit, while the other half is blocked by the diodes, resulting in a pulsating DC output. This form of rectification is considered "uncontrolled" because the output voltage cannot be adjusted or regulated by the circuit, making it suitable for applications where control over the DC output is not required.

In the 3-phase uncontrolled rectifier circuit, the operation is based on the behavior of three diodes (D1, D2, and D3). When the AC input is applied to the circuit, the first positive half-cycle of the AC voltage generates a positive R wave. During this cycle, current flows through diode 1 (D1) to the load and then back to the transformer, effectively allowing the positive portion of the AC voltage to pass. The negative half-cycle of the AC input is blocked by the diode, preventing any current from flowing during this period. As a result, the output voltage forms a positive pulse, corresponding to the positive cycle of the AC input.

The next phase of the rectification process occurs when a positive S wave is generated. During this cycle, current flows through diode 2 (D2), which leads the current from the AC supply through to the load and back to the transformer. Similar to the previous cycle, the negative portion of the AC waveform is blocked, and only the positive portion contributes to the output. This results in another positive pulse in the rectified output. The behavior of the rectifier is such that each diode in the circuit only conducts when the AC voltage is positive for that specific phase, ensuring that only positive portions of the waveform contribute to the DC output.

The final part of the process involves the generation of the positive T wave. During this phase, diode 3 (D3) conducts, allowing current to flow from the AC supply to the load and back to the transformer. As with the previous diodes, the negative half-cycle of the AC waveform is blocked, and the result is a continuous positive output waveform. This cycle repeats in a continuous manner, as the three diodes alternately conduct depending on the phase of the AC voltage. The resulting output is a series of positive pulses that, when smoothed, can be used as DC power.

This explanation of the 3-phase half-wave rectifier provides a foundational understanding of the circuit's operation, which is vital for the design and analysis of power systems in various engineering applications. The research and simulation of such circuits are essential for engineers and researchers working on power conversion, particularly in situations where high power efficiency is not a critical factor. However, this form of rectification remains a fundamental and widely used technique for specific industrial applications.

4. Conclusion

From the simulations conducted, it can be concluded that the half-uncontrolled 3-phase rectifier circuit effectively converts alternating current (AC) into direct current (DC). This rectifier operates by allowing the flow of current during one half-cycle of the AC waveform while blocking the other half-cycle, utilizing the diode's unique properties. Specifically, a half-wave rectification implies that only a single cycle of the input AC is utilized, while the remaining cycle is suppressed, resulting in a rectified DC waveform.

The output voltage of this type of rectifier is inherently uncontrolled, as the circuit lacks components to regulate or stabilize the output voltage. The diode, serving as the core component of the rectifier, is configured in a forward-biased arrangement. This setup enables the diode to conduct electric current in a single direction—from the load back to the transformer—while blocking reverse current. Consequently, the negative portion of the AC waveform is suppressed, ensuring that the resulting output wave remains entirely positive.

When alternating current (AC) is supplied to the circuit, the diode selectively passes only half of the waveform, allowing current flow during the positive cycle while blocking the negative cycle. This characteristic highlights the diode's critical role in achieving the rectification process and producing a DC output from an AC input, making it a fundamental element in power conversion systems.

Credit authorship contribution statement

Author Name: Conceptualization, Writing – review & editing. **Author Name**: Supervision, Writing – review & editing. **Author Name**: Conceptualization, Supervision, Writing – review & editing.

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