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Impact of 3-Phase Full-Wave Rectifier on 3-Phase AC Motors: Voltage Regulation and Power Output Efficiency

Aditya Achmad Safriansyah
Marine Electrical, Engineering, Shipbuilding Institute of Polytechnic Surabaya, Indonesia
Correspondence author: adityaachmad@student.ppns.ac.id

ABSTRACT

Practical training (practicum) plays a crucial role in the educational process, especially in vocational education institutions such as polytechnics. It is essential for enhancing student skills and facilitating effective teaching and learning, particularly in hands-on activities. This study aims to develop an experimental setup for an uncontrolled 3-phase rectifier practicum, where the rectification parameters closely align with theoretically calculated values. An experimental research approach is employed, involving the design, construction, and testing of both a Half-Wave and Full-Wave Rectifier, based on established rectifier theory. The test results demonstrate the performance of the rectifiers, showing the values of current, voltage, and output power under various operating conditions. This study contributes to the development of practical learning tools that help students better understand the principles of power electronics and rectification processes in a controlled environment, bridging the gap between theoretical concepts and real-world applications.

Key Word: *practicum trainer, controlled 3 phase rectifier, full wave converter.*

I.INTRODUCTION

Industrial development has been rapidly advancing, driven by the rapid evolution of technologies, especially in power supply systems such as rectifiers, which convert alternating current (AC) to direct current (DC) [1]. The demand for reliable and efficient power equipment has become critical, especially in industrial applications, where continuous control is necessary to achieve optimal performance of electrical systems [2]. Rectifiers, as key components in power electronics, are essential for converting AC power to DC, which is required by a wide range of electrical devices and systems [3].

In this study, we investigate the effect of a three-phase full-wave uncontrolled rectifier circuit on the performance of a 3-phase AC motor, focusing on voltage regulation and power output efficiency [4]. A three-phase full-wave rectifier, also known as a three-phase bridge rectifier, is typically employed in high-power applications where efficient and stable DC output is required [5]. This circuit operates by converting the AC input into a series of DC pulses, a process that is fundamental for ensuring power delivery in a variety of industrial systems [5].

The three-phase full-wave rectifier circuit utilizes six diodes, with two diodes per phase, similar to a single-phase bridge rectifier, but configured for three-phase operation [6]. This configuration offers several advantages over simpler rectifiers, such as reduced output ripple. In comparison to a three-phase half-wave rectifier, the full-wave rectifier's output ripple is significantly lower due to the higher frequency of six times the input AC waveform, which improves the quality of the DC output and enhances the overall efficiency of the system [7].

By exploring the impact of the rectifier on a 3-phase AC motor's voltage regulation and power output, this research aims to provide valuable insights into the operational characteristics of the rectifier under varying load conditions [8]. The study focuses on understanding how the rectifier affects the motor's performance, especially under different load scenarios, to ensure a more stable and reliable power supply. This exploration is crucial for evaluating the behavior of the rectifier and its interaction with the motor, helping to optimize both components for better overall system efficiency.

This study will also contribute to improving the understanding of how rectifiers influence motor performance, particularly in industrial settings where power stability and efficiency are paramount [9]. In industries that rely on AC motors for heavy-duty applications, having a consistent and efficient power supply is essential for minimizing downtime and ensuring smooth operation. By investigating the relationship between rectifiers and motor performance, the research provides insights that can help in fine-tuning control strategies and improving the overall stability of industrial motor systems.

The findings of this research have the potential to optimize motor drive systems, leading to more efficient energy consumption and enhanced operational longevity. With a deeper understanding of how rectifiers impact motor behavior, engineers can design better motor control systems, leading to reduced energy consumption and longer service life for the motors. This research will not only contribute to improving system efficiency but also enhance the overall reliability of motor-driven systems in various industrial applications, offering long-term benefits in terms of both performance and cost savings.

II.METHODOLOGY

1. Material

A. Diode

The diode, a fundamental component in power electronics, has two main terminals: the anode and the cathode. In its forward bias condition, the diode allows current to flow only in one direction, from the anode to the cathode. This unidirectional current flow is essential for the proper operation of rectifier circuits, such as the three-phase full-wave rectifier in power systems. The current flowing through the diode in the forward direction is referred to as the forward current, and the associated voltage drop across the diode is called the forward voltage[10].

Conversely, in the reverse bias condition, the diode blocks the current flow, preventing any current from traveling from the cathode back to the anode. This blocking action is crucial for controlling the direction of current in power electronics and is utilized in various types of rectifiers and inverters. However, the diode's ability to block current in the reverse direction is not infinite [11]. Each diode has a specified breakdown voltage, which represents the maximum reverse voltage the diode can withstand without being damaged. When this reverse voltage threshold is exceeded, the diode enters a state of breakdown, resulting in irreversible damage [12]. In such cases, the damaged diode must be replaced to restore the functionality of the circuit.

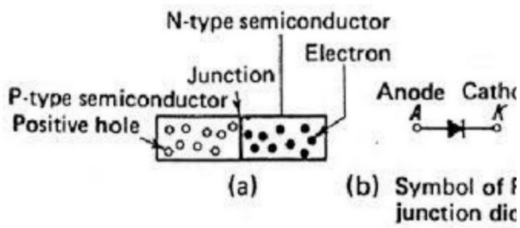

Figure 1. Diode behavior

In rectifier circuits, such as those used in three-phase AC to DC conversion, the silicon diode is commonly used due to its robust performance. A typical silicon diode starts conducting when the cut-in voltage reaches approximately 0.7 volts, which is the voltage required for the diode to overcome its internal junction barrier and allow current to flow. In contrast, germanium diodes exhibit a lower cut-in voltage of around 0.3 volts, making them more sensitive to small voltage levels but also more prone to reverse leakage currents.

B. Thyristor

Thyristors, which were first developed by research centers in the 1950s, became commercially available through General Electric in the 1960s. Thyristors, also known as Silicon Controlled Rectifiers (SCRs), are semiconductor devices that play a crucial role in industrial power electronics[13]. These devices are particularly significant due to their ability to handle high voltage and current levels, making them indispensable in a variety of high-power applications, including in rectifier circuits and motor control systems[14].

A thyristor has three primary terminals: the anode, cathode, and gate (often referred to as the control terminal). The anode and cathode are the two main terminals responsible for conducting current in the device, while the gate is used to control the turn-on and turn-off states of the thyristor. By applying a small current to the gate, the thyristor can be turned on, allowing current to flow between the anode and cathode. Once the thyristor is in the "on" state, it continues to conduct current even if the gate signal is removed, making it a latching device.

Thyristors come in two basic types based on the gate configuration: those with a P-gate and those with an N-gate [15]. The difference between the two lies in the type of semiconductor material used to create the gate, which influences the characteristics of the thyristor, such as its switching behavior and voltage tolerance.

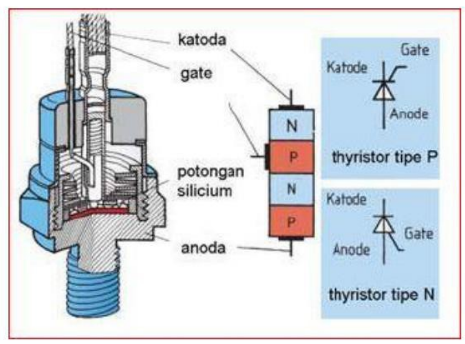

Figure 2. Thyristor

In the context of the research focused on the impact of three-phase full-wave rectifiers on 3-phase AC motors, the use of thyristors can significantly enhance the voltage regulation and power output efficiency. Thyristors enable variable control of DC voltage and current delivered to the motor, allowing for improved motor performance and energy efficiency, which are vital in industrial applications where motor control is a critical component.

A. Resistor

Resistors are fundamental passive electronic components widely used in electrical and electronic circuits to limit and regulate the flow of electric current. Their primary function is to provide a resistive impedance that controls the amount of current flowing through a circuit, thereby ensuring the proper functioning of various electronic devices and systems[16].

Figure 3. Resistor

In the context of power electronics and electrical engineering, resistors play a critical role in voltage regulation and the control of power distribution within complex circuits such as rectifier systems and AC motor drives. The resistance of a resistor is measured in ohms (Ω), a unit named after Georg Simon Ohm, a renowned German physicist who developed Ohm's Law. Ohm’s Law, which establishes the relationship between voltage (V), current (I), and resistance (R), is fundamental to understanding the behavior of resistors in circuits.

B. Inductor

Inductors, also known as reactors, are crucial passive components in electronic circuits, often designed in the form of coils or toroidal shapes [17]. They play a vital role in energy storage within a magnetic field, which is generated as an electric current passes through them [18]. This unique ability to store energy in the form of a magnetic field makes inductors essential in a variety of applications, especially in power electronics and AC motor control systems, where voltage regulation and current management are critical for optimal performance. The inductance of an inductor, which determines its ability to store energy, is typically measured in Henrys (H) and is directly related to factors such as the number of coil windings, core material, and coil geometry.

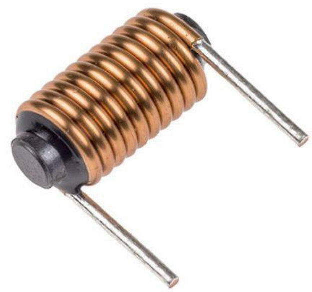

Figure 4. Inductor

The primary function of an inductor in a circuit is to resist changes in current, making it particularly effective in alternating current (AC) circuits [19]. When a current flows through the inductor, it creates a magnetic field around it, which opposes any change in the current due to Faraday's Law of Induction. This law states that a changing magnetic field will induce a current in a conductor, which is the principle behind inductors and their ability to smooth and filter currents. In the case of three-phase full-wave rectifiers used for controlling AC motors, the role of inductors becomes even more pronounced. They help smooth out rectified DC by reducing ripple, thus improving the stability and efficiency of the power supplied to the motor.

2. Method

This research adopts an experimental approach through the use of computer simulations[20]. The simulations are conducted using the PSIM simulation software. The study focuses on modeling a fully controlled three-phase rectifier system, with circuit and block diagrams, to analyze the effects of various load types on system performance. The system modeling in this research includes the following scenarios: 1) Modeling with Resistive Load, 2) Modeling with Inductive Dominant Load, and 3) Modeling with Ideal Current Source Load (Straight Resistive Load).

The operation of the system is simulated using PSIM, which includes testing under conditions of balanced voltage supply as well as simulations with unbalanced supply voltages, within permissible limits of voltage imbalance. The simulation results are used to evaluate the rectifier's performance and to identify any variances in voltage regulation and power output efficiency across different load types. This experimental methodology is particularly important for understanding the practical implications of rectifier performance in industrial applications, especially with the presence of real-world supply voltage fluctuations.

The study further incorporates the design of a rectifier circuit with varying resistive loads to simulate real-world conditions. These simulations are expected to generate diverse waveform outputs that reflect the system's dynamic behavior under different load conditions. The comparison between the results from simulations using resistive and RC (Resistive-Capacitive) loads is crucial for understanding the impact of different load characteristics on the rectifier's efficiency and performance.

By examining the output waveforms generated by these different load configurations in PSIM, the study aims to provide valuable insights into how load characteristics, both resistive and reactive, affect the rectifier's operation. The results from these simulations will allow for a better understanding of the impact of various load conditions on the voltage regulation and power output efficiency of the rectifier, which directly influences the performance of the connected 3-phase AC motor. The research thus contributes to improving the design and optimization of rectifier circuits in power electronics, ensuring more reliable and efficient industrial motor systems.

III.RESULT & DISCUSION

1.Variation of Simulation Circuit

A. Capacitor

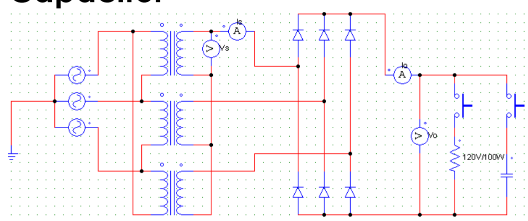

Figure 5. Capacitor

The circuit shown above is a simplified simulation model that was tested using the PSIM software, which allows for accurate modeling and analysis of power electronic systems. The testing was performed under controlled conditions, with the circuit subjected to specific input values and load configurations. This simulation approach facilitated the evaluation of the circuit's behavior and performance under various operating scenarios.

After the testing period, the results from the PSIM simulations were analyzed to assess the circuit's performance. Measurements were taken to determine key parameters, such as voltage and current values, which helped in understanding the system's efficiency and behavior. These results provide valuable insights for refining the design and optimizing future implementations of the circuit. Result of Simulation measurement can be seen in figure 6

Measure

Time	4.4897959e-003
Vs	2.3311177e+001
Vo	5.0021998e+001
Is	1.1929578e-005
Io	1.7763568e-009

Figure 6. Capacitor Measurement Result

B. Series Capacitor and Resistor

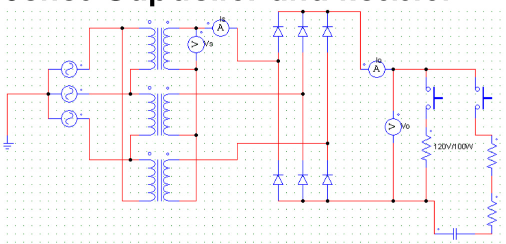

Figure 7. Capacitor

The circuit presented above is a simplified model simulated using PSIM software, a powerful tool for analyzing power electronic circuits. The simulation was conducted under controlled conditions, with specific input values and load configurations applied to observe the system's behavior. This approach allowed for a detailed examination of how different parameters affected the overall circuit performance.

Following the simulation, the results were carefully measured and analyzed to evaluate the circuit's functionality. Key parameters such as voltage and current were recorded to gain insights into the system's efficiency and response under varying conditions. These results are essential for further refining the circuit design and enhancing its performance in future applications. Result of Simulation measurement can be seen in figure 8

Measure

Time	4.4897959e-003
Vs	2.3311177e+001
Vo	5.0021998e+001
Is	1.1929578e-005
Io	1.7763568e-009

Figure 8. Series Capacitor and Resistor Measurement Result

C. Parallel Capacitor and Resistor

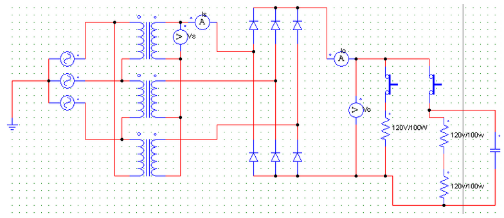

Figure 9. Capacitor

The circuit depicted above is a simplified model, simulated using PSIM software, a widely used tool for modeling power electronic systems. During the simulation, the circuit was subjected to controlled conditions, with specific input signals and load configurations applied to emulate real-world operating conditions.

The objective was to analyze how the system performs under various scenarios, including voltage and current fluctuations. Upon completing the simulation, key electrical parameters such as voltage, current, and power were measured and analyzed. These parameters were essential in evaluating the circuit's efficiency, stability, and dynamic response. The results of this analysis provide a technical foundation for optimizing the circuit design and improving its performance in practical applications, guiding further refinement in subsequent iterations. Result of Simulation measurement can be seen in figure 10.

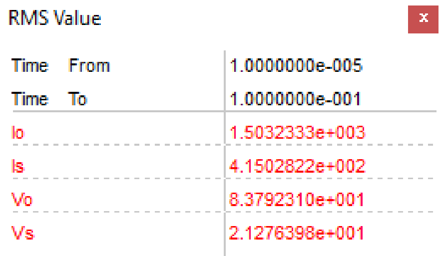

Figure 10. Series Capacitor and Resistor Measurement Result

2.Comparation

Table 1. Comparation result

Burden	Lo	Is	vo	vs
R	2.0343898 e+002	-4.39135 77e+001	8.3362043 e+001	2.193268 3e-004
RC	2.0343900 e+002	4.391358 1e+001	8.3362043 e+001	1.914542 8e+001

The analysis of the observed average voltage (AVG) in the system demonstrates the effects of using a varying inductive load. In particular, an inductor with a value of 0.22 Henries was employed to stabilize the waveform generated by the rectifier circuit. The inclusion of this inductive load serves a critical role in smoothing the voltage ripple that is often produced during the rectification process. By reducing these fluctuations, the inductance improves the overall voltage regulation, ensuring that the output from the rectifier remains as constant as possible. In the simulation, the system achieved an average output voltage of approximately 220V, which is a key requirement for maintaining stable operation of the connected 3-phase AC motor.

The results of this simulation highlight the importance of integrating inductive loads in rectifier circuits, particularly in systems where voltage regulation and power output efficiency are critical. The findings align with key principles in power electronics and motor control systems, demonstrating how well-designed rectification and filtering strategies, such as using an inductive load, can lead to significant improvements in system reliability and energy efficiency. For industrial applications, ensuring a stable voltage output is vital for optimizing both the performance of the 3-phase AC motor and the overall efficiency of the electrical system, thus reducing operational costs and minimizing wear on the components.

IV.CONCLUSION

Before delving into the key findings, it is important to acknowledge the significance of stabilizing voltage in power electronics and motor control systems. In power systems, maintaining consistent voltage is critical for ensuring efficient operation and prolonging the lifespan of components. One of the most effective ways to achieve this stability is through the integration of inductive loads into rectifier circuits, which play a vital role in improving the overall performance of these systems. By understanding the role of inductive loads, we can better appreciate how they contribute to the efficiency and reliability of motor control systems, particularly in industrial applications.

• The use of an inductive load with a value of 0.22 Henries in the rectifier circuit is critical in smoothing out the voltage ripple produced during the rectification process. This inductive component helps filter fluctuations in the output, ensuring a more stable voltage of approximately 220V, which is essential for maintaining the stable operation of the connected 3-phase AC motor. By reducing ripple, the inductive load ensures that the motor receives a steady, uninterrupted power supply, which is crucial for its performance and longevity.

• The inclusion of inductive loads in rectifier circuits significantly improves system efficiency and reliability, especially in industrial applications. The stabilization of voltage output not only optimizes the performance of the 3-phase AC motor but also reduces operational costs by minimizing energy wastage and maintaining efficient power usage. Additionally, the stable voltage helps to minimize wear and tear on system components, contributing to longer operational life and reduced maintenance needs. This makes the integration of inductive loads an invaluable strategy for improving the overall performance and reliability of motor control systems in various industrial settings.

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