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Design and Implementation of a Three-Phase Half-Wave Uncontrolled Rectifier for Enhancing Rural Livelihoods through Single-Phase AC Motor Applications

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ABSTRACT

Electricity serves as a vital energy source for the survival and daily activities of the Indonesian people, supporting both their livelihoods and modern conveniences. In daily life, many tools and devices integral to productivity rely on single-phase electrical systems, including single-phase AC motors. While the development of Indonesia's electrical grid has advanced rapidly, introducing high-voltage three-phase power systems, a significant portion of equipment, particularly AC motors, still depends on single-phase power sources. This study focuses on the design and implementation of an uncontrolled half-wave rectifier to convert three-phase electrical power for single-phase AC motor applications. The aim is to explore practical and efficient energy conversion solutions that can support rural communities where single-phase power systems remain prevalent. The analysis was conducted using the Proteus 8 Professional application to simulate and test the rectifier's performance under various conditions. To ensure a thorough understanding and reliable results, the research process included a preliminary online practicum using the PSIM application. By bridging three-phase power availability with single-phase motor requirements, this study contributes to addressing energy challenges in rural areas, supporting community empowerment, and enhancing productivity in underdeveloped regions.

Key Word: *Rectifier, 3 phase, Half Wave, 1 phase AC Motor*

I.INTRODUCTION

Power electronics has become increasingly significant with the advancement of technology, finding applications across diverse sectors, including industrial and household domains. Its implementation in electrical circuits has revolutionized various processes by enhancing efficiency and functionality[1]. The progress of science and technology plays a critical role in influencing developments in power electronics, making it an indispensable area of study in electrical engineering disciplines[2].

As technology evolves, the field of power electronics has become integral to academic curricula, particularly for students specializing in electrical power, insulation, and industrial control automation[3][4]. This course not only introduces theoretical concepts but also emphasizes their practical applications. It ensures that graduates acquire the knowledge and skills necessary to excel in the field.

The electricity supplied by the national grid (PLN) and most industrial power plants predominantly utilizes three-phase alternating current (AC)[5]. However, many electrical devices used in daily life require single-phase AC[6]. In this context, rectifiers play a vital role in converting three-phase AC into single-phase AC to meet these requirements.

Three-phase uncontrolled rectifiers offer distinct advantages over single-phase rectifiers. They generate direct current (DC) with significantly smaller wave ripples, resulting in a more stable output[7][8]. This characteristic reduces the need for large components or extensive filtering, making three-phase rectifiers more efficient for practical applications. These rectifiers are broadly classified into two types: half-wave and full-wave rectifiers, each with unique operational benefits.

This study examines the performance of a single-phase induction motor supplied with voltage converted from a three-phase AC source. The voltage is stepped down using a transformer and rectified through diodes before being fed into the single-phase motor. The investigation focuses on evaluating the impact of varying loads on the motor's voltage and rotational speed (RPM).

To ensure accurate measurements, the average values of voltage and RPM are recorded using the PSIM power simulation software. This approach simplifies data acquisition and provides reliable average measurement values.

By bridging theoretical knowledge with practical applications, this research not only contributes to advancements in power electronics but also addresses energy needs in communities where single-phase systems are prevalent. It underscores the importance of accessible and efficient energy solutions in supporting community development and improving livelihoods.

II.METHODOLOGY

The primary method employed in this study is a literature review, involving the collection of references from academic books and journal articles pertinent to the theoretical framework[9]. This step is crucial to provide a comprehensive foundation for the research. Subsequently, data collection is conducted using simulations to validate theoretical assumptions and analyze system performance under controlled conditions.

1. Material

a. Uncontrolled Rectifier Three Phasa Half Waves

The half-wave rectifier utilizing a bridge system consists of four current branches, each equipped with a diode[10]. During operation, the current flows through two branches simultaneously. Each diode carries an average of half the load current, enabling the circuit to utilize both alternating current (AC) waves from the transformer's output voltage.

The ripple factor of the direct current (DC) output in this configuration is similar to that observed in a half-wave rectifier using a center-tap transformer[11]. Additionally, the forward current during operation is twice the amplitude of the AC current pulse for each cycle of the AC voltage source[12]. This characteristic enhances the rectification process, making the bridge circuit a highly economical choice for rectifiers operating with a single-phase AC source.

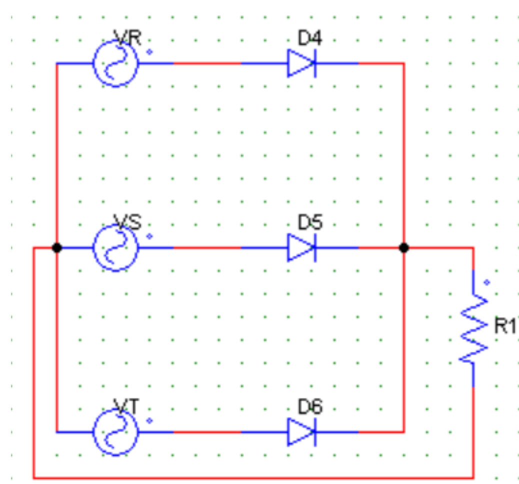

Figure 1. A Half-Wave Three Phasa Rectifiers with Resistor Loads

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Equation for DC Output and RMS can be seen below:

- The DC output voltage is:
  $Vo\ (dc) = 3\sqrt{3}V\ s(L-N)/2\pi$

  $Vo\ (dc) = 0{,}8274\ x\ V s \max (L-N)$

  $Vo\ (dc) = 1{,}17\ x\ Vs\ rms\ L-N$

- The output voltage rms is:
  $Vo(rms) = Vs\max\ L-N\ [\sqrt{3\pi}\ (3/2\pi + 1/2 \sin \sin 2\pi/3)]$

  $Vo\ (rms) = 0{,}841\ x\ Vs\max\ L-N$

  $Vo\ (rms) = 1{,}89\ x\ Vs\ rms\ L-N$

This study underscores the importance of leveraging efficient rectifier systems for practical applications, particularly in rural and underserved areas where energy access is often limited. By incorporating this advanced design into renewable energy solutions, communities can efficiently power essential devices, including single-phase AC motors, which are commonly used in agriculture, small-scale industries, and domestic applications. The reliability and cost-effectiveness of these rectifier systems make them an ideal choice for rural settings, where consistent and stable energy sources are critical to everyday activities.

Furthermore, the integration of such systems into local energy infrastructure promotes the use of affordable and sustainable energy technologies, reducing dependency on non-renewable energy sources and expensive alternatives like fuel-based generators. This approach aligns seamlessly with the broader objectives of community development and service, as it addresses the dual challenges of energy scarcity and economic constraints faced by rural populations. By empowering these communities with accessible energy solutions, this rectifier system design contributes to enhancing rural livelihoods, fostering economic growth, and improving overall quality of life.

b. Induction Motor

Induction motors are among the most commonly used electric motors in daily life, owing to their simplicity, durability, and ease of operation. Single-phase induction motors, in particular, are widely distributed and play a critical role in supporting various household and community activities [13][14]. Examples of their applications include fans, washing machines, and home water pumps devices.

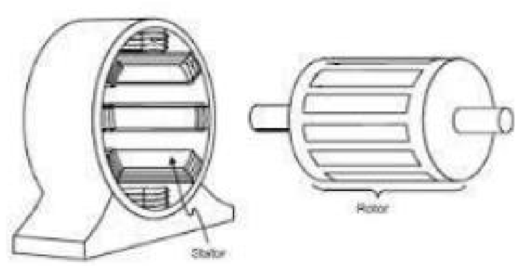

Figure 2. construction of a single-stroke ac motor

A single-phase induction motor consists of two main components: the primary winding (main coil) and the auxiliary winding (secondary coil), both of which are installed within the same slot of the motor structure [15]. These windings are designed to create a spatial separation of approximately 90 electrical degrees.

The primary (main) winding is constructed using copper wires with a larger cross-sectional area, which results in a lower impedance. Conversely, the auxiliary winding employs smaller-section copper wires with a greater number of turns, thereby producing a higher impedance.

The widespread use of single-phase induction motors highlights their significance in enhancing the livelihoods of communities, particularly in rural areas. Integrating these motors into energy-efficient systems powered by three-phase half-wave uncontrolled rectifiers offers an opportunity to address energy accessibility challenges[16]. Such applications can facilitate the deployment of cost-effective and reliable energy solutions for essential tasks, aligning with the goals of community service initiatives aimed at sustainable development.

c. Transformer

A transformer, commonly referred to as a "transformer," is a vital electrical component used to transfer electrical energy from an input to an output through the principle of electromagnetic induction. The amount of energy transferred is influenced by factors such as the frequency of the electrical current and the magnetic flux that passes through the core[17]. In this study, the transformer serves the primary function of lowering the voltage from a standard 220 volts to the desired level as specified in the observation table for the purpose of supplying power to various loads.

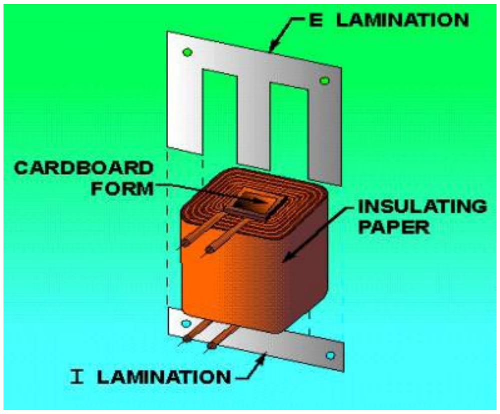

Figure 3. construction of the transformer

Transformers are essential components in electrical systems, particularly when adjusting voltage levels to meet the requirements of specific applications[18]. The process of lowering or raising the voltage is achieved through a combination of key transformer components that work in unison to ensure efficient energy transfer.

d. Diode (rectifier)

Diodes are fundamental electronic components categorized as passive components[19]. A diode consists of two distinct electrodes: the P-type and N-type semiconductors, which are essential for rectifying electrical current[20]. The junction between the P and N semiconductors allows current to flow in only one direction when subjected to alternating current (AC) [21][22]. This one-way flow property is central to the function of diodes in electrical systems. The P electrode is referred to as the anode, while the N electrode is called the cathode.

A rectifier, often used in electrical power conversion systems, serves to transform AC signals into direct current (DC)[23]. This process is essential for powering DC devices and providing stable electrical output in various applications. Rectifiers are typically classified into two main types: the half-wave rectifier and the full-wave rectifier.

In the context of rural community development, these rectifiers play a crucial role in the design and implementation of affordable energy solutions. For instance, half-wave rectifiers are commonly used in simpler electrical systems, such as single-phase motors, which are prevalent in rural industries and household applications. By converting AC power from the grid to a usable DC supply, these rectifiers enable the efficient operation of equipment like water pumps, fans, and small-scale machinery essential for daily life in rural areas.

III.RESULT & DISCUSION

In this experimental study, the input power source is a three-phase voltage with the following specifications: phase R at 220V, phase S at 220V, and phase T at 220V. This three-phase voltage is then stepped down using a transformer to reduced voltages of 110V and 50V. After the voltage is lowered, the current is directed through three rectifier diodes to convert the alternating current (AC) into direct current (DC). Following this, the rectified current is supplied to a single-phase AC motor.

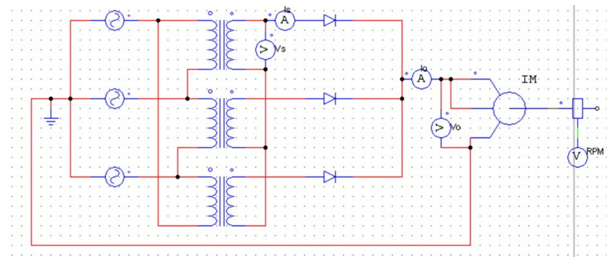

Figure 4. uncontrolled rectifier circuit of three half-wave phases to start the AC motor 1 stroke

Below is the table presenting the experimental results on starting a single-stroke AC motor. The data captures the motor's performance characteristics during the initial startup phase, providing valuable insights into its operational efficiency under various conditions. This experimental analysis is crucial for understanding the dynamics of single-stroke AC motors, which are commonly utilized in small-scale industrial and agricultural applications due to their reliability and simplicity.

The table serves as a foundational reference for evaluating the starting behavior of the motor, including parameters such as initial voltage, current draw, and any variations in rotational speed. Such details are vital for optimizing motor performance, ensuring energy efficiency, and addressing potential challenges in real-world deployment. By analyzing this data, it becomes possible to refine motor design and control systems, contributing to the development of more effective and sustainable energy solutions.

Table 1. Experiments on starting a single-stroke ac motor

Primary Voltage trafo (V)	Secondary Voltage trafo (V)	Is	Io	RPM
220	220	5.9499476e-016	9.71931393e-016	3.0624368e-048
220	110	2.6094035e-016	2.4290373e-016	4.3796693e-049
220	50	9.4682022e-017	1.2143727e-016	4.3527942e-050

Based on the data presented in the table above, where the transformer output voltage was adjusted to 220V, 110V, and 50V, a noticeable decrease in both current and RPM was observed. This reduction followed a direct proportional relationship with the drop in the transformer's secondary voltage. The simulation results obtained from these three variations in secondary transformer voltage are as follows:

When the transformer operated at a secondary voltage of 220V, the secondary current (Isl) was recorded at 5.95×10^{-16}A, and the output current (Io) was 9.72×10^{-16}A. The RPM under this condition was extremely low at 3.06×10^{-48}, indicating that while electrical energy was present, mechanical motion was negligible.

At a secondary voltage of 110V, Is decreased to 2.61×10^{-16}A, and Io reduced to 2.43×10^{-16} A, with an RPM value of 4.38×10^{-49}. Further reducing the secondary voltage to 50V resulted in the lowest current values, with Is at 9.47×10^{-17}A and Io at 1.21×10^{-16} A. The RPM under these conditions was recorded at 4.35×10^{-50}, confirming minimal mechanical activity.

The results demonstrate that decreasing the secondary voltage significantly impacts both the current and mechanical motion (RPM). The proportional relationship between voltage and performance highlights the dependency of mechanical and electrical outputs on the transformer's secondary voltage. This analysis emphasizes the importance of appropriate voltage selection in transformer applications to ensure desired system functionality.

- first simulation, with a fixed secondary transformer voltage of 220V, the system performance was evaluated.

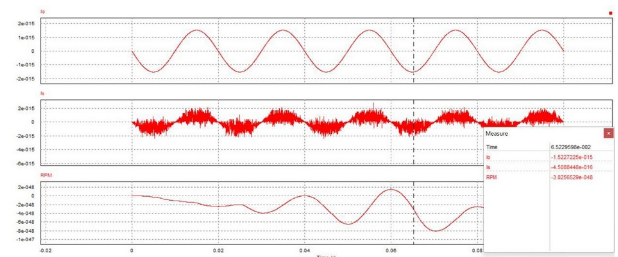

Figure 5. First experiment with a secondary voltage transformer of 220v

- Second simulation, with a secondary voltage transformer resistance of 110V.

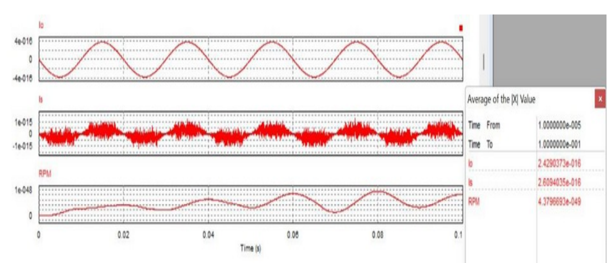

Figure 6. Second experiment with a secondary voltage transformer of 110v

- Third simulation, with a secondary voltage of the transformer resistance of 50V.

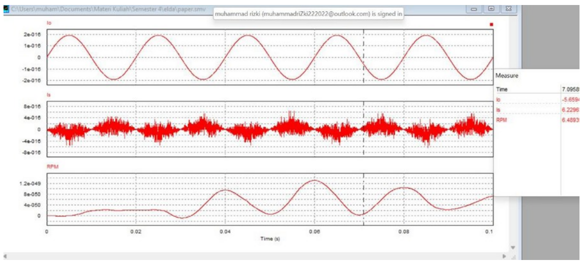

Figure 7. Third experiment with a secondary voltage of a 50v transformer.

IV.CONCLUSION

Here are the conclusions based on your analysis:

- RPM Decreases with Lower Voltage: The simulation results show a direct correlation between the applied voltage and the motor's rotational speed. As the input voltage is reduced, the RPM of the motor decreases accordingly. This behavior supports the fundamental relationship between voltage and motor speed.
- Adherence to Ohm's Law: The observed decrease in RPM with reduced voltage is consistent with Ohm's Law, where current is directly proportional to the applied voltage. As the voltage drops, the current through the motor is reduced, leading to a corresponding decrease in the motor's speed.
- Impact of Half-Wave Rectification: The use of an uncontrolled three-phase half-wave rectifier circuit to supply power to the motor results in a fluctuating DC voltage, which likely contributes to the variation in the motor's speed under different voltage conditions. This further emphasizes the influence of the power supply quality on motor performance.

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