Journal of Electrical, Marine and Its Application Technology **Vol. …...., No. …….**
ISSN xxxxxx **Publication Periode**

Effect of Thyristor on Speed Regulation of Single-Phase AC Motor with Frequency Parameter

Anggara Trisna Nugraha[1], Muhammad Hadi Cahyadi[2], Diego Ilham Yoga Agna[3], Moh. Ghafirul Pratama Aprilian Sugianto[4]
[1,2,3,4] Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya
[1] anggaranugraha@ppns.ac.id

Abstract

The use of an advanced motor speed regulator can provide several operational conditions for the motor, each offering different maximum values for the motor's output speed. This research investigates the effects of varying the number of pole pairs, external resistance controllers, armature input voltage, and the frequency converter of the power grid. Additionally, the study explores the incorporation of electronic components to enhance motor control. The integration of thyristor-based technology in speed regulation plays a crucial role in optimizing motor performance by improving the response time and efficiency under different operating conditions. Previous studies have highlighted the potential of electronic regulators in achieving better speed control and energy efficiency, with frequency modulation providing an innovative method for fine-tuning motor operation. By adjusting these parameters, the motor's speed and overall performance can be precisely controlled, leading to more efficient systems for industrial applications, especially in fields requiring high-speed precision. Furthermore, the study emphasizes the importance of frequency adjustments in the context of thyristor-controlled motors, providing valuable insights into energy optimization and performance enhancement.

Keywords: Speed, Current, Thyristor

1. Introduction

The rapid advancement of the industrial sector today is accompanied by the continuous development of cutting-edge technology, particularly in the field of electrical engineering. Induction motors, especially single-phase induction motors, are among the most widely used types in various applications, ranging from household environments to industrial settings (Atmojo & Aripriharta, 2013). The speed control of single-phase induction motors can be achieved using several methods, one of which is by regulating the input voltage. Traditionally, voltage regulation is performed using an autotransformer, which can be manually adjusted and is commonly referred to as a variable alternating current source, or "variac." However, with the advancement of power electronics, voltage control can now be efficiently implemented using power electronic devices (Kertiasih, 2017).

Series motors, often referred to as traction motors, have the advantage of providing high starting torque, which makes them suitable for applications such as elevators, electric trams, and other similar systems (Wisesa, 2020). Alternating current (AC) motors, which operate on alternating voltage, are widely used due to their versatility and compact size, making them ideal for both domestic and commercial applications. These motors operate in response to the load: under light load conditions, they run faster with low torque, while under heavy load conditions, they operate slowly but with higher torque. Nevertheless, speed regulation is required for certain applications (Putra & Rohman, 2021).

By integrating thyristors in series to regulate the voltage supplied to the motor, speed and torque control can be achieved. In motor speed control systems, thyristors are particularly useful due to their high power capacity, allowing large power motors to be controlled effectively using electronic circuits. The Triode for Alternating Current (TRIAC) is a common electronic component used in AC power control applications. TRIAC switches operate at high voltage levels and are suitable for both halves of the AC waveform (Suwarno, n.d.). Thyristors represent a class of power electronic components utilized in circuits such as converters, controlled rectifiers, and AC/DC voltage regulators, which can be applied in industrial settings. These components are commonly used in electric motor control (AC motor drives, DC motor drives), heating systems, and other power management applications (Hamid & Nurcahyo, 2008) .

The development of power electronics, particularly with the advent of thyristor technology, has led to the application of converters and inverters, representing a groundbreaking solution in electrical control systems. This technology offers an efficient, flexible, practical, and cost-effective method for controlling AC/DC voltage, as well as motor speed control/drives (Nurhayata, 2015). One of the most effective ways to stabilize electrical voltage is through the use of thyristors, which exploit the characteristics of wave cutting, providing a stable output voltage that automatically compensates for variations in the input voltage. The effectiveness of the system design in this study is compared with previous research, demonstrating its superior efficiency when implemented (Nurhayata, 2015). The goal of this paper is to review the effectiveness of the system, referring to the implementation of motor speed control regulators that create a simultaneous control system for motor speed, leading to optimized system performance. This paper highlights the selective nature of the system design, considering the different concepts, components, and designs applied in the system, and aims to identify the most efficient and applicable design for real-world motor applications (Saputra, 2014).

The purpose of this paper is to summarize the design concepts used in previous research, providing a foundation for more efficient system design. This article is structured using a literature review method, guided by a number of relevant scholarly journal sources. While comparing the different system designs and components used in the referenced journals, this article focuses on analyzing the core aspects of design efficiency, despite the differences in system configurations.

2. Material and methods

2.1. Universal Motor

A universal motor, as the name suggests, is an electric motor that operates on both alternating current (AC) and direct current (DC) sources due to its construction being similar to that of a series DC motor (Suhendra, 2014) . Carbon brushes are placed on the commutator's surface to facilitate the flow of current from the external power source into the motor's armature. When current flows into the armature, it generates a magnetic field, causing the armature to rotate between the magnetic poles located in the motor's stator. Nearly all universal motors are equipped with a cooling fan mounted at the shaft's end. The construction of a universal motor is shown in Figure 1.

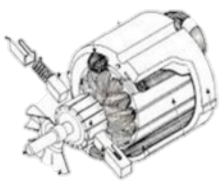


Figure 1. Universal Motor Construction

Universal motors are widely used in small to medium-sized electrical appliances such as vacuum cleaners, sewing machines, and similar devices. These motors can operate on both DC and AC power sources. The speed of a universal motor can be adjusted by using a rheostat, rectifier, or by changing the position of the carbon brushes that pass through the armature.

The universal motor has characteristics similar to that of a series motor. It operates at an average speed when the load is also average, and if the load is reduced, the speed increases. This motor behaves like a series DC motor, where, under light load conditions, it rotates at a high speed but produces a small torque. However, under heavy load conditions, the motor operates slowly with high torque. Therefore, the motor adjusts its speed according to the load connected to it. Such motors are commonly found in devices like blowers, sewing machine dynamos, drills, and mixers (Safrianti & Alpayadia, 2008) .

The speed control of a universal motor is achieved by regulating the voltage supplied to the motor. Since the universal motor is capable of operating on both AC and DC power sources, its speed can be controlled in two ways: by adjusting the AC voltage or by adjusting the DC voltage. The greater the voltage supplied to the motor, the higher its speed. Conversely, the lower the voltage, the lower the speed (Nurhayata, 2015).

The single-phase AC motor operates on alternating current and exhibits a reversal of current direction in both the field and armature at each half-cycle, which ensures that the direction of torque remains constant, allowing the motor to rotate in the same direction. While single-phase AC motors generally have lower performance and efficiency compared to their three-phase counterparts, they offer extensive use in smaller sizes, particularly in domestic and commercial environments (Hadidjaja, Setyawati, & Santoso, 2015).

DOI xxxxxx

The characteristics of single-phase AC motors include voltage drop, where the reactance of the field and armature absorbs part of the applied voltage. As a result, for a given torque and current, the counter-electromotive force (EMF) generated in the armature is lower, leading to reduced speed. Additionally, the magnetic circuit tends to saturate at the peak of the current waveform, which results in a smaller counter-EMF and, thus, a higher speed. In conclusion, since inductive reactance is directly proportional to frequency, the operating characteristics of an AC motor improve at lower frequencies.

2.2. One phase AC Motor

A single-phase AC motor operates on alternating current (AC) and experiences a reversal of current direction within the magnetic field and armature during each half-cycle. This reversal of current ensures that the direction of the generated torque remains constant, enabling the motor to continue rotating in the same direction (Safrianti & Alpayadia, 2008). While single-phase AC motors generally exhibit lower performance and efficiency when compared to their three-phase counterparts, they are widely used in smaller-sized applications, particularly in domestic and commercial environments where high power demands are not necessary Hadidjaja, Setyawati, & Santoso, 2015).

The advantage of single-phase motors lies in their simplicity and cost-effectiveness, which makes them suitable for a broad range of applications, including home appliances and small machinery. Despite having limitations in terms of efficiency and torque, the motor's ability to be used in compact systems makes it an essential component in many low-power electrical applications.

2.3. Thyristor

A thyristor, officially known as a Silicon Controlled Rectifier (SCR), is a crucial semiconductor device that plays a significant role in controlling and interrupting both small and large alternating currents (AC). The thyristor has the unique ability to convert alternating current (AC) to direct current (DC) and vice versa, which makes it versatile for various power control applications (Rahman & Nugraha, n.d.). The use of thyristors (SCR) in rectification and switching of electrical currents offers several advantages over mechanical switches, such as minimal energy consumption and reduced wear and tear since there are no physical contacts that can burn out, no arc formation, and minimal need for additional components.

Thyristors are made up of four alternating layers of N-type and P-type semiconductors, with three terminals: cathode, anode, and gate. The gate terminal allows for control of the current flow, enabling regulation of the output voltage. This makes thyristors highly effective as AC-to-AC voltage converters, which regulate the amount of voltage, current, and power supplied to the load from the AC source. When the load is a resistor, a simple schematic of a single-phase AC voltage regulator circuit can be used to depict its operation.

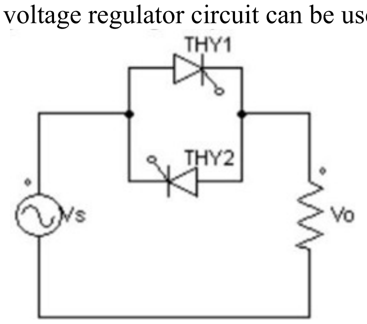


Figure 2. Single Phase AC Voltage Regulator Circuit with Resistor Load

The operation of a bidirectional triode thyristor (TRIAC) is symmetric, but electrically, it is asymmetric. It has three terminals: two main terminals (anode and cathode) and a gate terminal. TRIACs can block current flow in both directions between the two main terminals, and once triggered by the gate signal, they conduct in both directions until externally deactivated, similar to a unidirectional thyristor (Bahri & Mungkin, 2019). This characteristic allows the TRIAC to behave like two SCRs, each conducting in one direction.

The characteristics of TRIACs are typically symmetrical, as there is no significant difference between the forward and reverse characteristics. TRIACs are often referred to as bidirectional thyristors, consisting of five layers of semiconductors, and they are widely used in electronic switching circuits (Ruddianto et al., 2021). Unlike SCRs, which only conduct when a positive voltage is applied, TRIACs can be triggered by either positive or negative gate voltages, allowing for more flexible control. TRIACs are widely used in electronic switching and control circuits, activating when the anode is more positive than the cathode and when the gate is positively biased.

A thyristor inverter circuit is used to convert DC voltage into AC. Key components of the inverter circuit include transistors or thyristors. Using transistors limits the power capacity but eliminates the need for commutation circuits at high frequencies. In contrast, thyristors can handle higher power but require commutation circuits for low-frequency operation to interrupt the thyristor's conduction. In a typical thyristor inverter circuit, the thyristors (THY1 and THY2) are alternately triggered by signals from an astable multivibrator oscillator, as shown in the diagram. The commutation of the thyristors is achieved through a capacitor placed across the primary windings of a transformer. As the thyristors alternate between on and off states, the current flows alternately through the primary windings of the transformer, inducing an alternating current (AC) voltage on the secondary side. The frequency of the induced voltage can be adjusted by the oscillator controlling the gate signals for the thyristors (Utomo & Nugraha, 2021).

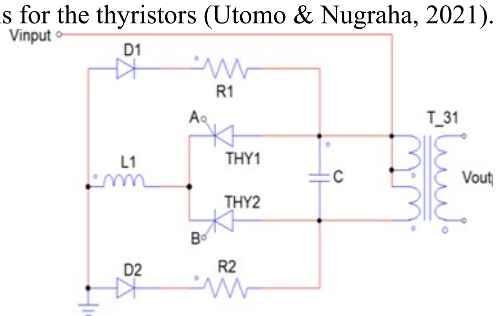


Figure 3. Thyristor Inverter

2.4. Full wave rectifier

A rectifier is an electronic circuit designed to convert alternating current (AC) into direct current (DC). This conversion process typically involves the use of diodes, which are semiconductor components that allow current to flow in one direction only. For AC voltage rectification, a full-wave rectifier circuit is commonly used, which is often implemented using a bridge rectifier configuration consisting of four diodes arranged in a bridge formation (Nugraha & Safitri, 2021). This type of rectifier is highly efficient as it utilizes both halves of the AC waveform, providing a smoother and more consistent DC output (Priyambodo & Nugraha, 2021).

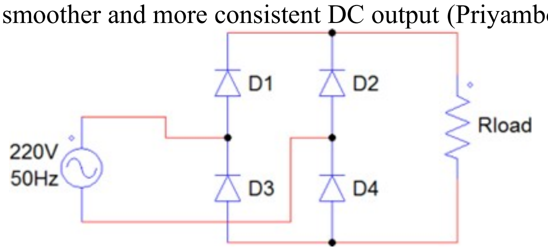
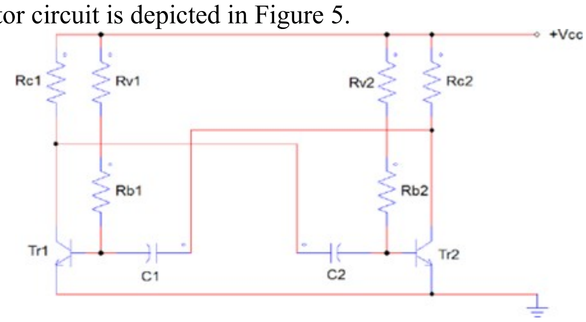


Figure 4. Full Wave Rectifier Circuit

The schematic of a full-wave rectifier, as shown in Figure 4, illustrates the arrangement of the diodes in a bridge rectifier configuration. This design allows for the rectification of the entire AC input, improving the overall efficiency and effectiveness of the power conversion process.

2.5. Astable Multivibrator Oscillator

An astable oscillator is an electronic circuit designed to function as a pulse wave generator. Unlike stable oscillators, an astable oscillator has no stable state and continuously switches between two states—saturation (ON) and cutoff (OFF) (Nugraha & Eviningsih, 2022a). This type of circuit, often implemented as a multivibrator, is fundamental in applications requiring continuous pulse or clock signals. The schematic of an astable multivibrator oscillator circuit is depicted in Figure 5.



Journal of Electrical, Marine and Its Application Technology **Vol. …...., No. …….**
ISSN xxxxxx **Publication Periode**

Figure 5. Astable Multivibrator Oscillator Circuit

In this circuit, transistors Tr1 and Tr2 alternate between ON (saturation) and OFF (cutoff) states. The continuous toggling between these states generates a pulsating voltage signal at the collectors of both transistors (Nugroho, Facta, & Sukmadi, 2015). The time interval during which each transistor transitions between ON and OFF states is referred to as the time constant of the oscillator. This time constant is a crucial parameter that determines the frequency of the output signal.

2.6. PSIM

The Power Simulator (PSIM) is a specialized computer software designed for modeling, designing, and simulating various power electronics circuits and motor control systems (Purwanto, Martanto, & Sutikno, n.d.). It serves as an essential tool for researchers and engineers in the field of electrical and electronic engineering, providing accurate simulation capabilities for analyzing power converters, designing control loops, and developing motor control strategies. PSIM includes a wide range of electronic components and modules that enable users to design and optimize circuits efficiently.

2.7. Schematic Circuit

In the design of a single-phase motor speed regulation system, the PSIM software was utilized as the primary simulation tool. This simulation framework was employed to model and analyze the performance of a full-wave rectifier circuit, an astable oscillator, a thyristor-based inverter, a center-tapped transformer, and a single-phase squirrel-cage induction motor (Nugraha & Eviningsih, 2022b). The simulation aimed to explore the dynamic interaction between these components and the effect of frequency parameters on motor speed regulation.

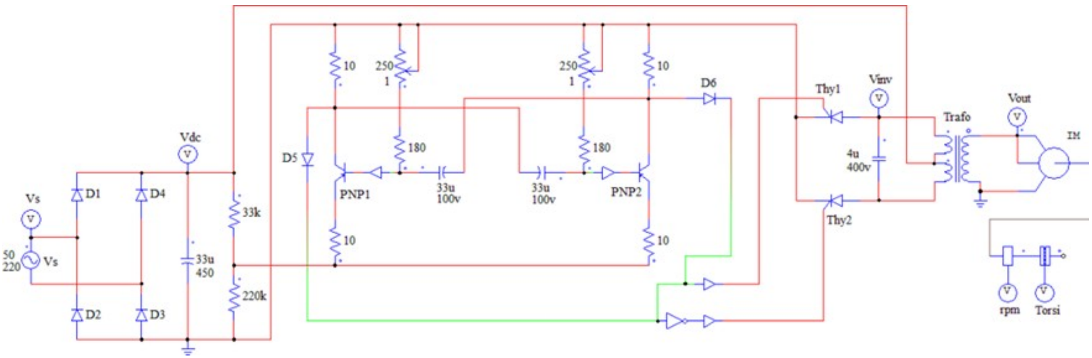


Figure 7. Circuit Design for Single-Phase Motor Speed Regulation with Frequency Parameters

The inverter circuit plays a critical role in converting DC voltage to AC voltage. This conversion is achieved through the alternating ON and OFF operation of silicon-controlled rectifiers (SCRs), which are triggered in sequence to produce the desired AC waveform. The switching of SCRs is controlled by a commutator circuit, comprising a 4 µF/400V capacitor connected in parallel with the primary winding of the transformer. This arrangement ensures efficient energy transfer and stabilization of the output AC signal.

2.8. Methods

The speed regulation system for the motor in this research was tested using Power Simulator software through four sequential stages of circuit design and simulation.

In the first stage, a full-wave rectifier circuit was constructed using four diodes and a source voltage of 220 volts. This rectifier served to convert the alternating current (AC) input into a direct current (DC) output, providing a stable power supply for subsequent stages.

In the second stage, an astable multivibrator oscillator circuit was designed. The primary function of this circuit was to prevent reverse induction currents generated by the thyristor, ensuring stable and efficient operation of the power regulation system.

The third stage involved the creation of an inverter circuit specifically tailored for thyristor-based control. The inverter was designed to reduce the power and frequency of the system, enabling precise control over the AC signal delivered to the motor. This step was critical for modulating the speed and torque output.

DOI xxxxxx

Finally, in the fourth stage, an installation circuit for a single-phase squirrel-cage induction motor was developed. This circuit allowed for the measurement and analysis of output torque and motor speed, providing valuable data to evaluate the system's performance under varying frequency and load conditions.

3. Results and discussion

3.1. Motor Speed Control Circuit Integration

After making all the circuits, the next step is to assemble the three circuits and simulate to determine the effect of adding thyristors on the output voltage value resulting from the circuit that has been made.

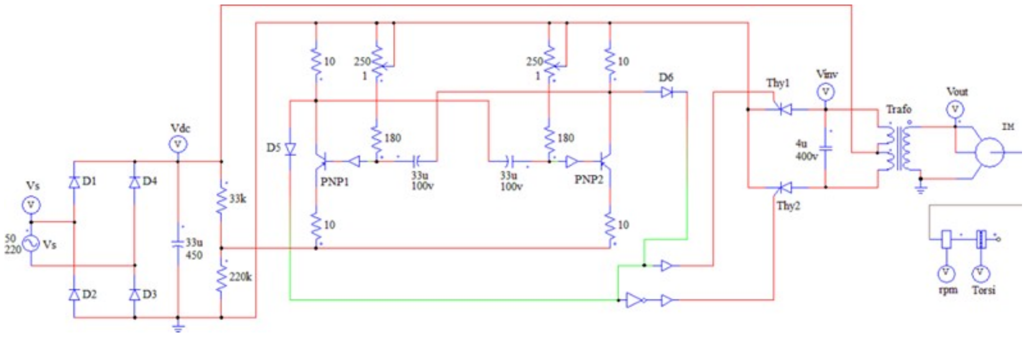


Figure 8. Single phase motor rotation control circuit with frequency parameters

Based on the results of data from a series of single-phase motor rotation settings with frequency parameters, several discussions were obtained regarding the experimental results of the circuit. The voltage that flows before passing through the full wave rectifier circuit can be seen in Figure 9.

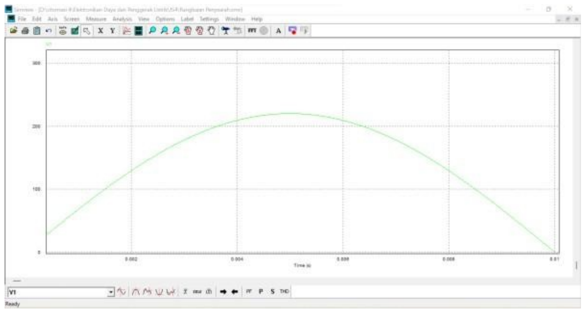


Figure 9. Wave appearance before passing through the wave rectifier circuit

Next is the measurement of the voltage wave after passing through the full wave rectifier circuit which can be seen in Figure 10 and continues with the wave measurement results for the inverting voltage which can also be seen in Figure 11.

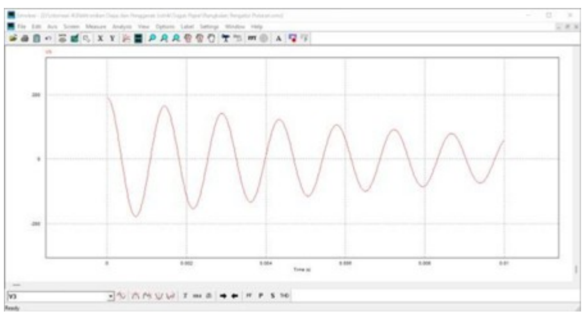


Figure 10. V3 Voltage waveform display

DOI xxxxxx

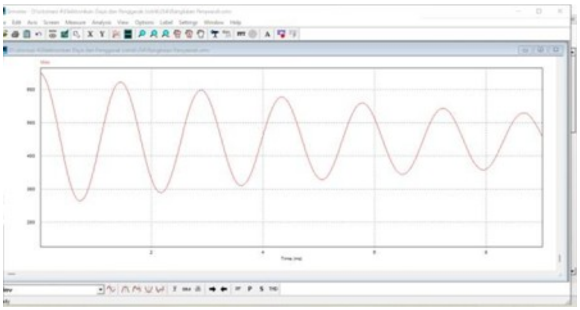


Figure 11. Inverting Voltage waveform display

Then the results of the waves produced by the speed sensor and torque sensor can be seen in Figure 12 and Figure 13. The use of the speed sensor and torque sensor is used to make it easier to practice reading the output voltage produced by the circuit on the motor being used.

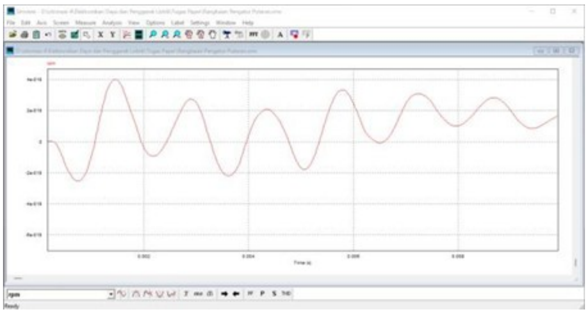


Figure 12. Rpm sensor voltage wave display

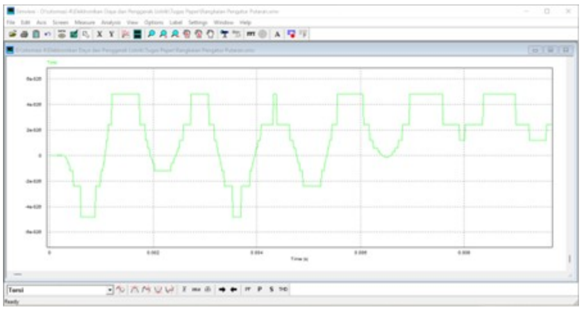


Figure 13. Torque sensor voltage wave display

The voltage wave generated in the circuit produces a constant and stable wave. Based on the analysis carried out. Based on the analysis carried out, it can be concluded that testing for starting a single-phase capacitor motor has functioned and worked well for energy savings and is also used to control the rotation speed of a single-phase capacitor motor. It can be concluded that the thyristor is able to control a voltage well and effectively. The load output voltage regulator is controlled by setting the TRIAC trigger angle. The use of semiconductor equipment to control the speed of a single-phase AC motor has several advantages. The application of a single-phase motor is highly recommended because it can be used for direct current (DC) or alternating current (AC).
To find out the rms value of the output voltage from this circuit, you can find it using the following formula:

$$V_{o(rms)} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi} [V_m \sin(\omega t)]^2 \, d(\omega t)}$$

$$V_{o(rms)} = \frac{V_{s(max)}}{\sqrt{2}} \sqrt{\frac{1}{\pi}\left[(\pi - \alpha) + \frac{\sin(2\alpha)}{2}\right]}$$

$$V_{o(rms)} = V_{s(rms)} \sqrt{1 - \frac{\alpha}{\pi} + \frac{\sin(2\alpha)}{2\pi}}$$

Where:
$Vm = Vrms \times\sqrt{2}$
$Vm = 30\times\sqrt{2}$
$Vm = 42{,}43V$

DOI xxxxxx

Then, after obtaining the theoretical calculation results, it is continued with a comparison of the comparison and experimental results in the PSIM software. The comparison results can be seen in the comparison table, namely table 1.

Table 1. Comparison of Theory Results with Experimental Results

	Vrms	**Irms**
Theory	1,85 Volt	0,457 A
Practical	1,86 Volt	0,461 A
Precent Error	0,01%	0,04%

The table compares the Vrms (effective voltage) and Irms (effective current) values in two conditions: theoretically and practically. Apart from that, the table also lists the percent error values between theoretical and practical values.

4. Conclusion

- High agreement between theory and practice
  The percent error values are very small for both Vrms and Irms, namely 0.01% and 0.04%, indicating that the practical results are almost identical to the theoretical values.
- Voltage is more consistent than current
  The percent error value for Vrms is smaller than Irms, indicating that voltage measurements are more accurate than current.
- Reliability of measurement methods or tools
  Very small differences between theoretical and practical results reflect that the theoretical calculation methods and measurement tools used are quite reliable.

Credit authorship contribution statement

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

References

H. N. Atmojo and Aripriharta, "Pengaturan Kecepatan Motor Induksi Satu Fasa dengan Metode Burst Firing," J. Tekno, vol. 20, pp. 13–16, 2013.

N. W. Kertiasih, "Seminar Internasional , ISSN 1907-2066 Seminar Internasional , ISSN 1907- 2066," Pap. Semin. Sist. Inf. Manaj., no. 232, pp. 1307–1312, 2017.

T. Wisesa, "Perancangan Pengaturan Kecepatan Motor Induksi Satu Fasa dengan PWM Menggunakan Pengendali PID Berbasis Arduino," pp. 1–49, 2020.

A. D. Putra and M. Rohman, "Analisis perancangan service special tools shock absorber dengan generator ac menggunakan finite element methods Analysis of the design of service special tools shock absorber with ac generator using finite element methods," vol. 9, no. 1, pp. 1–14, 2021.

D. U. Suwarno, "Visualization of Rectified Sine Waves and Triggering Angles on Thyristor Using Geogebra," pp. 62–68.

M. A. Hamid and E. Nurcahyo, "Pembuatan harmonic filter pada motor induksi 3 fasa menggunakan thyristor anti-paralel di laboratorium konversi energi elektrik itn malang," Pros. Semin. Nas. Teknoin 2008 Bid. Tek. Elektro, vol. 20, no. 1, pp. 43–49, 2008.

I. G. Nurhayata, "Sistem Pengaturan Kecepatan Motor Universal Satu Fasa Dengan Metode Kontrol Sudut Fasa Berbasis Mikrokontroler At89S52," J. Pendidik. Teknol. dan Kejuru., vol. 12, no. 1, 2015, doi: 10.23887/jptk.v12i1.4902.

R. Saputra, "Rancang Bangun Alat Pengatur Kecepatan Motor Induksi Satu Fasa Melalui Pengaturan Frekuensi Menggunakan Multivibrator Astable," pp. 1–38, 2014.

D. Suhendra, "Perancangan alat pengontrolan frekuensi dalam pengaturan kecepatan motor induksi satu fasa menggunakan kontrol pid," 2014.

E. Safrianti and O. Alpayadia, "Alat Penstabil Tegangan Bolak-Balik satu fasa 220 V , 50 Hz Menggunakan Thrystor Dengan Daya 1 , 5 kVA," vol. 9, no. 1, pp. 1–7, 2008.

D. Hadidjaja, O. Setyawati, and D. R. Santoso, "Analisis Pengaturan Putaran Motor Satu Fasa dengan Parameter Frekuensi Menggunakan," J. EECCIS, vol. 9, no. 2, pp. 157–162, 2015, [Online]. Available: http://jurnaleeccis.ub.ac.id/index.php/eeccis/article/view/398.

Y. A. Rahman and D. W. Nugraha, "EFEK PENGGUNAAN SCR MOTOR CONTROLLER UNTUK PENINGKATAN EFISIENSI PADA MOTOR INDUKSI TIGA FASA."

Z. Bahri and M. Mungkin, "Penggunaan SCR sebagai alarm peringatan dini pada saat terjadi gempa bumi," JET (Journal Electr. Technol., vol. 4, no. 3, pp. 101–105, 2019.

Ruddianto, Ruddianto, et al. "The Experiment Practical Design of Marine Auxiliary Engine Monitoring and Control System." Indonesian Journal of Electronics, Electromedical Engineering, and Medical Informatics 3.4 (2021): 148-155.

Utomo, Agung Prasetyo, and Anggara Trisna Nugraha. "Speed Adjustment on Variable Frequency Induction Motor Using PLC for Automatic Polishing Machine." Indonesian Journal of Electronics, Electromedical Engineering, and Medical Informatics 3.2 (2021): 70-75.

Nugraha, Anggara Trisna, and Lailia Nur Safitri. "Optimization of Central Air Conditioning Plant by Scheduling the Chiller Ignition for Chiller Electrical Energy Management." Indonesian Journal of Electronics, Electromedical Engineering, and Medical Informatics 3.2 (2021): 76-83.

Priyambodo, Dadang, and Anggara Trisna Nugraha. "Design and Build A Photovoltaic and Vertical Savonious Turbine Power Plant as an Alternative Power Supply to Help Save Energy in Skyscrapers." Journal of Electronics, Electromedical Engineering, and Medical Informatics 3.1 (2021): 57-63.

Nugraha, Anggara Trisna, and Rachma Prilian Eviningsih. Penerapan Sistem Elektronika Daya: AC Regulator, DC Chopper, dan Inverter. Deepublish, 2022.

F. Nugroho W, M. Facta, and T. Sukmadi, "Perancangan Modul dan Perbandingan Metode Starting dan Pengaturan Kecepatan Motor Induksi 3 Fasa," Transient, vol. 4, no. 1, pp. 58–68, 2015. J. Purwanto, A. Martanto, and T. Sutikno, "Pengendali Motor Induksi Satu Fasa," pp. 93–100.

Nugraha, Anggara Trisna, and Rachma Prilian Eviningsih. Konsep Dasar Elektronika Daya. Deepublish, 2022.