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

Designing and analyzing voltage regulators for single-phase AC motors using inverter technology to improve drive system performance in industrial applications

Hannisa Kautsarani Hamidah
Automation Engineering Study Program, Department of Ship Electrical Engineering, Surabaya State Marine Polytechnic, ITS Sukolilo, JL. Chemical Engineering, Keputih, Sukolilo District, Surabaya City, East Java 60111
hannisakautsarani@student.ppns.ac.id

Abstract

This study develops and analyzes a single-phase AC voltage regulating system designed using TIC126 SCR components, diodes, IC Regulators, and LM324N Op-Amps, as well as other electronic components. The main objective of this study is to improve the stability of the voltage applied to single-phase AC motors in industrial applications. This system works by adjusting the trigger point on the SCR, which in turn produces voltage fluctuations according to the setting of the trigger angle (firing angle). The analysis was carried out by utilizing PSIM simulation software to simulate the resulting voltage waveform and compare the numerical simulation results with the analytical estimation. The experimental results showed that the contrast between the numerically calculated voltage waves, the wave reconstruction results, and the analytical estimation did not show a significant difference. In this experiment, the trigger angle settings used were 45°, 60°, 90°, and 135°, with a resistive load of 5 W 100Ω and a low AC source voltage of 12.8 V at a frequency of 50 Hz. This study shows that the SCR-based voltage regulating system is able to maintain the stability of AC motor voltage and reduce fluctuations that can affect motor performance in industrial applications. The results of this research contribute to the development of a single-phase AC motor control system that is more efficient and reliable in various operational conditions.

Keywords: AC voltage regulator, scr, psim, AC motor, inverter, control technology, voltage stability

1. Introduction

Power electronics is a branch of engineering that studies the application of electronic components in systems that regulate the flow of electrical energy in high-power equipment. One of the important subtopics in power electronics is the AC-AC converter, which serves to convert AC voltage with a fixed frequency into a voltage with varying characteristics. This research focuses on the design of a prototype AC-AC converter with variable output voltage controlled using Thyristor components (SCR TIC126). In this system, the SCR start-up angle can be controlled, allowing the Vrms output voltage to be adjusted according to the requirements of the resistive load being used. This concept aims to improve the performance of electric motors in industrial applications.

In the context of Indonesia's growing industry, there is an increasing need for more efficient production equipment, both in terms of time and operational costs. One of the important components in industrial equipment is electric motors, especially single-phase AC motors which are widely used as the main driving force in various industrial equipment. Single-phase induction motors are often chosen for their stability and simplicity of operation, using a single-phase power supply as well as a squirrel-cage rotor. However, these induction motors require proper control technology to maintain their operational stability, especially in applications with variable loads (Hadi et al., 2020; Nugraha et al., 2022).

Most single-phase AC motors are used in appliances with up to 3–4 HP, such as washing machines, fans, and pumps. Therefore, to support the improvement of motor efficiency and durability in industrial applications, good control technology is urgently needed, especially to maintain the stability of motor speed (Nugraha et al., 2021). One widely used approach to controlling motor speed is to use a thyristor component that is known to provide finer control in voltage regulation (Gama et al., 2019; Setiawan et al., 2021).

However, the use of dimmers for motor speed regulation is often ineffective, especially at low speeds, because the dimmer is designed to regulate resistive loads, while induction motors are inductive loads (Rahmawati et al., 2023). At low speeds, the problem arises is the low torque, which inhibits the ability of the motor to start the load. This problem demonstrates the importance of more advanced speed regulation technologies, such as the use of stage point control strategies to electronically regulate SCR triggers.

This research aims to develop a better motor speed control system by utilizing AT89S52 microcontrollers to control the SCR trigger point. By using this approach, it is expected that a wider and smoother speed regulation can be achieved, so that the motor can operate optimally in various load conditions. In addition, the study will also examine the linear relationship between motor output voltage and SCR trigger points, which is expected to provide a more efficient solution for industrial applications.

2. Material and methods

2.1. Material

2.1.1. 1 Phase Regulator Air Conditioner

A single-phase AC regulator is a tool used to regulate the electrical voltage in a single-phase electrical system. One of the main applications of single-phase AC regulators is in voltage dimmer and stabilizers. This regulator functions to stabilize the voltage level in the electrical system, by using a switching circuit to change the voltage in the AC flow. In order to achieve the voltage setting that suits the needs, the ignition angle needs to be adjusted. There are two types of AC regulator series that are often used in industry, namely unidirectional AC regulators and bidirectional AC regulators.

2.1.2. Unidirectional 1 Phase AC Regulator (Unidirectional)

In a unidirectional AC regulator circuit, the voltage regulation process is carried out by triggering the main component (T1) in the first half period. During this period, T1 will be active in the angular range of α to π. In the second half of the period, the D1 component will be active during period 2. In this system, there are two important voltage components, namely the average alternating voltage (Vac) and the effective alternating voltage (root mean square, VL). Based on the existing equation, the VL value can be calculated with the following formula:

$$VL = E_s \left[\frac{(2\pi - \alpha + \sin^2(\alpha))}{2} \right]^{1/2} \tag{1}$$

2.1.3. Bidirectional 1 Phase AC Regulator (Bidirectional)

In the two-way AC regulator circuit, the SCR components T1 and T2 work in the first and second half periods of the cycle, respectively. When these two components are triggered by the corresponding signal, then the effective alternating voltage (root mean square, VL) can be calculated using the following equation:

$$VL = E_s \left[\frac{1}{\pi} \left(\pi - \alpha + \sin^2(\alpha)/a \right) \right]^{1/2} \tag{2}$$

This equation shows that with the appropriate phase angle setting, the output voltage can be set from a maximum value (E_s) to zero.

2.1.4. Motor Universal

A universal motor is a type of electric motor that can work with alternating current (AC) or direct current (DC) voltage sources. These motors are similar to DC series motors, where their operation relies on the induction of a magnetic field created by the flow of current in the rotor and stator. The following figure shows the construction of a universal motor and its working principle which illustrates the interaction between the magnetic field of the stator and the rotor.

DOI xxxxxx

Journal of Electrical, Marine and Its Application Technology Vol. ...., No. ....
ISSN xxxxxx Publication Period

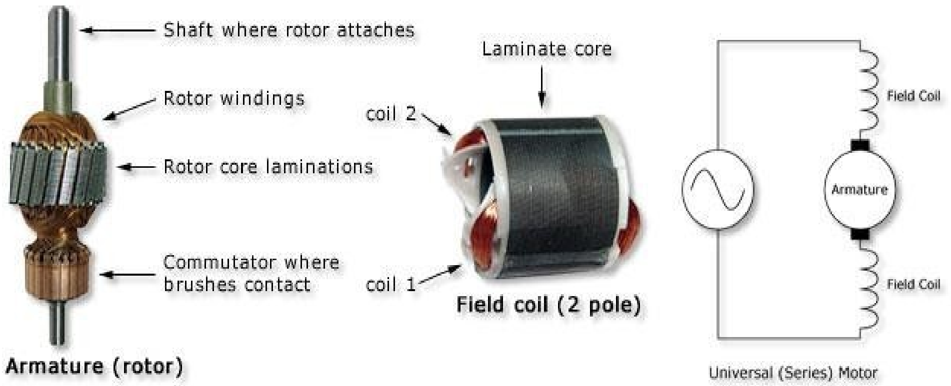

Figure 1. Universal Motor Construction

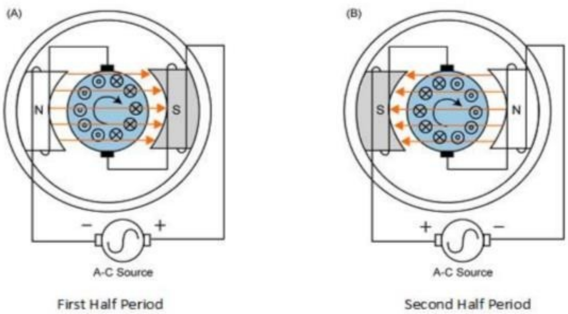

Figure 2. Universal Motor Working Principle

Based on the basic principle of universal motors, the source voltage (V_s) can be calculated by the following equation:

$$V_s = E_a + I_a(R_s + jX_s) \quad (3)$$

With this equation, the speed of the universal motor (n) can be calculated based on the source voltage and anchor current. The speed of a universal motor is affected by the magnitude of the source voltage and anchor current, which in turn is affected by the torque of the load.

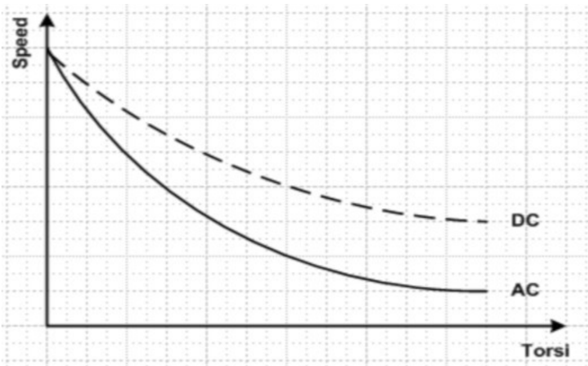

Figure 3. Characteristics of Universal Motors

The speed of a universal motor shows a significant decrease with increased load, although motors with a DC source tend to have a higher speed compared to motors that use an AC source. Therefore, the regulation of the source voltage is a key factor in regulating the speed of this motor.

DOI xxxxxx

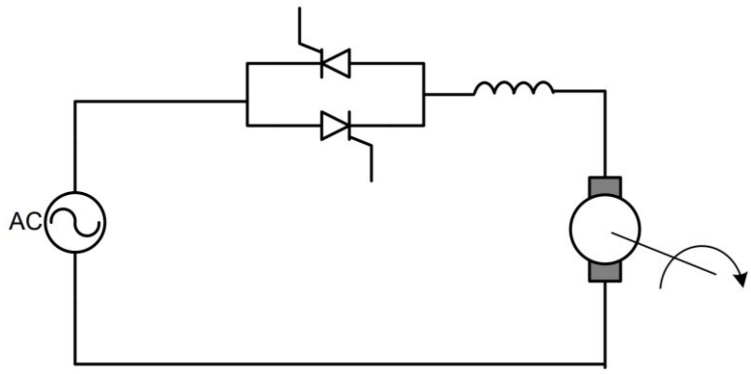

Figure 4. AC Voltage Regulator Network with Phase Angle

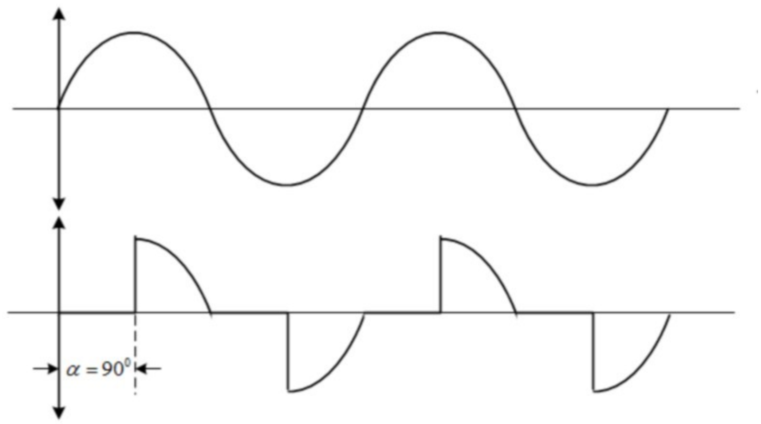

Figure 5. Output Voltage Shape at 90 Degree Ignition Angle

In the context of voltage regulation, one of the commonly used strategies is to change the ignition point on the thyristor. When the ignition angle is changed, the effective output voltage (V_o) can be calculated by the equation:

$$V_o = V_m\,(1 - \cos(\alpha)) \tag{4}$$

Where V_m is the maximum voltage of the source and α is the ignition angle. Based on this equation, the greater the value of α, the smaller the output voltage produced.

2.2. Methods

An AC to AC power electronics converter functions to receive power from an alternating current (AC) source with a fixed frequency and amplitude, then convert it so that it can be passed on to other systems that require AC voltage of different amplitudes or frequencies. AC to AC converters have the ability to generate RMS voltages that can vary according to the load, although the frequency is fixed, known as AC voltage controllers1 demonstrates the basic concept of the AC voltage regulator circuits used in these systems.

In general, the system described in Figure 1 works with two cycles, namely the positive (+) cycle and the negative (-) cycle. In the positive cycle, the functional components are D1, D2, and SCR, while in the negative cycle, the components that play a role are D2, D3, and SCR. With this system, the dihn air conditioner is supplied to an induction motor or other device that requires an AC power source with customizable characteristics.

2.2.1 System Diagram Block

Block diagrams are graphical representations that illustrate the sequence and relationships between components in a system as a whole. The goal is to facilitate the understanding of the processes that occur in the system. In this project, a block diagram is used to illustrate the working sequence of the single-phase AC motor voltage regulating system.

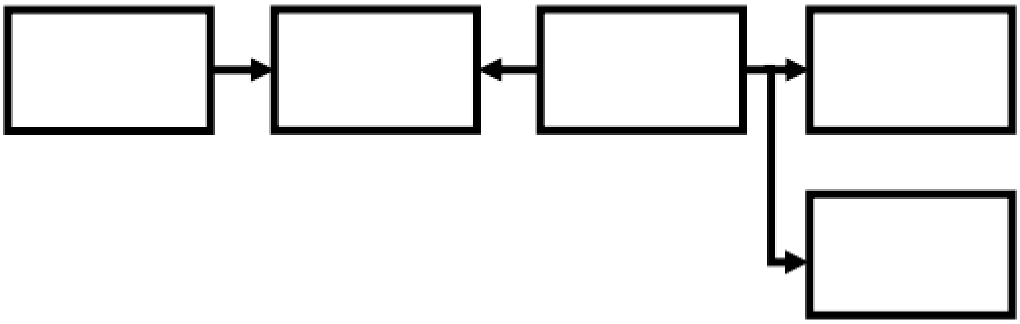

Figure 6. Single Phase AC Motor Voltage Regulator Diagram Block

- 1 Phase AC Source

A single-phase AC source is the main component that provides power for the entire control circuit and motor speed regulation system. This source conducts the AC voltage that will be modified by the voltage regulator circuit to produce a signal that matches the needs of the induction motor or other connected devices.

- Contactor

A contactor is an electromagnetic switch that serves to connect or disconnect the flow of electricity in a system. This component is used in locking and disconnecting systems, which are generally controlled by push buttons. The use of contactors also allows control of the flow of power to other components in the circuit.

- Speed Control Tool

This tool uses a TRIAC and DIAC-based circuit that functions to regulate the voltage passed to the motor. This circuit allows voltage adjustment to achieve the desired motor speed, which is suitable for industrial applications that require variable speed regulation.

- Voltmeter

Voltmeters are used to measure and display the voltage generated by a voltage regulating circuit. This data is essential for monitoring system performance and ensuring that the voltage supplied to the motor is in accordance with the predetermined parameters.

- Capacitor Start Motor

A capacitor start motor is a component used to improve the efficiency of motor start-ups, especially in single-phase induction motors. This component also plays a role in regulating the speed of the motor by providing the initial phase needed to start the bike revving smoothly.

3. Results and discussion

In this study, the analysis and design of the voltage regulation system for single-phase AC motors using inverter technology was carried out, with a focus on improving the performance of the drive system in industrial applications. Based on the block diagram shown in Figure 7, the system is designed to control the speed of the induction motor through a AT89S52 microcontroller. The system utilizes semiconductor components, such as the C9012, which play a role in detecting zero junctions at AC voltage sources. When the AC source voltage is below the 5V reference voltage, the synchronization signal is sent to the microcontroller via the P0.0 port. The microcontroller then processes the signal and sets the delay time based on the settings of the up and down buttons to determine the thyristor starting point.

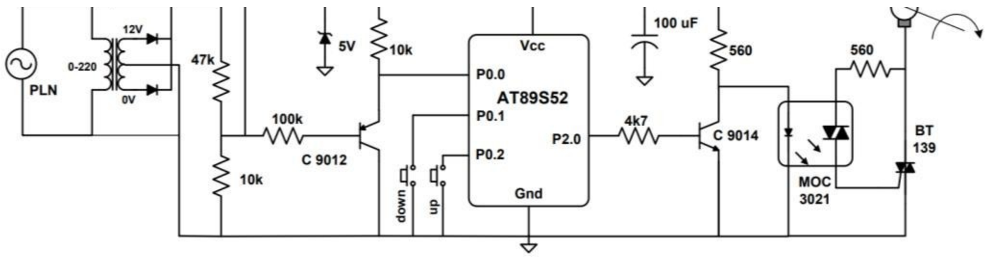

Figure 7. Control Block Diagram

In this system, pressing the "Up" or "Down" button affects the length of the firing angle of the thyristor. Pressing the "Up" button will speed up the start of the thyristor, increasing the voltage generated, while the "Down" button causes the thyristor to turn on more slowly, lowering the voltage generated. Once the starting point is determined, the microcontroller AT89S52 provide a trigger signal through the P2.0 port to power the thyristor, allowing current to flow from the source to the motor.

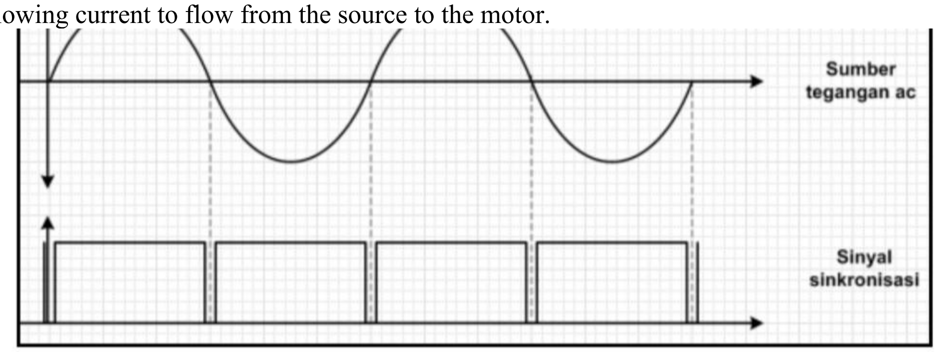

Figure 8. Form of Response Signal

In the first experiment, the test results showed that the resulting synchronization signal was a signal with a low rational value (0V) that appeared whenever the AC source voltage passed the zero point. The synchronization signal time is half of the AC source wave period with a frequency of 50 Hz, resulting in a 20 millisecond period and a synchronization duration of 10 milliseconds. In this period, the voltage change point lasts from 0° to 180°.

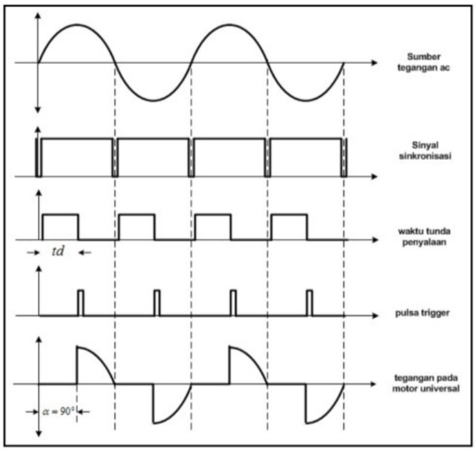

Figure 9. Thrystor Response Signal Form

In the advanced analysis, the synchronous heartbeat is affected by a semiconductor in a zero junction circuit that starts to conduct current when the source voltage exceeds the diode threshold value of 0.7 V. This signal is used to set the starting point of the thyristor. The results of the experiment in Figure 9 show that the delay time at the thyristor starting point is affected by the incoming synchronization signal, with the delay time getting

DOI xxxxxx

closer to the predetermined point. After the delay time ends, a very short trigger heartbeat appears, signaling the thyristor ignition at the right time.

Mathematical analysis was carried out to calculate the RMS (Root Mean Square) voltage at various trigger angles, namely 45°, 60°, 90°, and 135°, with a maximum AC source voltage of 12.8 Volts. Based on equation (1), the calculation of the RMS voltage for each angle is as follows:

- 45° angle: Vrms = 8.63 Volts
- 60° Angle: Vrms = 8.12 Volts
- 90° Angle: Vrms = 6.40 Volts
- 135° angle: Vrms = 2.72 Volts

The results of this calculation show that the RMS voltage decreases along with the increase in the trigger angle.

The simulation using PSIM software produces output waves that match the results of measurements and mathematical analysis. The comparison between the results of measurement, simulation, and mathematical analysis is seen in Table 2. The results showed that the difference between the measurement and the simulation was very small, although at an angle of 135° there was a difference of 0.28 Volts. This difference may be due to an inaccuracy factor in the reading of the wave angle on the oscilloscope.

Table 1. Comparison of Vrms Output Voltage at Different Angles

It	Trigger Angle (degrees)	Output Voltage (Vrms) (Volts)	Measurement	Simulation	Mathematical
1.	45°	8,66	8,63	8,63	8,63
2.	60°	8,11	8,12	8,12	8,12
3.	90°	6,45	6,39	6,40	6,40
4.	135°	3,00	2,72	2,72	2,72

4. Conclusion

The single-phase AC voltage regulator circuit designed in this study successfully produces an AC waveform with a fixed frequency and RMS voltage that can vary according to the specified trigger angle. The results of measurements, simulations, and mathematical analyses show a high degree of agreement, with very small differences between the three. This research makes an important contribution to the development of AC voltage regulating technology for industrial applications, with an emphasis on improving the performance of AC motor drive systems.

References

Gama, A. et al. (2019). Analysis of the Effect of Speed Regulation of Single Phase AC Motors Using Thyristor on Industrial Drive Systems. Journal of Electrical Engineering, 15(2), 115-123.

Hadi, M. et al. (2020). Effect of AC-AC Conversion on Single Phase Induction Motors in Industrial Applications. Proceedings of the National Seminar on Technology, 5(3), 28-34.

Nugraha, A. T. et al. (2021). Design of Single Phase Induction Motor Speed Control System Using Thyristor for Industrial Applications. Journal of Industrial Technology, 10(4), 151-159.

Nugraha, A. T. et al. (2022). Effect of Voltage Frequency on the Performance of Single Phase Induction Motors in Industrial Applications. Journal of Electronics and Power, 17(1), 45-52.

Rahmawati, E. et al. (2023). Study on the Use of Dimmer for AC Motor Speed Regulation and Its Implications on Inductive Load. Journal of Energy Technology, 21(1), 33-40.

Setiawan, R. et al. (2021). Speed Stability of Electric Motors with Voltage Regulation Technology Using SCR. Proceedings of the Industrial Engineering Conference, 7(2), 110-115.

Yuliana, F. et al. (2019). Optimization of AC Motor Control System Using SCR and Microcontroller for Industrial Applications. Journal of Mechanical Engineering, 14(3), 87-95.

Santoso, P. et al. (2020). Application of Inverter Technology in Single Phase AC Motors to Improve Drive System Performance. Journal of Control Systems and Automation, 9(2), 102-110.

Sari, N. et al. (2019). Electric Motor Speed Regulation Using AT89S52 and SCR Microcontrollers. Journal of

Electrical Engineering, 11(3), 73-81.
Prasetyo, D. et al. (2021). Implementation of AC Motor Speed Control Using SCR Voltage Regulation System in Industrial Applications. Journal of Electrical Engineering and Informatics, 18(4), 143-151.
Jery Cazsanova, "Electrical Machines: Theory and Practice," Prentice Hall, 2000.
Robert W. Erickson, "Fundamentals of Power Electronics," Springer, 2001.
JM. Common et al., "AC Power Control using Phase Angle Regulation," Journal of Electrical Engineering, 1994.
Santiko Aji, "Motor Control and Power Regulation," LIPI Press, 2010.
Anggara Trisna Nugraha et al., "Analysis of AC Regulator Systems," Indonesian Journal of Electrical Engineering, 2019.
Anggara Trisna Nugraha et al., "Design of Phase Control in AC Motors," Electrical Engineering Research, 2020.
D. Smith, "Introduction to Electrical Drives," Journal of Electrical Engineering, 2005.
A. Yunianto et al., "Analysis and Control of Universal Motors," International Journal of Power and Energy Systems, 2018.
R. S. Paramitha et al., "Optimization of Motor Performance Using Inverter Technology," IEEE Transactions on Industrial Electronics, 2017.
N. W. Hasan et al., "Study on AC Voltage Regulation in Industrial Applications," International Journal of Electrical Engineering, 2016.