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

Design and Analysis of a Thyristor-Based Controlled Rectifier Circuit for Stabilization of Speed and Rotation in DC Motors

Jefry Setyo Fambudi[1], Rama Arya Sobhita[2]
[1] Automation Engineering, Shipbuilding Institute of Polytechnic Surabaya
[2] Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya
[1] jefryfambudi@student.ppns.ac.id , [2] ramasobhita@student.ppns.ac.id

Abstract

Controlling the speed of a DC motor is relatively simpler compared to regulating the speed of other types of motors [1]. Various methods can be employed for DC motor speed control, including frequency adjustment, pole number variation, autotransformer modification, and regulation of the armature input voltage. Among these, the most commonly used technique involves controlling the input voltage supplied to the DC motor. This voltage control method leverages an optocoupler to handle low-voltage regulation and a Silicon Controlled Rectifier (SCR), also known as a Thyristor, to manage the input voltage via its gate terminal. The other terminals, "anode" and "cathode," function similarly to those of standard diodes. The SCR, a critical component in the Thyristor family, plays a pivotal role in regulating voltage in this application. In this study, a controlled rectifier circuit was designed and implemented for DC motor speed and rotation stabilization. The system comprises two primary subsystems: the control circuit and the power circuit. The control circuit employs an optocoupler to ensure precise power supply regulation and an SCR or Thyristor as the main controlling device. Meanwhile, the power circuit utilizes a 120 Volt AC input, which is subsequently converted to supply a DC motor. This research emphasizes the integration of these subsystems to achieve efficient and reliable speed stabilization, making it a significant contribution to the field of motor control systems and electrical engineering.

Keywords: Thyristor, Rectifier, DC Motor

1. Introduction -

Technological advancements have profoundly influenced various aspects of human life, including the widespread utilization of single-phase induction motors in household appliances (Hudaya, 2002). These advancements are not limited to the adoption of new motor types but extend to improvements in motor speed regulation systems. The effectiveness of controlling motor rotational speed is determined by the design and functionality of the motor speed control circuit. Such a system operates by adjusting the input voltage from the power source, which directly impacts motor performance.

In addition to regulating speed, monitoring systems play a crucial role in real-time observation of motor performance. This monitoring can be achieved by analyzing the waveform outputs and rotational speed of the motor. These capabilities provide valuable insights into system efficiency and operational reliability.

The principles of speed regulation and monitoring can be effectively applied to DC motors, specifically those with a voltage capacity of 190 Volts. The rotational speed of a DC motor is highly dependent on the magnitude of the applied voltage. Higher input voltage results in faster motor rotation, allowing the motor to reach its maximum speed in a shorter duration. Conversely, a lower input voltage slows down the motor's rotation, requiring more time to achieve maximum speed.

This study focuses on the design and implementation of a controlled rectifier circuit employing a Thyristor-based system to regulate the speed and stabilize the rotation of a DC motor. By addressing the challenges of efficient speed control and system monitoring, this research contributes to advancements in electrical engineering and control systems.

2. Material and methods

DOI xxxxxx

2.1. DC Motor

A DC motor converts direct electrical energy into mechanical energy, primarily in the form of torque, which serves as the driving force. These motors are indispensable in applications where precise speed and torque control are required. Speed regulation is achieved by adjusting the voltage supplied to the motor, making DC motors versatile for various engineering applications (Rifdan & Hartono, 2018). Common implementations of DC motors are seen in servomotors and dynamo drives, where high precision and reliability are essential.

A. Working Principle

The operation of a DC motor is based on electromagnetic principles (Nugraha et al., 2023). When the field coil is energized, it generates a magnetic field that interacts with the armature coil. This interaction converts electrical energy into mechanical motion through the medium of the magnetic field (Setiawan, 2017). When a DC motor is supplied with power, it rotates at a speed proportional to the voltage applied. Higher voltage accelerates the motor, while lower voltage slows it down, making it suitable for applications requiring adjustable speed (Nugraha et al., 2023).

B. Construction

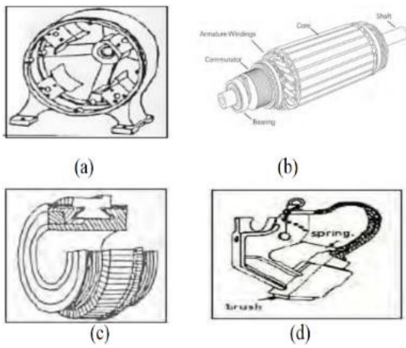

Figure 1. DC Motor Construction

A DC motor comprises key components that facilitate its function:

- Stator

The stator acts as the magnetic circuit and is equipped with field poles mounted on its interior surface. These poles create the necessary magnetic flux for motor operation. The stator's role is fundamental to sustaining the electromagnetic interactions within the motor (Yuski, Hadi, & Saleh, 2017). An illustration of the stator is shown in Figure (a).

- Rotor

The rotor is the dynamic component that converts electrical energy into mechanical motion (Nugraha et al., 2020). It consists of a steel shaft surrounded by laminated iron cores and copper windings. The rotor's construction ensures efficient energy conversion and durability. A depiction of the rotor can be seen in Figure (b).

- Commutator

This component consists of copper bars insulated with mica, functioning to collect the induced current from the armature windings and convert it into direct current. This ensures smooth operation and steady energy flow. The commutator is illustrated in Figure (c).

- Brushes

Brushes, typically made of carbon or graphite, maintain electrical contact between the rotor and external circuitry. These are supported by compression springs to ensure consistent contact. An image of the brush system is shown in Figure (d). Brushes are critical for efficient current transfer and motor longevity (Zumain, 2009).

C. Rotation direction

The rotation direction of a DC motor is determined by the interaction of the current in the conductor with the magnetic field. According to Fleming's Left-Hand Rule, the direction of force (Lorentz force) acting on a conductor can be deduced. This force results from a magnetic field interacting with a direct current flowing through the conductor, producing rotational motion. The magnetic field direction extends from the north pole to the south pole, and the conductor's motion

DOI xxxxxx

aligns with the thumb in Fleming's Left-Hand Rule. The magnitude of this force increases with the current through the conductor (Muttaqin, 2013).

2.2. SCR (Silicon Controlled Rectifier)

Thyristors are officially known as SCR (Silicon Controlled Rectifier) (Nugraha & Eviningsih, 2022). Thyristor is one of the important semiconductor devices for controlling and disconnecting small and large alternating currents. Thyristors have the convenience of influencing the rectification of alternating current to direct current and vice versa, namely the conversion from direct current to alternating current (Yandri, 2011). The use of SCR in the controller circuit is used as a controller of the size of the voltage so that it can affect the speed of the motor. The working principle of the SCR is the same as a diode, but the difference is in the SCR when the SCR is forward biased current cannot flow if the gate is not triggered or triggered (Hartono & Nurcahyo, 2017). SCR has three legs namely the anode (+), cathode (-), and Gate (gate).

Figure 2. Thyristor

2.3. Optocoupler

An optocoupler is an electronic component that functions as a liaison based on optical light. Basically the optocoupler consists of 2 main parts, namely the transmitter which functions as an optical light sender and the receiver which functions as a light detector (Mulyadi, 2019). In the optocoupler controlled rectifier circuit is used as a motor speed controller which is connected directly to the SCR. Optocoupler control mechanism by changing the DC supply voltage from the anode, the voltage will affect the gate on the SCR (Nugraha & Eviningsih, 2022). The optocoupler can also be used as a safety or protection for the circuit in the event of a short circuit.

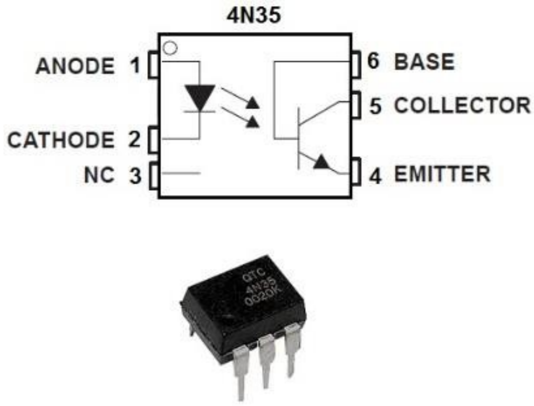

Figure 3. Optocoupler

2.4. PSIM Software

PSIM software is one of the useful software for simulating various characteristics of electronics and electric power systems running on MS Windows XP and later operating systems (Saolika, Mahardika, & Yushardi, 2020). In the PSIM circuit, it is used as a circuit and wave simulation software (Sunarhati, 2018). To run the PSIM software, the first step must be to install this software from the master program. The installation process is almost the same as installing MS Windows-based software in general (Atmam, 2017).

2.5. Capacitor

Capacitors are electronic components that can store and release electric charges (Safrizal et al., 2016). Capacitors can store a temporary electric charge (Setiawan & Sari, 2016). The capacitor consists of two metal plates separated by a dielectric material. This dielectric material is inserted between the two capacitor plates. Dielectric material is an insulating material that is able to accommodate electron charges for a certain voltage level. In the controlled rectifier circuit, the capacitor functions as a motor stabilizer so that the motor starting current does not jump too high and as a power saver (Sanjaya, Supriyanto, & Pauzi, 2017). In the capacitor circuit, it functions as a stabilizer for the motor starting current so that the starting current wave is not too high.

2.6. Methods

A. Procedure

The simulation procedure for controlling the speed of a DC motor using a thyristor involves several systematic steps to ensure accurate measurements and analysis. First, the necessary tools and components are prepared. Next, a circuit is constructed according to the given circuit diagram.

Once the circuit is set up, the conversion angle is calculated and translated into divisions, allowing for adjustments via the angle adjustment potentiometer to achieve the desired value. Subsequently, key electrical parameters are measured, including the input RMS voltage, input RMS current, DC output voltage, DC output current, output RMS voltage, and output RMS current.

The waveform of both the input voltage and output voltage is then observed using an oscilloscope to analyze their characteristics. Following this, the measurement results are compared for various data points, and the percentage difference between the experimental results and theoretical values is determined.

Finally, the circuit's characteristic parameters are calculated, providing a basis for in-depth analysis and conclusions. Through these steps, the simulation delivers a comprehensive understanding of the system's behavior and performance.

B. Schematic circuit

In the design of DC motor speed regulation, it is done using PSIM software as a simulation. In the simulation a DC motor speed controlled rectifier is used to design a one-way AC voltage regulation circuit.

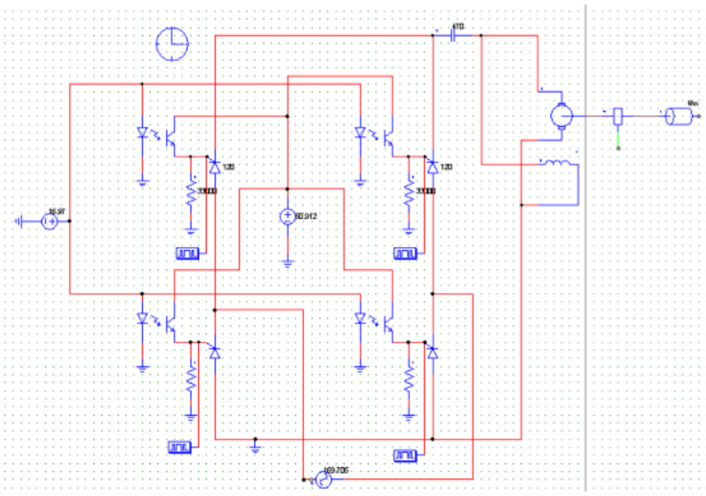

Figure 4. Schematic circuit

The voltage-to-speed controlled rectifier circuit consists of two different circuits, namely the control circuit and the power circuit. The control circuit consists of a DC voltage source, optocoupler, and SCR while the power circuit consists of an AC voltage source, capacitors, and a DC motor.

3. Results and discussion

3.1. Simulation

A controlled rectifier circuit with a thyristor uses a DC motor using an optocoupler and four SCRs or thyristors and is connected together to form a control circuit. The output of the control circuit will control the

DOI xxxxxx

power circuit with a voltage of 120 volts AC. The design of the power circuit uses an alternator component, a capacitor with a value of 470uF, and a Volt DC motor.

A. Voltage Circuit
The power circuit uses a 120 Volt AC source voltage as the motor input voltage.

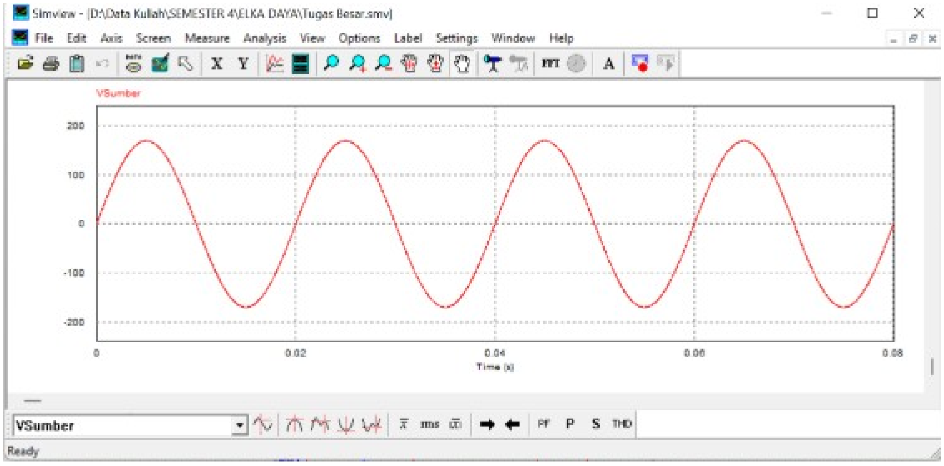

Figure 5. Voltage waveform

Table 1. Simulation Result

Control Voltage (V)	Max Motor Voltage (V)	Time reach max speed (s)
15	9,5	23,08
18	10,25	22,20
24	14,25	21,03
36	17,75	19,70
45	27,0	16,25

The table illustrates the relationship between control voltage, maximum motor voltage, and the time required for the motor to reach its maximum speed. As the control voltage increases, the maximum motor voltage also rises. At a control voltage of 15 V, the maximum motor voltage is 9.5 V, while at 45 V, the maximum motor voltage peaks at 27.0 V. This trend demonstrates a direct correlation between the control voltage and the motor's ability to achieve higher output voltage.

Additionally, the time required to reach maximum speed decreases as the control voltage increases. For instance, at a control voltage of 15 V, the motor takes 23.08 seconds to reach maximum speed. However, at 45 V, the time drops significantly to 16.25 seconds. This indicates that a higher control voltage not only boosts the motor voltage but also enhances the motor's responsiveness by reducing the time required to achieve maximum performance.

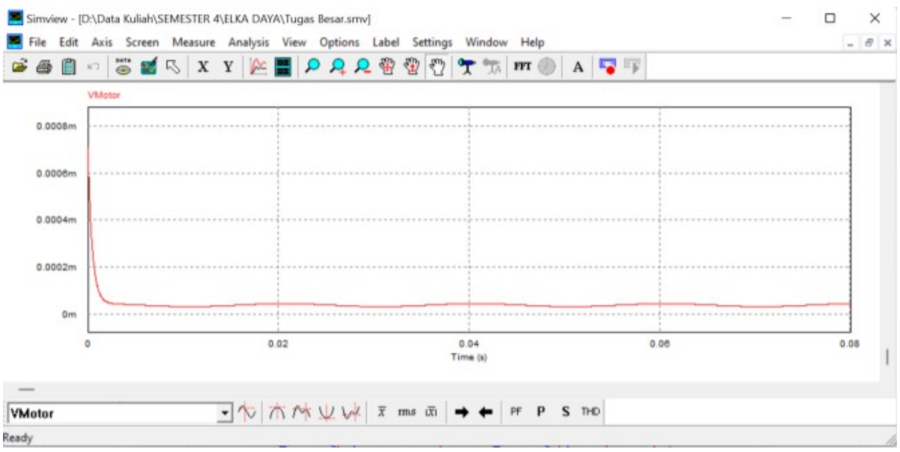

Figure 6. Spike Voltage waveform

The voltage on the DC motor is less than perfect because there is still a little sine wave because the motor used is an induction motor. In the 0 second wave there is a voltage spike due to starting the motor. The starting wave can be minimized using a capacitor to make it more stable.

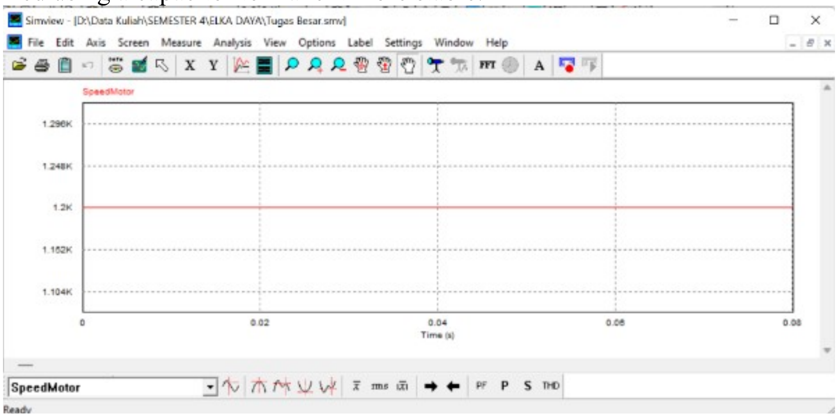

Figure 7. Motor speed

The motor speed graph is at 1200 rpm and the graph is straight because it has reached a maximum speed of 1200 rpm. The motor speed will increase if the AC input voltage is increased and vice versa the motor speed will decrease if the AC input voltage is reduced. In the control circuit, if the voltage value is increased, the motor acceleration to reach the maximum speed will be very fast and requires less time and it is better if the control voltage is reduced, the motor acceleration to reach the maximum speed will be slower and takes a long time.

4. Conclusion

Based on the experiments conducted, the following conclusions can be drawn:

1. The power circuit operates on AC voltage, while the control circuit is powered by DC voltage, with each circuit serving a distinct function. The power circuit provides the AC power required by the DC motor, while the control circuit regulates this power using an SCR (Silicon Controlled Rectifier), enabling control over the motor's speed.
2. The motor speed is directly influenced by the input voltage. An increase in the input voltage results in a higher maximum speed of the motor, indicating that voltage control plays a crucial role in adjusting motor performance.
3. In the control circuit, higher control voltage values lead to faster motor acceleration, allowing the motor to reach its maximum speed in a shorter time. Conversely, lowering the control voltage reduces the acceleration rate, resulting in slower motor response and a longer time to reach maximum speed.
4. At motor startup, a surge wave occurs due to the high power demand, which can be mitigated by the use of a capacitor. This capacitor helps stabilize the waveform and contributes to improved power efficiency, preventing unnecessary energy losses.
5. Although the ideal waveform for the motor should be a pure DC signal, the use of an induction DC motor causes the output to resemble a sine wave with a very small amplitude. This deviation from a pure DC wave is characteristic of the motor's design but does not significantly impact its functionality.

In conclusion, the experimental results highlight the importance of proper voltage control in optimizing motor performance and energy efficiency, while also suggesting methods for minimizing power surges and improving waveform stability..

Credit authorship contribution statement

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

References

Kharla Aji Wahyu Hudaya, "PEMBUATAN PENYEARAH TERKONTROL PENUH SATU FASA SEBAGAI PENGEMUDI MOTOR DC 3 HP," *Universitas Diponegoro.*, vol. 46, pp. 695-701, Januari 2002.

Rifdan I.S., Hartono, "RANCANG BANGUN PULSE WIDTH MODULATION (PWM) SEBAGAI PENGATUR KECEPATAN MOTOR DC BERBASIS MIKROKONTROLER ARDUINO," *Politeknik Penerbangan Surabaya.*, vol. 3, Maret 2018.

David Setiawan, "SISTEM KONTROL MOTOR DC MENGGUNAKAN PWM ARDUINO BERBASIS ANDROID SYSTEM," UIN Sultan Syarif Kasim Riau, vol.15, pp. 8-9, Desember 2017.

Moh. Nur Yuski, Widyono Hadi, Azmi Saleh, "Rancang Bangun Jangkar Motor DC," *Universitas Jember*, vol. 5 No 46, pp. 98-103, 2017.

Nugraha, Anggara Trisna, et al. "TRAINER KIT KOORDINASI PROTEKSI PADA SISTEM DISTRIBUSI PT. X MENGGUNAKAN TEORI GRAPH." Seminar MASTER PPNS. Vol. 8. No. 1. 2023

Zumain, M. A., "Prototipe Mobil Listrik dengan Menggunakan Motor DC 0,37 HP," 11-14, 2009.

Syaoqi Muttaqin, "Analisa Karakteristik Generator dan Motor DC," *Universitas Diponegoro*, 2013.

Yandri., "Penentuan Parameter Dan Arus Asut," Pontianak : Jurnal Teknik Elektro, *Universitas Tanjungpura*, 2011.

Bambang Prio Hartono, Eko Nurcahyo, "Analisis Hemat Energi Pada Inverter Sebagai Pengatur Kecepatan Motor Induksi 3 Fasa." *Institut Tekonologi Nasional Malang*, Vol.1, September 2017.

Cecep Deni Mulyadi, "PERANCANGAN PENGENDALIAN LAMPU MENGGUNAKAN BERBASIS ARDUINO UNO DENGAN DIMMER LAMPU." *Universitas Sangga Buana YPKP*, Vol.12, Desember 2019.

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

Muhammad Danil Saolika, I Ketut Mahardika, Yushardi. "MENINGKATKAN MULTI REPRESENTASI FISIKA SISWA MELALUI PENERAPAN MODEL PROBLEM SOLVING SECARA KELOMPOK DISERTAI SOFTWARE PSIM DI SMK." *Universitas Jember*, Vol.1, Februari 2020.

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

Atmam, "PENGGUNAAN FILTER KAPASITIF PADA RECTIFIER SATU PHASA DAN TIGA PHASA MENGGUNAKAN POWER SIMULATOR (PSIM)." *Universitas Lancang Kuning Pekanbaru*, Vol.1 No.1, Desember 2017.

Marliyus Sunarhati, "ANALISA PENGATURAN KECEPATAN PUTARAN MOTOR DC PENGUAT DENGAN MENGGUNAKAN THYRISTOR," *Universitas Palembang*, Vol.8, 2018

Nugraha, Anggara Trisna, et al. "Analisa Kontrol Kecepatan Motor Brushless DC Menggunakan Cuk Konverter." Elektriese: Jurnal Sains dan Teknologi Elektro 10.02 (2020): 69-83.

Safrizal[1], Martias[2], Dwi Sudarno Putra[3], "Analisis Penggunaan Variasi Kapasitor Booster Pada Sistem Pengapian Terhadap Tegangan Output Primer Dan Sekunder Koil Sepeda Motor Shogun 125 R Tahun 2006," *Universitas Negeri Padang*, Vol.5, 2016.

Nugraha, Anggara Trisna, et al. "Penyearah Terkontrol Satu Phasa Gelombang Penuh terhadap Motor DC 3 HP." Elektriese: Jurnal Sains dan Teknologi Elektro 13.01 (2023): 42-49.

Santoso Setiawan[1], Selvi Novita Sari[1], "PEMBUATAN ALAT KEAMANAN BRANKAS MENGGUNAKAN KARTU AKSES BERBASIS MIKROKONTROLER ATMEGA16," *Jakarta*, Vol.10, September 2016.

Hardaniyus Sanjaya[1], Amir Supriyanto[2], Gurum Ahmad Pauzi[3], "Perancangan Alat Ukur Kadar Gula pada Produk Pangan Menggunakan Sensor Kapasitor Keping Sejajar Berbasis Mikrokontroler ATMega8535," *Universitas Lampung*, Vol.5, 2017.

DOI xxxxxx