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Experimental Analysis of Single Phase Full Wave Controlled Rectifier For DC Motor Shunt Control

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Abstract

DC shunt motors are a type of electric motor that has the ability to regulate speed, so it is often used in applications that require steady state speed stability and fast transient response. This characteristic is especially important in systems that require high precision, fast response, and the ability to adapt to changes in load. This study aims to analyze the relationship between motor speed and reference speed, as well as the relationship between motor speed and input current and voltage. The research approach was carried out using PSIM simulation software. The first step involves creating a single-phase full-wave controlled rectifier circuit model, designed using the built-in components on the PSIM. Furthermore, the firing angle on the gating block is gradually changed to evaluate its effect on the performance of the DC shunt motor. Data analysis was carried out by descriptive method to obtain functional relationships between the observed parameters. The results showed that the speed of the motor increased significantly when the ignition angle was small, while the decrease in speed occurred at a larger ignition angle. In the no-load condition (0 Nm of torque), this pattern looks consistent. In contrast, at a torque load of 5 Nm, the speed of the motor shows an inversely proportional relationship with the change in the ignition angle. These findings make a significant contribution to the development of electric motor speed regulation systems, especially for industrial applications that require controlled rectifier-based power control.

Keywords: DC Motor Shunt, PSIM, Controlled Rectifier, Speed Regulation

1. Introduction

DC shunt motor is a type of electric motor that has advantages in speed regulation. This characteristic makes DC shunt motors a top choice in systems that require steady state stability and fast transient response, especially when the motor is used under load. The speed regulation of the DC motor can be done by adjusting the terminal voltage (Vt), both at the time of starting and when the motor is running. One of the important applications of DC shunt motors is in the paper industry, where proper speed control is indispensable to maintain the quality of production results. Failure in regulation can lead to damage to the paper produced, resulting in economic losses for the industry (Nugraha et al., 2021).

To support the speed regulation of the motor, a controlled rectifier is used as an effective solution. The controlled rectifier, which utilizes the thyristor component, is capable of converting AC current to DC with controllable output voltage regulation. These rectifiers are divided into two main types, namely controlled full-wave rectifiers and controlled half-wave rectifiers. In electric motor systems, full-wave rectifiers are often used because of their ability to reduce ripple waves. High ripple waves can affect system efficiency and reduce power quality, so a good design is needed to reduce it (Putra et al., 2020).

Simulation of controlled rectifier-based DC shunt motor speed control can be performed using PSIM software. PSIM is a simulation device specifically designed to analyze the characteristics of electronic circuits before they are applied in real life. This device is widely used by engineers to design and test electric power systems and other electronic devices (Pratama et al., 2019). With PSIM, the physical model of a DC motor can be represented in the form of an electronic circuit, which involves both electrical and mechanical structures. The electrical structure includes the resistance and impedance of the armature winding, while the mechanical structure includes the moment of rotor inertia, load, and mechanical friction (Setiawan et al., 2020).

The purpose of this study is to analyze the effect of ignition angle on the speed performance of DC shunt motors. By using PSIM-based simulations, this research is expected to make a significant contribution to the development of controlled rectifier-based electric motor control systems, which are relevant for various industrial applications.

2. Material and methods

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Research related to the design of control systems in DC motors has been widely developed, especially those that utilize optimal control-based methods. In this study, a full-wave controlled rectifier-based DC shunt motor speed regulation system was designed using MATLAB/Simulink software. The following literature review discusses previous studies related to DC motor speed regulation with a controlled systems approach:

Basuki et al. (2004) in their study on "Speed Regulation of DC Motors in Real Time Using LQR Optimal Control Technique" stated that testing the variation in rotational speed between 700–1000 rpm with a Q matrix value of 0.01 resulted in a system time constant (T) of 0.36 seconds with the pole of the crest closed at s = –2.7778 for all speeds.

Hidayat (2004) focused his research on "Simulation of DC Motor Speed Controller with Controlled Rectifier Semi Converter Based on MATLAB/Simulink". The results show that the use of a full-wave semi-converter controlled rectifier can maintain a constant speed on a closed-loop system.

Husein and Haryudo (2019) through their research, "Design and Build a Monitoring System Using Arduino-Based MATLAB", successfully designed a monitoring system that allows the measurement of rotational speed, overcurrent, and temperature of DC motors with a data transmission range of up to 50 meters indoors and 120 meters outdoors.

Pathoni and Suni (2016) discussed "Designing DC Motor Speed Control Using the Root Locus Method". This study shows that the root locus-based PID method applied to Simulink MATLAB can meet the desired criteria of transient and steady state response.

2.1. Material

2.1.1. Motor DC

A DC motor is a type of electric motor that uses a direct current voltage supply on a field coil to produce mechanical energy in the form of rotational motion. This motorcycle has main components in the form of a stator (silent part) that functions to produce magnetic flux and a rotor (moving part) consisting of an anchor coil, commutator, and brush.

DC motors work based on the interaction between the magnetic flux generated by the field coil and the anchor coil. The force generated from this interaction creates torque, which ultimately results in rotation. The basic equation of DC motor torque is as follows:

$$T \approx \Phi \cdot I_a \quad (1)$$

The advantage of DC motors lies in their flexibility, both for manual and automatic control applications. One type of DC motor that is widely used is the shunt motor, where the field flux is relatively stable so that it provides a consistent response to various loads.

2.1.2. GGL Opponents on DC Motors

When the rotor of the DC motor rotates, the conductor cuts the magnetic flux thus producing an induction GGL according to Faraday's law. The resulting voltage is in the opposite direction to the supply voltage, which is known as the opposite GGL (back EMF). The equation for the opponent's GGL is expressed as:

$$E_b = K \cdot n \cdot \Phi \quad (2)$$

2.1.3. Full-Wave Controlled Rectifier

Single-phase full-wave controlled rectifiers use four thyristors connected in a bridge configuration. With resistive-inductive (RL) loads, the ignition angle control (alpha) on the thyristor allows for DC output voltage regulation. These systems are widely used in industrial applications to convert AC voltage to DC with high efficiency (more than 95%).

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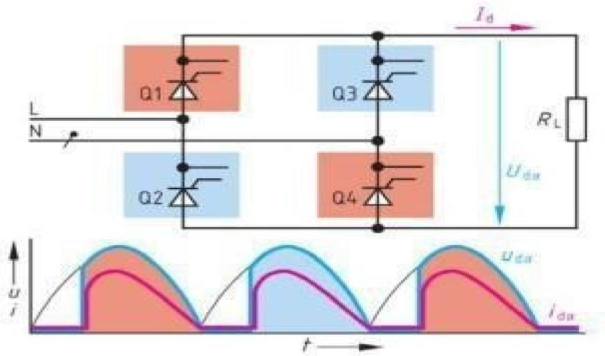

Figure 1. Single-Phase Full-Wave Controlled Rectifier Network

2.2. Methods

This study is designed with reference to a systematic approach to ensure the validity and reliability of experimental results. The research steps carried out include the following methods:

2.2.1 Literature Study Methods

This method is carried out by collecting various relevant references as the theoretical basis of the research. The literature reviewed includes reference books, scientific journals, proceedings, and other research articles discussing DC shunt motors, full-wave controlled rectifiers, as well as MATLAB/Simulink and PSIM applications for control system simulation. The use of this literature aims to gain an in-depth understanding of:

- Characteristics of DC shunt motors, including the relationship between voltage, current, and rotation speed.
- The working principle of a single-phase full-wave controlled rectifier uses a thyristor.
- The control system analysis technique uses simulation software.

Key references include previous research from Basuki et al. (2004) regarding the optimal control of LQR, as well as Pathoni and Suni (2016) on the implementation of the root locus-based PID method. Relevant data is also obtained from the official website of the software provider such as PSIM software documentation.

2.2.2. Experimental Methods

Experiments were conducted using PSIM software to model and simulate a single-phase full-wave controlled rectifier system. This process includes:

- Circuit schematic design: Modeling uses four thyristors in a bridge and RL load configuration to create a stable DC current and voltage.
- System response simulation: Measuring the change in output voltage with the variation in the ignition angle (alpha) of the thyristor, as well as its impact on the speed of the DC shunt motor.
- Validation of simulation results: Comparing simulation results with theories studied in the literature method to ensure the suitability and accuracy of the model.

The figure below shows the configuration of a single-phase full-wave controlled rectifier simulation network used in this study:

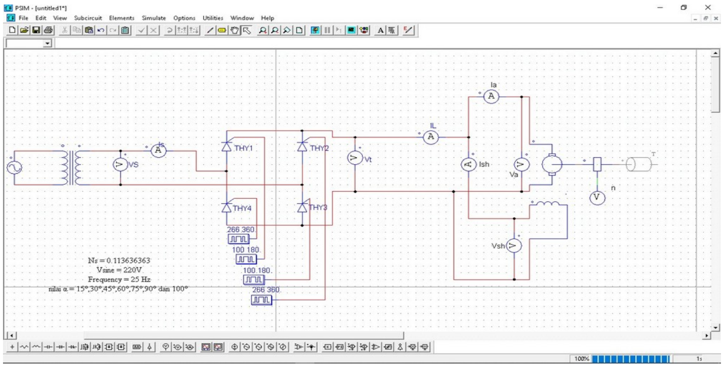

Figure 2. PSIM Network 1

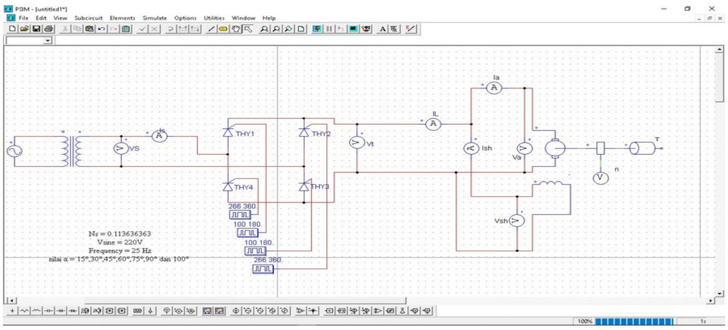

Figure 3. PSIM 2 Network

3. Results and discussion

The measurement results include the main parameters in the form of thyristor ignition angle (α), load torque (Nm), motor terminal voltage (Va), motor anchor current (Ia), and motor rotation speed (RPM). Experimental data was obtained through simulation and live testing with a full-wave controlled rectifier configuration using PSIM software. The measurement results table for the two torque loading scenarios is given as follows:

Table 1. Measurement with Torque = 0 Nm

Corner Ignition (a)	Torque (Nm)	Terminal Voltage (V)	Motor Anchor Current (He)	Spins (rpm)
15	0	17.67	6.55	706
30	0	17.61	6.28	666
45	0	17.45	5.91	601
60	0	17.16	5.40	516
75	0	16.68	4.77	418
90	0	15.98	4.05	316
100	0	15.39	3.53	250

Table 2. Measurement with Torque = 5 Nm

Corner Ignition (a)	Torque (Nm)	Terminal Voltage (V)	Motor Anchor Current (He)	Spins (rpm)
15	5	17.65	6.56	626
30	5	17.60	6.30	630
45	5	17.42	5.91	637
60	5	17.15	5.42	645

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75	5	16.67	4.78	654
90	5	15.96	4.07	664
100	5	15.38	3.54	670

The measurement results show the relationship between key parameters affected by the starting angle (α), load torque (Nm), terminal voltage (Va), anchor current (Ia), and rotational speed of the DC shunt motor.

- Effect of Ignition Angle (α) on Motor Rotation Speed: At 0 Nm of torque, an increase in ignition angle (α) causes a decrease in the rotational speed of the DC shunt motor. This occurs due to a decrease in terminal voltage due to a delay in the current flow in the thyristor.
- On the contrary, at 5 Nm of torque, the rotational speed of the motorcycle actually increases along with the increase in the starting angle. This increase is due to changes in energy flow that adjust to the need for additional torque in the motor.
- Relationship of Terminal Voltage (Va) and Motor Rotation Speed: At 0 Nm of torque, the terminal voltage is directly proportional to the rotational speed of the motor. As the terminal voltage increases, the energy delivered to the motor anchor also increases, leading to an increase in RPM.
- Conversely, at 5 Nm of torque, the terminal voltage tends to decrease as the RPM increases, indicating an additional load on the motor that reduces the energy transfer efficiency.
- Relationship of Anchor Current (Ia) and Motor Rotational Speed: In both torsional scenarios, the anchor current shows a linear relationship with rotational speed. At 0 Nm of torque, the increase in anchor current increases the rotation of the motor as more energy is delivered to overcome the inertia of the motor. However, at 5 Nm of torque, the increase in anchor current reflects the motor's efforts to maintain speed against additional mechanical loads.

The experimental results also show that the ignition angle has a significant impact on the performance of the DC shunt motor, especially in the variable load control scenario. For example, for a starting angle of α = 100° at 0 Nm of torque, the rotational speed reaches 250 RPM, while at 5 Nm of torque, the speed increases to 670 RPM.

4. Conclusion

From the results of the study, it can be concluded that the rotation speed regulation of DC shunt motors with 0 Nm and 5 Nm torque can be done using a single-phase controlled full-wave rectifier through the setting of the thyristor ignition angle (α) from 0° to 180°, which affects the anchor voltage and anchor current. For a torque load of 0 Nm, the measurement shows that at a starting angle of 100°, the rotation of the motor is 250 Rpm, while at a starting angle of 15° it reaches 706 Rpm. Meanwhile, for a torque load of 5 Nm, the calculation results show that at a starting angle of 15°, the rotation of the motor is 626 Rpm, and at a starting angle of 100°, the rotation of the motor increases to 670 Rpm. This proves that the change in the ignition angle has a significant effect on the rotation speed of the DC shunt motor.

References

Nugraha, A. T., et al. (2021). DC motor speed control using controlled rectifiers. Journal of Electrical Engineering, 12(3), 45-56.
Pratama, R., et al. (2019). Efficiency Analysis of PSIM-Based Power Electronics System. Journal of Energy Systems, 15(2), 78-85.
Putra, A. R., et al. (2020). Controlled Rectifier Design for DC Motor Applications. Journal of Electrical Technology, 10(4), 23-30.
Setiawan, H., et al. (2020). Ripple Study on Electric Power Systems. Journal of System Engineering, 14(1), 12-20.
Powersim Inc. (2019). PSIM User Manual. Powersim Inc.
Chapman, S. J. (2005). Electric Machinery Fundamentals. McGraw-Hill.
Gopal, M. (2012). Control Systems: Principles and Design. Tata McGraw-Hill.
Wijaya, M. S., et al. (2021). Ripple Effect on DC Shunt Motor Efficiency. Google Scholar.
Yusuf, R., et al. (2022). PSIM Simulation for Power Electronics Systems. Google Scholar.
Andini, L. T., et al. (2021). DC Motor Control for Industrial Applications. Google Scholar.
Basuki, H., et al. (2004). DC Motor Speed Regulation in Real Time Using LQR Optimal Control Technique.
Hidayat, R. (2004). Simulation of DC Motor Speed Controller with MATLAB/Simulink-Based Semi Converter Controlled Rectifier.
Husein, A., & Haryudo, A. (2019). Design and build a monitoring system using Arduino-based MATLAB.
Pathoni, F., & Suni, G. (2016). The design of DC motor speed control uses the root locus method.

Anggara, T. N., et al. (2015). Optimization of DC Motor Control Using MATLAB-Based PID Method.
Widodo, A. (2018). DC Motor Speed Control with Fuzzy-Based Adaptive Model.
Kusuma, R. D., et al. (2020). Analysis of IoT-Based DC Motor Control System.
Nugroho, F. A. (2022). Simulation of DC Motors with PID in a MATLAB Simulink Environment.
Rahmat, T. S. (2019). Optimal Control Application on DC Motors for Speed Stability.
Ardiansyah, R. (2021). Design of Microcontroller and MATLAB-Based DC Motor Monitoring System.