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

DC Motor Speed Control Optimization Using Uncontrolled Full-Wave Rectifier For Engineering Applications

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Abstract

DC motor speed control has become one of the main topics in the field of electrical engineering and industrial applications. Various methods have been applied, including changing the number of pole pairs, setting external resistance, regulating anchor voltage, vector controllers, pulse width modulation (PWM), to the use of modern electronic devices[1]. This research develops a novel approach using an uncontrolled full-wave rectifier to achieve optimal DC motor speed control. The proposed control system allows for multiple motor operating conditions at varying maximum output rate prices, providing greater flexibility in industrial applications. With simultaneous control based on speed regulators in a cascade configuration, this study successfully improves the efficiency and response of the system to load changes. In addition, the ease of implementation using widely available and economical components makes this method very relevant for a wide range of engineering needs. DC motors, with their diversity of types and capabilities, continue to be a reliable solution in powering various machines in the industrial sector. The contribution of this research lies in: An innovative approach in the use of uncontrolled full-wave rectifiers. Detailed analysis of the performance of DC motors in variable operating scenarios. Provision of economical and practical solutions for motor speed control in a wide range of engineering applications. This research is expected to provide new insights in the development of DC motor control systems that are more efficient and in accordance with modern industrial needs.

Keywords: DC Motor, Speed Control, Full Wave Rectifier, Electrical Engineering, Industrial Applications.

1. Introduction

The current development of the industry, both in large and small sectors, shows rapid growth. This encourages an increase in the need for electric motors as one of the main elements driving various industrial processes (Alimuddin et al., 2020). Direct current (DC) motors are one type of electric motor that is often used because of its ability to convert electrical energy into mechanical energy with high efficiency. The main advantage of DC motors is their ease of setting up over a wide speed range, which is very relevant to the needs of modern industries (Nugraha et al., 2021).

In general, DC motor speed control is carried out by three main methods, namely field current control, armature circuit resistance control, and armature terminal voltage control (Rahman et al., 2022). This method requires changes or additions to certain components that have an impact on the efficiency of the DC motor. One simple and economical technique that is often used is a speed regulation scheme using a potentiometer, as it does not require a complex series for its implementation (Prasetyo et al., 2023).

This study aims to evaluate the effectiveness of the speed control system of DC motors based on uncontrolled full-wave rectifiers. This approach proposes a simultaneous setup system that is able to selectively improve system performance according to its design and technical application needs (Nugraha et al., 2021). Through a systematic literature review, this study compares various system design concepts that have been developed previously to produce an efficient and applicable method of controlling motor speed (Sugiharto et al., 2023).

This paper is compiled based on a literature study method that refers to various journals and relevant scientific sources. This article also limits the scope of the study to the comparison of motor speed control systems with a focus on the efficiency of the components and systems used. Thus, it is hoped that this research can make a real contribution to the development of DC motors to meet the increasingly complex needs of modern industries (Kurniawan et al., 2022).

2. Material and methods

2.1. Material

2.1.1 Working Principle of Direct Current (DC) Motor

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Direct current (DC) motors work based on the interaction between the magnetic field and the electric current flowing in the conductor. When a current-driven conductor is placed in a magnetic field, it will experience a mechanical force, which can be seen in the following illustration:

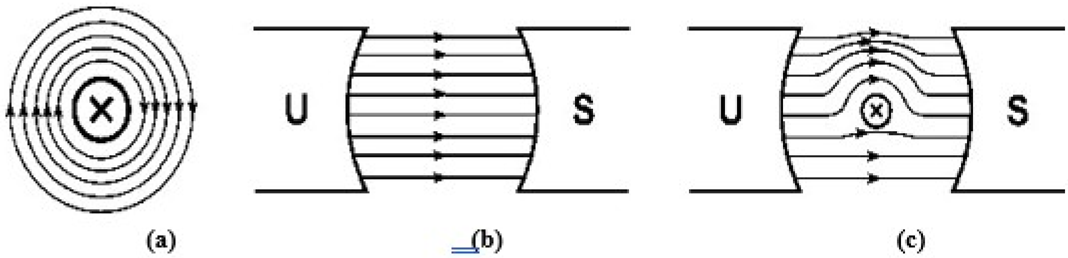

Figure 1. Effect of placement of current conductors in magnetic field

In Figure 1(a), a conductor that is passed through a current generates a magnetic field around it. The direction of the resulting field can be determined by the right-handed rule, where the strength of the magnetic field depends on the magnitude of the current flowing. Figure 1(b) depicts the magnetic field from the north pole to the south pole. When a conductor with a current away from the reader is placed in a unidirectional field, the resulting electromagnetic force strengthens the field above the conductor and weakens the field below the conductor, as seen in figure 1(c).

2.1.2 Motor DC Shunt

DC Shunt motor is a type of self-reinforcing motor in which the magnetic reinforcing winding is connected in parallel with the anchor winding, or directly connected to an external voltage source. This system is designed to provide stability in speed regulation even when experiencing load fluctuations (Hermawan et al., 2021). This motorcycle has the advantage of maintaining a constant speed under various load conditions, although it decreases slightly when fully loaded, usually between 5-15% of its nominal speed (Setiawan et al., 2023).

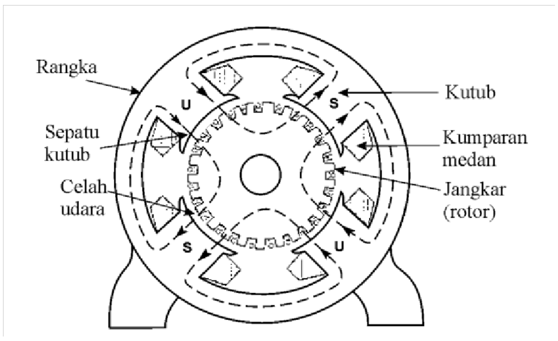

Figure 2. Construction DC Motor Shunt

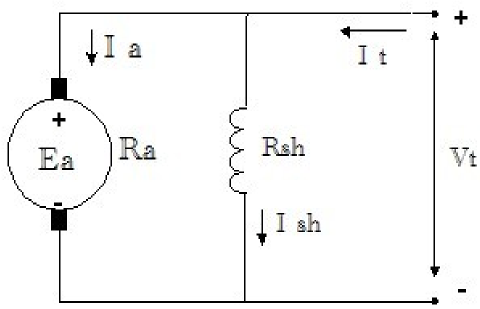

Figure 3. DC Motor Shunt Electrical Circuit

The equations applicable to DC shunt motors are as follows:

$$V_t = E_a + I_a R_a \quad (1)$$

Where:

- Vt = Terminal voltage (Volts)
- EaE = Induced electromotive force (Volts)
- It = Anchor Current (Ampere)
- Ra = Anchor resistance (Ohms)
- Ish = Shunt field coil current (Ampere)
- Rsh = Shunt field resistance (Ohms)

2.1.3 Diode

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Diodes are very popular electronic components due to their simple yet crucial function in rectifiers, cutters, clamps, and voltage multiplier circuits. Diodes conduct current in only one direction, which makes it a major component in alternating current (AC) rectifier circuits into direct current (DC). Commonly used types of diodes include silicon diodes, germanium diodes, and zener diodes (Rahmadani et al., 2022).

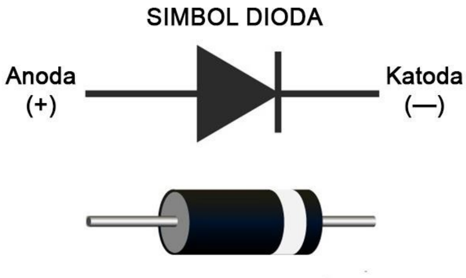

Figure 4. Diode Symbol

The diode works on the principle of only flowing current at forward voltage conditions and holding current at reverse voltage conditions. This property is used in a wide range of applications, especially in rectifier series.

2.1.4 Full-Wave Rectifier

A full-wave rectifier is a circuit that converts alternating current (AC) into direct current (DC) by using two diodes in a bridge configuration. At each AC input cycle, the full-wave rectifier ensures that the current flows in the same direction, both in the positive and negative cycles of the input signal (Fahri et al., 2020).

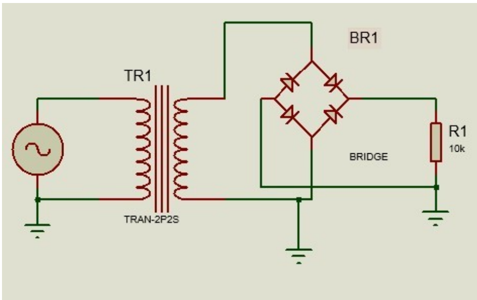

Figure 5. Full-Wave Rectifier Network

2.1.5 DC Voltage Regulator

The voltage regulator functions to ensure the stability of the voltage output from the power source or power supply even if there is a change in input voltage or load fluctuations. These regulators are commonly used in electronic circuits to prevent damage to devices that are sensitive to voltage changes (Hidayat et al., 2021).

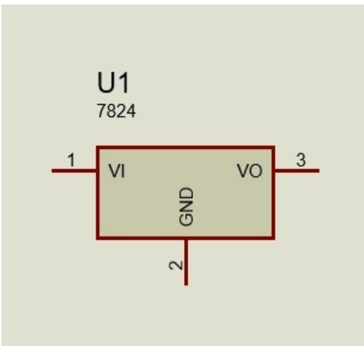

Figure 6. DC Voltage Regulator

2.1.6 Software Proteus

Proteus is a PCB design software that also comes with schematic-based electronic circuit simulation features. Using Proteus, designers can virtually verify the correctness of the circuit before printing the PCB layout. This software is very useful for designing and studying microcontroller applications in electronic circuits (Priyanto et al., 2020).

2.2 Methods

This research method was carried out at the Power Electronics Laboratory from May to June 2022. The hardware used includes a laptop with an Intel Core i5 configuration, 8 GB of RAM, and a 512 GB SSD. The components and tools used include Single Phase Uncontrolled Full-Wave Rectifier modules, 18V DC motors, voltmeters, ammeters, transformers, diodes, resistors, capacitors, inductors, variable resistors, DC voltage regulators, oscilloscopes, and cables. The software used is Proteus to simulate the effect of input voltage changes on DC motor speed.

The research procedure begins with preparing the necessary tools and components, followed by designing and building the circuit according to the drawings. Furthermore, measurements are made on various parameters, such as input voltage, input current, DC output voltage, DC output current, RMS output voltage, and RMS output current. The voltage waveform was observed using an oscilloscope, and the measurement results were compared with the theory for difference analysis. The characteristic parameters of the circuit are calculated, and conclusions are made based on the analysis.

The circuit used in this study consists of a step-down transformer, a full-wave rectifier, a voltage filter, a DC voltage regulator, and a DC motor. Voltage regulation is done using a potentiometer as a voltage divider to change the output voltage. The motor speed control system is tested using a pre-designed circuit, with simulated steps in the Proteus software to measure the performance of the system.

3. Results and discussion

In this study, the speed regulation of the DC motor was carried out using a simulation of Proteus software. This simulation aims to design several key components in the DC motor speed regulation system, including a step-down transformer, a full-wave rectifier circuit, a voltage filter, a DC voltage regulator, a voltage divider that uses a potentiometer, as well as the DC motor itself. All such components are integrated to achieve an efficient and stable setup according to the needs of the engineering application.

3.1. Full Wave Rectifier Planning

The full-wave rectifier circuit is designed using a bridge diode. In this system, the full-wave rectifier serves to convert the alternating current (AC) signal into direct current (DC) required for the purposes of the motor and voltage regulator. The components used in this design include a diode, capacitors rated at 680uF and 1000uF, and resistors rated at 10kΩ, as shown in Figure 7.

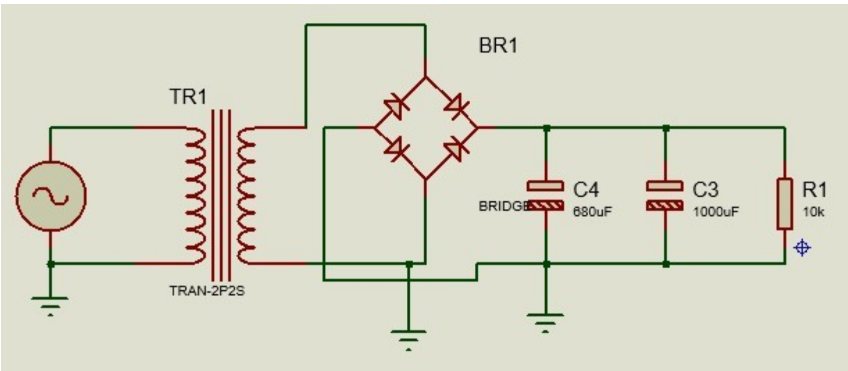

Figure 7. Full Wave Rectifier Circuit using bridge diodes in PSIM

In the next step, a step-down transformer is used to lower the voltage from 220V to 24V, according to the voltage requirements of the electronic system. The process of calculating the inductance of a transformer is carried out with the following formula to ensure that the secondary voltage is in accordance with the requirements:

$$Lp = \left(\frac{Vin}{Vout}\right)^2 \cdot Ls \tag{2}$$

With the value of Vin = 220V and Vout = 24V, and assuming Ls = 1, an Lp value of 84.028 H is obtained.

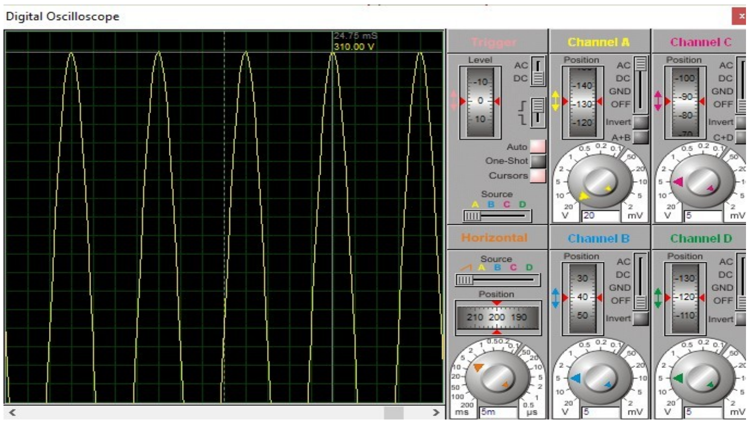

Figure 8. Sinusoidal AC waveform on the primary side of the transformer

The result of a step-down circuit and a full-wave rectifier using a bridge diode produces a wave as seen in Figure 8. The readable peak voltage is 311V, which after calculation by conversion factor to get the value of the RMS (Root Mean Square) voltage is 220V. These waves are then passed to the filter to eliminate fluctuations or ripple that can damage electronic components.

3.2. DC Voltage Regulator Design

The DC voltage regulator serves to stabilize the voltage generated by the rectifier circuit to match the needs of the DC motor. The use of DC voltage regulators is essential to maintain the stability of the voltage received by the motor and prevent damage due to voltage fluctuations. This process also involves further filtering to ensure a pure DC voltage output, as shown in Figure 9.

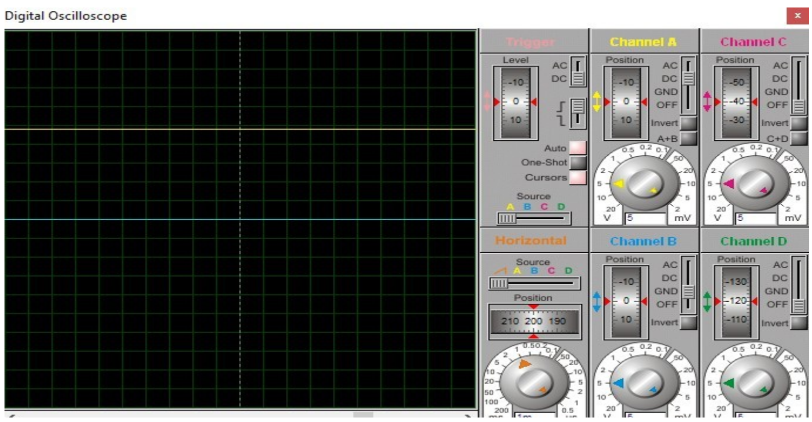

Figure 9. Output waveform of DC voltage regulator

3.3. Testing on DC Motors

The test is carried out after all circuits are connected and operating normally, to ensure that the DC motor can rotate at the desired speed. However, testing showed that there was a voltage drop of 1.6V at the load of the DC motor. This drop occurs because the load of the motor comprising the inductor causes a phase difference between the load current and the supply current, which is seen in Figure 10.

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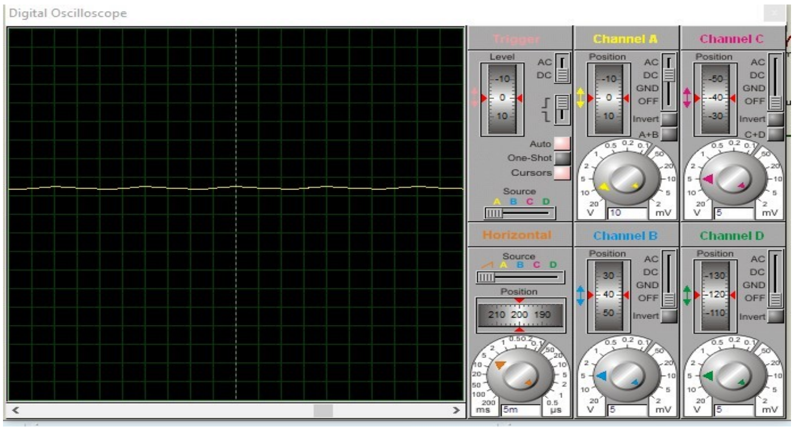

Figure 10. Waveform of the regulator output voltage when loaded with a motor

From the results of the tests and designs carried out, it can be concluded that the DC motor can be controlled in speed through the regulation of anchor voltage. However, it is crucial to keep the input voltage within a safe range, as too high a voltage can cause the motor to heat up and catch fire, while too low a voltage can cause the motor to not operate properly.

4. Conclusion

Based on the results of simulation and testing, it can be concluded that the DC motor has an excellent response to the anchor voltage regulation as a method to regulate its speed. However, the design of the DC motor speed control system needs to be done carefully, ensuring that the input voltage is always within safe limits to avoid damage to the motor and other components. Although the simulation provides a fairly clear picture, practical conversations on the ground need to be carried out to ensure the reliability of these control systems.

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