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Controlled Circuit for Three-Phase Characteristics Control of Shunt Direct Current Motor

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Abstract

The precise control of electric motor speed is essential in modern industrial applications, where variable direct voltage is often required to achieve optimal performance. This research focuses on the design and implementation of an SCR (Silicon Controlled Rectifier)-based rectifier circuit, aimed at supplying the necessary variable direct voltage for a shunt direct current (DC) motor. The key advantage of the SCR-based rectifier is its ability to regulate the output voltage by adjusting the delay angle of the SCR. This adjustment allows for precise control over the voltage supplied to the motor, which directly influences its speed and torque characteristics. Through experimental testing, the effectiveness of the proposed circuit in controlling the motor's performance was verified. The results showed that the rectifier circuit could efficiently regulate both speed and torque, providing a stable and adjustable output for the shunt DC motor. This ability to fine-tune motor characteristics offers significant potential for improving the operational efficiency of industrial systems, particularly in applications where variable speed and load handling are crucial. By optimizing the motor's performance, the SCR-based rectifier circuit can contribute to energy savings, enhanced productivity, and reduced wear on motor components, which ultimately leads to lower maintenance costs and extended motor life. These findings underscore the practical advantages of using SCR-based rectifiers in industrial motor control systems, positioning this approach as a valuable solution for modern manufacturing and automation.

Keywords: Rectifier circuit, Three phases, Shunt motor, Characteristics

1. Introduction

Direct Current (DC) motors are widely recognized for their simplicity in speed control and starting mechanisms, making them highly suitable for industrial applications (Nugraha & Eviningsih, 2022). Speed regulation in DC motors is achieved by adjusting the terminal input voltage. Consequently, industries utilizing DC motors as primary driving systems necessitate a reliable and variable DC voltage source (As'ad, Yuniza, & Nugraha, 2022). However, most power plants predominantly supply constant Alternating Current (AC) voltage sources, posing a challenge for variable voltage requirements.

Modern control systems for DC motors address critical functionalities such as dynamic speed adjustments, smooth start-stop operations, braking, and reversal of rotation direction (Faj'riyah, Setiyoko, & Nugraha, 2021). These capabilities are effectively managed using rectifier circuits that incorporate advanced semiconductor devices such as diodes, transistors, thyristors (SCRs), and triacs. The inherent advantages of semiconductor devices, including their absence of moving parts, low maintenance requirements, and operational safety in hazardous environments, make them ideal for industrial use (Nugraha & Eviningsih, 2022). Unlike traditional systems, these devices do not produce sparks or arc discharges, ensuring safe operation even in environments with flammable gases or vapors.

The output voltage of an SCR-based rectifier is governed by the firing angle of the thyristor. Phase-controlled thyristors are activated through a short pulse applied to the gate and deactivated via natural commutation. Such controlled thyristor rectifiers offer a highly efficient and adaptable solution for regulating motor speeds, catering to a range of motor capacities from small-scale devices to megawatt systems (Nugraha et al., 2020).

This study focuses on developing a three-phase semi-controlled rectifier circuit utilizing SCR technology. The rectifier circuit is designed to accept an input voltage of 3 × 110 VAC and generate a variable output voltage ranging from 0 to 220 VDC, with a current capacity of 7.5 amperes. The circuit is then employed to control the operation of a shunt DC motor by modulating the rectifier output voltage. Through precise adjustment of the output voltage, the motor's performance characteristics, including speed and torque, are evaluated and analyzed.

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This approach not only addresses the practical challenges of speed control in DC motors but also contributes to the development of efficient, safe, and flexible control mechanisms for industrial applications.

2. Material and methods

2.1. Three phase uncontrolled rectifier

Motor control with semiconductor equipment using a three-phase controlled rectifier circuit using an SCR is shown in the figure below.

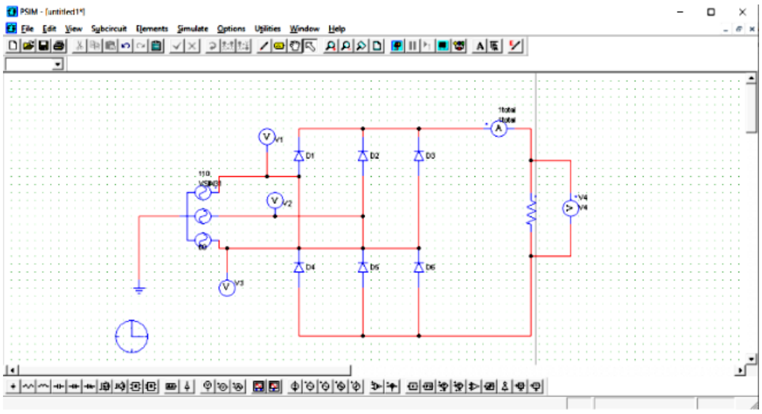

Figure 1. Three-phase controlled rectifier circuit

This rectifier circuit consists of three thyristors and three diodes (Pangestu et al., 2024). The ignition angle (α) can be adjusted in steps from 0 to 180°. During the period from 30° to 210°, thyristor T1 is forward biased. When T1 is turned on at t = 30° +, T1 and D1 are connected and the line voltage Vac appears across the load. At t = 210°, Vac starts negative and the freewheeling diode Dm is connected (Handandi et al., 2023). The load current continues to flow through Dm. T1 and D1 are off. Without the freewheeling diode Dm, thyristor T2 is turned on at t = 150° + and T1 remains connected until operation freewheeling produced by T1 and D2. At 60°, any thyristor connected to a diode with 120° freewheeling Dm will not be connected (Khabibi, Poetro, & Nugraha, 2020) (Yuski, Hadi, & Saleh, 2017).

If the corresponding line to line voltage is defined as follows:

$$Vab = Van - Vbn = \sqrt{3}V\angle{+30°}$$
$$Vbc = Vbn - Vcn = \sqrt{3}V\angle{-90°}$$
$$Vca = Vcn - Van = \sqrt{3}V\angle{+150°}$$

Atau $Vac = \sqrt{3}V\angle{+150°}$

2.2. Direct Current motor (DC Motor) shunt

In this motor, the armature circuit and the shunt field circuit are connected by a DC power supply with a fixed voltage Vt (Fauzi et al., 2024) (Aprilyani, Irianto, & Sunarno, 2020). The external field shear resistance (Rtc) is used in the field circuit to control the motor speed (Ananda, 2002). As this motor draws power from the DC power supply, the motor current flows into the machine from the positive terminal of the DC power supply (Muhammad et al., 2021).

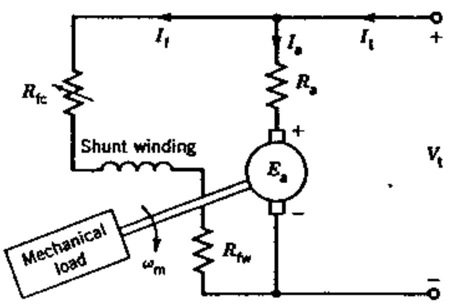

Figure 2. The equivalent circuit of a shunt direct current motor

The motor equation for steady state operation is as follows:

$$Vt = IaRa + Ea$$
$$It = Ia + If$$

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$Ea = Ka\ \phi\omega m$
$Ea = Vt - IaRa$
The armature current Ia and motor speed ωm depend on the mechanical load connected to the motor shaft.

2.3. Methods

This research was conducted in several structured stages to ensure the successful construction and testing of a controlled three-phase rectifier circuit (Rahman et al., 2024). The first stage involved preparing the necessary tools and materials required to build a controlled three-phase commutator circuit. Once the preparations were complete, the next step focused on constructing the rectifier circuit. The process began with designing and implementing the circuit wiring paths on a PCB board, followed by installing each component in its designated position according to the routing plan. After assembly, an initial test was conducted by supplying a 15-volt voltage from a step-down transformer, which received an input of 3×110VAC from a three-phase transformer powered by a three-phase power supply. This test verified the functionality of the control circuit.

Following the successful assembly and initial testing of the rectifier circuit, the system was further tested with a shunt winding DC motor to assess its performance and determine the motor's characteristics. During this phase, all measuring instruments, such as ammeters and tachometers, were prepared and activated. The transformer power supply was then turned on, providing an output of 3×110VAC. Experimental data was collected by recording measurements from the instruments, and two types of experiments were conducted: one with a constant load and another with varying loads. Upon completing these experiments, the collected data was analyzed to evaluate the circuit's performance and the motor's operational characteristics. This systematic methodology ensured reliable results and validated the effectiveness of the constructed system (Ahmad, Zondra, & Yuvendius, 2020).

A. Research work

This rectifier circuit uses a power transformer which acts as a three-phase line voltage ballast. This is because a rectifier circuit that uses a thyristor (SCR) cannot withstand relatively high unstable voltages. If the voltage becomes unstable, it may not be possible to properly control the start time of the thyristor. The ignition angle of the rectifier circuit is regulated by a control circuit that acts as a pulse angle transmitter (α) in the rectifier power circuit. The step-down transformer used has a rated current of 1 amp and an output voltage of 15 volts and is used as a power source for the processor IC pins. This IC acts as a sine wave synchronizer and produces a sawtooth wave. The processor, as a form of launch at the gate, uses the TCA 785 chip, which acts as a gate signal generator for the thyristor, to operate the thyristor and generate a DC waveform at the output terminal. Capacitors and filters are used to form a better DC filter (Primadi, Prasetya, & Eng, 2019). With filter capacitors, when the voltage rises, the capacitor is charged, and when the voltage reaches zero, the capacitor discharges that charge to the load (Putri et al., 2022). Whereas in the inductor filter, the inductor accumulates current when the current decreases, and the inductor discards the stored current when the current increases (Susanto & Ulinuha, 2017).

B. Control circuit

The TCA 785 chip processor SCR trigger control circuit uses the TCA 785 chip processor to control the ignition angle of the rectifier circuit to create a DC voltage variable (Azizi, Hadi, & Kalandro, 2020). Pulse Transformer Driver Circuit A pulse transformer is used as a component to form a trigger pulse which is supplied to the gate of the SCR. The trigger pulse is generated from the square wave signal generated by the switching transistor (Jumanto & Supardi, 2014). Transistor-based controllers, on the other hand, emit pulses from the TCA . chip processor 785.

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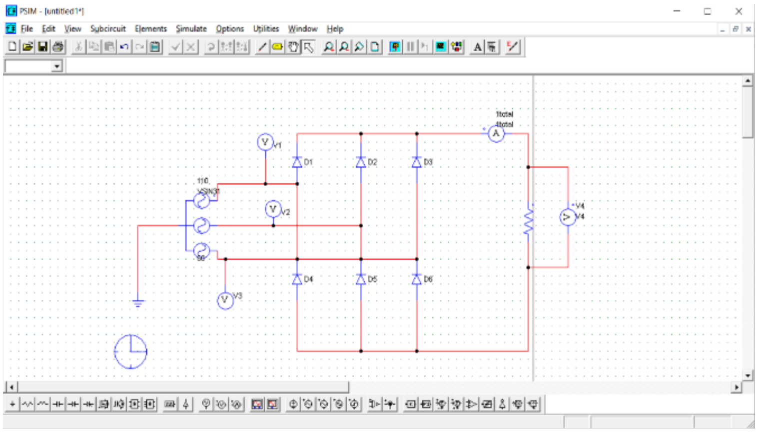

Figure 3. Three-phase controlled rectifier control circuit

3. Results and discussion

3.1. Measurement with constant load, torque (T) = 0,1 N-m

Table 1. Measurement data with constant load

No	Trigger angle (a)	Output Voltage (Volt)	Motor Current (mA)	Anchor Current (A)	Load Current (A)	Torque (N-m)	Speed (rpm)
1	50	210	90	0,24	0,45	0	2600
2	55	200	86	0,24	0,58	0,1	2500
3	65	180	76	0,28	0,65	0,1	2250
4	75	160	68	0,3	0,68	0,1	2050
5	85	140	60	0,32	0,7	0,1	1875
6	95	120	50	0,34	0,73	0,1	1700
7	105	100	42	0,32	0,78	0,1	1500
8	115	80	32	0,32	0,95	0,1	1150

From the above experiment, it can be seen that the greater the delay angle of the rectifier, the lower the output voltage of the rectifier which is equal to the motor input voltage. When the input voltage to the motor decreases, the motor speed m decreases. It can also be seen that the field current decreases as the input voltage to the motor decreases, and the load current increases as the voltage decreases. Figure 5 shows a graph of the rectifier output voltage and motor speed as a function of the discharge angle when torque T = 0.1 N – m (constant).

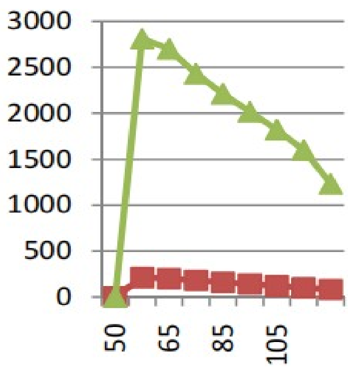

Figure 4. Graph of rectifier output voltage (red) and motor speed (green) as a function of angle

3.2. Measurement with changing load.

Table 2. Measurement data with changing load

No	Trigger angle (a)	Output Voltage (Volt)	Motor Current (mA)	Anchor Current (A)	Load Current (A)	Torque (N-m)	Speed (rpm)
1	85	140	58	0,32	0,4	0	2000
			57	0,36	1,15	0,3	1675

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			56	0,42	1,6	0,45	1500
			56	0,54	2,4	0,6	1300
2	105	100	40	0,32	0,42	0	1700
			39	0,42	1,55	0,3	1050
			38	0,48	1,9	0,35	800
			38	0,60	2,5	0,45	500
3	115	80	34	0,37	0,5	0	1500
			34	0,35	0,8	0,1	1350
			32	0,38	1,4	0,2	900
			32	0,42	1,8	0,3	400

Image 5 shows a graph of the rectifier output voltage and motor speed as a function of the discharge angle at torque T = 0 N –m.

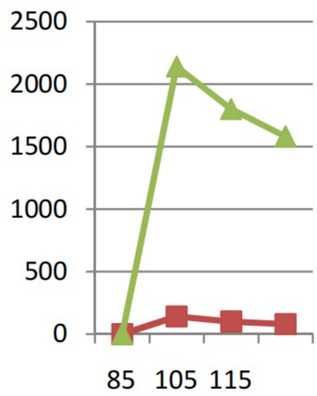

Figure 6. Graph of rectifier output voltage and motor speed as a function of trigger angle

3.3. Discussion

The relationship between torque (T) and armature current (Ia) When the terminal voltage Vt is constant, the magnetic amplifier current (Im) is also constant, so it is constant. When the terminal voltage is constant, the torque of the shunt winding motor depends only on the armature current (Ia). From the torque equation, when T = K.Ia.Φ. Therefore, T depends on the armature current (Ia). In the above experiment, the greater the torque, the greater the torque. Torque characteristics as a function of armature current at 140 volts.

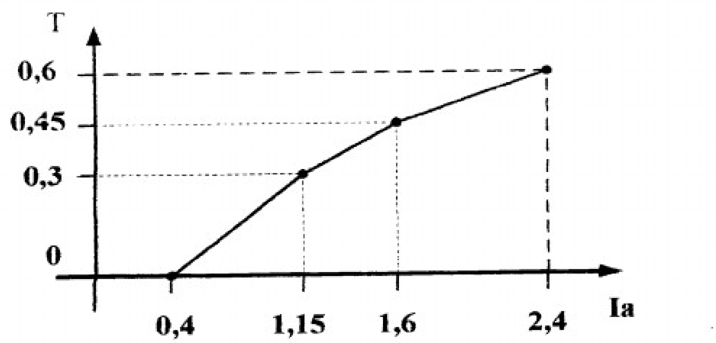

Figure 7. Graph of torque as a function of armature current

4. Conclusion

In conclusion, using a thyristor in a rectifier with phase control techniques proves effective, though the performance depends on improvements in the trigger pulse generator for optimal operation. Proper synchronization of the control signal with the input signal is crucial, as delays in sampling and pulse generation can reduce performance.

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- In constant load tests, the maximum output voltage occurs at a trigger angle of 50°, giving 210 volts and a motor speed of 2600 rpm. As the output voltage drops to 80 volts, the motor speed decreases to 1150 rpm, demonstrating that a higher delay angle reduces the motor's input voltage and speed.
- In tests with varying loads, motor speed decreases as torque increases. For example, with an input voltage of 140 volts, the motor speed drops from 2000 rpm to 1300 rpm as torque increases from 0 to 0.6 Nm.
- Overall, the rectifier circuit performs well for testing the characteristics of a shunt-winding DC motor.

Credit authorship contribution statement
Author Name: Conceptualization, Writing – review & editing. **Author Name**: Supervision, Writing – review & editing. **Author Name**: Conceptualization, Supervision, Writing – review & editing.

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