Conference of Electrical, Marine and Its Application
Vol. xx, No xx, Month-Year ISSN:

Analysis of Thyristor Usage in Controlled Half-Wave Rectifiers on DC Motor Speed Control

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ABSTRACT

Speed control of a motor can be achieved in several ways, one of which is by varying the armature voltage (Vt) supplied to the motor. A DC motor operates with the aid of a rectifier circuit to convert AC signals into DC. The controlled half-wave rectifier circuit is one of the simplest forms of rectifier circuits, as it requires fewer components and provides an adjustable output voltage through changes in the firing angle of the thyristor. This makes the circuit suitable for controlling the speed of a DC motor. A simulation in PSIM software was selected to investigate the relationship between the thyristor firing angle in the controlled half-wave rectifier circuit and the speed of a series DC motor. The simulation was conducted by varying the thyristor firing angle at 0°, 15°, 30°, 45°, 60°, 90°, 120°, and 150° to observe the effects on the speed of the series DC motor. Additionally, different torque loads, including 0 Nm, 0.5 Nm, and 1 Nm, were applied to assess the impact on motor speed. The results showed that increasing the thyristor firing angle leads to a decrease in motor speed due to the reduction in armature voltage. Similarly, higher torque loads resulted in lower motor speed. Motor speed increased with higher source voltage and firing angle if a full-wave rectifier was used, as it provides a higher output voltage compared to a half-wave rectifier.

Key Word: *Motor DC, PSIM, Thyristor*

I.INTRODUCTION

The DC motor is one of the most widely used types of motors in various applications, ranging from household appliances to industrial machinery[1]. Speed regulation of DC motors can be achieved through various methods, one of the most common being the adjustment of the terminal voltage (Vt) supplied to the motor. By modifying the terminal voltage, the rotational speed of the motor can be controlled both during startup and continuous operation[2][3]. This adjustment is more efficient and simpler when using a single-phase controlled rectifier circuit. This research aims to analyze the influence of the thyristor firing angle on the performance of a half-wave rectifier circuit and its impact on the speed control of a DC motor[4].

In general, the electrical power available in homes and industries is alternating current (AC), which is not directly compatible with devices that require direct current (DC) input. As a result, a rectifier circuit is necessary to convert the AC signal into a usable DC signa[5]l. A rectifier circuit serves the purpose of converting AC voltage into DC voltage, enabling compatibility with DC-powered devices and systems. Among various types of rectifiers, the half-wave rectifier circuit is the simplest and most basic form, consisting of minimal components but still providing the essential conversion from AC to DC[6].

Rectifiers can be categorized into two types: controlled rectifiers and uncontrolled rectifiers. A controlled rectifier circuit utilizes thyristors as rectifying components, which offer the advantage of adjustable output voltage. This adjustability is achieved by controlling the firing angle of the thyristor, which regulates the output voltage and consequently influences the motor speed[7]. By altering the thyristor firing angle, the voltage supplied to the motor can be modulated, allowing precise control over the DC motor speed. The controlled rectifier circuit thus provides an effective means to regulate the speed of DC motors, making it an important tool in industrial applications and various automation systems.

II.METHODOLOGY

1. Single Phase Half Wave Controlled Rectifier

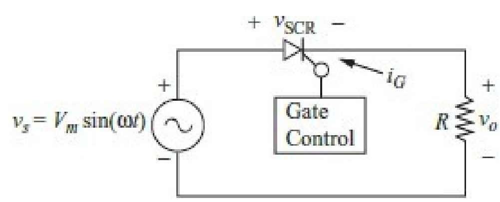
A controlled rectifier circuit can generally be defined as a power electronic circuit designed to convert alternating current (AC) into direct current (DC), with an output voltage that can be regulated to meet specific needs. The regulation of the output voltage is achieved through the use of Silicon Controlled Rectifiers (SCRs), which provide precise control over the voltage waveform[8]. Similar to uncontrolled rectifier circuits, a capacitor filter is often employed to smooth the DC output and enhance the quality of the voltage waveform. Additionally, the inclusion of DC power regulation and proper voltage smoothing are essential for ensuring stable operation, particularly when supplying power to sensitive devices like DC motors[9].

The half-wave controlled rectifier is one of the simplest forms of rectification, utilizing a single thyristor to control the direction of current flow[10]. In this configuration, the rectifier provides a unidirectional DC output with a varying level of controlled voltage that is directly proportional to the firing angle of the thyristor. The simplicity of the half-wave controlled rectifier makes it ideal for applications where cost-effectiveness, simplicity, and moderate control are required. This circuit is frequently employed as a power supply for the armature windings of DC motors, where the armature voltage is adjusted to regulate the motor speed.

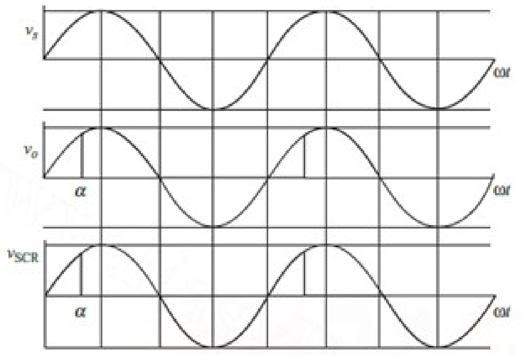
The relationship between the firing angle of the thyristor and the output voltage is fundamental to understanding how this circuit can be applied for motor speed contro[11]l. In the context of a DC motor, the output voltage directly influences the speed of the motor, making this controlled rectifier a critical component in systems that require variable speed control. By adjusting the thyristor's firing angle, engineers can fine-tune the voltage supplied to the motor, thereby adjusting its rotational speed according to operational needs.

The rms voltage or DC output voltage (Vdc) of a half-wave controlled rectifier circuit can be calculated using the following equation, which represents the relationship between the input AC voltage, the firing angle of the thyristor, and the DC output voltage (Vo)[12]:

$$V_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} V_0^2(\omega t)d(\omega t)}$$
$$= \sqrt{\frac{1}{2\pi}\int_\propto^{\pi} [V_m \sin(\omega t)]^2 d(\omega t)}$$
$$= \frac{V_m}{2}\sqrt{1-\frac{\alpha}{\pi}+\frac{\sin(2\alpha)}{2\pi}}$$



(a)



(b)

Figure 1. (a) Controlled Half Wave Rectifier Circuit;(b) Half Rectifier Circuit Output Waveform Controlled Waves

2. Thyristor

The Thyristor, also known as Silicon Controlled Rectifier (SCR), is a semiconductor-based component that functions as a switch in various power electronic applications. A key feature of the thyristor is its ability to control the flow of electrical current through it by adjusting its firing angle, which is governed by the gate terminal[13]. While the thyristor shares similarities with a diode in its basic operating principle, it is distinct in that it includes a gate which allows external control over its conductivity.

when the voltage at the anode is more positive than the cathode and a positive pulse current is applied to the gate terminal, the thyristor enters its on state, conducting current between the anode and cathode[14]. Once activated, the thyristor remains in this on state, even if the gate pulse is discontinued. This characteristic is crucial for applications where continuous conduction is required. The thyristor will remain in the on state until the voltage at the anode equals the voltage at the cathode, at which point the thyristor turns off.

The act of applying a positive current to the gate terminal is referred to as triggering or firing the thyristor[15]. This process is essential for initiating its conduction, and it is typically achieved through carefully controlled pulses. The transition from on to off state is known as commutation, and this process is fundamental for controlling the flow of electric current in AC to DC rectifiers. By adjusting the firing angle (the timing of the gate pulse), the average output voltage can be varied, which is crucial for applications such as motor speed control in DC motors.

Thyristors are widely used in controlled rectifier circuits for various purposes, including voltage regulation and speed control of DC motors[16]. By varying the firing angle of the thyristor, the amount of DC voltage supplied to the motor can be controlled, thus regulating its speed. This method is often employed in systems requiring precise speed adjustments, such as industrial motor drives, electrical appliances, and automated systems.

In the context of engineering research, the use of thyristors in controlled rectifiers is a critical area of study. This research focuses on understanding how SCRs can be employed to efficiently control the output voltage of a half-wave controlled rectifier, a simple yet effective way of converting AC to DC. The ability to control the firing angle of a thyristor allows for fine-tuned regulation of motor speed, making it a valuable tool in DC motor control applications.

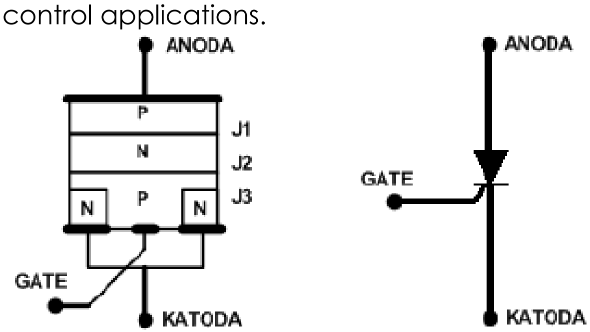


Figure 2. Structure and symbol of thyristor

3. Motor DC

A DC motor, or Direct Current motor, is one of the most widely used devices in converting electrical energy into mechanical energy or kinetic motion. The primary function of a DC motor is to drive mechanical systems by generating rotary motion[17]. The direction of the motor's rotation can be controlled by altering the polarity of the electrical input—either clockwise or counterclockwise, depending on the direction of the current supplied to the motor terminals[18]. This characteristic makes DC motors versatile in various applications, ranging from robotics to automated systems.

The operating principle of a DC motor relies on the phenomenon of electromagnetism. When an electric current is passed through a coil (the armature) placed within a magnetic field, the interaction between the magnetic field and the electric current generates a torque that causes the armature to rotate[19]. Specifically, the armature's sides experience forces that cause it to rotate, with the north pole of the armature coil being repelled by the north pole of the stationary magnet, and the south pole of the armature being attracted to the south pole of the magnet. As the coil rotates and its poles change, the commutator reverses the direction of current in the windings to ensure continuous motion. This interaction between the magnetic field and the current in the coil generates a rotational force, which ultimately drives the motor.

However, when the poles of opposite charge meet, they create an attractive force, which can halt the motion of the armature if not properly managed. The DC motor speed can be regulated in several ways, such as by controlling the voltage applied to the armature, adjusting the field current, or using power electronics to modify the supply voltage efficiently.

In the context of motor speed control, the relationship between input voltage and motor speed is critical. The speed of a DC motor is directly proportional to the voltage applied to the armature. Hence, controlling the voltage allows for precise speed regulation, which is essential in applications requiring dynamic control, such as in automated systems, electric vehicles, and industrial drives.

One of the most effective methods for controlling the speed of a DC motor is by using power electronic circuits, such as controlled rectifiers[12][13]. These circuits, when used in conjunction with components like thyristors, can provide a smooth and efficient way of varying the output voltage and thus controlling the speed of the motor[15]. A half-wave controlled rectifier is particularly useful in DC motor speed control systems, where the phase control of the thyristor determines the amount of voltage delivered to the motor, thus regulating its speed. This is a fundamental area of research in power electronics and motor control systems, and it provides significant potential for innovation in industries ranging from robotics to automated manufacturing.

$$E_b = C \bullet N \bullet \emptyset$$

Information: E_b : Oposite electric (V)
C : constant
N : anchor rotation speed (RPS)
Φ : magnetic flux (Wb)

$$E_b = V_t - I_a \bullet R_a$$

Information: V_t : terminal voltage (V)
I_a : armature current (A)
R_a : anchor resistance (Ω)

From these equations, if combined, it will become:

$$N = \frac{\hat{V}_t - I_a \cdot R_a}{C\emptyset}$$

From this equation it is obtained that the rotation speed of the armature can be adjusted by changing the voltage or current value of the field winding, providing a series resistor to the armature resistance, and changing the terminal voltage of the armature winding. Meanwhile, the torque produced by the motor uses the following equation:

$$T = \frac{E_b \cdot I_a}{2\pi \cdot N}$$

When a DC motor starts, the starting current can reach 20 to 30 times greater than the nominal current at full load. From the equation above it can be proven as follows:

$$V_t = E_b + I_a \cdot R_a$$

$$I_a = \frac{V_t - E_b}{R_a}$$

When Eb Starting Eb=0, So:

$$I_a = \frac{V_t}{R_a} = I_{st}$$

4. Metode

In this study, a simulation-based approach will be employed using the PSIM software to analyze the impact of the firing angle of the thyristor in a controlled half-wave rectifier circuit on the speed control of a DC motor[19][20]. The simulation is aimed at providing insights into how the thyristor's triggering angle influences the motor speed, allowing for an efficient method of speed regulation.

As is well-established in the field of electrical engineering, the speed of a DC motor can be adjusted by varying the armature voltage (Vt). The motor speed is directly proportional to this applied voltage, which makes it a critical parameter for speed control in DC motor systems[17]. In a rectifier circuit, the output voltage can be controlled by adjusting the firing angle of the thyristor. By varying this angle, the duration for which the rectifier is conducting is altered, thus modifying the DC output voltage and, consequently, the speed of the DC motor.

Therefore, the core focus of this research involves systematically adjusting the firing angle of the thyristor in the half-wave controlled rectifier circuit and studying its effects on the speed of the DC motor. This methodology enables a thorough investigation into how small changes in the triggering phase of the thyristor can have a substantial impact on the motor's rotational speed. This approach provides valuable insights into power electronics and the application of thyristors in motor control systems.

The methodological framework for this research involves the following steps:

- Simulation Setup: The PSIM software will be used to model a half-wave controlled rectifier system. This will allow the simulation of different firing angles and their effects on the DC motor's speed.
- Adjustment of Thyristor Firing Angle: The thyristor's triggering angle will be varied in increments (e.g., 0°, 15°, 30°, etc.), and the resulting changes in the motor speed will be recorded. This step is crucial to establish the relationship between the firing angle and motor speed.
- Data Analysis: The output data from the simulation will be analyzed to observe how changes in the firing angle impact the DC motor's rotational velocity. Special attention will be given to the effects of both underload and varying load conditions on the motor's performance.
- Interpretation of Results: The results will be discussed in the context of engineering applications for motor control systems, specifically in terms of optimizing speed regulation in industrial settings, where precision control is required.

The findings from this research are expected to contribute significantly to the understanding of thyristor-based control systems for DC motors, and the simulation methodology will allow for a detailed exploration of how firing angle influences output voltage and motor performance. This work will have relevance not only in academic research but also in industrial applications where efficient motor speed control is essential.

A. Motor DC Specification

Table 1 presents the technical specifications of the DC motor used as the reference in this study. These specifications are critical for understanding the motor's operational characteristics and will serve as the foundation for analyzing the effects of the controlled half-wave rectifier circuit on its speed control. By examining these parameters, the relationship between the motor's performance and the rectifier configuration can be assessed, providing valuable insights into the efficiency and precision of motor speed regulation using thyristors.

Tabel 1. Motor DC Spec

Description	Parameter	Value
anchor resistance	R_a	0.5 ohm
Anchor Inductance	L_a	0.01 H
Filed resistance	R_f	20 ohm
Field inductance	L_f	0.02 H
Inertia momment	l	0.4
Terminal Voltage Rating	V_t	185 V
Terminal Current Rating	I_a	13.5 A
Playback Speed Rating	n	1500 Rpm
Field Current Rate	I_f	0.8 A

B. Simulation Model

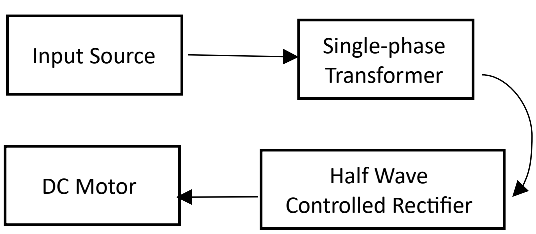


Figure 3. Block Diagram

The explanation of the system block diagram from Figure 3 is as follows:

1. Input source as a power source which is a single phase voltage source (220V, 50Hz).
2. The transformer is used to reduce the voltage from 220V to 100V from the input source to rectifier circuit.
3. t Rectifier is a half wave rectifier with thyristors for converts AC signals to DC.
4. DC motors are electrical machines which are the object of research.

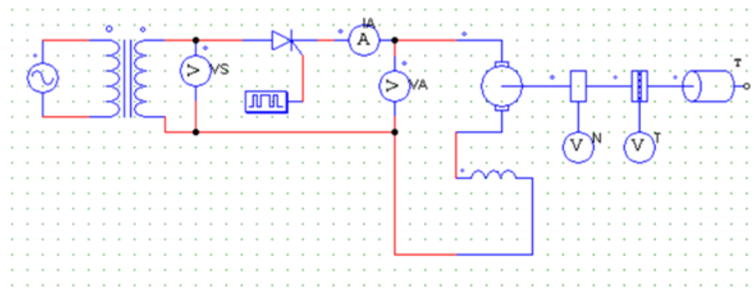


Figure 4. PSIM Simulation circuit

III.RESULT & DISCUSION

1.Result

After conducting measurements using the PSIM software, the results obtained include values for armature voltage (Va), armature current (Ia), and the speed of the separately excited DC motor (N). The DC motor was then subjected to torque loads of 0 Nm, 0.5 Nm, and 1 Nm. The detailed measurement results are presented in the following table.

Table 2. Simulation result with Torque = 0 Nm

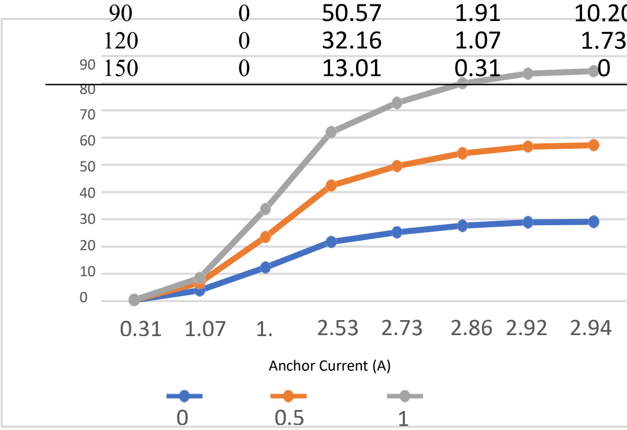
Ignition Angle Thyristors (°)	Torque (Nm)	Anchor Voltage (Va) (Volt)	Anchor Current (Ia) (A)	Rotation (Rpm)
0	0	71.10	2.93	29.07
15	0	70.96	2.91	28.77
30	0	70.08	2.85	27.56
45	0	67.82	2.73	25.19
60	0	63.87	2.53	21.63
90	0	50.56	1.90	12.23
120	0	32.15	1.07	3.86
150	0	13.01	0.31	0.32

Table 3. Simulation result with Torque = 0.5 Nm

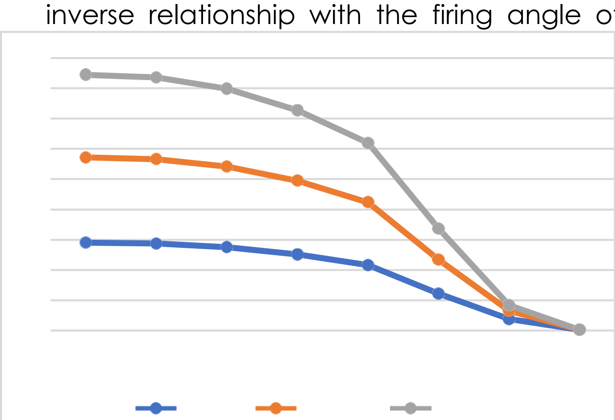
Ignition Angle Thyristors (°)	Torque (Nm)	Anchor Voltage (Va) (Volt)	Anchor Current (Ia) (A)	Rotation (Rpm)
0	0	71.10	2.94	28.14
15	0	70.96	2.92	27.84
30	0	70.08	2.86	26.63
45	0	67.83	2.73	24.24
60	0	63.87	2.53	20.66
90	0	50.57	1.90	11.21
120	0	32.15	1.07	2.80
150	0	13.01	0.31	0

Table 4. Simulation result with Torque = 1 Nm

Ignition Angle Thyristors (°)	Torque (Nm)	Anchor Voltage (Va) (Volt)	Anchor Current (Ia) (A)	Rotation (Rpm)
0	0	71.10	2.94	27.22
15	0	70.96	2.93	26.91
30	0	70.09	2.87	25.69
45	0	67.82	2.74	23.29
60	0	63.87	2.54	19.67
90	0	50.57	1.91	10.20
120	0	32.16	1.07	1.73
150	0	13.01	0.31	0



Based on the measurements presented in Tables 2, 3, and 4, it can be observed that the motor speed exhibits an inverse relationship with the firing angle of



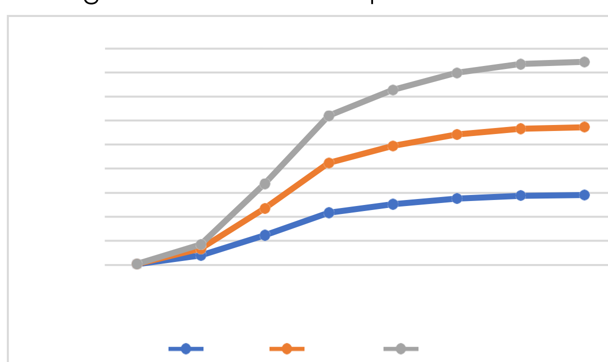
the thyristor. As indicated by the measurement data, increasing the firing angle of the thyristor results in a decrease in the motor speed. Additionally, an increase in the torque load on the motor also leads to a reduction in the motor's rotational speed. This relationship is further illustrated in Figure 4, which depicts the corresponding graphical representation.

2. Discussion

Figure 4. Graph of the Function of the Ignition Angle on the Rotational Speed of a Series Self-amplifying DC Motor

Based on the results presented in the measurement tables, both the armature voltage and current are directly proportional to the motor's rotational speed. As the values of armature voltage and current increase, the motor speed also increases accordingly. This direct correlation is clearly demonstrated in Figures 5 and 6, where the graphical representation highlights the relationship between the armature voltage, current, and the motor's speed.

Figure 5. Graph of the Function of Armature Voltage on the Rotational Speed of a Series



Self-amplifying DC Motor

Figure 7. Graph of Armature Current Function Against Rotation Speed of Series Self-amplifying DC Motor

IV.CONCLUSION

- Effect of Firing Angle on DC Motor Speed: The firing angle of the thyristor significantly influences the rotational speed of the DC motor. As the firing angle increases, the motor speed decreases.
- Decrease in Voltage and Current: An increase in the firing angle leads to a reduction in the voltage and current output from the half-wave rectifier supplied to the motor's armature windings.
- Comparison of Half-Wave and Full-Wave Rectifiers: The voltage generated by the half-wave rectifier is inherently lower than that produced by a full-wave rectifier.
- Motor Speed Optimization: The motor speed will be higher when the source voltage and thyristor firing angle are optimized, particularly when using a full-wave rectifier, as it provides higher output voltage compared to the half-wave rectifier.
- Relationship Between Voltage and Motor Speed: Higher voltage from the full-wave rectifier contributes to an increase in the speed of the DC motor.

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