Three Phase Controlled Rectifier Circuit for Characteristic Control in DC Shunt Motor

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Abstract: A modern control of electric motor's speed in an industry needs a variable direct voltage. Mostly, the variable of the DC motor speeds needs to be control simply by adjusting the voltage variable at the terminal. In industries, the usage of DC power is limited. Therefore, the support of rectifier in the DC motors is needed to change AC voltage to DC voltage. Moreover, industries need a concrete rectifier to increase performance of its DC shunt motor. The variable direct voltage can be supplied by semiconductor devices such as SCR. The output voltage of a SCR rectifier depends on the delay angle of the SCR. The aim of this research is to make a SCR rectifier circuit and applying it for observing the characteristics of a shunt direct current motor. The result shows the circuit can work to demonstrate the shunt motor characteristic. The support of proper rectifier will be maximizing the performance of DC shunt motor. So that, supported the productivity in each industry. This rectifier 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 which acts as a pulse angle transmitter (α) in the rectifier power circuit. The testing on this research is using PSIM software to test the performance of rectifier design before it applied in a prototype. The testing result show relationship between velocity ω_m and armature current Ia, the relationship between torque (T) and armature current (Ia). The result of this research show 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. The effectiveness of the usage thyristor component in this experiment is supporting the performance of rectifier. The processor that use in this rectifier, 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. Therefore, customize design in this research can be used to test the characteristics of a shunt winding DC motor.

1 INTRODUCTION

DC motor is basically an electric motor with a speed that can be controlled simply. Speed control for this type of motor is carried out by adjusting the voltage at the input terminal (Angga et al). Therefore, industries that use DC motors as their driving devices require a DC (variable) voltage source (Applied Technology and Computing Science Journal 4.1:31-46., 2021). Most power plants issue AC voltage, so that distribution to consumers is provided with an AC voltage source (Febrianto., 2021). Therefore, a voltage rectifier is needed to change the type of AC voltage to DC (Fitzgerald et al., 1996). The voltage rectifier used is a controlled rectifier which aims as a control system to regulate the speed of a DC motor (Heraja et al, 1984).

Modern control systems need to control DC motor speed changes, dynamic braking, smooth start and stop, or reversal of the motor rotation direction (Jacob

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M et al, 1990). All this can be done easily and well with rectifier devices that use semiconductor components such as diodes, transistors, thyristors (SCRs), and triacs (Kenjo.,1995). These semiconductor devices have no moving parts and are easy to maintain. In addition, these semiconductor devices are safer to use in hazardous environments, such as the presence of flammable gases and vapors, as there is no spark or arc discharge (M Agus Praztyio., 2016).

The output voltage generated by the thyristor component (SCR) depends on the firing angle of the thyristor (Malvino and Barmawi (1996). The phase control thyristor is turned on by applying a short pulse to the gate and turned off by natural commutation. The controlled thyristor rectifier is a simple and efficient rectifier for controlling motors with adjustable speed, from small motors to megawatt motors (Nugraha et al., 2022).

This research was conducted to make a three-phase semi-controlled rectifier circuit using SCR (Petruzella., 2001). This three-phase semi-controlled rectifier has an input voltage of 3 x 110 VAC and a variable output voltage of 0 - 220 VDC with a current of 7.5 amperes. Furthermore, this rectifier circuit is applied to control the shunt direct current motor by adjusting the rectifier output voltage (Priyambodo et al., 2021). From setting the output voltage of this rectifier, the characteristics of the motor can be tested (Putra et al., 2021).

Through this research there were several problems were found in this paper, including the arrangement of controlled rectifier circuit and the working principle of the rectifier circuit to regulate the rotational speed of DC motor. So that, by this study it will fulfilling some purpose there were knowing the arrangement of the controlled rectifier circuit and the working principle of rectifier circuit so it can control the speed of DC motor.

2 LITERATURE RIVIEW

2.1 Three Phase Controlled Rectifier

Motor control with semiconductor equipment using a three-phase controlled rectifier circuit using SCR is shown in Figure 1 (Raysid.,(1999).

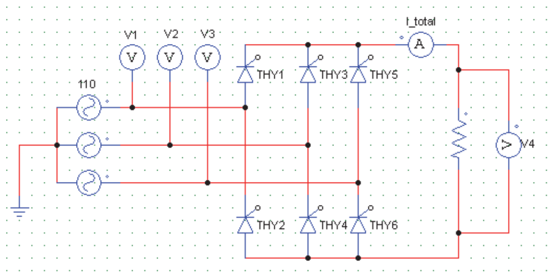

Figure 1: Controlled Rectifier Circuit Model 3-Phase with Thyristor.

This rectifier circuit consists of three thyristors and three diodes. 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. 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 freewheeling operation is produced by T1 and D2. At 60°, any thyristor connected to a diode with 120° freewheeling Dm will not be connected (Realdo et al., 2021).

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

$$V_{ab} = V_{an} - V_{bn} = \sqrt{3V\angle} + 30° \quad (1)$$

$$V_{bc} = V_{bn} - V_{cn} = \sqrt{3V\angle} - 90° \quad (2)$$

$$V_{ca} = V_{cn} - V_{an} = \sqrt{3V\angle} + 150° \quad (3)$$

$$\text{Or} \quad V_{ac} = \sqrt{3V\angle} + 150° \quad (4)$$

The schematic of a shunt winding DC motor is described. In this motor, the armature circuit and the shunt field circuit are connected by a DC power supply with a fixed voltage Vt. The external field shear resistance (Rtc) is used in the field circuit to control the motor speed. Since 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. Three-phase controlled rectifier circuit has components that are connected so that it can rectify AC voltage into DC voltage. The components in a three-phase controlled rectifier circuit, including:

2.1.1 Thyristor

Thyristors are active electronic components that can be used like doors, namely, to withstand AC current or pass AC current using a small input source. The use of thyristors in electronic circuits is generally used as a switch. Thyristor is a semiconductor component that is made of silicon. The thyristor has three legs including the anode, cathode and gate pins.

2.1.2 Transformator Stepdown

A step-down transformer is a transformer that is useful for lowering the mains voltage, which is the opposite of a step-up transformer. In an electronic circuit, this type of step-down transformer is widely used in power supplies, both regulated and unregulated power supplies. The function of this type of transformer in the field of electronics is already familiar because it is used to replace batteries. Without a power supply that uses a step-down transformer, the battery power supply system in electronic circuits is very inefficient, especially in terms of cost.

2.2 Direct Current Motor Shunt

The schematic of a shunt winding DC motor is described by Sen (1987) as shown in Figure 2 in this motor, the armature circuit and the shunt field circuit are connected by a DC power supply with a fixed voltage Vt.

The external field shear resistance (Rtc) is used in the field circuit to control the motor speed. Since 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.

The motor equation for steady state operation is as follows:

$$V_t = I_a R_a + E_a \tag{5}$$

$$I_t = I_a + I_f \tag{6}$$

$$E_a = K_a \phi \omega_m \tag{7}$$

$$E_a = V_t - I_a R_a \tag{8}$$

The armature current (I_a) and motor speed ω_m depend on the mechanical load connected to the motor shaft.

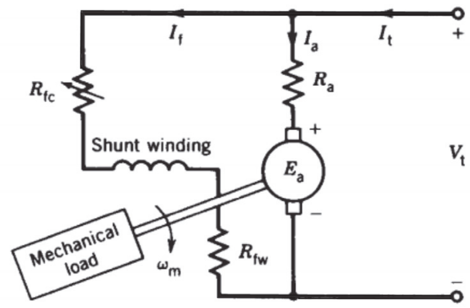

Figure 2: The equivalent circuit of a shunt direct current motor (Priyambodo et al., 2021).

3 METHODS

This research will be conducted virtually using PSIM software. Schematic of the design in Figure 1. The research was carried out with the initial stages of preparing tools and components that would later be used to make a controlled three-phase rectifier circuit.

Making a controlled three-phase rectifier circuit begins with setting and taking the components that will be used, then pulling the circuit wiring path on the schematic board, as shown in Figure 1. After that, the input voltage amplitude setting on each Variac is set to 110V. After setting up and making the scheme, the voltmeter and ammeter were installed which aims to determine the value of voltage and current on the source side and the load side.

After the circuit is ready, then a test is carried out by turning on the power supply. During the trial, sampling of experimental data will be carried out by recording the values that appear on the voltmeter and ampere meter measuring instruments to the experimental results table. This research was conducted with two types of experiments, namely experiments with constant loads and experiments with varying loads. After the experiment is complete, the power will be turned off.

4 RESULT OF THE STUDY

The specifications of the rectifier made are as follows:

$$V_{OUT} = 0 - 100 V_{DC} \tag{9}$$

$$V_{IN} = 3 \times 110 V_{AC} \tag{10}$$

$$V_{OUTMAX} = 7{,}5 A \tag{11}$$

4.1 Block Diagram

This rectifier 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.

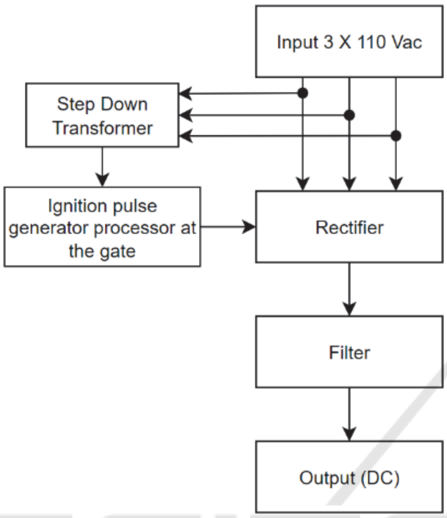

Figure 3: Block circuit diagram.

The ignition angle of the rectifier circuit is regulated by a control circuit which 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 sync 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. 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. Whereas in an inductor filter, the inductor accumulates current when the current decreases, and the inductor discards the stored current when the current rises.

4.2 Control Circuit

The control circuit consists of the following:

1. 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.
2. 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. Transistor-based controllers, on the other hand, emit pulses from the TCA 785 chip processor.

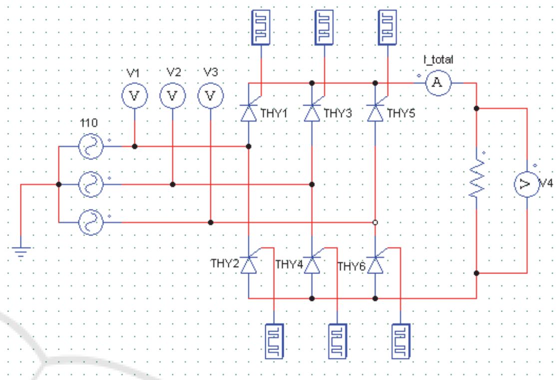

Figure 4: Control circuit of three-phase controlled rectifier.

4.3 Testing

Figure 4 is the implementation used for the circuit and will be simulated for discussion. The following is a table containing test result data, including the following:

4.3.1 Measurement with Constant Load, Torque (T) = 0.1 N-M

Table 1: Measurement data with constant load.

No	Trigger Angle (α)°	Rectifier Output Voltage (Volt)	Field Current (mA)	Anchor Current (A)	Load Current (A)	Torque (N-m)	Speed Motor (RPM)
1	50	210	90	0,24	0,45	0	2600
2	55	200	86	0,24	0,575	0,1	2500
3	65	180	76	0,28	0,65	0,1	2250
4	75	160	68	0,3	0,675	0,1	2050
5	85	140	60	0,32	0,7	0,1	1875
6	95	120	50	0,34	0,725	0,1	1700
7	105	100	42	0,325	0,775	0,1	1500
8	115	80	32	0,32	0,95	0,1	1150

From the above experiment, 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 at torque T = 0.1 N–m (constant).

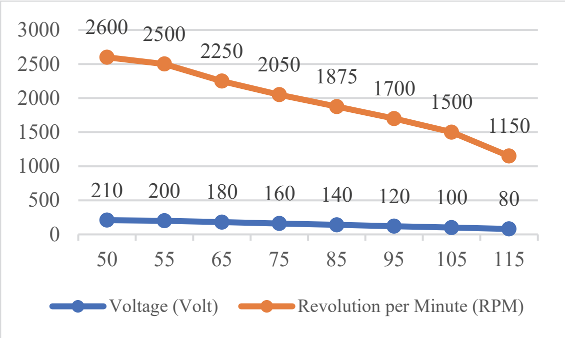

Figure 5: Graph of rectifier output voltage and motor speed as a function of trigger angle.

4.3.2 Measurement with Changing Load

Table 2: Measurement data with changing load.

No	Trigger Angle (α)°	Rectifier Output Voltage (Volt)	Field Current (mA)	Anchor Current (A)	Load Current (A)	Torque (N-m)	Speed Motor (RPM)
1	85	140	58	0,32	0,4	0	2000
			57	0,36	1,15	0,3	1675
			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

Figure 6 shows a graph of the rectifier output voltage and motor speed as a function of the discharge angle at torque T = 0 N–m.

From the experimental data above, we can see the characteristics of the motor, including:

Relationship between velocity ω_m and armature current Ia. In this experiment, the magnetic flux is assumed to be constant, so m is proportional to Ea, and if the motor rotation is also constant, Ea will be constant. Ea and magnetic flux decrease with increasing load. As the load increases, the rotor speed decreases and the counter electromotive force (Ea) decreases. The smaller Ea, the greater the ratio of Ea to Vt (Ea << Vt). Therefore, the armature current (Ia) drawn from the source by the motor increases. Lowering Ea affects speed when slowing down. As the load increases, the speed will decrease.

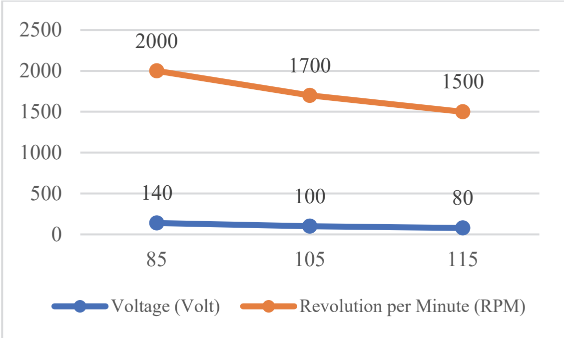

Figure 6: Graph of rectifier output voltage and motor speed as a function of trigger angle.

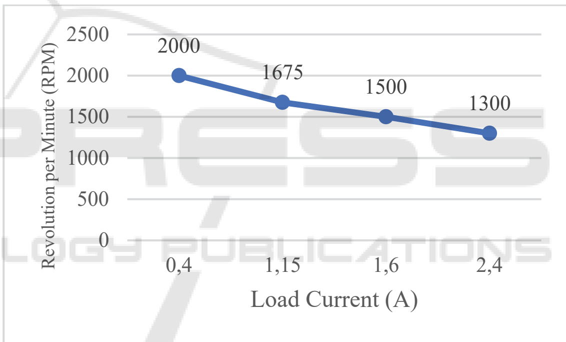

Figure 7: Graph of velocity as a function of armature current ω_m= f(Ia), Vt constant.

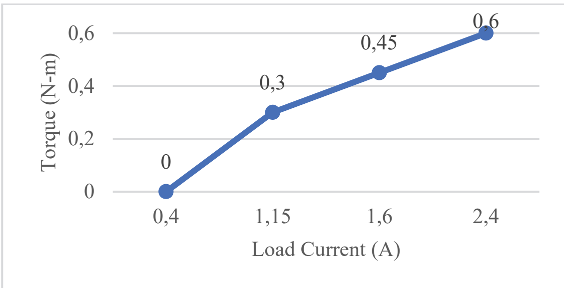

Figure 8: Graph of torque as a function of armature current, T = f(Ia), Vt konstan.

When viewed through 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.

5 CONCLUSIONS

After testing the three-phase controlled rectifier circuit, conclusions can be drawn, including:

1. In general, the effectiveness of using a thyristor as the main component of a rectifier using phase control techniques is very good, but this is actually a refinement of the trigger pulse generator control circuit to achieve maximum performance, depending on the degree. In this tool, the synchronization of the control signal processing output with the network input signal is a very important part because the delay in the input signal sampling time and trigger pulse generation for control is increased.
2. In a constant load test, the maximum output voltage occurs at a trigger angle = 50°, or 210 volts at a motor speed of 2600 rpm. When the output voltage of the rectifier drops to 80 volts, the motor speed also drops significantly to 1150 rpm. In this experiment, it was found that as the delay angle of the rectifier increases, the input voltage of the motor decreases. When the input voltage drops, the motor speed m drops.
3. From testing with different loads, at a constant motor terminal voltage, the motor speed decreases with increasing load (the torque value increases). Example: If the motor input voltage is 140 volts, the motor speed is 2000 rpm and the torque is 0. Increasing the torque to 0.3 N – m will decrease the motor speed to 1675 rpm. If the torque is increased to 0.45Nm, the engine speed will drop to 1500rpm. Then, when the torque increases to 0.6 Nm, the engine speed drops more significantly to 1300 rpm.
4. Adjusting the angle on the thyristor used in this rectifier can affect the output voltage for the motor, thus causing a decrease or increase in RPM. So this controlled rectifier is very suitable for use when requiring changes in RPM speed without changing the input voltage value.

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