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Implementation of four-quadrant DC Chopper for driver DC motor using Arduino

Ainul Ridwan[1], Muldi Yuhendri[1]
[1]Department of Electrical Engineering, Faculty of Engineering, Universitas Negeri Padang, Padang, Indonesia

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ABSTRACT

This study aims to design and implement a DC motor control system using a four-quadrant DC chopper to enhance motor operation flexibility and efficiency. Conventional DC motor control methods often suffer from high starting currents and limited speed control capabilities. The proposed system utilizes an H-Bridge chopper circuit controlled by MOSFETs with Pulse Width Modulation (PWM) signals generated by an Arduino Mega 2560 and programmed through MATLAB Simulink. The four-quadrant chopper enables motor operation in forward motoring, forward braking, reverse motoring, and reverse braking modes. Experimental results demonstrate that the system effectively regulates motor speed and direction while minimizing excessive inrush current. The test results indicate a direct correlation between PWM duty cycles and output voltage, validating the system's ability to provide precise motor control. Furthermore, the integration of regenerative breaking enhances energy efficiency. This study provides a robust solution for DC motor control applications requiring bidirectional operation and dynamic speed adjustments.

Corresponding Author:

Ainul Ridwan
Department of Electrical Engineering, Faculty of Engineering, Universitas Negeri Padang
Kampus UNP Pusat, Jl. Prof. Hamka, Air Tawar, Padang 25131, Indonesia
Email: ainullridwan@gmail.com

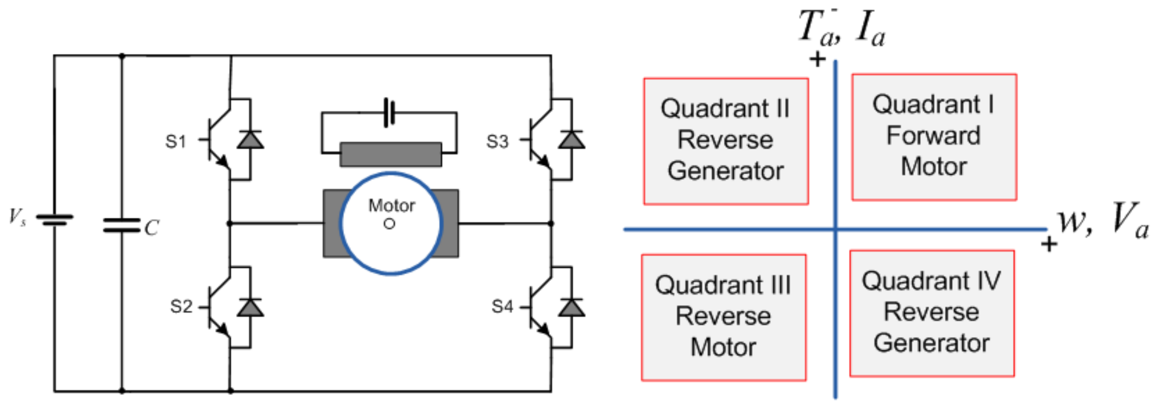
1. INTRODUCTION

A DC motor is an electric machine that uses direct current (DC) to produce torque [1],[2]. Its advantages include easy speed control and large initial torque, so it is widely used in industry. DC motor speed control can be done in three ways, control with insert resistance on the anchor coil, motor anchor voltage control and field current control. One effective method is the armature voltage control using DC-DC Chopper, which can increase or decrease the voltage as needed [3],[4]. The application of DC motors can be operated with the on/off method, but this can cause a very large starting current on the motor so that it will cause overload in a short time or damage to the device, in addition to the on/off method the motor speed cannot be adjusted according to needs

Previous research used a two-quadrant DC chopper that only supports forward motoring and forward braking without being able to handle high starting currents [5]. Therefore, this study aims to design a DC motor control system using a four-quadrant DC Chopper, which allows the motor to operate in four modes, namely forward motoring, forward braking, reverse motoring, and reverse braking modes [6],[7]. Where by using a four-quadrant DC Chopper, it can minimize the starting current on the motor, can regulate the motor speed and is able to reverse the direction of the motor rotation [8]-[10]. This four-quadrant DC chopper is controlled by MOSFET using PWM signal regulated by Arduino Mega 2560 and programmed in MATLAB Simulink. This circuit is designed in H-Bridge configuration, allowing positive and negative voltage control as needed. This research is expected to optimize DC motor performance with more flexible and efficient speed and direction control.

2. METHOD

The 4-quadrant DC motor control using this four-quadrant DC Chopper is designed using the Arduino Mega 2560 as the brain or main processor with voltage sensor and current sensor inputs, where the control of the DC motor uses Matlab Simulink by adjusting the PWM input on the Arduino Mega 2560. Figure 1 shows a block diagram of the DC motor control system with a 4-quadrant chopper. Figure 1 shows the scheme of four quadrant DC chopper.



This system consists of several main components that work together to control the DC motor using the 4-quadrant DC Chopper. The 12V power supply serves as a power source for components such as the Arduino Mega 2560 and Gate Drive, while the 220V power supply is the main power source for the 4-quadrant DC Chopper [11], [12]. Arduino Mega 2560 acts as a data processing center in the DC motor control system, controlling the 4 quadrant DC Chopper, and receiving input from the potentiometer used as an output voltage reference [13]. To control the MOSFET in the chopper circuit, a Gate Drive is used which functions as a driver by increasing the voltage of the PWM pulse generated by the Arduino according to the modulation needs of the MOSFET gate [14]. Figure 2 shows the block diagram of proposed four quadrant DC Chopper.

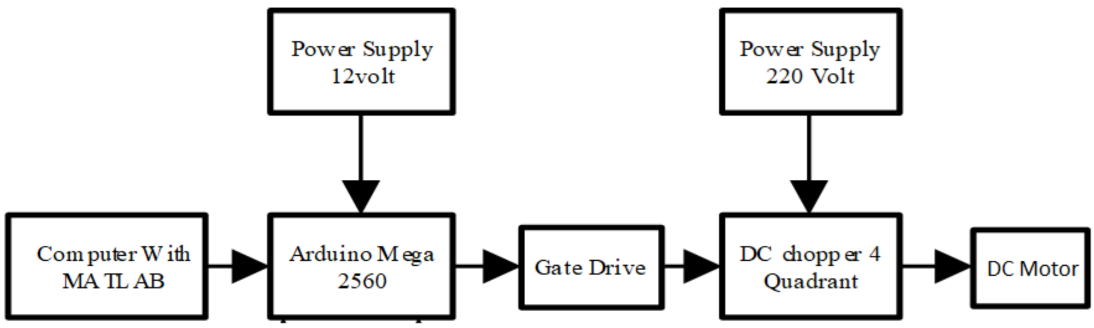


Figure 1. Block diagram system

DC Chopper 4 quadrant or H-bridge chopper has a major role in converting constant DC voltage into adjustable DC voltage. The four-quadrant concept refers to the system's ability to regulate the direction of load current and voltage, both in positive and negative polarity power or voltage conditions [15]. The first quadrant occurs when the motor moves forward with energy flowing from the source to the motor, where the voltage and current are positive, so the motor works with positive torque. The second quadrant is still in a condition where the motor moves forward, but the current flows in the opposite direction (negative), which means the motor is doing regenerative braking, where energy from the motor is returned to the source, while the voltage remains positive. The third quadrant occurs when the motor rotates backward with energy coming from the source to the motor, where the voltage and current are negative, so the motor works with negative torque. The fourth quadrant occurs when the motor continues to rotate backward, but energy is returned to the source due to regenerative braking, where the voltage is negative, while the current is positive [2], [7], [12].

These four quadrants allow the system to control the motor with full flexibility, whether in forward, reverse, or regenerative braking. Each quadrant is activated by a combination of appropriate power switches, such as switches S1 and S2 to control the forward voltage and current, switches S3 and S4 to control the reverse voltage and current, and a freewheeling diode that allows current flow when the switch is in the off state [8]. To ensure accurate measurements, this system is equipped with a current sensor and a voltage sensor that function to measure the current and output voltage of the DC Chopper. The input from the voltage sensor is used by the Arduino Mega 2560 as voltage control feedback, while the input from the current sensor is used by the Arduino Mega 2560 to measure the output current of the DC Chopper.

DC Chopper works to lower or increase the 220V DC voltage supplied by a DC power supply with a load in the form of a resistor load. The controller block is programmed in MATLAB Simulink, while the Arduino Mega 2560 functions as an interface between MATLAB Simulink on a PC and the hardware. The output voltage of the 4-quadrant DC Chopper is determined by the switching time of the DC Chopper power switch, which is regulated using the pulse width modulation (PWM) method, where the PWM pulse width is determined by the duty cycle. The power switch used in this DC Chopper is the MOSFET IRFP460. The working principle of this tool can be seen more clearly through the flowchat in Figure 3.

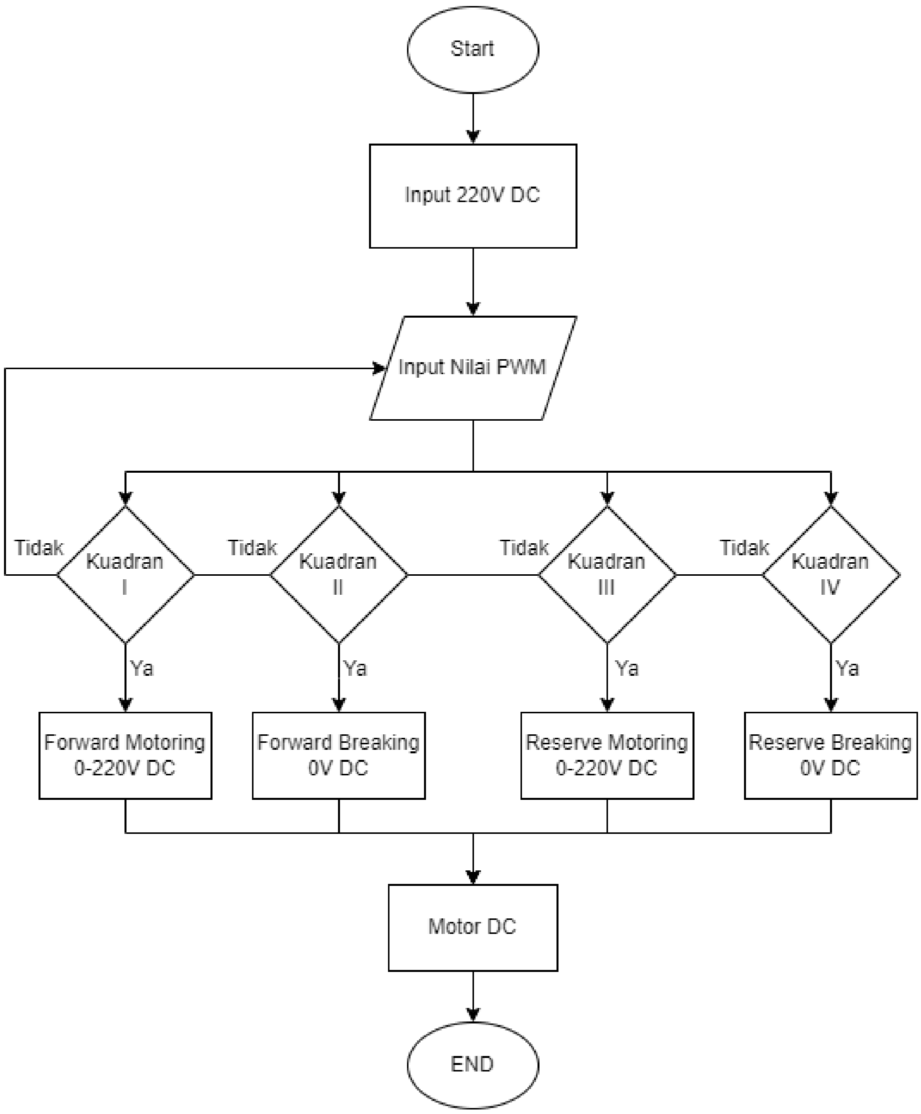


Figure 3. Flowchart system

This research is designed on a control box that is owned to facilitate and reduce the level of error in hardware testing so as to obtain maximum results. With this mechanical design, the system can be used in real life and can work well. The circuit design of four-quadrant DC Chooper can be seen in Figure 4.

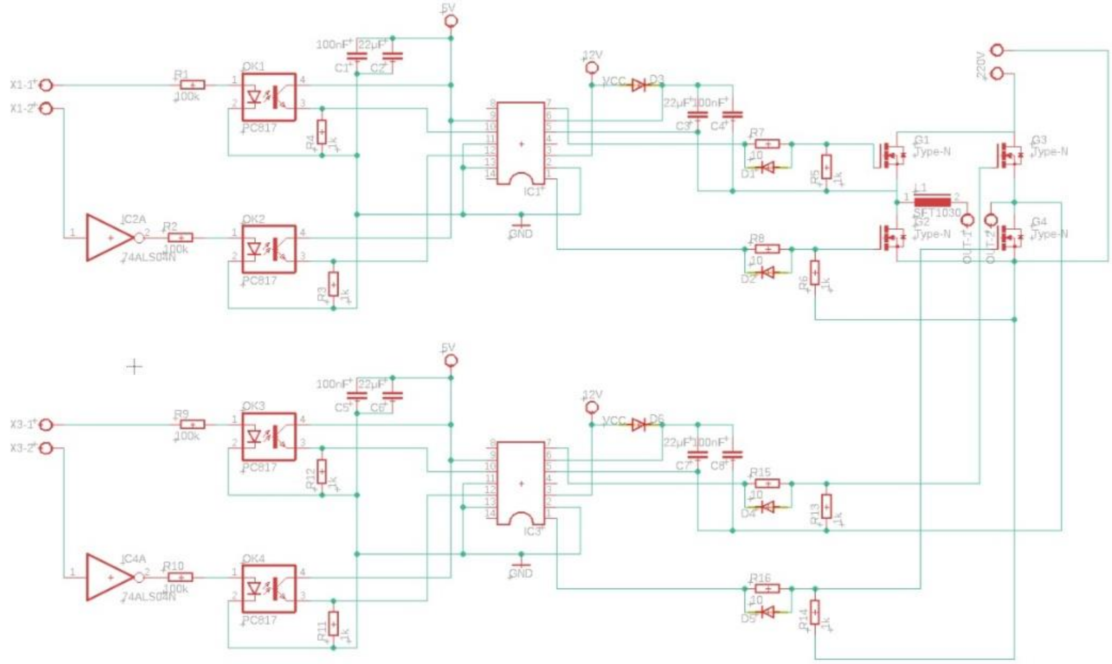


Figure 4. Circuit design of four quadrant DC Chopper

3. RESULTS AND DISCUSSION

The testing and measurement of the tool is carried out to ensure that all components on the tool function properly and work as they should. In this study, a DC Chopper design test was carried out as a 4-quadrant DC motor controller, this system was tested in two operating modes, namely forward and reverse, where each operating mode was tested with two variations of PWM input, namely for forward conditions tested at duty cycles of 0.6 and 0.9 while reverse at duty cycles of 0.4 and 0.1. The tool testing circuit can be seen in Figure 5.

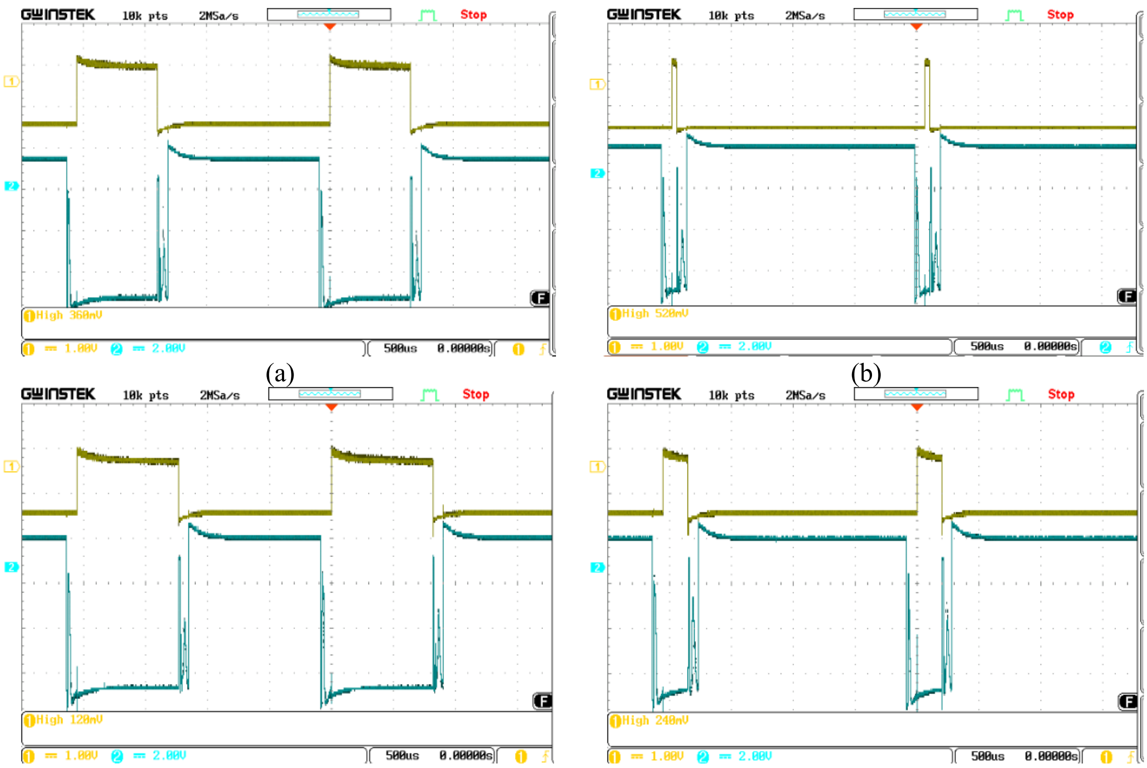
Figure 5. Tool testing circuit

Table 1. System test results

No	Operation Mode	Setting PWM	Measurement		Ouput PWM			
					Gate Drive 1		Gate Drive 2	
			Voltage Input	Voltage Output	Low	High	Low	High
1	Forward	0.6	150	42.9	On	Off	Off	On
2	Forward	0.9	150	109.1	On	Off	Off	On
3	Reverse	0.4	150	-12.6	Off	On	On	Off
4	Reverse	0.1	150	-108.6	Off	On	On	Off

Based on Table 1 above, the test results of the DC Chopper system as a 4-quadrant DC motor controller show that the system can operate in two modes, namely forward and reverse. In forward mode, increasing the PWM duty cycle from 0.6 to 0.9 causes the output voltage to increase from 42.9 V to 109.1 V with a constant input voltage of 150 V. This result confirms that the system works according to the PWM principle, where a higher duty cycle increases the average power supplied to the motor. In this mode, Gate Drive 1 operates with the configuration (Low: On, High: Off), while Gate Drive 2 operates with the configuration (Low: Off, High: On), which is consistent with the forward motor rotation control principle.

In reverse mode, the output voltage is negative, indicating that the motor rotates in the opposite direction. At PWM duty cycle 0.4, the output voltage is -12.6 V, while at duty cycle 0.1, the output voltage reaches -108.6 V. This pattern shows that reducing the PWM duty cycle in reverse mode increases the negative output voltage, which corresponds to higher power supplied in the opposite direction. In this condition, Gate Drive 1 operates with the configuration (Low: Off, High: On), while Gate Drive 2 operates with the configuration (Low: On, High: Off), which is in line with the working principle of the H-Bridge Chopper for reverse motor control. Figure 6 shows the PWM pulse.



(c) (d)

Figure 6. Waveform of PWM. a) Forward 0,6. b) forward 0,9. c) Reverse 0,4. d) Reverse 0,1

Overall, the test results show that the designed DC Chopper system functions effectively in controlling a 4-quadrant DC motor. The system is able to regulate both the direction of rotation and the magnitude of the output voltage according to the applied PWM duty cycle. This demonstrates that the proposed method is effective in providing precise control of motor speed and direction according to application requirements.

4. CONCLUSION

This research successfully designed and tested a DC-DC Chopper as a four-quadrant DC motor controller, in accordance with the stated objectives of building and testing a motor control system capable of regulating both speed and direction of rotation. The test results show that the system performs well in forward and reverse motoring modes, with MOSFET IRFP460 used as the power switch and Arduino Mega 2560 as the main controller. Testing with PWM duty cycles of 0.6 and 0.9 in forward mode produced output voltages of 42.9 V and 109.1 V, respectively, while testing with duty cycles of 0.4 and 0.1 in reverse mode produced output voltages of -12.6 V and -108.6 V. These results confirm that the output voltage is directly influenced by the PWM duty cycle, allowing precise control of motor speed. In addition, the switching pattern observed using an oscilloscope indicates signal stability and proper operation of the system in accordance with the H-Bridge Chopper principle.

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