

DC motor speed control using two quadrant DC Chopper based on Sliding Mode Controller

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Article Info

Article history:

Received July 28, 2025

Revised August 24, 2025

Accepted October 21, 2025

Keywords:

DC Motor

Sliding mode controller

MATLAB

Arduino Mega 2560

ABSTRACT

DC motors are vital components in the industrial world, thanks to their ability to provide precise control over speed and torque. In various manufacturing processes, these motors are used to drive machines, conveyor systems, and other automated applications. However, the challenge faced is speed instability when the motor operates under variations in load and speed. To overcome this problem, this study focuses on controlling the speed of a DC motor using a two-quadrant DC chopper based on a Sliding Mode Controller (SMC). The SMC method has the ability to overcome disturbance models and provide consistent performance under dynamic conditions, making it very effective in maintaining the performance of a DC motor control system in various operational situations. In addition, the SMC is able to ensure the output system can track the desired reference and generate a control signal that minimizes tracking errors. The control signal in the SMC consists of two components, namely the reach mode and the slide mode. The design process in this study includes programming the Arduino Mega 2560 microcontroller, and the implementation of the SMC control system is carried out using MATLAB Simulink. Simulation results show that the SMC-based control can maintain a stable motor speed despite significant changes in load and speed. Thus, this research makes a significant contribution towards the development of more effective DC motor control systems for industrial applications.

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1. INTRODUCTION

DC (Direct Current) motors are a common type of drive used in industry and everyday equipment. The advantages of DC motors over AC (Alternating Current) motors lie in their wider speed control range, easy speed control, high starting torque, and ease of operation [1]. The speed of a DC motor is often unstable due to external disturbances such as changes in load or changes in parameters from the fabrication process, thus affecting the system performance of the DC motor [2],[3]. DC motor speed can be regulated using several methods, one of which is by regulating the DC motor current. DC motor current can be regulated by controlling the voltage using a power converter, such as a controlled rectifier or DC chopper. Simply put, a DC chopper chops the input voltage for a specified duration, resulting in a variable output voltage [4].

This paper suggests the use of a DC Chopper to change the value of the DC input voltage, either to be larger or smaller, according to its type [5]-[7]. Various studies have been conducted to control DC motors, including the use of Fuzzy Logic, PI, PID, and PWM methods [8]-[11]. In this final assignment, the author carried out a development with the title DC Motor Speed Control Using a Two-Quadrant DC Chopper Based on a Sliding Mode Controller, the program of which uses Simulink Matlab [12].

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Sliding Mode Control (SMC) is a nonlinear control method designed for systems with nonlinear characteristics. This method directs the system's state toward a sliding surface, and once reached, the system remains stable despite disturbances or parameter changes. SMC offers high robustness and is particularly effective in applications requiring reliable control under changing conditions [13]-[15]. The reliability and effectiveness of an SMC design are significantly influenced by the selection of parameters within the sliding function. Inappropriate selection or tuning can lead to problems such as excessive "chattering" (high-frequency oscillations) or degraded performance under extreme conditions. Advances in adaptive sliding mode control and intelligent tuning techniques are recent approaches being explored to improve the adaptability of SMCs to varying system dynamics, thereby further enhancing their reliability in control applications in DC motors and other nonlinear systems [16].

2. METHOD

This research on a DC motor speed control system using a two-quadrant DC chopper based on a sliding mode controller was conducted in the form of a laboratory experiment. The DC motor to be controlled is a separately excited DC motor. A separately excited DC motor is a type of DC motor that requires two different voltage sources to operate, namely one for the armature coil and another for the field coil [17].

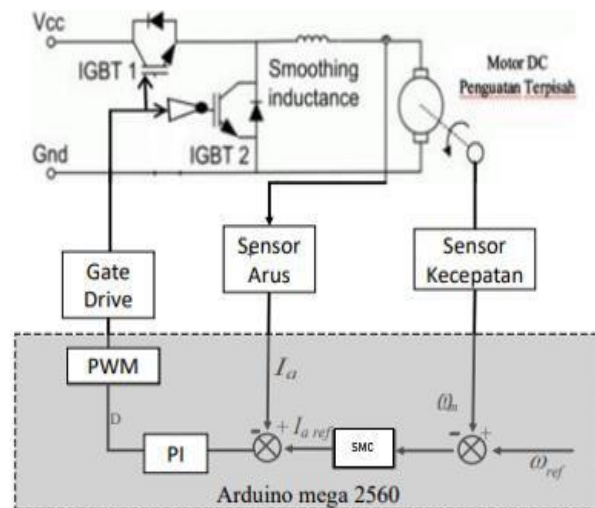


Figure 1. Scheme of sliding mode control for DC motor

Figure 1 illustrates a DC motor speed control system designed with two control loops, namely current control and speed control. This second loop uses the SMC and Fuzzy approaches. Speed control functions to generate a reference armature current based on the difference between the desired speed and the speed measured by the sensor. On the other hand, current control functions to determine the PWM duty cycle required for modulating the two-quadrant DC chopper switch, based on the difference in armature current. This armature current difference is calculated from the difference between the reference armature current generated by the speed control and the current measured by the current sensor [18]. These two control loops are implemented using Arduino Mega 2560 and programmed via Matlab Simulink [19]. Figure 2 shows the sliding mode control concept.

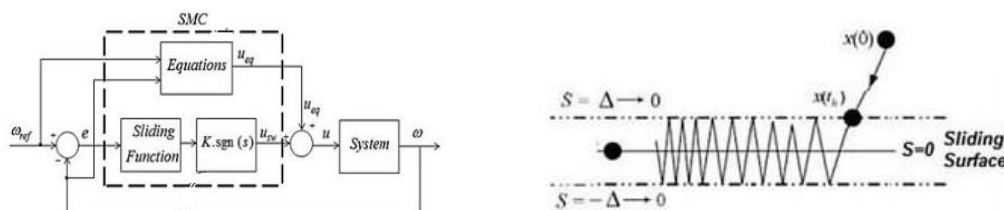


Figure 2. Sliding mode control

Figure 2 shows that the SMC controller works by bringing the state of the system to the sliding surface and then to the center point, while the transition of the control signal that tracks the sliding surface to the origin. The sliding surface is a condition where the transition function (s) is zero ($s = 0$). At the top and bottom of the sliding surface, there are limiting transition values $\pm \Delta$. If the state $x(t)$ is $x(t) > \Delta$ then the transition will be off, otherwise if $x(t) < -\Delta$ then the transition will be on. The system reaches the sliding surface by making a transition between stable and unstable trajectories and the error converges to zero at the sliding surface [20]. The steps in designing an SMC controller, starting with the design of the switching function is :

$$s = Ce + e = C(\omega r - \omega) + (\omega r - \omega) \quad (1)$$

$$s = C(\omega r - \omega) + (\omega r - \omega) \quad (2)$$

$$K \operatorname{sgn}(s) = 1 \text{ if } s > 0$$

$$K \operatorname{sgn}(s) = 0 \text{ if } s = 0$$

$$K \operatorname{sgn}(s) = -1 \text{ if } s < 0$$

The goal of SMC is to have the system output track to a desired reference and generate a control signal that minimizes tracking error. The sliding mode control signal can be written as equation (3), while the switching control is defined as :

$$u_{SMC}(t) = u_{eq} + u_{sw} \quad (3)$$

$$u_{sw} = K \operatorname{sgn}(s) \quad (4)$$

Where $u_{SMC}(t)$ is sliding mode controller, u_{eq} is equivalent controller, u_{sw} is switching controller and $K \operatorname{sgn}(s)$ switching function.

3. RESULTS AND DISCUSSION

The developed DC motor speed control system was tested on a 2.2 HP separately amplified DC motor. The test was conducted with varying speeds under two conditions: no load and loaded with varying reference speeds. The motor under test was connected to a DC machine that served as a load, where the machine operated as a generator with a load resistor during the test. To measure the motor rotational speed, a tachogenerator was used connected to an analog input on the Arduino. Figure 3 shows the installation of the DC motor speed control system proposed in this study. This test was carried out by providing reference speed input values of 300 and 400 RPM, with a duration of approximately 60 seconds. Then every 15 seconds the speed will be varied with the speed that has been determined in Matlab Simulink to see the controller response can work properly. The following are the results of the speed and current on the DC motor.



Figure 3 Hardware setup for experiment

First experiment is carried out with variable speed no load. Figure 4(a) shows that the measured speed of the motor successfully follows the reference speed inputted via Matlab Simulink. This indicates that the motor speed control system design using a two-quadrant DC chopper motor based on the SMC controller has functioned well. However, overshoot and undershoot still occur when the speed reaches a varied point. This satisfactory control system performance is inseparable from the effectiveness of the SMC controller in regulating the motor armature current. Figure 4(b) displays the motor armature current response during this test. Figure 4(b) shows that the measured armature current from the motor has been able to follow the reference armature current. Errors in the armature current only occur during transient conditions or speed changes that were previously varied. In the initial phase of motor operation, armature current regulation occurs due to the starting process, but under conditions of constant or non-varying speed, the armature current can follow the reference current generated by the SMC controller output in the speed control block. These results indicate that both control loops, namely the speed control loop and the current control loop designed with the PI controller to regulate the speed of the DC motor, have functioned well

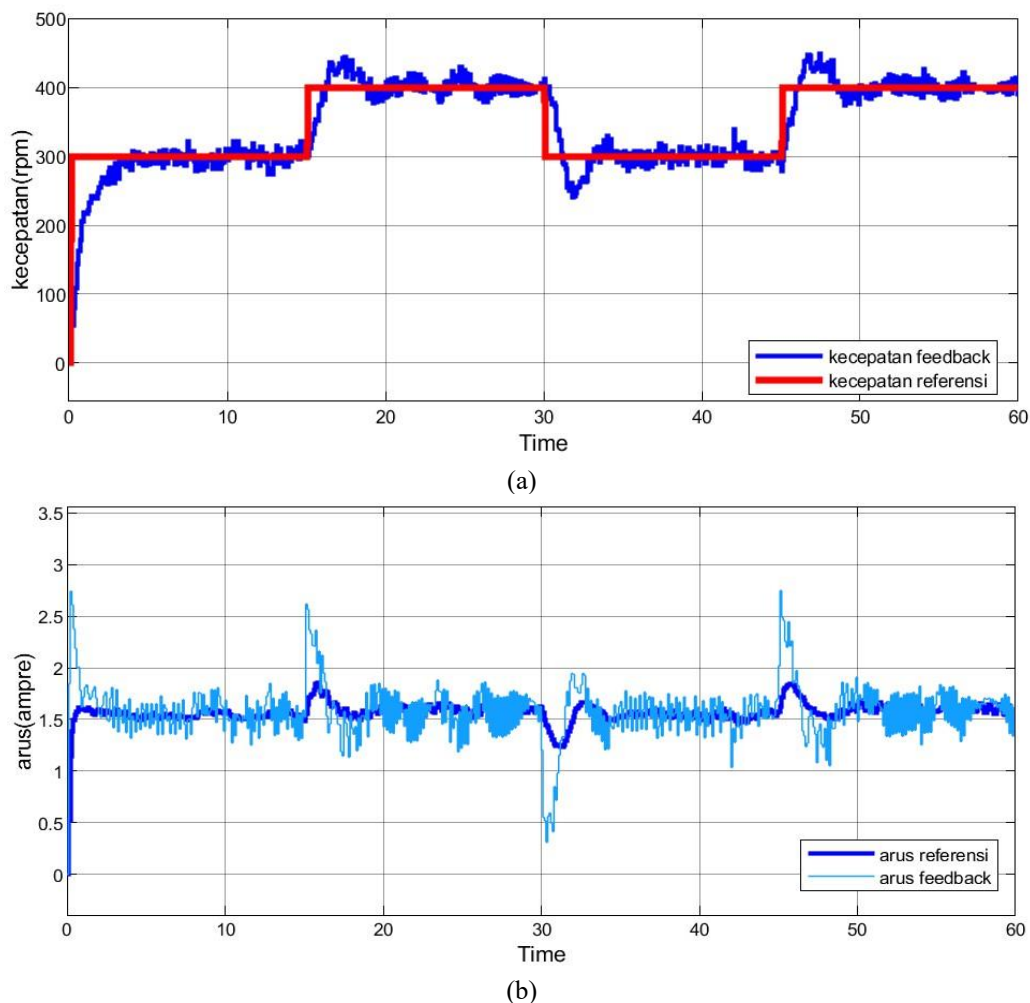


Figure 4. Experimental result with no load. a) motor speed, b) motor current

The second experiment is carried out by variable load. Figure 5(a) shows the schematic and (b) installation of the DC motor speed control system test. This test is basically almost the same as the test in point number 3.1, but the condition of the DC motor in this test is coupled to a 1.2 KW DC generator load and connected to a MV 1100 2A load resistor so that the DC motor load increases. The reference speed given is 300 and 400 RPM, and the duration is 60 seconds. Then every 15 seconds the speed will be varied with the speed that has been determined in the Matlab Simulink to see that the controller response can work well. The following are the results of the speed and current of the DC motor

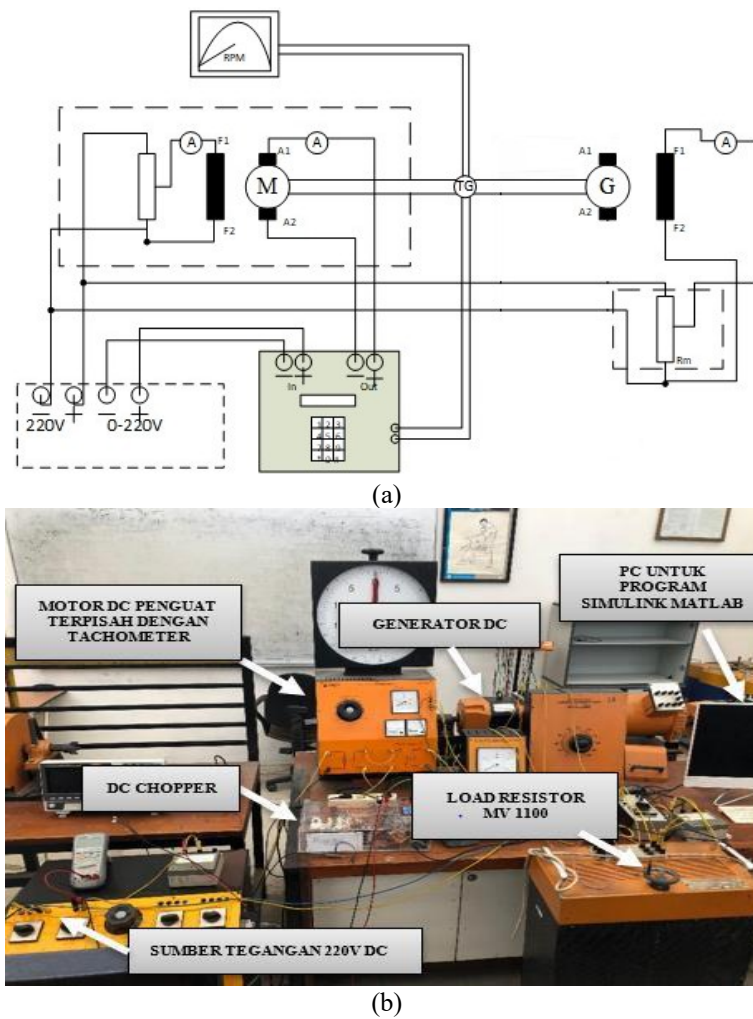


Figure. 5. Hardware setup for second experiment. a) Symbolic circuit for testing a DC motor with a load, b) circuit installation Testing

Figure 6 shows that the measured speed of the motor successfully follows the reference speed input via Matlab Simulink. Furthermore, the control system using SMC is able to function properly, as evidenced by the absence of overshoot and undershoot when the speed is varied. Figure 10 shows the motor's armature current response during this test.

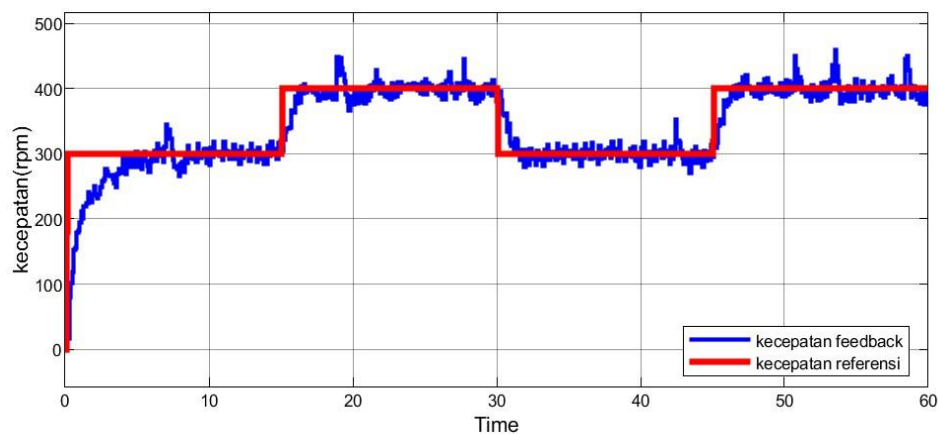


Figure 6. Speed response graph of a loaded DC motor against varying reference speeds

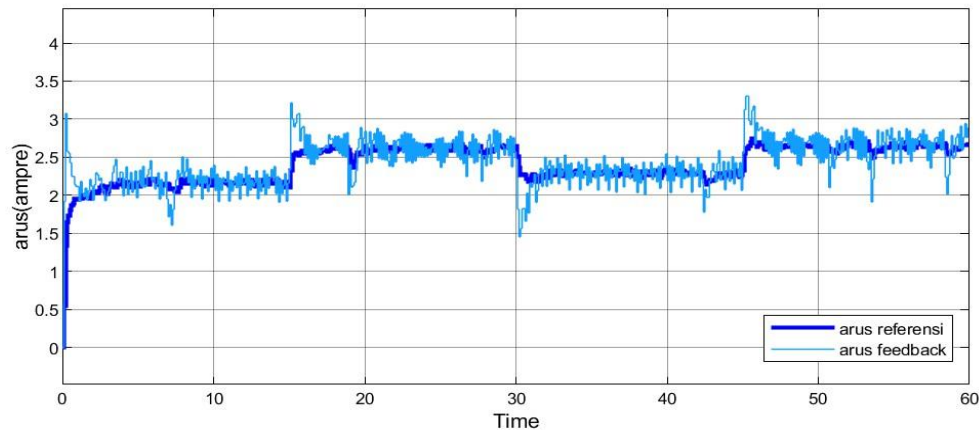


Figure 7. The response graph of a DC motor current under load against varying reference speeds

Figure 7 shows that the measured armature current from the motor has been able to follow the reference armature current. And in this process, the SMC control is also able to reduce current changes when there are speed variations in the DC motor under load.

4. CONCLUSION

Based on the system design and testing that has been carried out, it can be concluded that the implementation of a DC motor speed control system using a two-quadrant DC chopper based on a Sliding Mode Controller (SMC) has been successfully achieved. This can be seen from the test results which show that the DC motor control system functions well, where the motor speed can follow the reference speed both under no-load and loaded conditions. In addition, in this test, the SMC is able to provide a fast response to changes in the speed setpoint and is also able to reduce overshoot and undershoot even when the motor experiences changes in load and speed.

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