DC motor control using a four-quadrant chopper based on artificial neural networks

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ABSTRACT (10 PT)

DC motors are widely used as drives in various industrial applications. To ensure optimal performance, precise control of DC motors is essential, including managing rotation direction, speed, braking, and starting current. This paper presents a speed control system for a DC motor using a 4-quadrant DC chopper with a neural network as the control core. The system is designed and implemented on a 12V DC motor and tested under varying speed conditions. Motor speed is adjusted in MATLAB Simulink according to operational requirements. The results confirm that the proposed DC motor speed control system, utilizing a four-quadrant chopper, functions effectively, providing accurate speed control through MATLAB Simulink.

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1. INTRODUCTION

DC (Direct Current) motor is one of the most widely used types of electric motors in industrial and electronic applications due to its easily controllable characteristics and good dynamic response [1]. Speed and direction control of a DC motor are crucial to ensuring optimal performance in various applications [2]. One efficient and flexible control method is using a four-quadrant chopper, which allows motor control in four quadrants of operation: forward, reverse, acceleration, and deceleration [3].

A four-quadrant chopper is a power converter that utilizes switching techniques to regulate the voltage supplied to the DC motor[4]. This method offers more precise and efficient control compared to conventional methods such as rheostats [5]. Additionally, a four-quadrant chopper enables regenerative operation, where the energy generated during deceleration or braking can be fed back to the power source, increasing overall system efficiency [6]-[7].

However, controlling a four-quadrant chopper requires an advanced control algorithm to ensure a fast and stable response under various load conditions and disturbances [8]. One promising approach for this is the use of Artificial Neural Networks (ANN). ANN is a computational system inspired by biological neural networks and can learn the nonlinear relationships between inputs and outputs through a training process [9]-[10].

The use of ANN in DC motor control with a four-quadrant chopper offers several advantages [11]-[12]. ANN can handle system nonlinearities, adapt to changes in system parameters, and generalize from training data to operating conditions that have not been encountered before [13]. Moreover, ANN can be implemented in real-time using modern computing hardware such as Field Programmable Gate Arrays (FPGA) or Digital Signal Processors (DSP) [14]-[15].

2. METHOD

The research on applying backpropagation-based Artificial Neural Networks (ANN) for controlling a four-quadrant chopper was carried out through a series of experiments, including design, development, testing, and analysis. The block diagram illustrating a four-quadrant chopper control using backpropagation-based ANN is presented in Figure 1

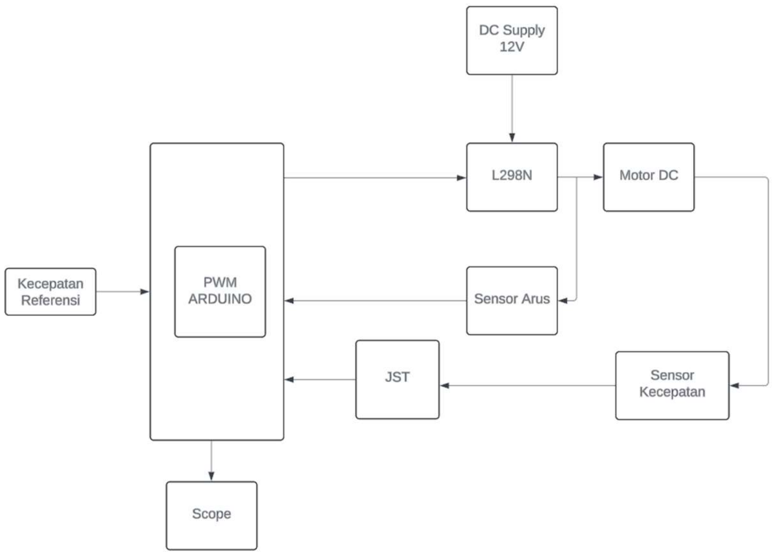


Figure 1. DC Motor control block diagram

Figure 1 shows all the component that used in the system. Arduino is used as main control that processes all program that created through Matlab Simulink by using PC. As the Arduino receive a speed reference, it will send signal as the form of PWM signal that will make the motor DC rotate through L298N. If speed sensor detect different value from reference speed, then ANN will receive that value, and convert it as reference current. Then Arduino will increase or decrease PWM based on the difference between current sensor and reference sensor

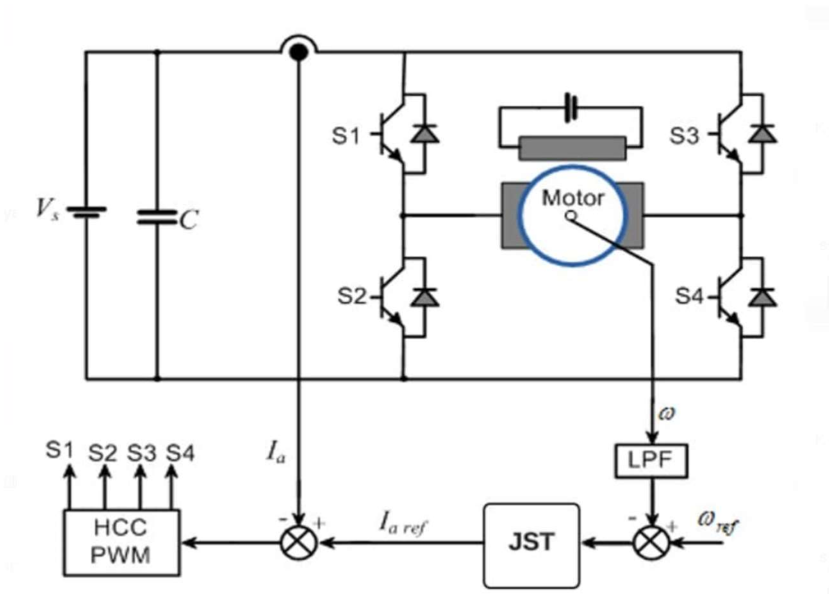


Figure 2. Scheme of Bacpropagation neural network control for four quadrant dc motor control

Figure 2 illustrates the four-quadrant DC motor control scheme based on backpropagation ANN. As shown in Figure 2, the backpropagation-based ANN determines the change in duty cycle (ΔD) based on the speed error of the DC chopper. The speed error is calculated by comparing the desired reference speed with the feedback speed obtained from the sensor.

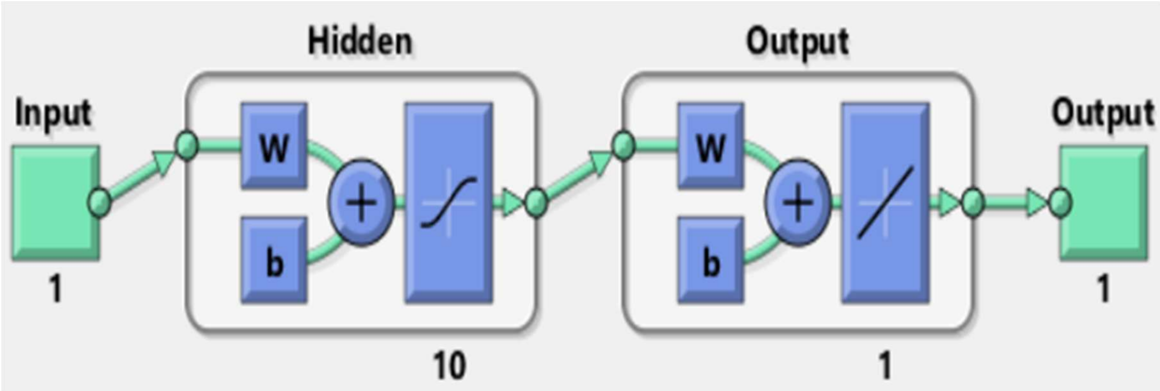
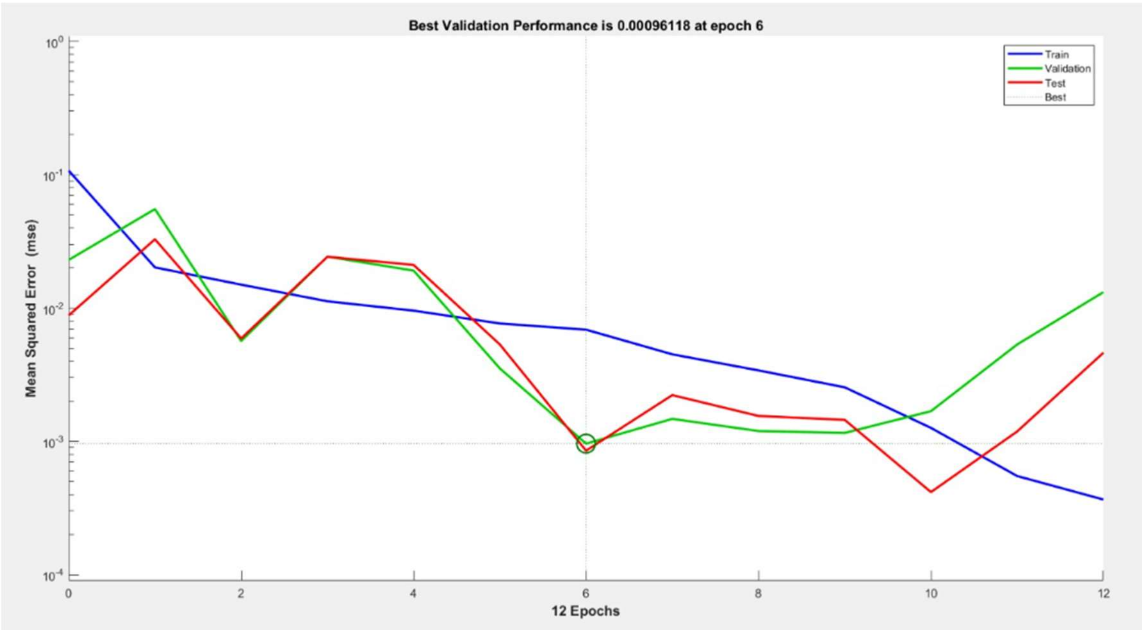


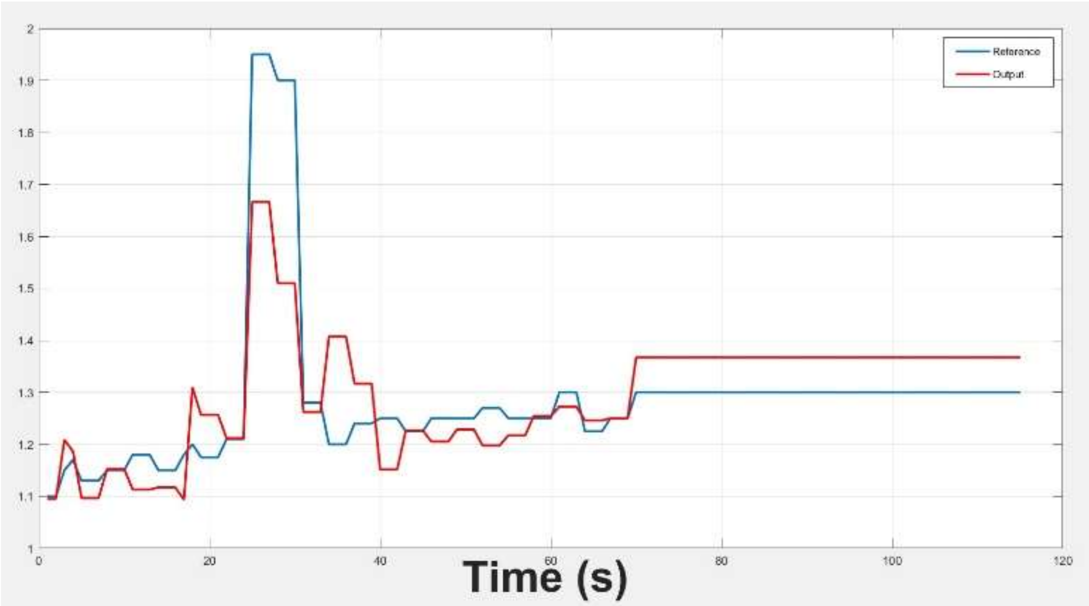
Figure 3. Structure of Bacpropagation neural network

3. RESULTS AND DISCUSSION

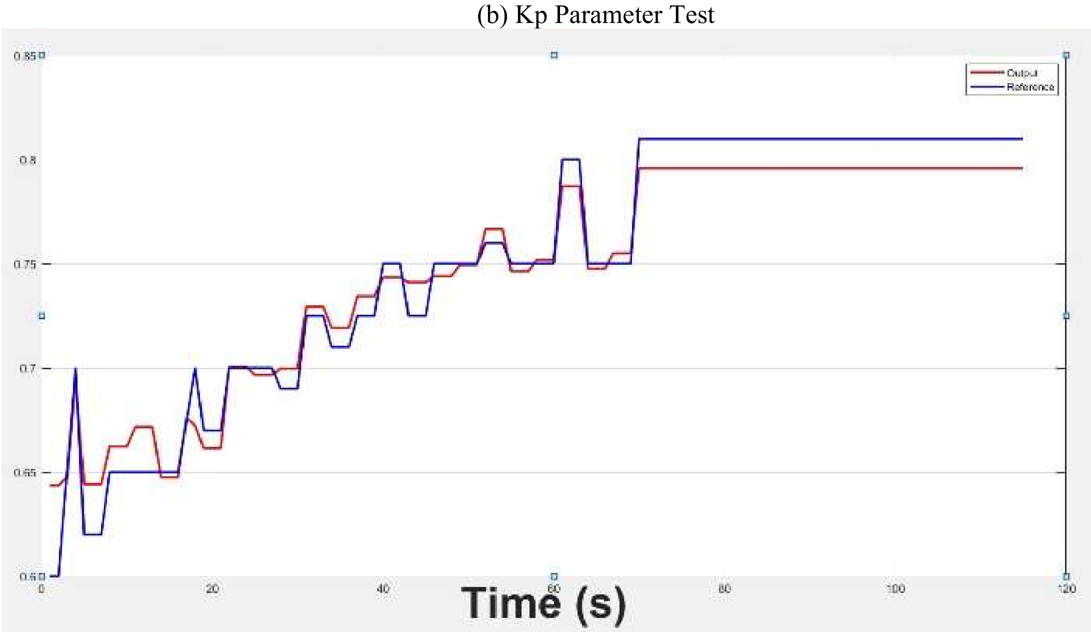
After assembling the circuit, the first step is to develop a backpropagation neural network model for controlling the boost converter voltage. This model is created using the JST toolbox in MATLAB. The backpropagation neural network model is designed with two inputs—speed error 1 and speed error 2—and two outputs—Proportional gain and Integral gain. Additionally, the model includes 10 hidden layers, as illustrated in Figure 3. Figure 4 presents the training results of the ANN model created using MATLAB's ANN toolbox. Figure 4(a) displays a graph of input, output, and target data during both training and testing phases. The graph indicates that the output data closely matches the target data, demonstrating that the trained ANN model successfully produces output values that align with the target, as further illustrated in Figure 4(b).



(a) Mean Squared Error



(b) Kp Parameter Test



(c) Ki Parameter Test
Figure 4. Training results of Bacpropagation neural network

Once the ANN model is validated for DC motor speed control, it is integrated into the DC motor speed control program developed in MATLAB Simulink. Figure 5 illustrates the DC motor speed control program based on ANN in Simulink. This model utilizes two Arduino analog input pins—one for the current sensor and another for the speed sensor. Meanwhile, the PWM signal is generated on a digital PWM pin with a switching frequency of 3906.25 Hz, as depicted in Figure 5. Each input signal is processed through a low-pass filter to obtain accurate speed and current data. These values are then displayed graphically using the scope block in MATLAB Simulink

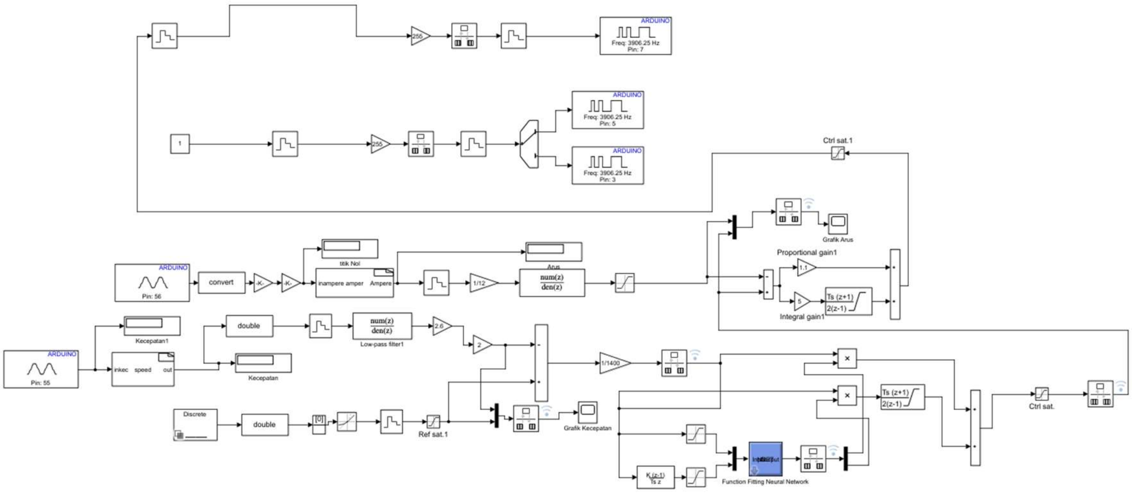


Figure 5. Control block usingBacpropagation neural networkin Matlab Simulink

Next, the ANN-based DC motor speed control system developed in MATLAB Simulink is validated using hardware implementation. Figure 6 shows the hardware setup for testing the ANN-based DC motor speed control system using an Arduino Mega 2560. In this experiment, the L298N motor driver receives a 12V input voltage and drives a DC motor as the load

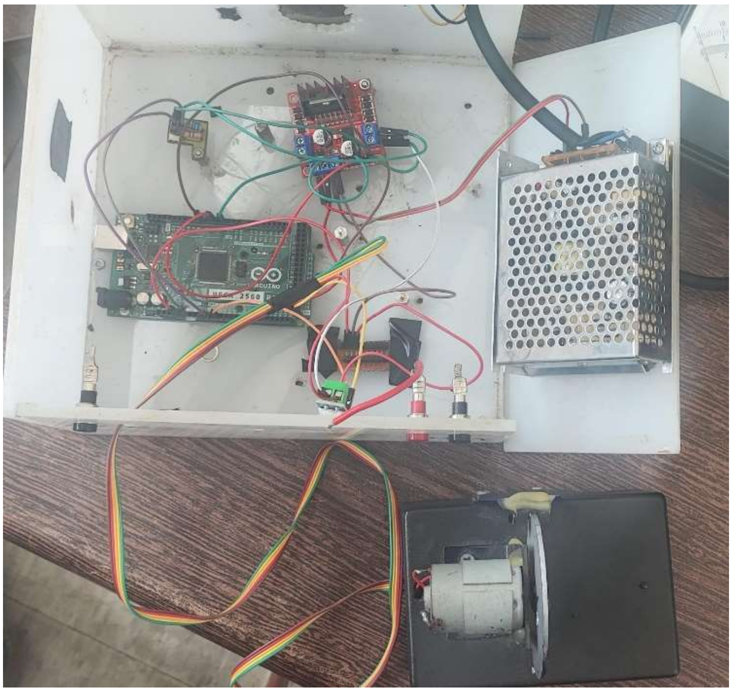
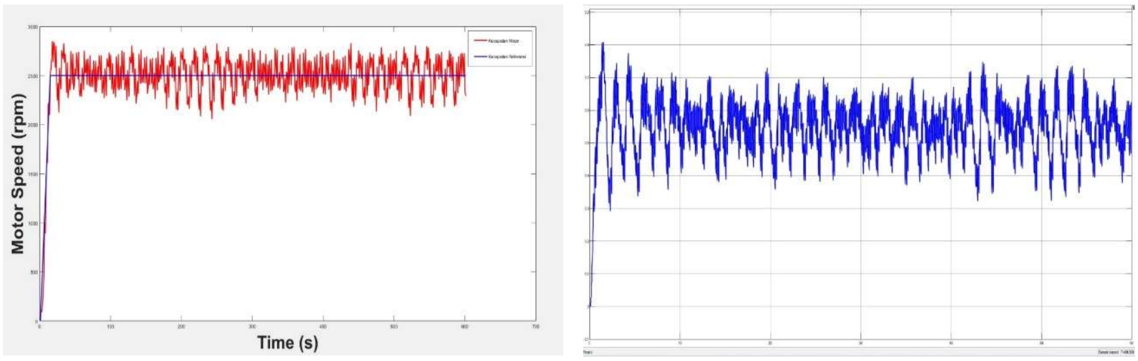


Figure 6. Setup

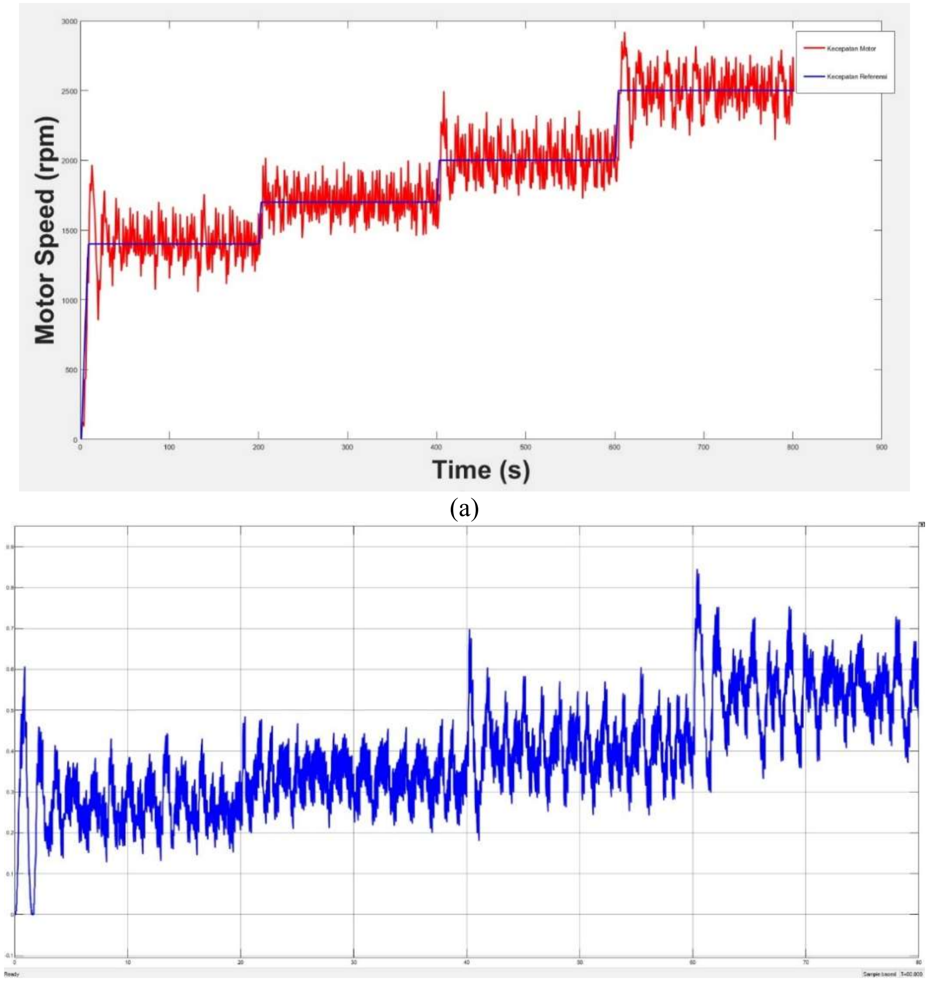
Hardware testing was conducted through multiple experiments. The first experiment involved setting a constant reference speed of 2500 RPM. The results of this test are presented in Figure 7. The speed graph in Figure 7(a) indicates that the output speed of the L298N remains stable between 2400-2600 RPM, closely following the reference value. This confirms that the ANN-based backpropagation speed control system effectively regulates the motor speed according to the reference, as illustrated in the graph in Figure 7(b).



(a) (b)

Figure 7. First experimental result with 2500 rpm, (a) rpm, (b) current

The second experiment was conducted by varying the reference speed, starting at 1400 RPM in the initial condition, then increasing to 1700 RPM at 20 seconds, 2000 RPM at 40 seconds, and finally reaching 2500 RPM at 60 seconds, as shown in Figure 8. The speed graph in Figure 8 demonstrates that the L298N output speed successfully follows the reference speed at each variation. These results confirm that the DC motor speed control system using backpropagation ANN effectively regulates the output speed across different setpoints. Furthermore, they indicate that the ANN-based DC motor speed control system can accurately adjust the motor speed as intended.

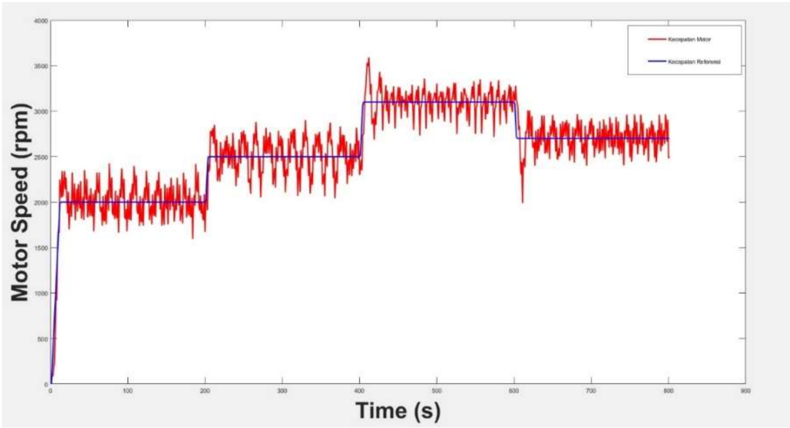


(a)

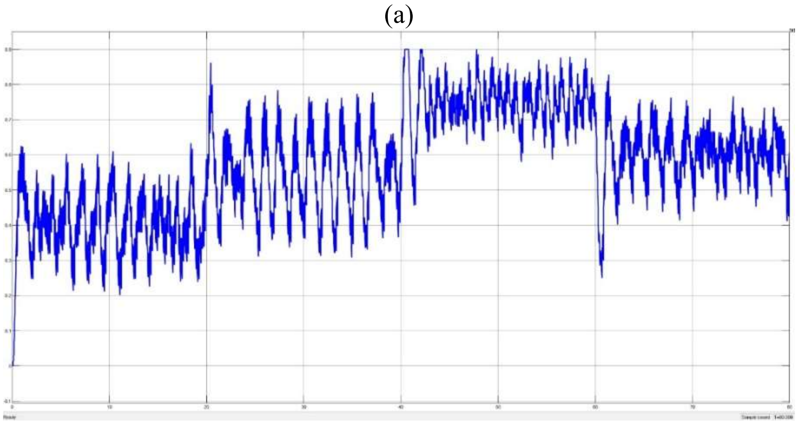
(b)

Figure 8. second experimental result, (a) rpm, (b) current

The final experiment was conducted by varying the reference speed, starting at 2000 RPM in the initial condition, then increasing to 2500 RPM at 20 seconds, 3000 RPM at 40 seconds, and finally decreasing to 2700 RPM at 60 seconds, as illustrated in Figure 9. The speed graph in Figure 9 demonstrates that the L298N output speed successfully tracks the reference speed throughout the variations. These results confirm that the DC motor speed control system utilizing backpropagation ANN effectively maintains speed regulation across different setpoints. Moreover, they demonstrate that the ANN-based DC motor speed control system accurately adjusts the motor speed as intended.



(a)



(b)

Figure 9. last experimental result, (a) rpm, (b) current

4. CONCLUSION

The four-quadrant DC motor speed control system based on a backpropagation neural network is designed specifically for DC motor applications. This control system is implemented using an Arduino Mega 2560. The backpropagation neural network model developed for this system achieves a mean squared error (MSE) of 0.000001 during training and 0.01 during testing. The four-quadrant DC motor speed control system was evaluated through various experiments. The results from all experiments confirm that the backpropagation neural network successfully regulates the motor speed, ensuring it follows the reference values across different test conditions.

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