

Experiment - 6

Four-Quadrant Operation of DC motor

IT IS PREFERRED that students ANSWER THE QUESTION/S BEFORE DOING THE LAB BECAUSE THAT provides THE BACKGROUND information needed for THIS LAB. (10% of the grade of the lab)

Q1: Refer to Chapter 22 of our text and other web references to better explain in detail the Four-Quadrant Power Electronic Drive ?

6.1 Introduction

In the previous experiment, you controlled the motor to run under speed control. The objectives of this experiment are:

- 1) To observe the four-quadrant operation of a DC motor.
- 2) To control a motor under torque-control.
- 3) To couple the speed control motor and torque controlled motor, and observe the effect of a stepped torque.

6.2 Four quadrant operation of a DC motor

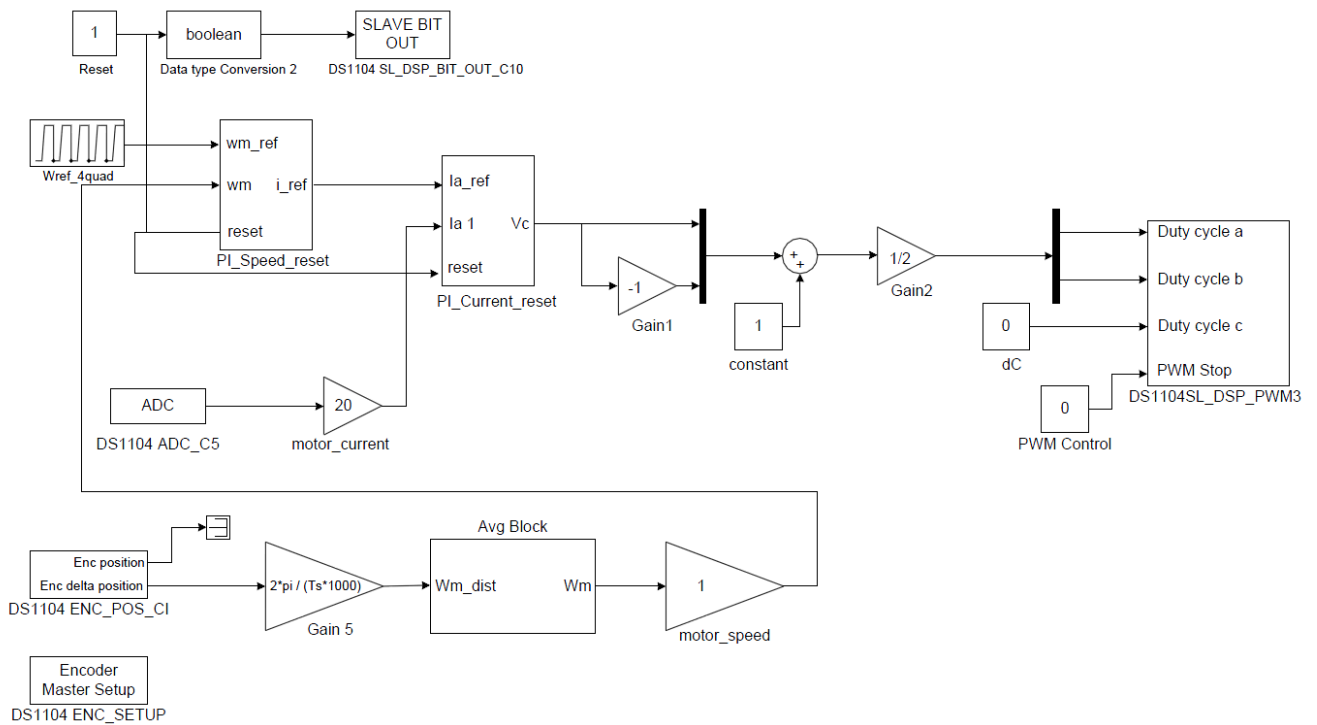
The four-quadrant operation is performed by giving an alternating reference-speed command to the DC-motor, from positive speed (200 rad/sec) to negative speed (-200 rad/sec) with a constant ramp. The speed controller designed in the previous experiment is used to track the instantaneous reference-speed command. Fig. 6.1 shows the Simulink model file of the system, and Fig 6.2 shows the hardware connections. To keep the same inertia the same as the ones used to design the speed-control-loop in the experiment-5, another DC-motor is coupled to the DC-motor whose four quadrant operation is desired. The terminal voltage V_a , current I_a , and speed & torque relations are given below.

$$I_a = \frac{V_a - E_b}{R_a}; \quad E_b = k_E \cdot \omega_m \quad (1)$$

$$T_{em} = k_T I_a; \quad k_T = k_E \quad (2)$$

Real-time implementation

Modify the file obtained from experiment-5, which was used for speed control of the dc motor to give a stepped waveform that goes from -200 rad/sec to -200 rad/sec (Fig 6.1). **Save the waveform for the reference speed and measured speed and label the quadrant of operation.**



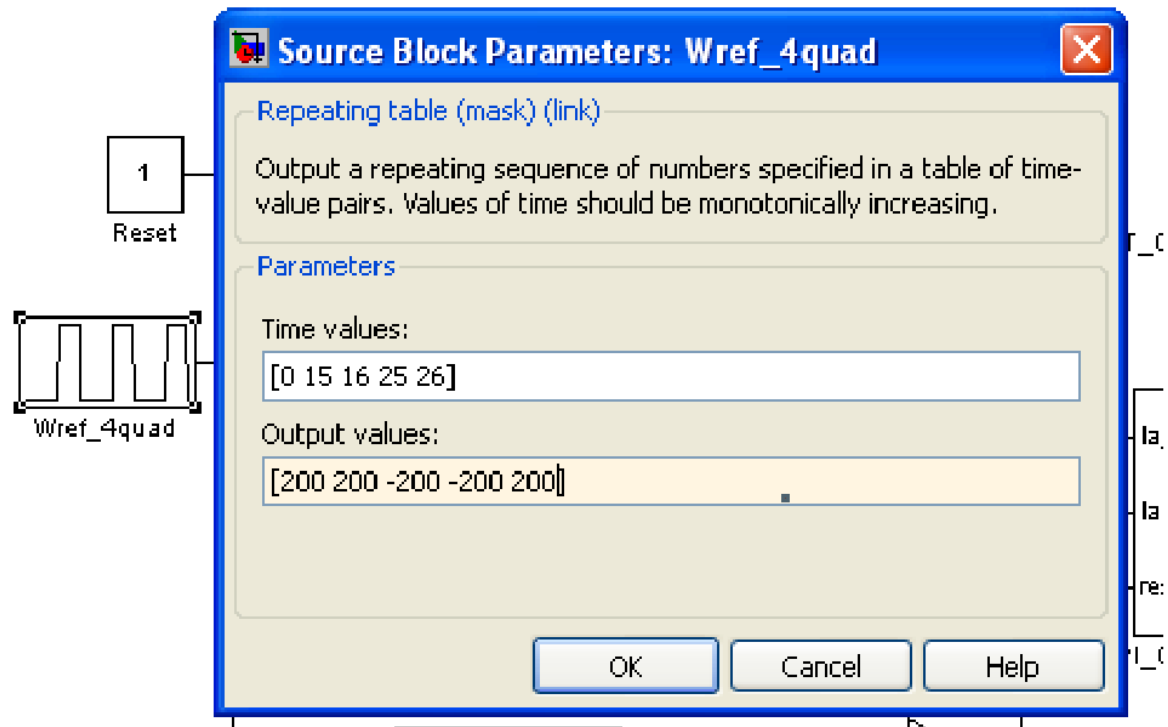


Figure 6.1: Simulink model for four-quadrant operation of DC motor

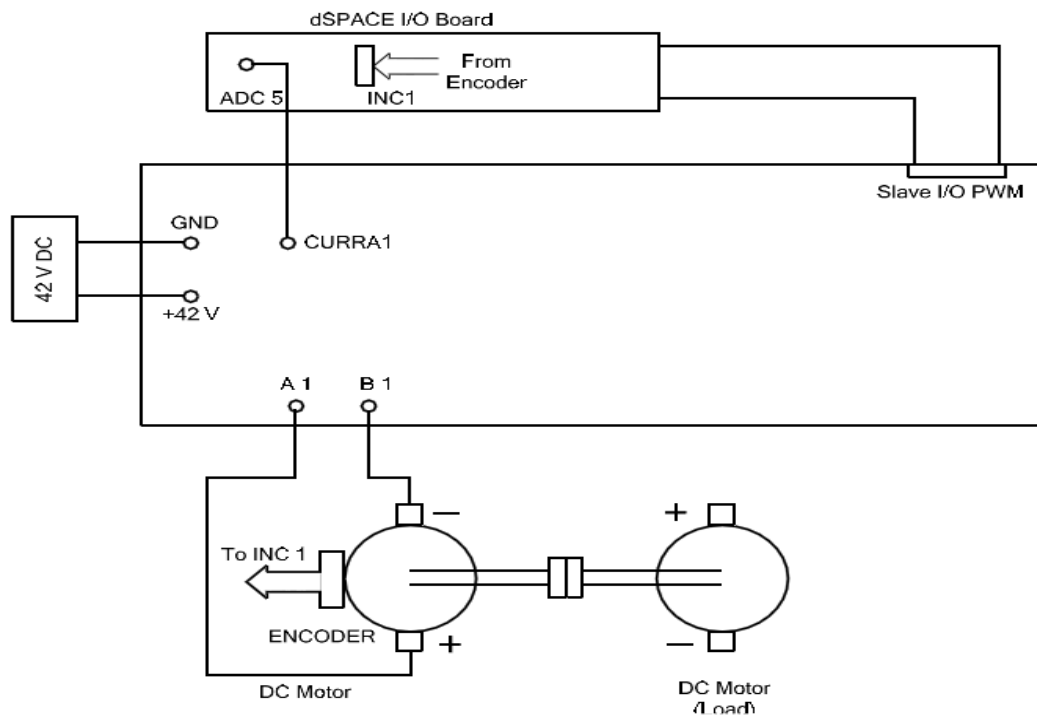


Figure 6.2: Connections for four-quadrant operation of DC motor

6.3 DC motor under torque control

Part a: Modeling of a constant load

The Simulink model for constant torque on DC motor is shown in Fig. 6.3. Open the file ‘**torque_control.mdl**’. Assign suitable values to the PI current controller that was obtained from the previous experiment-5. Enter the value of $V_d = 42$ and $T_s = 1e-4$ at command prompt. Build the model (Ctrl+B) and start dSpace ControlDesk. Open the (.sdf file) and the layout file “**torque_control.lay**” setup the capture setting window (View→Controlbars→Capture setting window) as shown in Fig 6.4 and the connections are shown in Fig. 6.5.

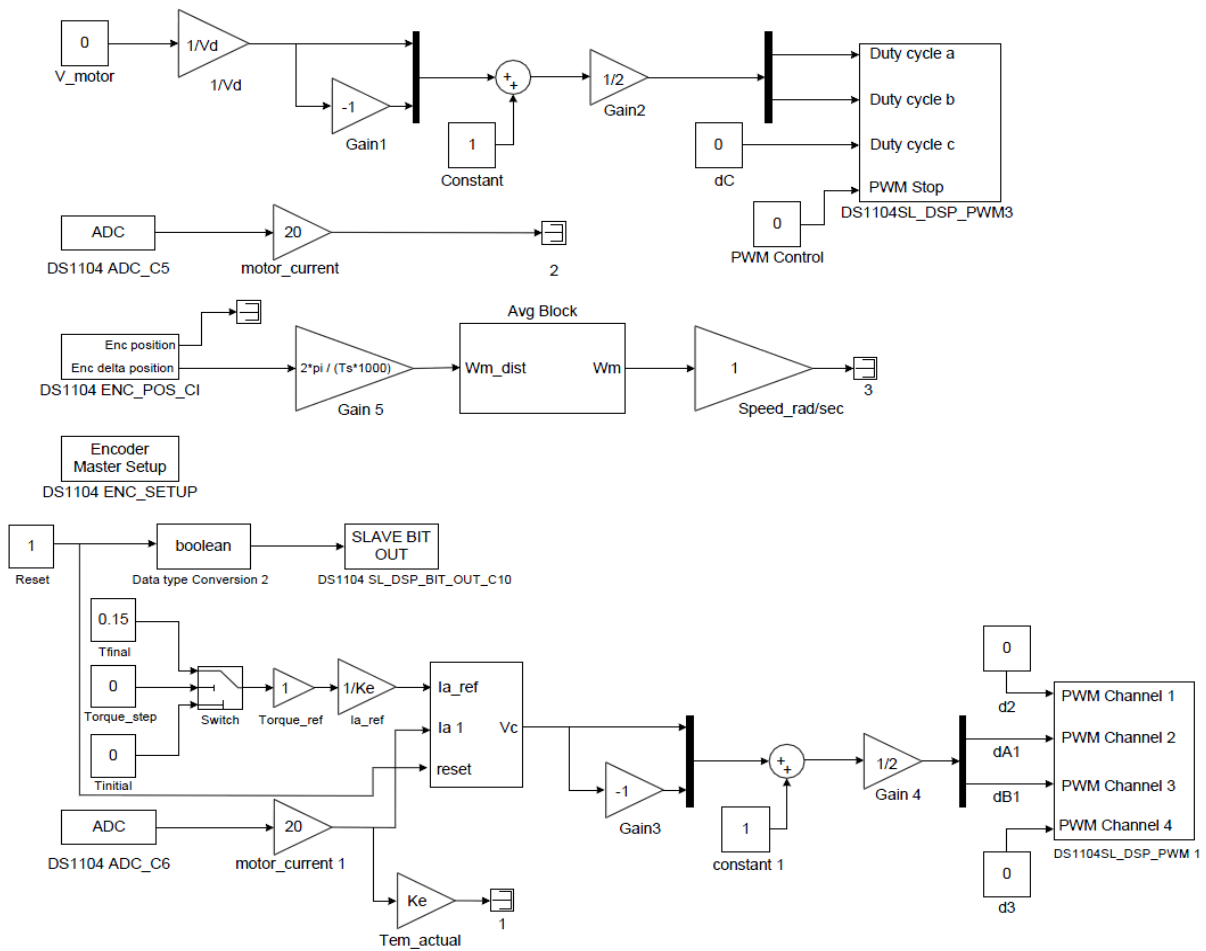


Figure 6.3: Simulink model for constant torque on DC motor

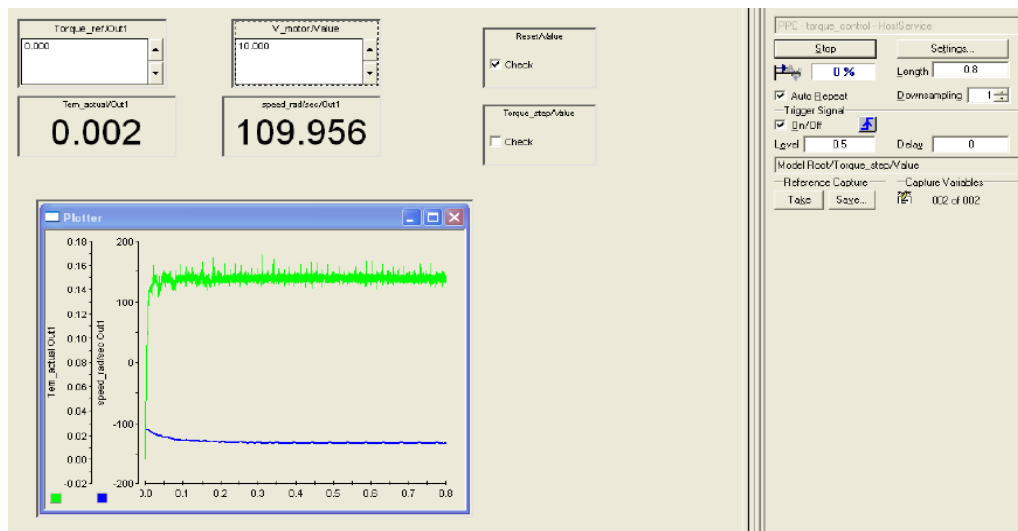


Figure 6.4: dSpace Control Desk layout for constant torque on DC motor.

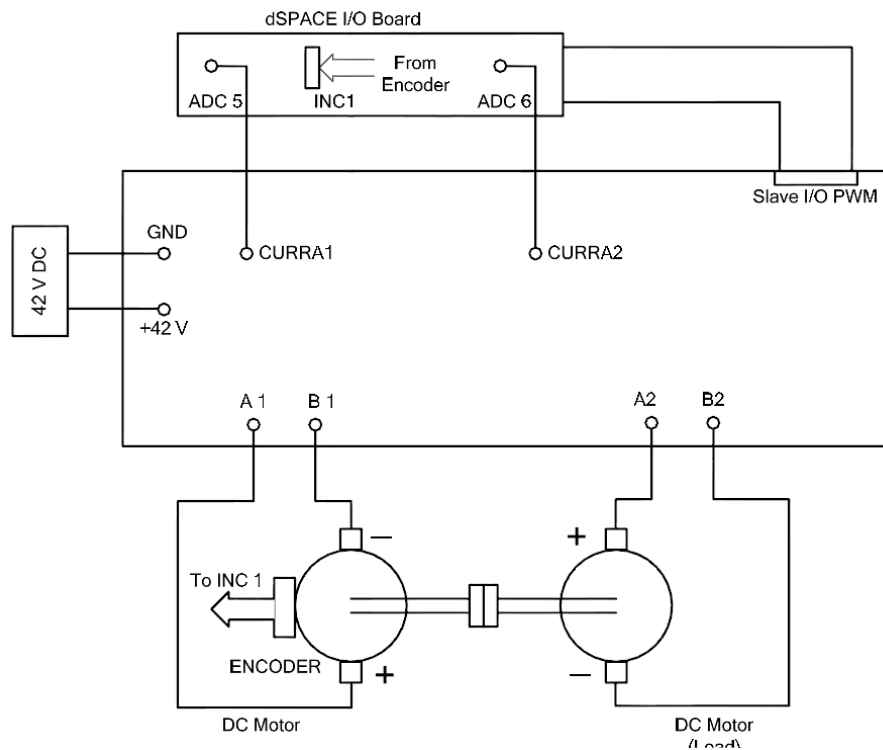


Figure 6.5: Connections for constant torque on DC motor

1. Apply a constant voltage to the dc motor of value **12V**.
2. Note down the speed of motor when the load torque is zero.
3. Give a step change in load torque from **0 to 0.15Nm** (check the box Torque_step) and note the resultant speed.
4. Theoretically estimate the speed value in rad/s.
5. What is the net power supplied by the motor? What is the quadrant of operation?

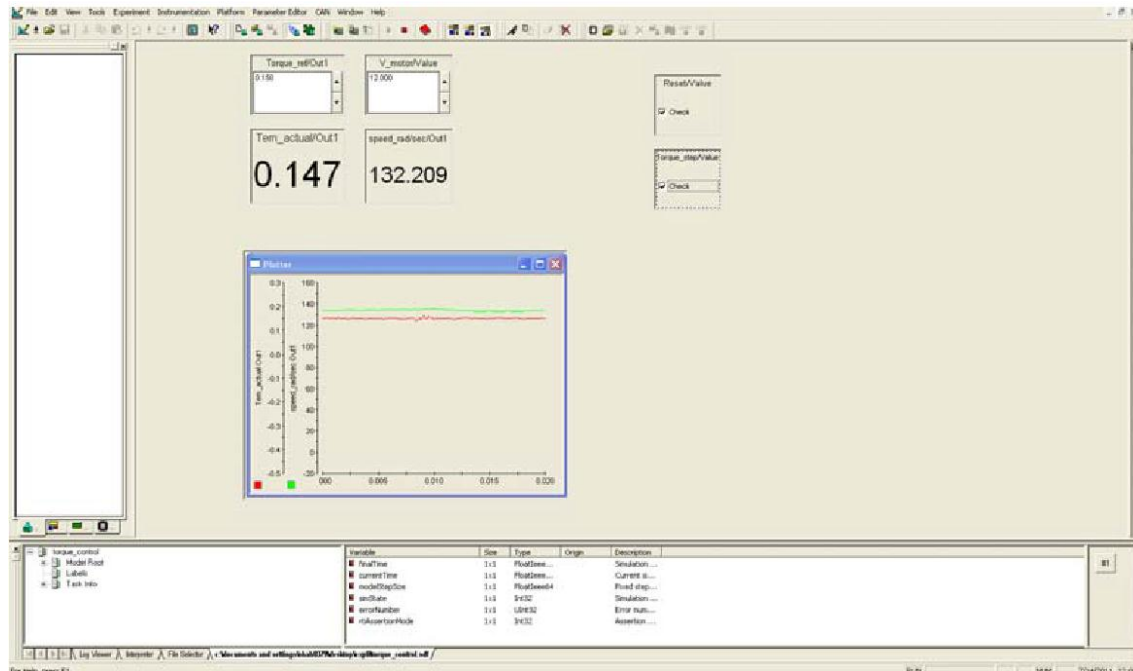


Figure 6.6: Modeling of a constant load

The torque T_{em} and speed of the motor can be viewed on the control desk window as in Fig. 6.6.

Part b: Modeling of a crane load

Modeling of a crane load (constant load torque) is done in ‘Part a’ for lifting action. In this part, the crane is used to lower the heavy load i.e., the load torque retains the same direction but the speed reverses.

1. Set up the experiment as shown in Fig. 6.5. The response of torque and speed can be seen in Fig. 6.7.
2. Use the given simulink model “**torque_control.mdl**” and the layout file “**torque_control.lay**”.
3. Apply a constant voltage to the dc motor of value **-12V** to make the motor rotate in opposite direction.
4. Note down the speed of the motor.
5. Give a step change in load torque from **0 to 0.15Nm** and note the resultant speed.
6. Theoretically estimate the speed in rad/s.

7. What is the net power supplied to the motor? What is the quadrant of operation?

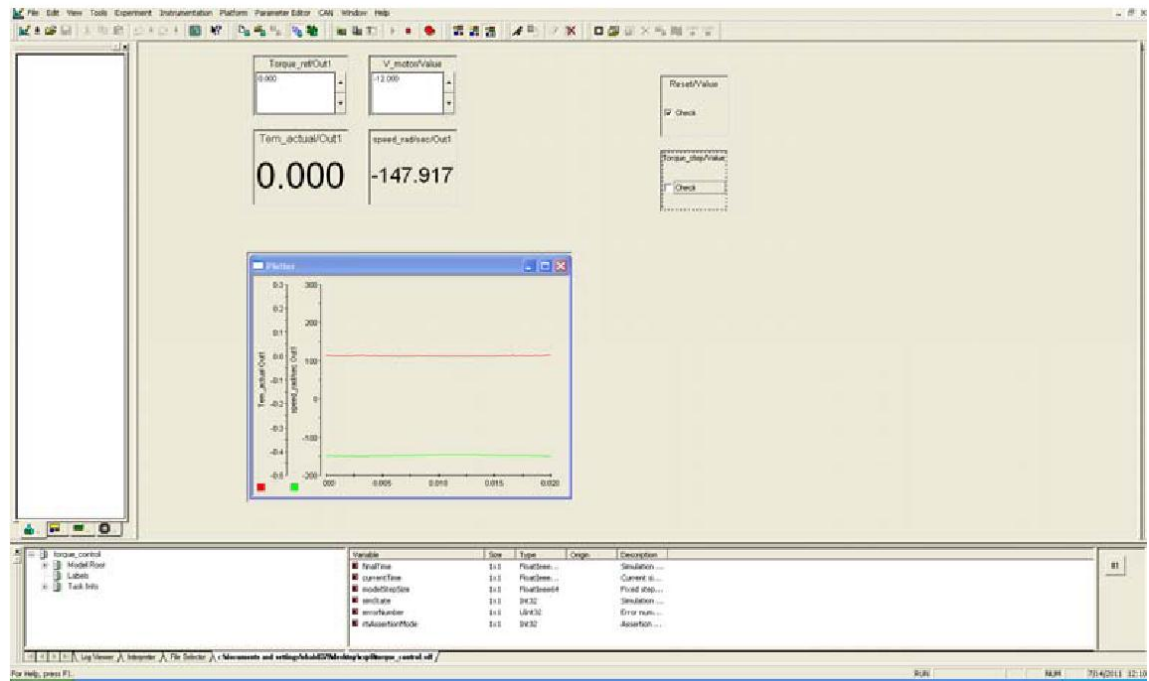


Figure 6.7: Modeling A Crane Load

6.4 Closed loop speed control

In speed control the motor speed is maintained constant irrespective of load torque variations.

Let us say you have to maintain the speed of the motor at **150 rad/sec**.

1. Set up the experiment as shown in Fig. 6.5.
2. Open the file '**torque_control_w_control.mdl**'. Your model should look like Fig.6.8. In this model, inverter 1 controls the motor with speed control and inverter 2 controls the second motor (load) with torque control. Note that these motors are identical. Assign the values to all the PI controllers. (run the m file which contains all values, the values of Kp and Ki are obtained from the previous experiment).

3. Build the model (Ctrl+B) and restart dSpace ControlDesk. Open the (.sdf) file and open the layout file '**torque_control_w_control.lay**'.
4. In the capture setting window set the length to 1s and level to 0.5 Drag Torque_step value to the gray box such that Model Root/Torque_step/Value is displayed there. Check On/Off.
5. Ramp up the speed to **150 rad/sec**.
6. Give a step change in load torque from **0 to 0.15Nm** and note the resultant speed.
Capture this waveform (Fig 6.9.).
7. Theoretically estimate the voltage required to maintain the same speed from the equations (1) and (2).
8. Verify this value displayed in Control Desk. The duty ratio value is displayed in the control desk. Estimate using that.
9. Change the direction of rotation **-150 rad/sec**.
10. Give a step change in load torque from 0 to 0.15 Nm and note the resultant speed.
11. Theoretically estimate the voltage required to maintain the same speed using eq. (1) & (2).
12. Verify this value displayed in Control Desk.
13. **BONUS!** Give a sinusoidal disturbance of 0.05 Nm in load torque over a constant value of 0.15Nm. (use frequency of 1Hz). Observe how the control system responds to the disturbance.

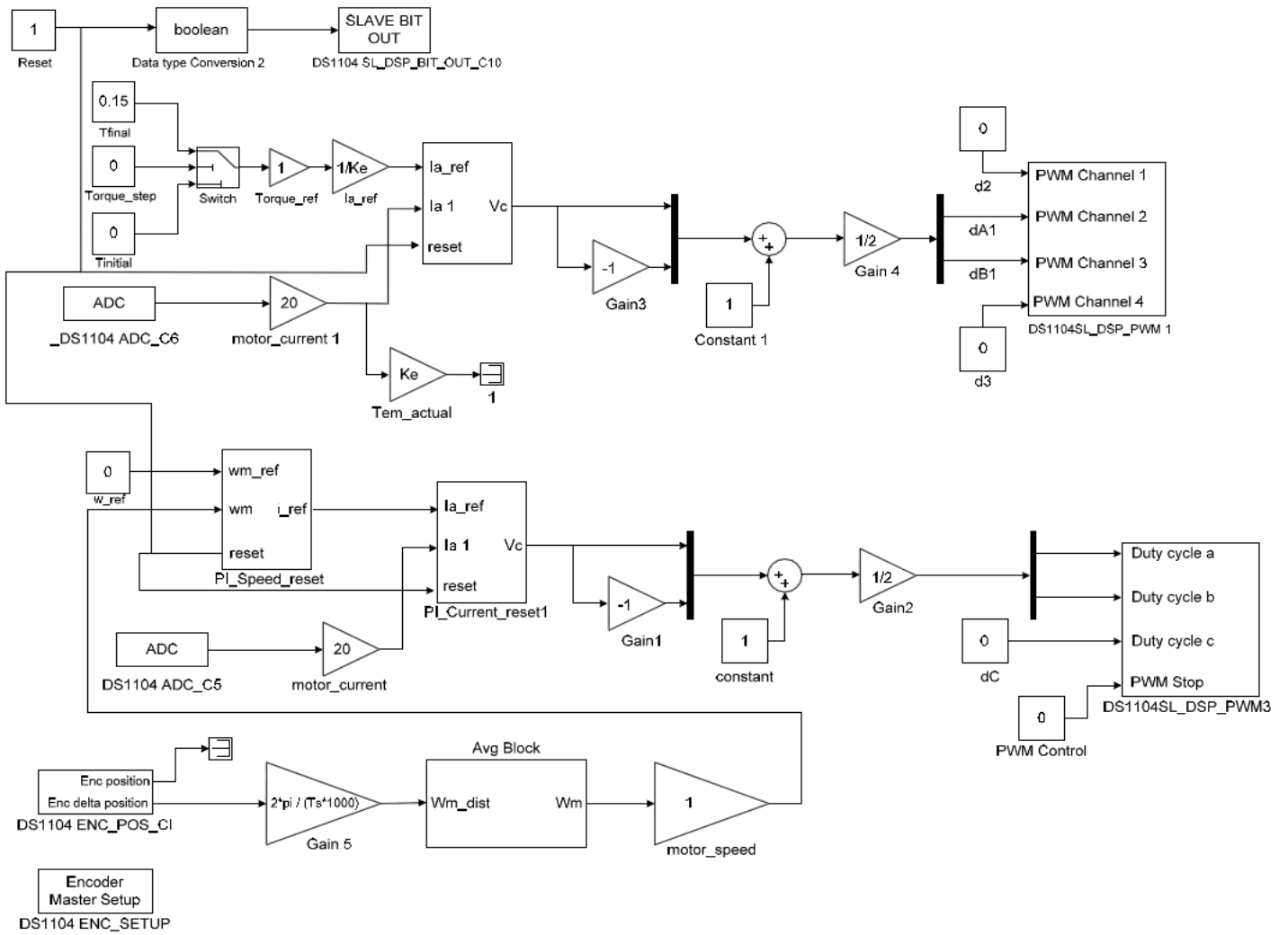


Figure 6.8: Simulink model file for speed controlled DC motor with torque controlled load.

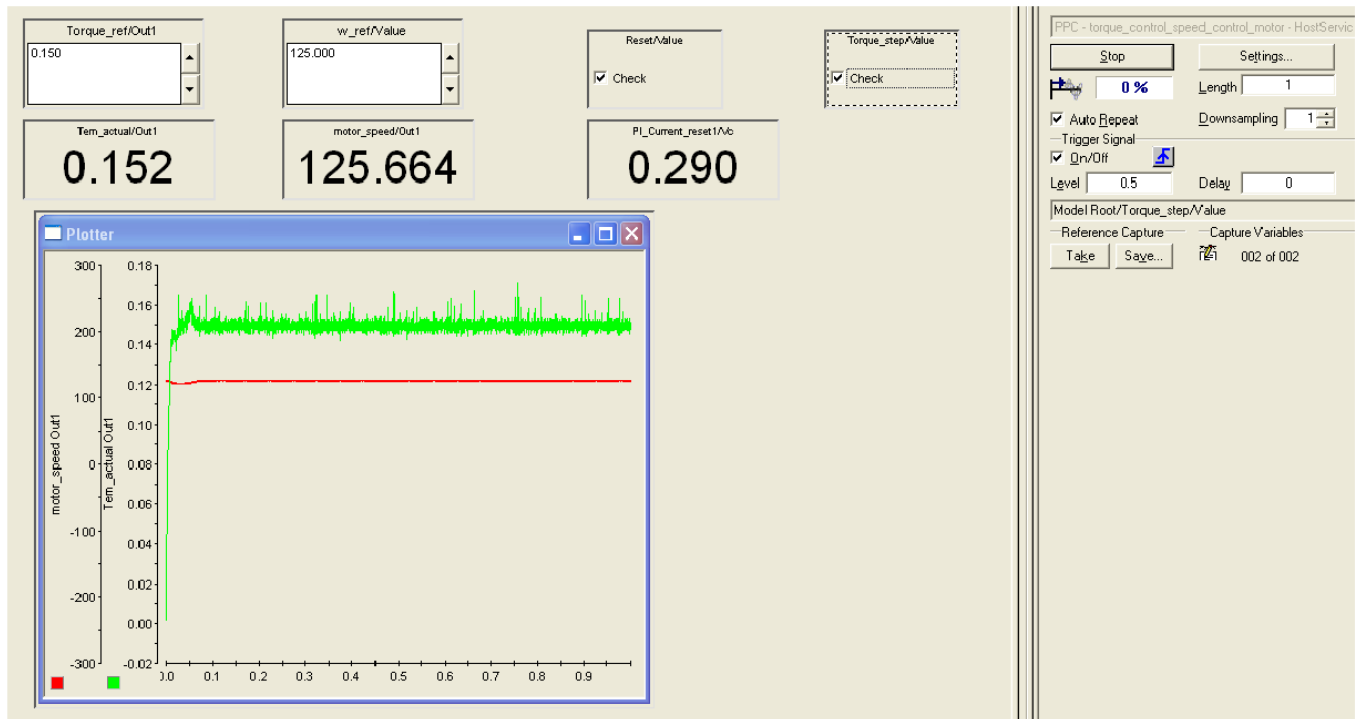


Figure 6.9: dSpace ControlDesk -speed controlled DC motor with torque controlled load.

6.5 Lab Report *(10 points)*

1. Section 6.2: Save the waveform for the actual speed and measured speed and label the quadrant of operation. *(2 points)*

2. Section 6.3:

- Part a → Attach the waveform from dSpace ControlDesk when the torque step is applied to the motor. *(1 points)*

- Answer Part a → 3 to 6 (including 3 and 6) *(1 points)*

- Part b → Attach the waveform from dSpaceControlDesk when the torque step is applied to the motor. *(1 points)*

- Answer Part b → 3 to 6 (including 3 and 6) *(1 points)*

3. Section 6.4:

- Attach the waveform for 6.3 → 5 and 8 *(2 points)*

- Answer 6.3→5 to 11(including 5 and 11) *(2 points)*

4. Bonus! Keep the speed of the motor constant at 150 rad/sec. Give a sinusoidal disturbance (use frequency of 1Hz) of 0.05 Nm in load torque over a constant value of 0.15Nm. Observe how the control system responds to the disturbance. Attach the waveform of the reference torque, actual torque developed by the motor and the speed of the motor. *(3 points)*