

Experiment – 3

Characterization of DC Motor: Part 1

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 the Textbook (Chapter 4)

Why are the brushes of the DC Machine always placed at the neutral point?

Q2: Refer to the Textbook (Chapter 5)

Explain two methods that are used to vary the speed of a DC Motor.

3.1 Introduction

The output voltage control of a two-pole DC-Switch-mode-converter was implemented in real-time, in the last experiment. The purpose of the real-time implementation was to obtain a variable DC-voltage at the output of the power converter, while controlling its amplitude with a dSPACE-based Control-desk user interface. In this experiment, a DC-motor will be connected to the output of the power converter. With this arrangement, a variable voltage can be applied to the terminals of the DC-motor. We will observe that by changing the magnitude of the applied voltage, the speed of the motor can be varied. This is also referred as open-loop voltage controlled DC-motor. The electrical parameters of the motor can be calculated by the open-circuit and blocked rotor tests and the voltage vs speed characteristics can be verified.

The objectives of this experiment are

- 1) To observe open-loop speed control of a DC motor
- 2) To calculate the motor back-emf constant k_E
- 3) To calculate the electrical parameters (R_a and L_a) of the motor using the blocked rotor test
- 4) Verify the voltage vs speed characteristics of the DC motor

3.2 Control of a DC Motor in Open Loop

Varying its supply voltage can change the speed of a DC motor. The model of output voltage control of the switch-mode dc converter was discussed in experiment – 2 and the same will be used.

- Use the model for the two-pole switch-mode converter (Fig 3.1) OR download the file ‘two_pole.mdl’ from online.
- Change the name of the Constant block from **V_ab** to **V_motor**; this will be the input voltage of the DC-motor.

3.2.1 Adding current measurement blocks

For measuring the current, **Channel 5** of the A/D converter (**ADCH5**) on CP 1104 will be used. Remember that the data have to be scaled by a factor of 10. In addition, the current sensor outputs 1V for 2 amps of current; therefore it actually needs to be scaled by 20 (shown in Fig. 3.1).

- *Drag and drop the **DS1104ADC C5** block from the dSPACE library.*
(*dSPACERT11104→DS1104 MASTER PPC→ **DS1104ADC C5***)
- *Connect a **Gain** block at its output and set its value at 20.*
- *Connect a **Terminator** at the output of the **Gain** block (rename this block ‘**motor_current**’) and label the signal as Ia.*

3.2.2 Adding speed measurement blocks

To measure speed we shall use the **DS1104ENC_POS_C1** block from the dSPACE library. This block provides read access to the delta-position and position of the first encoder interface input channel. The delta position represents the scaled difference of two successive position values of a channel. To receive the radian angle from the encoder the result has to be multiplied with $\frac{2\pi}{\text{encoder_lines}} = \frac{2\pi}{1000}$ where, **encoder_lines** is 1000 for the encoders used in the laboratory setup.

The delta-position scaled to a radian-angle has to be divided by the sampling time to obtain the speed, as in:

$$\omega = \frac{d\theta}{dt} = \frac{\Delta\theta}{t_{k+1} - t_k} = \frac{\Delta\theta}{T_s} \quad (1)$$

- Drag and drop the **DS1104ENC_POS_C1** block from the dSPACE library. In addition the encoder set-up block **DS1104ENC_SETUP** is to be added to the model. Both these blocks are in dSPACERTI1104→DS11DS1104ENC_POS_C104 MASTER PPC.
- Connect a **Terminator** block to the Enc position which is located in DS1104ENC_POS_C1 (Simulink→Sinks→Terminator)
- Connect a **Gain** block at Channel 1 output (i.e. Encdelta position) and set its value as $\frac{2\pi}{(T_s*1000)}$ where, T_s is the sampling time set in the simulation parameters under the fixed-step box. The output of this block is the motor speed in rad/s. However, at low speeds, there will be oscillations in the measured speed values. Hence an averaging to get more accurate readings are needed.
- Download the file ‘Avg_Block.mdl’ and copy it to your folder. Connect it as shown in Fig.3.1. The output of this block is the average speed in radians/sec.
- Add another **Gain** block (rename this ‘speed_rpm’) in series with this to convert the rad/s value to RPM. Change the gain value to $\frac{60}{2\pi}$.

Your real-time model is now ready and should look like in Fig 3.1.

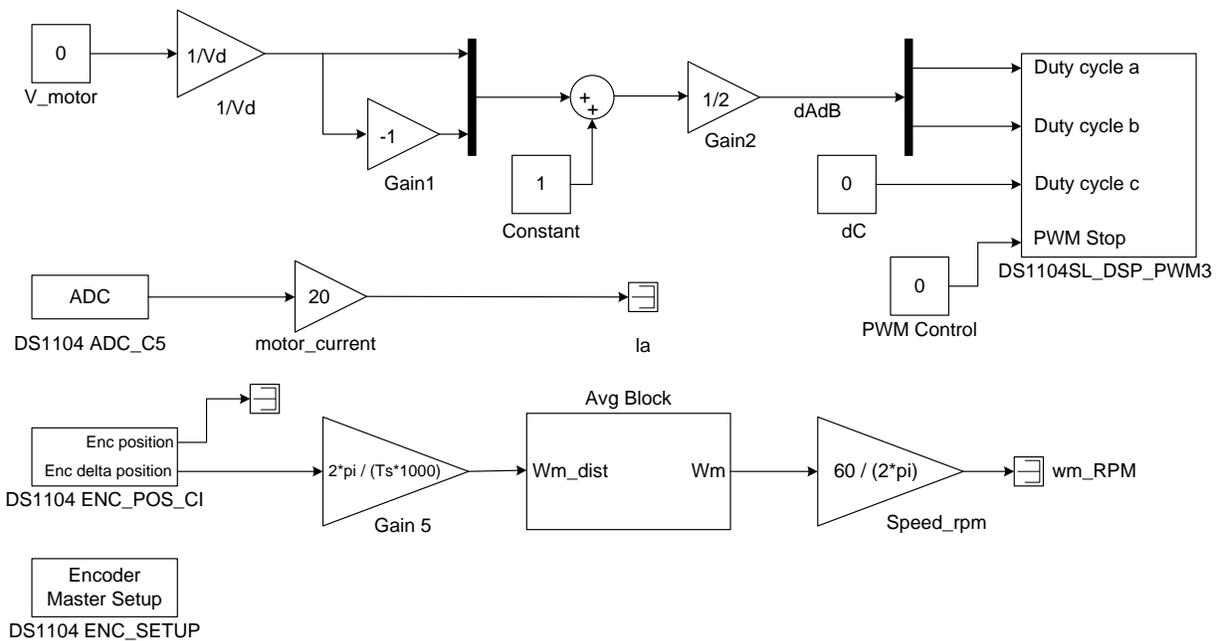


Figure 3.1: Real time Model for Open-Loop Speed Control of a DC Motor.

- Make the following changes:

Simulation → Configuration Parameters

→Solver→ Start time=0, Stop time = inf

Type: Fixed-step, Solver: ode1 (Euler)

Fixed-step size: 1e-4

→Optimization→ in Simulation and code generation, uncheck everything except 'Implement logic signals as Boolean data'

→Code Generation → System target file → rt1104.tlc

- Enter in command prompt:

>>Vd = 42; (Enter the value of the DC supply voltage here)

>>Ts = 1e-4;

- Build it (Ctrl+B) (Make sure the current directory is the same as the location of the .mdl file)
In Matlab main window, you will see,
'MAKE PROCESS SUCCEEDED'

3.2.3 Connections on the Board as per Fig. 3.2

Couple the DC generator and DC motor under test (MUT). Connect the armature of the DC Motor to the output of two converter poles A1 and B1. Connect the **CURR. A1** (phase-current measurement port) on the drives board to the **Channel ADCH5** of CP 1104 I/O board. Also, connect the encoder output (mounted on the DC-motor) to the **INC1 9-pin DSUB** connector on CP 1104 I/O board. Connect the MUT to a DMM to measure the value of E_b .

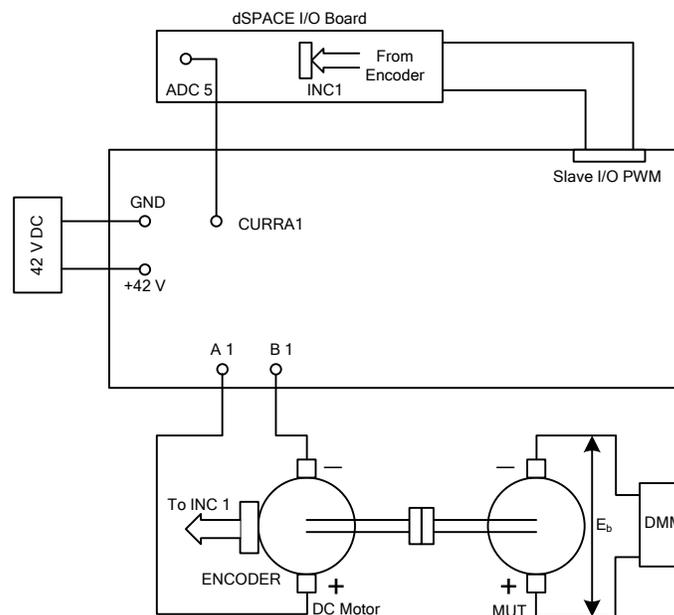


Figure 3.2: Connections for measurement of k_E

3.2.4 Creating Control Desk Layout

- Open dSPACEControlDesk
- Open Variable file (.sdf) select the generated .sdf file.
- File → New → Layout
- Select and draw the following as shown in Fig 3.3.

Virtual Instruments → Slider, Numerical Input, Display

Data Acquisition → PlotterArray

- Drag and drop the appropriate values into the Slider, Numerical Input etc.

OR you can download the **ke.lay** file and drop the appropriate values into the instruments.

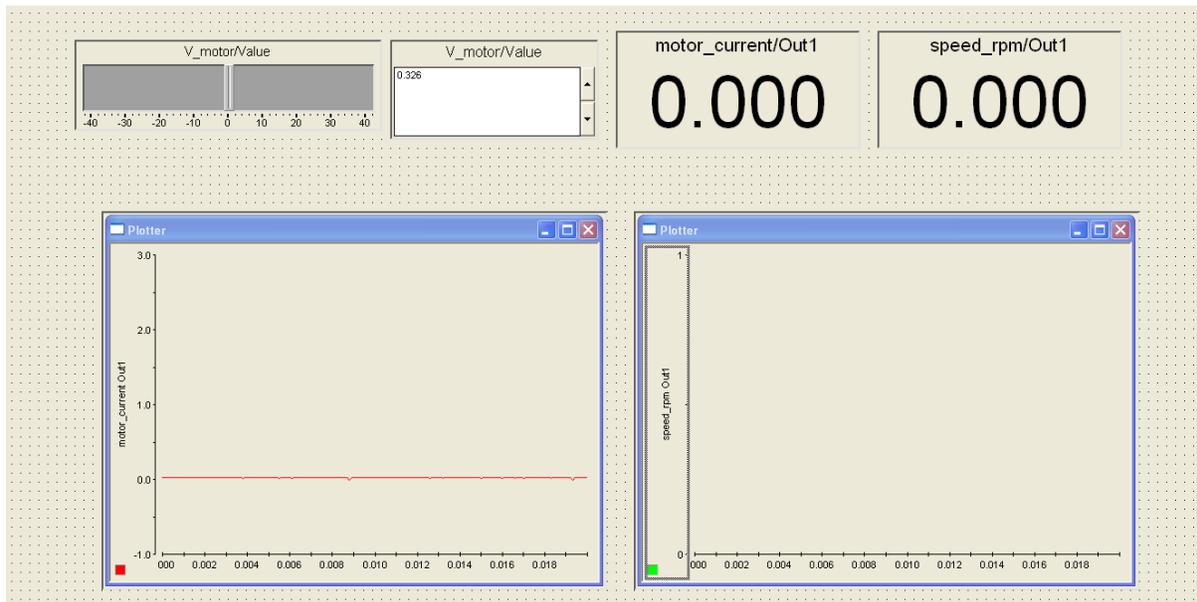


Figure 3.3: Layout files for measurement of k_E

3.3 Determination of k_E (Open Circuit Test)

The back emf that is generated in the motor is directly proportional to the speed of the motor (Equation (2)). In this section, the MUT is driven at a certain speed by another motor (in this case a DC generator running as a motor). The open circuit voltage (E_b) is measured using a DMM. For 10 different values of speed from 0 rpm till around 2000 rpm, measure the value of E_b . Enter this in Table 1. Plot these values in Matlab and find the slope of this line (k_E).

NOTE: Do not exceed $V_{(A1 B1)}=20V$ (~2000 rpm)

$$E_b = \omega k_E \tag{2}$$

Table 1: (Take 10 readings from 0 to 2000rpm)

Motor Speed (RPM)	Measured E_b

REMEMBER, THE RPM HAS TO BE CONVERTED TO rad/sec BEFORE YOU PLOT

3.4 Determination of electrical parameters (Blocked Rotor Test)

$$V_a = R_a I_a + k_E \omega + L_a \frac{di_a}{dt} \quad (3)$$

To estimate the armature inductance, the motor must be held a standstill, $\omega = 0$. If the rotor is blocked and a step voltage is then applied to the armature terminals, the current increases exponentially in time and equation (3) becomes:

$$V_a = R_a I_a + L_a \frac{di_a}{dt} \quad (4)$$

The solution for this differential equation is (5),

$$i_a = \frac{V_a}{R_a} (1 - e^{-t/\tau}) \quad (5)$$

Where, $\tau = \frac{L_a}{R_a}$

The current increases exponentially to the final value $\frac{V_a}{R_a}$. The slope of the curve measured at $t=0$, is dependent on the value of L_a and R_a is given by $\frac{di_a}{dt} = \frac{V_a}{L_a}$.

NOTE: Do not exceed $V_{(A1 B1)} = 3V$ in the blocked rotor test. Think why?

3.4.1 Real-Time model

A step voltage can be given to the motor using the **SHUTDOWN and RESET** signal on the drives board. The **SHUTDOWN** signals are controlled by the **DIGITAL I/O** channels 11 and 12. When **IO11/12** is **0** (OFF state) the switching signals are inhibited and the switches are opened. Setting **IO11/12** to **1** (ON state) and resetting (**IO10**) resumes the regular operation of the converters. The **IO10/11/12** digital channels will be added as slave bit out blocks for our model from the slave library. In addition two constant locks and two **BOOLEAN** conversion blocks (Select Commonly used Blocks from Simulink Library Browser → look for the block “Data Type Conversion” in settings change *output data type* to *Boolean*) should be added with **SD1** and **SD2** using the same signal. The model should like the one shown in Fig. 3.4

dSPACE RTI1104 → SLAVE BIT OUT → DS1104SL_DSP_BIT_OUT_C11

change the *Channel Number* to 11/12.

Similarly, Add a **RESET** button on channel 10. Your model must look like Fig. 3.4

Build the model (Ctrl+B).

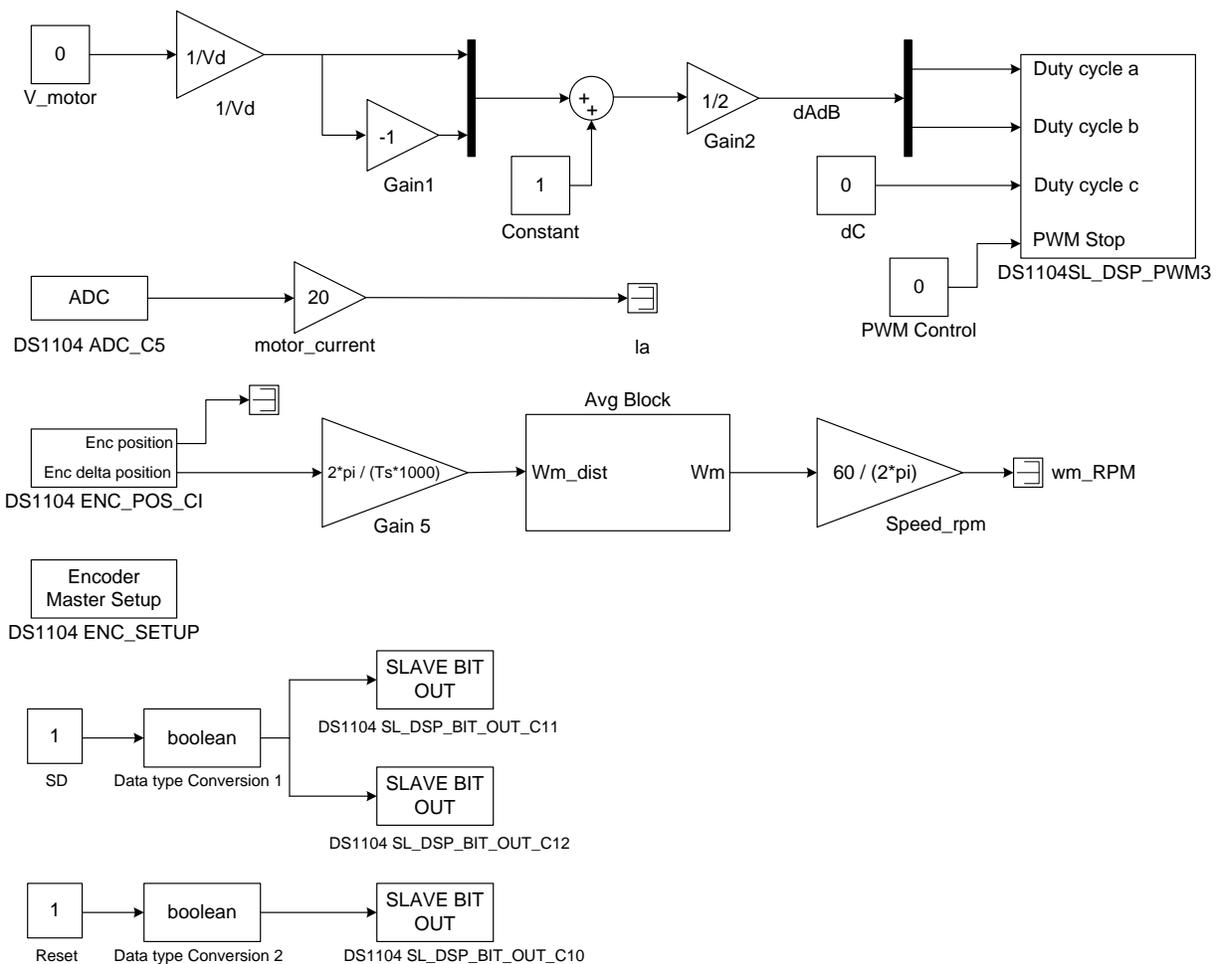


Figure 3.4: Simulink model for blocked rotor test

3.4.2 Creating Control Desk Layout

Reload the variable file and modify the layout to include a CheckButton for SD and Reset. (Virtual Instruments → CheckButton) as in Fig 3.5 or open the **exp3sdreset.lay** file.

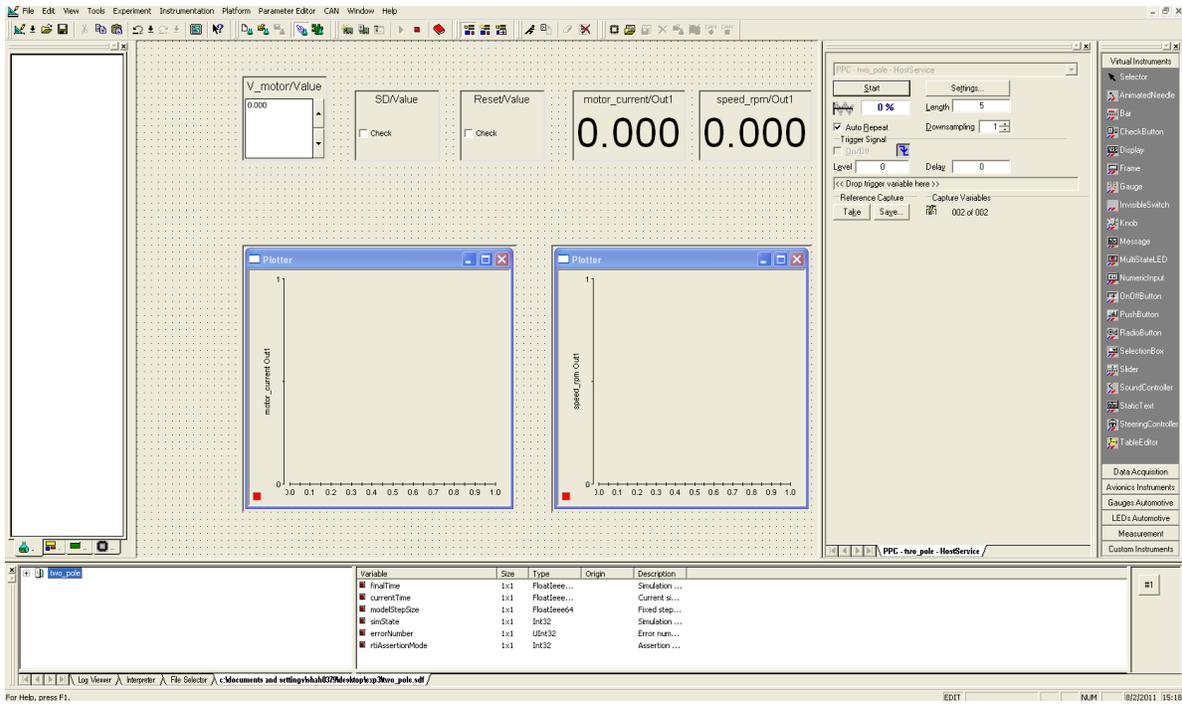


Figure 3.5: Layout for blocked rotor test

3.4.3 Connections on the Board

Make connections for blocked rotor test as in Fig 3.6.

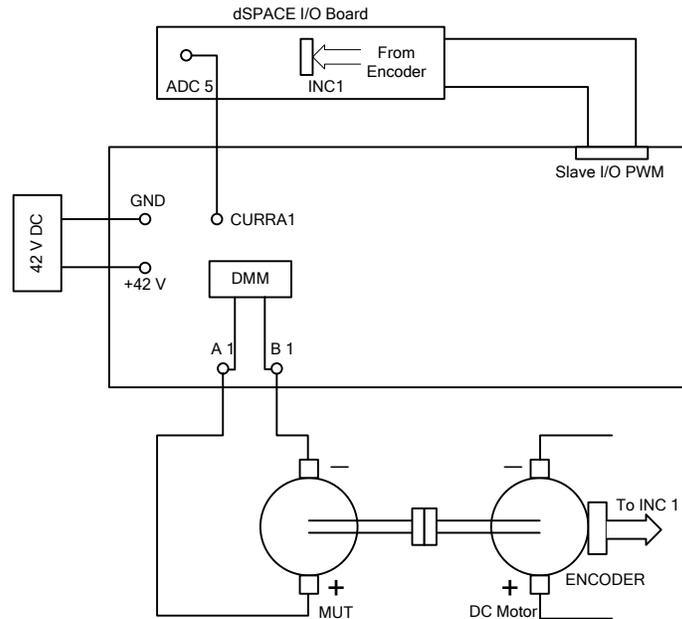


Figure 3.6: Connections for blocked rotor test and no load characteristics

3.4.4 Inductance determination

1. Open View Control bars/Capture Setting Window. Change the setting in the capture setting window as shown in Fig 3.7. Drag the reset signal from the model root values into the grey box situated below the level-delay set boxes. Check the box called ON/OFF, check the edge direction, and the set the level value to 0.5. Also set the length to 0.4.

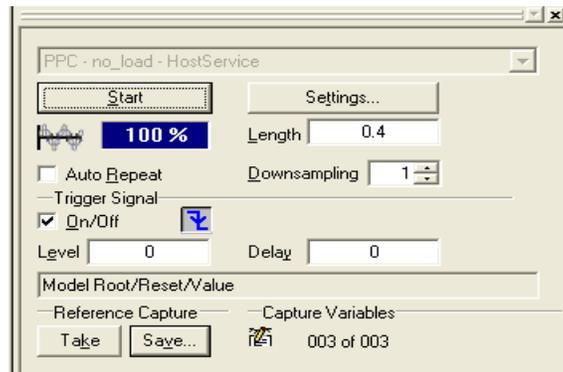


Figure 3.7: Capture setting window

2. Block the rotors firmly.
3. Uncheck and then recheck the SD control. This button works as a switch to connect and disconnect the machines from the power supply.
4. Set the V_{motor} to a low value (not exceeding 3 V) and uncheck Reset to give a step input voltage. The current should increase exponentially and reach a constant steady state value.
5. Now, you will observe that every time you uncheck the Reset control in the layout, the plot area will display the current and it will stop when it reaches the maximum measurement time. The **Length** is set to 0.4. This will set the data capture time as 0.4s which is large enough to observe the whole transient process in current. The screen shots are shown in Fig 3.8 & 3.9.
6. Check and uncheck SD and Reset to make some measurements. After you are satisfied with the data displayed go to the Capture Settings Window and press the SAVE button. The dialog box will ask you to name the .mat file that will contain the graphic data in all plot areas.

7. Download the file 'br.m' which has instructions on plotting from the .mat file and additional code to calculate the value of, L_a and, R_a from the graph.
8. Measure the voltage between terminals Phase A1 and B1 using the DMM when the rotor is blocked.

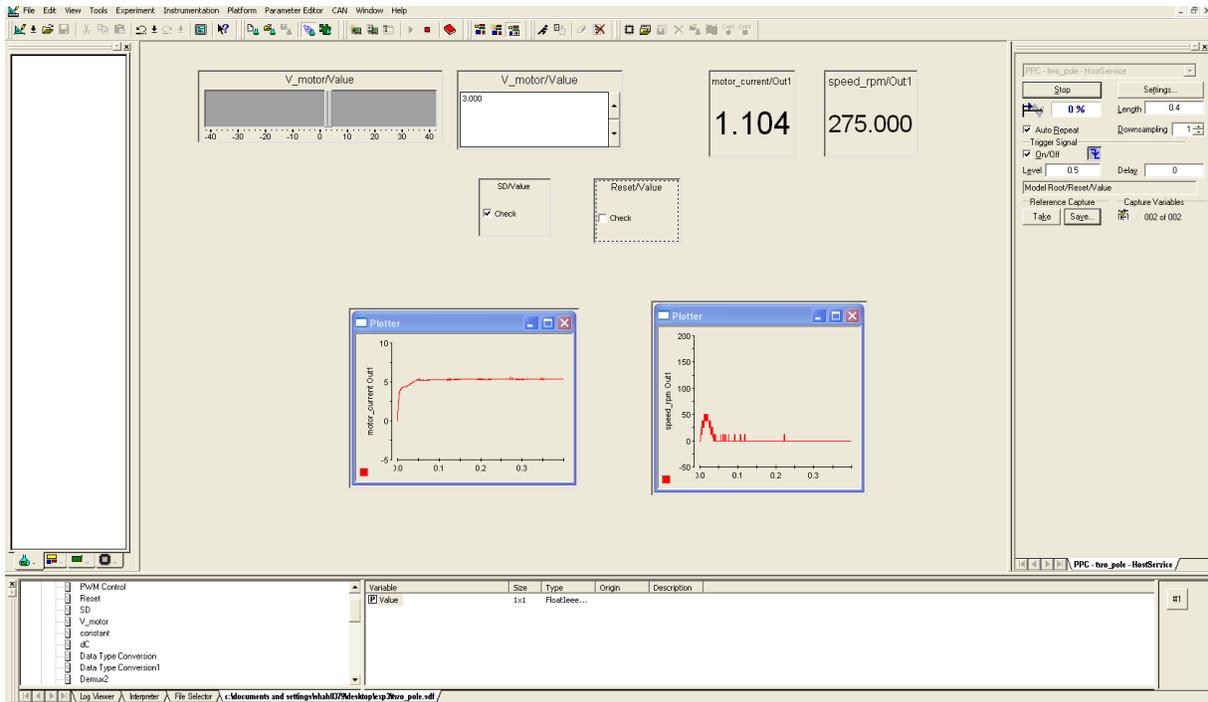


Figure 3.8: Screen shot of dSPACE control desk

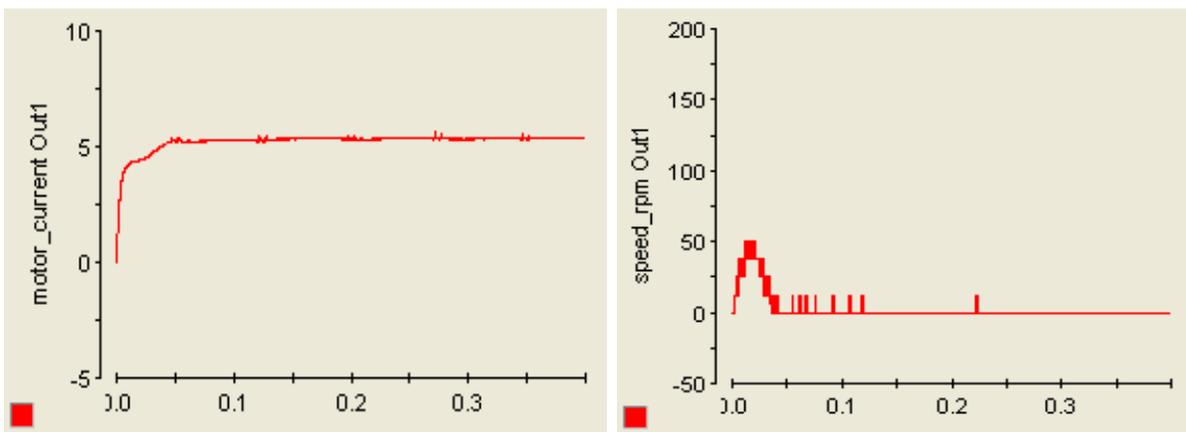


Figure 3.9 Waveform of motor current and speed (rpm) as observed from the dSPACE control desk.

3.5 Open-loop speed control (voltage vs speed characteristics)

In steady state, with voltage V_a applied to the armature terminal of a DC-motor, following equation can be written:

$$V_a = R_a I_a + k_E \omega \quad (6)$$

From equation (6), the armature voltage can be calculated in real-time to run the DC-motor at a desired speed ω (rad/s). Note that, there is no feedback here, we are calculating the equivalent amount of voltage that need to be applied, to run the motor at a desired speed. Hence this type of speed control can be termed as open-loop voltage control. The values of armature resistance R_a and the back-EMF constant k_E should to be known beforehand. The calculated and measured speed is compared at the end of this section.

3.5.1 Measurements

The connections for this section are the same as in section 3.4.3. Record the values of current and speed for different values of voltages specified in Table 2.

NOTE: Use the DMM to measure the actual motor voltage between terminals Phase A1 and B1.

Table 2.

V_{motor}	(V)	0.5	1	3	5	7	10	15	20
$V_{\text{-A1-B1}}$	(V)								
Speed	(RPM)								
Current	(A)								

3.6 Lab report: (10 points)

- 1) In Section 3.3, (3 points)
 - a) Table with values of Motor speed and Measured E_b . (1pt)
 - b) Plot the values of E_b vs speed and (1 pt)
 - c) Calculate the value of k_E . (0.5 pt)
 - d) Does the line pass through the origin? Should it? (0.5 pt)

2) Section 3.4, (3.5 points)

- a) Why do we apply a reduced voltage to the motor? (0.5 pt)
- b) Attach the plot of motor current when a step voltage of 3V is given to the motor (1 pt)
- c) Calculate the value of R_a from this plot. (1 pt)
- d) Calculate the value of L_a from the initial slope of the current. (1 pt)

3) Section 3.5, (2.5 points)

- a) Plot the voltage vs speed characteristics of the DC motor. (1 pt)
- b) Comment on the graph. (0.5 pt)
- c) Using the value of R_a , k_E , and measured I_a , calculate speed and plot the measured speed and calculated speed on the same graph. (1 pt)

Report :(1 point)