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A Proposed Simulation Approach for Teaching the Design of a DC Motor using MATLAB

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Abstract:

This paper deals with the design of speed and torque control of DC motor drive. The PI control scheme is proposed for the system, and it is usually used in DC motor drives. The proposed control schemes guarantee the asymptotic stability of the closed-loop system. The converter that is used in the system is a 4-quadratic switch-mode DC-DC converter. The design is based on a small signal model and verified using a large signal model. To illustrate the developed control schemes, the performance of the closed loop system is simulated using MATLAB. The simulation, analysis, and discussion are introduced to present the efficiency of the scheme.

Keywords: Simulation, Teaching, DC Motor, MATLAB.

1. Introduction

The performance of DC drives depends on the type of speed controlled as well as torque-controlled converters used in a system. In DC drives, controlling the amount of voltage that is applied to the armature of the DC motor is important to establish the system. Moreover, controlling current is essential to prevent large damaging armature current during start-up. Thus, a good current loop is very important when setting up a DC drive. When the control of the current loop as well as the speed loop

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is good, the steady state motor should respond exactly with the reference and should be fast and well-damped. This can be achieved by appropriately tuning the parameters of the PI controller.

During the design of speed and current-controlled converter in modeling the DC drives, the non-linear characteristic of the converter in practical application is a major limitation in the designing of such systems. The PI controller is designed through the linear analysis in MATLAB using the average or linearized model. As the intention of the design is to get zero or very small steady error as well as a fast response, the DC gain of the open loop plot of the average model must be so large bandwidth.

2. Abbreviations

Vdc;	DC Voltage across the load or armature
Vc;	Voltage from control signal
Vtri;	Voltage from triangular signal
Va;	Average Voltage
Ra;	armature resistance
La;	internal inductance

3. Four Quadrant Converter

The model developed for the two-quadrant converter can be used as a building block in developing the model for the four-quadrant converter. As illustrated in Figure 1, the four-quadrant converter is collected of two legs, A and B, with each leg related to each other and consists of the two-quadrant converter.

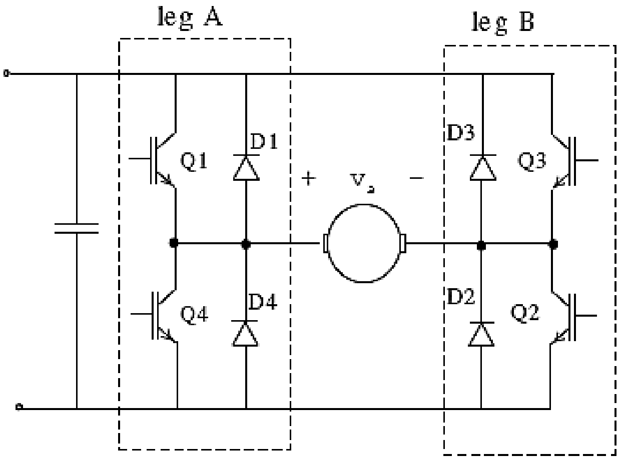

Figure 1. A model was developed for the four-quadrant converter.

The instantaneous voltage Va can be made either equals:

For negative current

Va = Vdc when D1 and D2 are ON

Va =-Vdc when Q3 and Q4 are ON

Va = 0 when current freewheels through Q & D.

For positive current

Va = Vdc when Q1 and Q2 are ON

Va =-Vdc when D3 and D4 are ON

Va = 0 when current freewheels through Q & D.

In a four-quadrant converter, two switching schemes are normally employed:

(1) Bipolar switching scheme,

(2) Unipolar switching scheme.

In this work, we will deal with a unipolar switching scheme.

4. Unipolar Switching Scheme

In the unipolar switching scheme, the switching signal for Leg B is obtained from the inverse of a control signal for Leg A. Figure 2 illustrates the unipolar switching scheme, and Figure 3 shows the resultant waveform, q and $\bar{q}$.

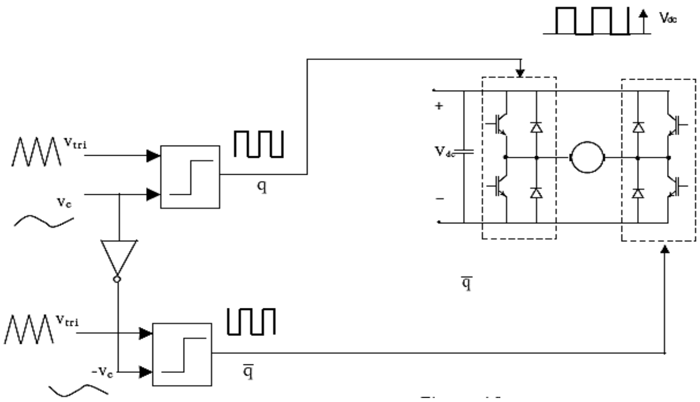

Figure 2: The control signal, Vc, and triangular waveform, Vtri in a unipolar switching scheme.

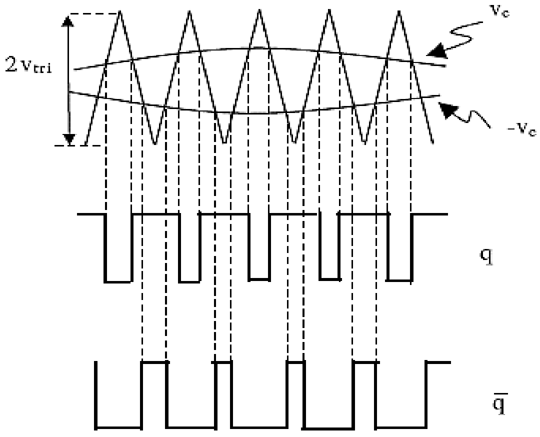

Figure 3: The resultant waveform in a unipolar switching scheme.

The waveform q and $\overline{q}$ were obtained from the following rules:

$$q = \begin{cases} 0; V_c < 2V_{tri} \\ 1; V_c > 2V_{tri} \end{cases}$$

and

$$\overline{q} = \begin{cases} 0; -V_c < 2V_{tri} \\ 1; -V_c > 2V_{tri} \end{cases}$$

$$\frac{V_a(s)}{V_c(s)} = \frac{V_{dc}}{V_{tri}} \qquad (1)$$

5. Design Pi Controller for The System

In most of the applications, normally cascade con troll is used to control the current (torque) and the speed (voltage) of the DC motor drives. Cascade control consists of different control loops with the innermost is the current (torque) loop then followed by the speed (voltage) loop. In this paper, both current and speed will be discussed and controlled by using PI controller. Design for PI controller is done in open loop condition with the supposition that the close loop system would alternate gradually at the crossover frequency for open loop system, or basically in essential response.

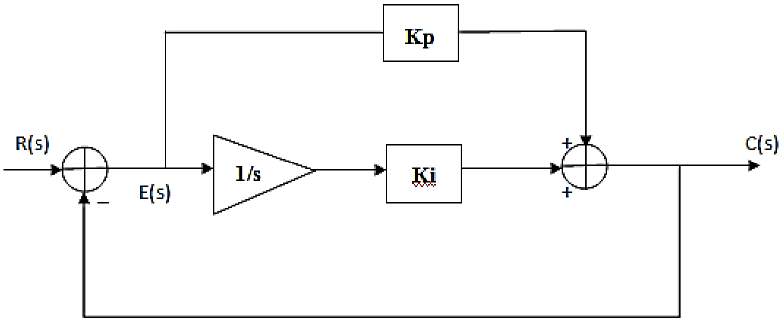

Figure 4. Block diagram of PI controller

The transfer function of PI controller is:

$$G_c = \frac{K_i + K_p s}{s} = \frac{K_i(1 + \frac{s}{K_i/K_p})}{s}$$

Before the controller of the switch-mode converter can be verified using the large signal mode, both current and speed must be first evaluated using the small signal model. Then, simulation of the large signal for controllers' verification. In Figure 5. the DC motor-small signal model is presented.

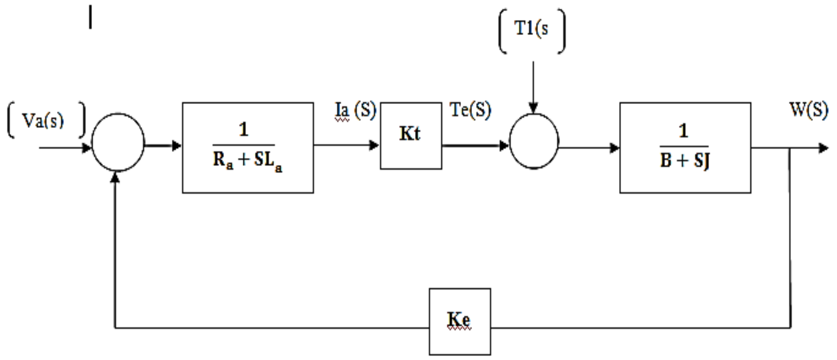

Figure 5.DC motor-small signal model

5.1 Linear Small Signal Analysis

For the switch mode converter with the frequency at 33 KHz, the close loop bandwidth for torque is designed to decade at 3.3KHz. as well as the close loop bandwidth for speed is designed to be lower. It is decade at 330Hz. This is to ensure good response and performance of the controller. The open loop linearization strategy is carried out in MATLAB/Simulink using a linear analysis function. Table (1): Shows the values of parameters of system.

Component	Value
V_{dc}	200 v
V_{tri}	5 v
f_{tri}	3.3KHz
R_a	2 Ω
L_a	5.2 mH
K_T	0.1 vs/rad
J	130e-6 $Kg.m^2$
B	0.01 N.m.s

Table 1: parameters of the system

To design a suitable PI controller, verification of the PI parameter is carried out until the desired frequency is achieved. In MATLAB/Simulink, the response of the open loop gain of current and speed can be plotted using Bode plot. The transfer function of open loop current and as well as open loop speed are given by Eq. (2 and 3) respectively.

$$\frac{1}{S5.2e^{-3}+2} \qquad (2)$$

$$\frac{1}{S130e^{6}+0.01} \qquad (3)$$

The reason of using the open-loop transfer function is to estimate the closed-loop response.

(1) Torque-Loop

The reference current is evaluated with the actual current and the error is fed to the PI controller. The output of the PI controller is compared with the triangular waveform to find out the duty ratio of the switches – either to increase or reduce the current. However, the bandwidth of the current loop is limited by the triangular waveform as shown in the preview section. In Figure 6, the open loop of the small signal for current is introduced.

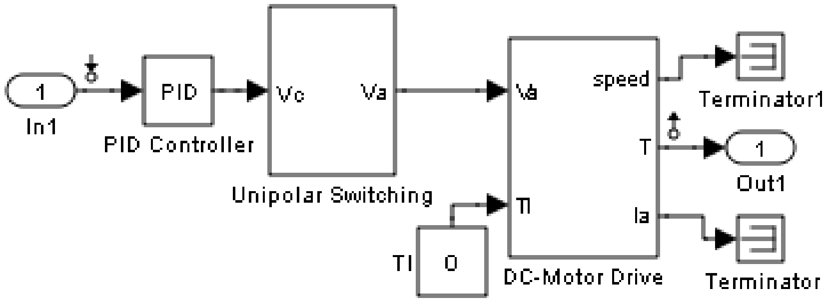

Figure 6. Open loop current

The zero of the PI controller is set such that it will cancel out the pole of open loop gain. In figure 7(a) and 7 (b), the uncompensated and compensated current loop gains as well as pole of the open loop gain of switch-mode converter with Kp=1 and Ki=0 are presented.

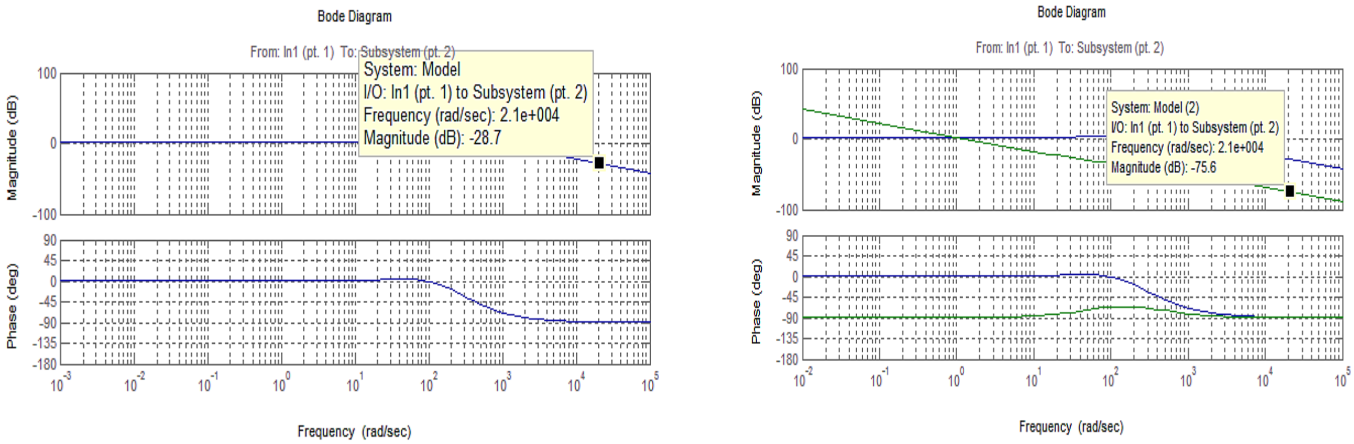

Figure 7(a): Bode diagram current loop gain.

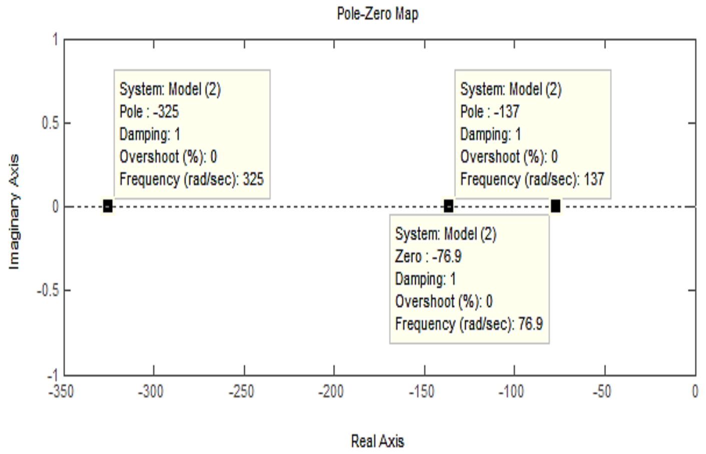

Figure 7(b): pole and zero of open loop current.

From Figure 6(b), the system has poles at 325 (rad/sec) and 137(rad/sec) as well as zero at 76.9 (rad/sec). If the zero of PI is set at 220 (rad/sec), then $K_i/K_p = 220$ (rad/sec). If the DC gain is set to unity (by setting $K_i = 1$), then K_p must be set to (1/220). The Bode plot for this situation is shown in Figure below.

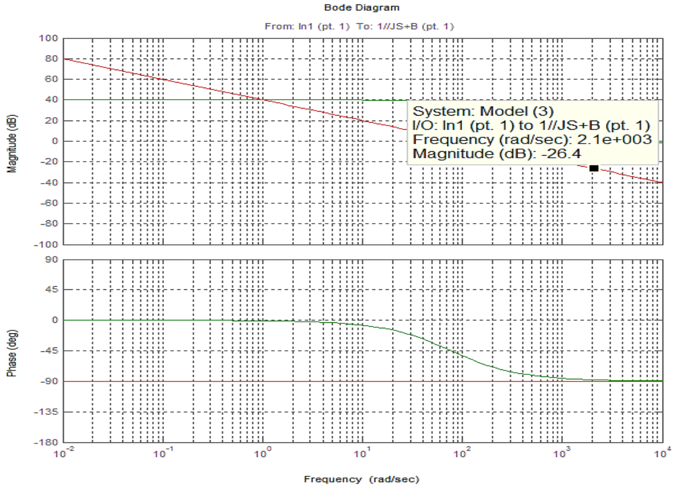

Figure 8: Open loop gain with $K_i = 1$ and $K_p = 1/220$

From Figure (8), it can be seen that the cross-over frequency or the bandwidth is too low. To increase the bandwidth while keeping the zero at 220(rad/sec), the value of K_i needs to be increased. At the same time, K_i needs to be changed consequently so that the zero at 220(rad/sec) is maintained. Since the bandwidth is 3.3 KHz = 2.1×10^4 rad/sec, we need to increase the gain by 75.6 db.

$$20 \log K_i = 75.6$$

$$K_i = 10^{(75.6/20)} = 6025.59, \qquad K_p = 79.7$$

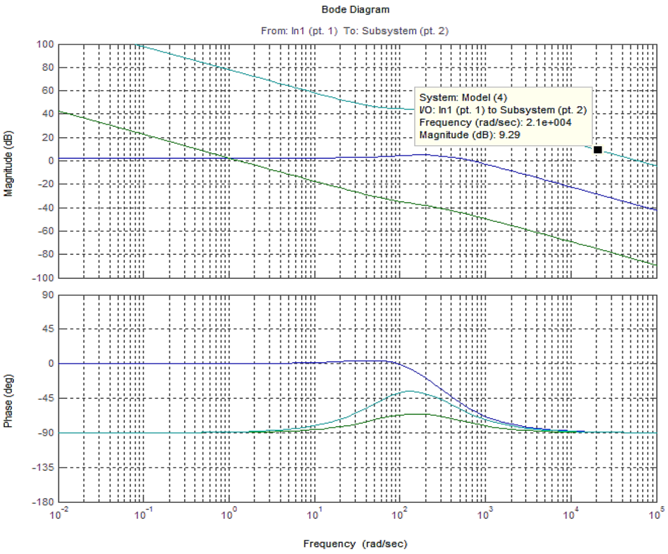

Figure 9: Bode plot for K_i = 6025.59 & K_p = 79.7

From Figure 9, the magnitude is nearly (0) db and the phase margin is greater than 65°, and then we take the calculated values of Ki and Kp to be implemented into a large signal simulation.

(2) Speed-Loop

A similar method is applied to the design of the speed controller. The parameters of PI speed controller are mainly determined by the viscous friction B and moment of inertia J in Eq (3). The bandwidth of the speed loop is set at least an order lower than the torque bandwidth, i.e., about 330 Hz. By assuming that the closed-loop current gain is unity, which will simplify the design of the speed controller.

In Figure 10(a), shows the Simulink block of open loop gain.

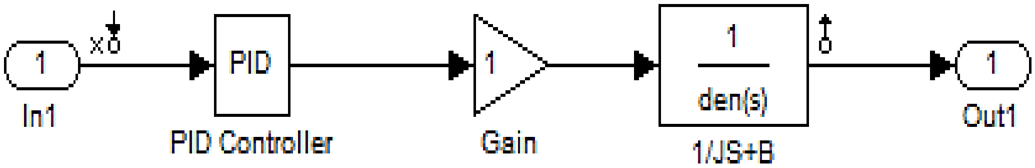

Figure 10(a): open loop speed

The zero of PI controller was set such that it will cancel the pole of open loop gain. From the Figure below it can be seen that there is a pole at 76.9 (rad/sec). The zero of the controller can be set at this frequency. The Bode plots of the speed loop as well as pole location are shown in figure 10(b) and 10(c).

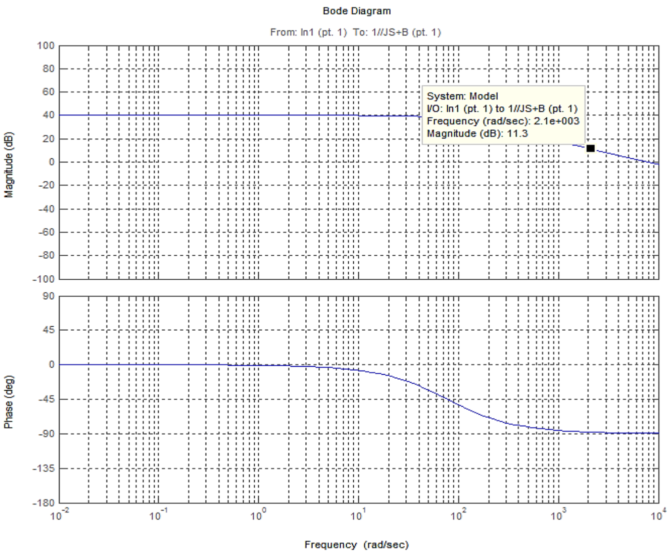

Figure 10(b): Bode plot for Ki=0 and Kp=1

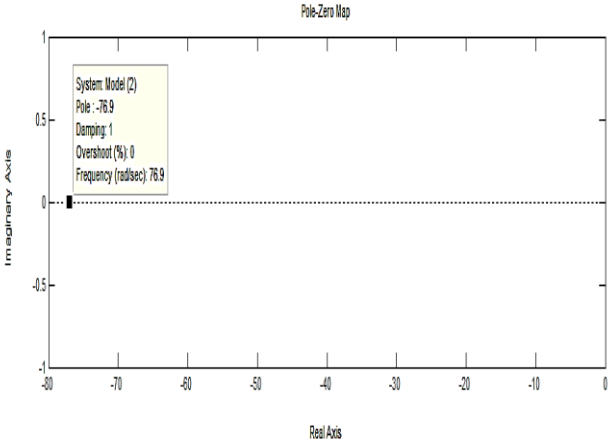

Figure 10(c): pole and zero of open loop speed.

To cancel out the pole, the zero must be set as Ki/Kp=76.9(rad/s). Therefore, the PI controller parameter for proportional gain, Kp is set to 1/76.9 and the integral gain, Ki is kept constant at one. In Figure 11 (a), the open loop gain with Ki =1 and Kp =1/76.9 is presented. This process will lead to cancel the pole of open loop gain.

From the Figure above, it can be seen that the cross-over frequency or the bandwidth is low. To enlarge the bandwidth while keeping the zero at 76.9(rad/sec), the magnitude of Ki needs to be increased. At the same time, Ki needs to be changed consequently so that the zero at 76.9(rad/sec) is maintained. Since the bandwidth is 330Hz = 2.1×103 (rad/sec), we need to increase the gain by 26. 4db. Then, the corresponding PI controller's parameters for speed-control gain will set as Kp = 0.272 and Ki = 20.89.

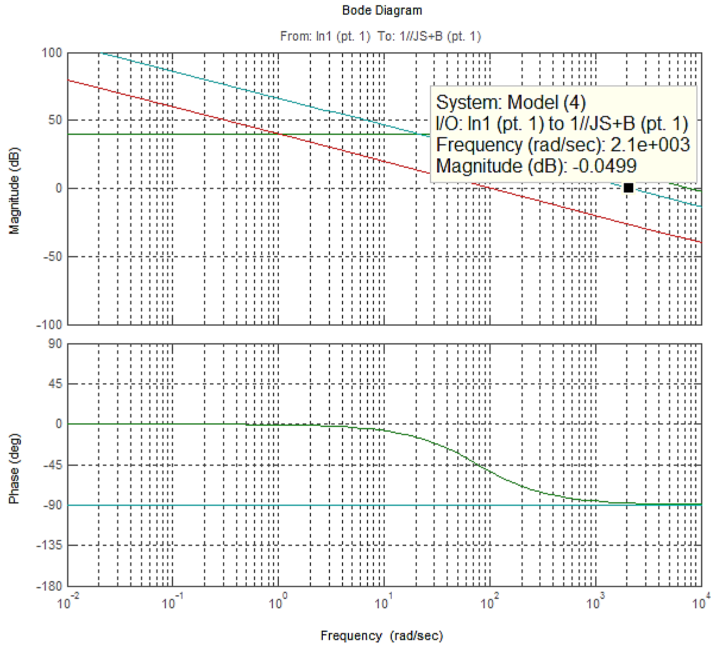

Figure 11 (b): Bode plot for Ki = 20.89 & Kp = 0.272

From Figure 11(b), the magnitude is nearly (0) db and the phase margin is greater than 65°, and then we take the determined values of Ki and Kp to be employed into large signal simulation.

5.2 Large Signal Analysis

The final values of parameters for the PI controllers will be used in large signal simulation that is shown in Figure 12. The unipolar switching scheme for the converter is used.

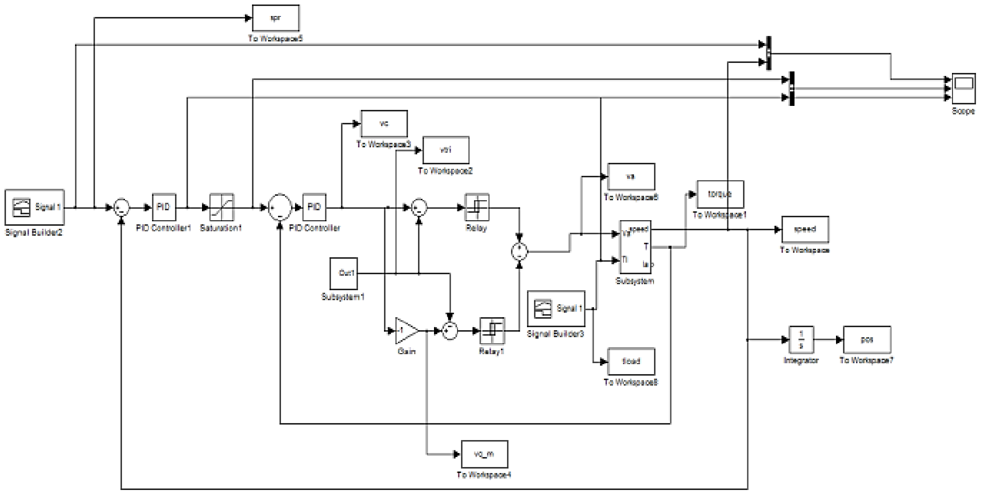

Figure 12: large signal simulation

6. Simulation Results

In this section, the results of the simulation are presented and discussed in detail. Discuss will be on the speed and torque responses obtained from simulation. The parameters of PI controller as described in the previous section are used in this simulation.

The response of the system in terms of speed and torque is verified by input signal (speed) and the disturbance acting the system. In the figures below the output speed and output torque from large signal are introduced.

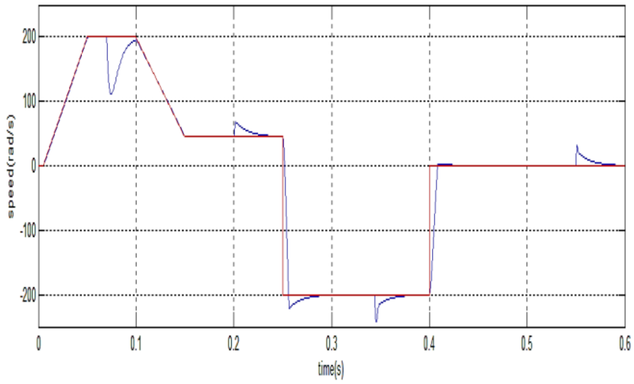

Figure 13: output speed of the large signal simulation

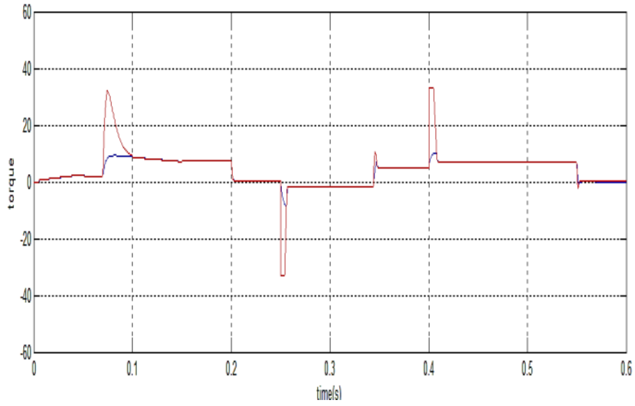

Figure 14: output torque of the large signal simulation

The simulation of the output speed response of a large signal (blue color) and the reference input speed (red color) is shown in Figure 13. From the figure, it can be seen that the output speed exhibits almost no ripple, and the robustness of the controlled system to disturbance acting on the system and velocity of the speed response signal to follow reference signal was good.

In figure 14. the output torque response (blue color) with torque reference (red color) is shown. It can be seen clear that the torque follows the reference in most time. These results had been getting with acting disturbance signal.

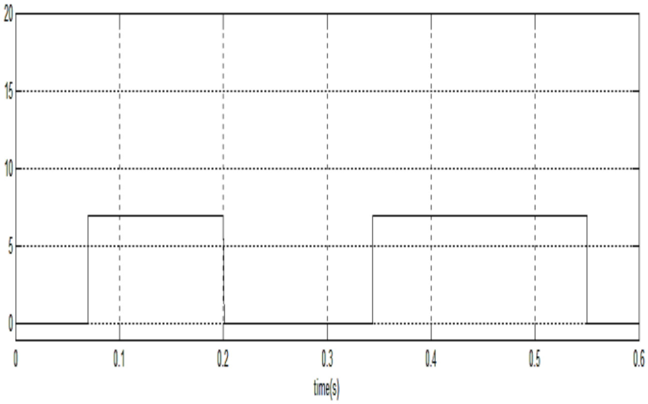

Figure 15: the step disturbance signal in the system

7. Conclusion

The speed-torque control of DC machine is addressed in this work. The PI controller scheme is proposed for the system. The performance of the controlled system is studied under the system parameters and in the presence of step disturbance acting the system.

The simulation results indicate that the proposed control scheme works very well and is robust to the disturbances acting on the system.

References

[1] Dr. Nik Rumzi Nik Idris, “DC Drives”, MEP 1422 Lecture Notes, Malaysia: University of Technology Malaysia, 2008.

[2] N. Mohan, “Electric Drives: An Integrative Approach”, University of Minnesota Printing services, 2000, pp. 7-2.

[3] Krishnan, R. “ELECTRIC MOTOR DRIVES” Modeling, Analysis, and Control. 2001: Prenlicc Hall. Inc.

[4] Simulink, Model-based and System-based Design, using Simulink, Math Works Inc., Natick, MA, 2000.

[5] Sim Power System for use with Simulink, User’s Guide, Math Works Inc., Natick, MA, 2002.

[6] S. Li and R. Challoo, Restructuring an Electric Machinery Course with an Integrative Approach and Computer-assisted Teaching, IEEE Trans. Edu., 49 (2006), 16-28.