ECE 5670/6670 – Lab 7

Brushless DC Motor Control with 6-Step Commutation

Objectives

The objective of the lab is to implement a 6-step commutation scheme for a brushless DC motor in simulations, and to expand the control system first to regulate the current and then to regulate the speed of the motor. Experimentation with the physical system is deferred to the final project.

1. Introduction

A standard circuit for the control of a brushless DC motor is the three-phase inverter shown in Fig. 1.

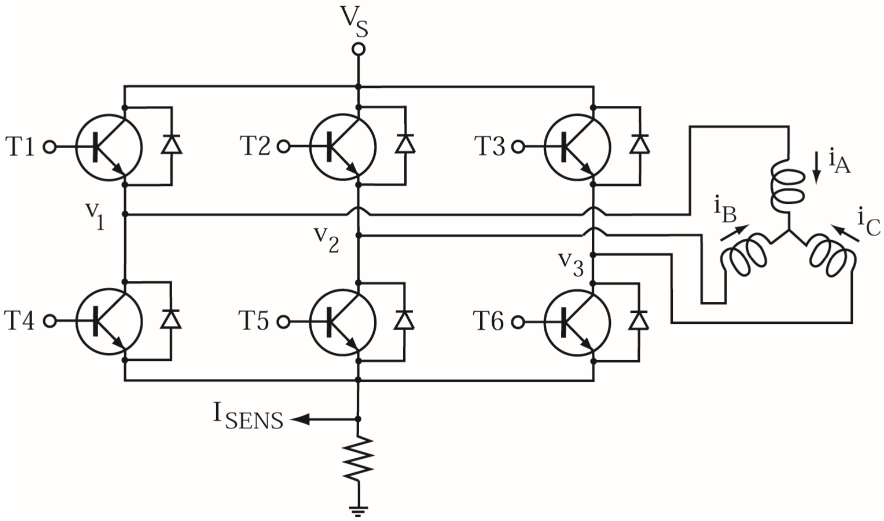

Figure 1: Three-phase inverter and brushless DC motor

Transistors are turned on based on the following commutation table (other transistors are turned off). All transistors are turned off for zero torque command.

Step	$n_p\theta$	$\underline{\tau_e}>0$	$\underline{\tau_e}<0$
1	330° → 30°	T2, T6	T3, T5
2	30°→90°	T2, T4	T1, T5
3	90° →150°	T3, T4	T1, T6
4	150°→210°	T3, T5	T2, T6
5	210° →270°	T1, T5	T2, T4
6	270°→ 330°	T1, T6	T3, T4

2. Experiments

2.1 Open-loop stepping

Download the file *Lab7.mdl* from the lab web page. The file contains a block implementing a simulation of the brushless DC motor with the following inputs and outputs:

- *vol*: the DC supply voltage (in V)
- *t1* to *t6*: the six transistor commands (0 for off, 1 for on)
- *th*: the position of the motor (in rad)
- *om*: the velocity of the motor (in rad/s)
- *v1, v2, v3*: the voltages on the motor windings (in V)
- *vsense*: the voltage on the sensing resistor (in V)
- *ha, hb, hc*: the Hall effect sensor outputs (0 for off, 1 for on)

The simulation also includes a block that implements the six steps of the commutation logic and a signal generator that moves from one step to the next twice across the table. Run the simulation and observe the response of the motor, which is reminiscent of the response of the stepper motor.

2.2 Quadrature control using six-step commutation

Modify the open-loop commutation block to implement quadrature control using the Hall effect sensors. The decoding of the Hall effect sensors described in the course notes can be used. The new commutation block should have as inputs the three Hall effect sensors, a variable *dir* defining the sign of the torque (positive torque for *dir=1*, negative torque otherwise), and a variable *on* defining whether to turn on the transistors at all (all transistors off for *on=0*). Also add blocks in Simulink to process the voltage from the 0.5Ω sensing resistor as follows:

- first scale the voltage measured on the resistor to read a value in A,
- take the absolute value of the current,
- filter the signal with a first-order filter having unity gain and a pole at -5,000 rad/s.

Finally, add blocks so that the commands to the commutation are sequentially *dir*=1 with *on*=1, *dir*=1 with *on*=0, *dir*=-1 with *on*=1 (each for 0. 03 seconds), *dir*=-1 with *on*=0 (for 0.02 seconds). Let the DC supply voltage be 6V.

A block diagram of a possible solution is shown in Fig. 2. Run the simulation for 0.11 seconds. Plot the transient responses of the velocity and of the filtered current. Next, run another simulation with *dir*=1 and *on*=1 for the whole period, and plot the responses of the velocity and of the filtered current, as well as the variables T1 to T6, v_1, v_2, v_3, h_A, h_B, and h_C. Keep the presentation compact without sacrificing clarity by plotting 2-3 variables in a row using the subplot function in Matlab. Also plot the complementary transistors (*e.g.,* T1 and T4) on the same graph. Comment on the responses, in particular the different segments of the voltages v_1, v_2, v_3.

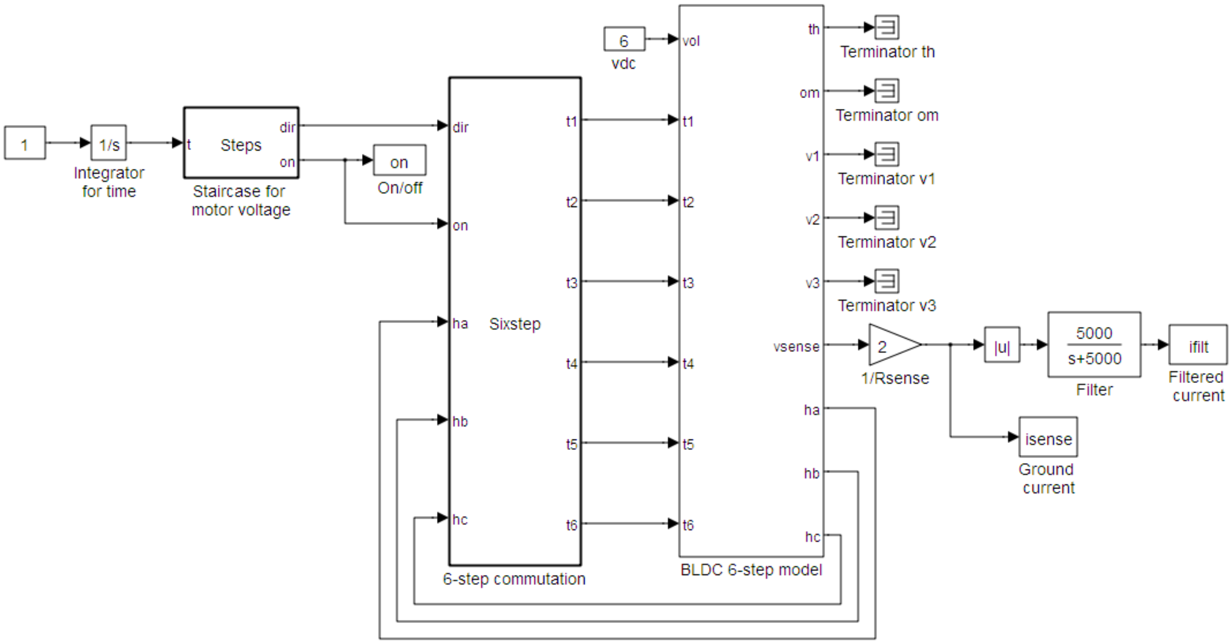

Figure 2: Implementation of six-step commutation

2.3 Current control

Having completed the six-step commutation block, augment the controller to achieve current regulation. A block diagram of a possible implementation is shown in Fig. 3. The sign of the reference current determines the *dir* variable of the six-step commutation block (a positive reference current implies a positive torque command, and a negative reference current implies a negative torque command). The current loop then compares the absolute value of the current reference to the filtered measurement of the ground current (also taken in absolute value). The error drives the on/off switch of the commutation block through a hysteresis controller. This block (Relay) can be found in the Simulink library. Set its parameters so that the *switch on point* is 0.001, the *switch off point* is -0.001, the *output when on* is 1, and the *output when off* is 0. Raise the supply voltage to 12V.

Test the current controller with a reference I_{ref} = 0A, 0.5A, 1A, 0.5A, 0A, -0.5A, -1A, -0.5A (each for 0.01 seconds), and 0A (for 0.03 seconds). Simulate the responses for 0.11 seconds. Plot the velocity and the filtered current as functions of time. Comment on the responses, and explain how a model

$$\frac{\omega(s)}{I_{ref}(s)} = \frac{k}{s}$$

is approximately valid. Give the value of k with its units.

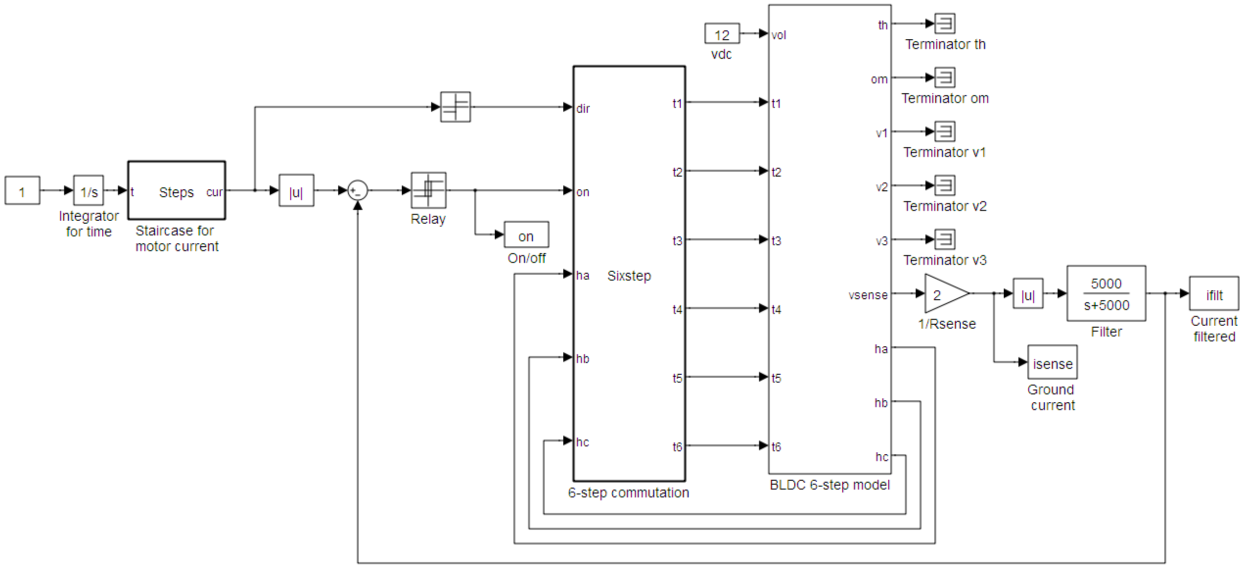

Figure 3: Implementation of current command

2.4 Velocity control

On the basis of the previous results, observe that a proportional control law for the velocity using the reference current as a control input yields a stable first-order system. Compute the gain k_P that results in a system with a time constant equal to 3ms. Implement the proportional velocity control loop in the simulation and test it with a reference velocity equal to 0 rad/s for 0.01 seconds, followed by 40 rad/s, 80 rad/s, 40 rad/s, 0 rad/s, -40 rad/s (each for 0.02 seconds), followed by 0 rad/s (for 0.03 seconds). Run the simulation for 0.14 seconds and plot the velocity and the filtered current as functions of time. Comment on the responses.

<u>Requirements for Full Credit</u>: The list below is a reference for your benefit. Be sure to include comments and explanations for all work performed and results observed/produced.

- Introduction with stated objectives.
- Six-step commutation
    - Plot of velocity and filtered current for varying commands with explanations
    - Plot of velocity and filtered current for fixed commands with explanations
    - Plot of transistor commands, line voltages, and Hall effect sensors with explanations
- Current control
    - Plot of velocity and filtered current for varying current profile with explanations
    - Computation of the constant *k*
- Velocity control
    - Computation of the proportional gain
    - Plot of velocity and filtered current for varying velocity profile with explanations
    - Verification of the closed-loop system response

***Be sure to LABEL the axes of all your plots and to include UNITS on all of your values. Comments should also always accompany any plot.**