Laboratory 2
Simulation of Brushless DC Motor

INTRODUCTION:

This laboratory will demonstrate how to design and simulate the Brushless DC (BLDC) motor operation using Matlab Simulink where a six-step commutation system is used to drive the motor.

OBJECTIVES:

- Identify the difference between back emf profiles of Trapezoidal BLDC machine and a Sinusoidal BLDC machine.
- Design and configure the main components of a BLDC motor drive which uses six-pulse commutation in Matlab Simulink.
- Analyse the simulation results obtained from a Matlab Simulink model.

PRE-LAB:

Reading:

Read and study the Background section of this Laboratory.

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RESOURCES NEEDED:

- Matlab Software

BACKGROUND:

Brushless DC Motors

BLDC motors have become popular alternative for conventional DC motors due to the following issues of conventional DC motors.

- Excessive sparking
- High speed operation increases brush wear and requires regular maintenance
- Cannot operate in explosive and hazard conditions
- High electromagnetic interference (EMI) and audible noise

Unlike conventional motors, in BLDC motors the commutation is done electronically which removes the need for brushes and commutators in the construction. Brushless DC motors are sometimes called as brushless permanent magnet DC motors or permanent magnet synchronous machines (PMSMs) as rotor consist of permanent magnets.

BLDC machines can be classified into two types based on the back emf profile.

1. Trapezoidal BLDC machine
2. Sinusoidal BLDC machine

In order to drive trapezoidal BLDC motors, six-step commutation is commonly used and for sinusoidal BLDC motors, field-oriented control is used. Under this laboratory, a six-step commutation system will be modeled for a trapezoidal BLDC motor.

Six-Step Commutation of Trapezoidal BLDC Motors

Six-step commutation, also known as trapezoidal commutation, is a commutation technique used to control three-phase BLDC motor. It controls the stator currents to achieve a motor speed and direction of rotation. Six-step commutation uses these conduction modes:

- 120^0 mode conducts current in only two stator phases
- 180^0 mode conducts current in all three stator phases

At a given time, 120^0 conduction mode energizes only two stator phases and electrically isolates the third phase from the power supply. Either a Hall or quadrature encoder position sensors are used to detect the rotor position. The BLDC motor drive based on six step commutation uses the Hall sequence or rotor position inputs to determine the 60^0 sector where the rotor is present. Then it generates a switching sequence that energizes the corresponding phases. As the motor rotates, the sequence switches the stator currents every 60^0 such that the torque angle (angle between rotor d-axis and stator magnetic field) remains 90^0 (with a deviation of 30^0). Therefore, the switching signals operate switches to control the stator currents, and therefore, control the motor speed and direction of rotation. Under this lab session, 120^0 mode is used for the model. A schematic diagram of a 120^0 mode six step commutation system for a trapezoidal BLDC motor is shown in figure 1.

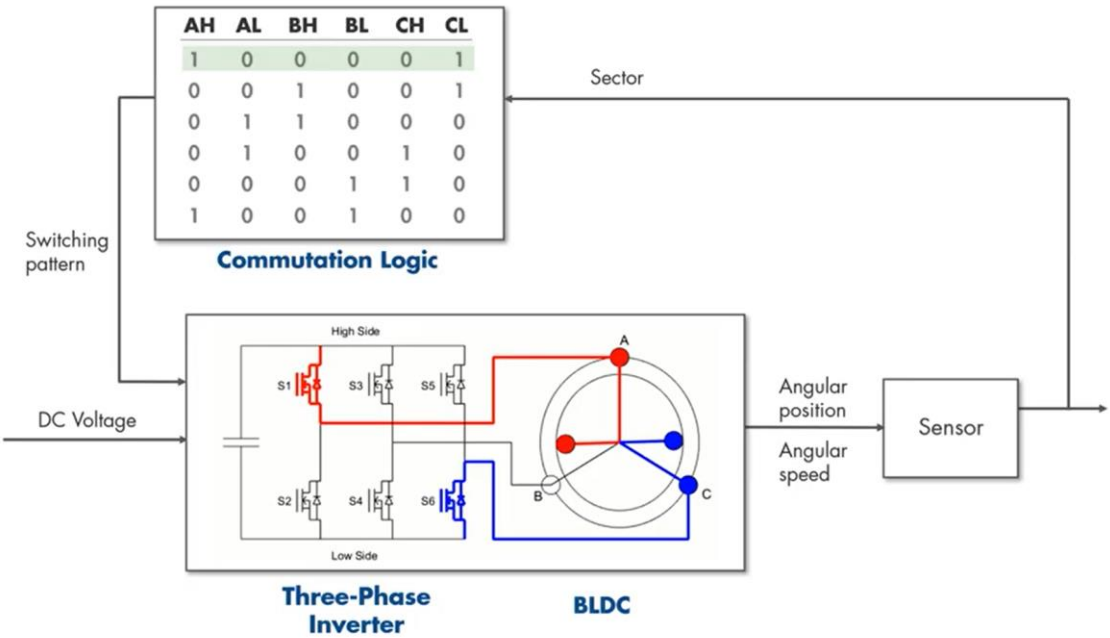

Figure 1: Six-step commutation system for a trapezoidal BLDC motor

PROCEDURE:

Part A: Back EMF profiles of Trapezoidal and Sinusoidal BLDC motors

1. Open Matlab/Simulink interface and create a new model.
2. Insert Brushless DC Motor block and Permanent Magnet Synchronous Motor block to the canvas and configure them using parameters given in table 1.
3. Use an Ideal Angular Velocity Source to apply a constant speed to the motor blocks.
4. Observe the back-emf profiles in the stator windings for input speeds of 100 rpm, 200 rpm and 300 rpm. Run the simulations for 2 se. Use the Backward Euler solver with a sample time of 10^{-3} s.

Table 1: Machine parameters for the motors

Parameter	**Value**
Maximum permanent magnet flux linkage	1.5 Wb
Rotor angle over which back emf is constant (BLDC)	120^0
Number of pole pairs	1
Stator d-axis inductance	6 mH
Stator q-axis inductance	6 mH
Stator resistance per phase	50 mΩ
Rotor inertia	0.02 kgm^2

Part B: Six-step commutation of a trapezoidal BLDC motor

1. Open Matlab/Simulink interface and create a new model.
2. Insert Brushless DC Motor block to the canvas and configure it using parameters given in table 1.
3. Insert an Ideal Rotational Motion Sensor to measure the rotor speed and angular position.
4. Use a 50 V DC voltage source to energize the stator windings.
5. Observe the final rotor angular positions by varying the connection of voltage source between phases as shown in Table 2. Use the Backward Euler solver with a sample time of 10^{-3} s. Run the simulations for 5 s.

Table 2: Rotor angular position for different connections of DC voltage source

Positive connection	Negative connection	Rotor angle (Deg)
Phase a	Phase b	
Phase a	Phase c	
Phase b	Phase c	
Phase b	Phase a	
Phase c	Phase a	
Phase c	Phase b	

6. Propose the commutation logic to drive the BLDC motor in the positive (counter clockwise) direction.
7. Insert a Converter Block and configure it as an inverter with MOSFETS (Threshold voltage = 0.5 V and Drain-source on resistance = 0.002 Ω) to energize the stator.
8. Use a Six-Pulse Gate Multiplexer to drive the 3-phase inverter.
9. Use a Multi-Port Switch and a Matlab Function block to implement the commutation logic proposed in step 6.
10. Inset a load inertia of 0.25 kgm^2.
11. Observe the motor speed, motor torque, input currents and input voltages to the motor. Simulate the model for 0.3 sec. Use the Backward Euler solver with a sample time of 10^{-6} s.
12. Use the m-file (animate.m) provided to visually see the motor operation.

RESULTS:

1. Plot the back emf profiles observed in part A.
2. Tabulate the commutation logics to drive BLDC motor in counter clock wise and clock wise directions.
3. Plot the variation of motor speed, motor torque, motor input line currents and motor input line to line voltages for DC voltages of 50 V, 100 V and 150 V.

DISCUSSION:

1. Comment on the results you obtained.
2. Explain how you can develop the final model to control the speed of the BLDC motor.