ECE 411 – Introduction to Electric Drives – Fall 2023

Due Date: Monday., Oct. 9 Name:________________________

Required Homework #1-2

Lec. 1-5 through 1-8: DC Machine Operating Envelopes, Dynamics, and Brushless DC Concepts

Note: Please fill in the answers on these sheets to simplify grading but attach separate sheets that include all calculations, graphs and code used to complete your homework so that the grader can assign partial credit when appropriate.

DC Machine Operating Envelopes

1) Consider a 30hp, 2500rpm DC machine connected to an adjustable DC power supply, the specifications of which will be given below. Solve using data from the DC machines datasheet, using the "hot resistance" value for all calculations. Assume that the maximum armature current is determined by the supply limit rather than the rated machine current based on its rated power. Similarly, assume that the maximum applied armature voltage amplitude is determined by the maximum supply output voltage rather than the rated machine voltage.

   a) Assume the DC supply can output between -100 V and +100 V at between 0 A and +25 A. Plot the complete boundary envelope (i.e., capability curve) of the drive system's torque-speed operating capabilities on a set of T - ω axes, with torque T on the y-axis [in N-m] and speed ω on the x-axis [in rad/s]. Assume that the field flux is constant at its rated (100%) value. What are the torque, speed, <u>machine shaft power</u> P_{mech}, and supply voltage V_s (which equals the armature voltage V_a) at the four corners of the operating envelope? (Hint: Do not be surprised if P does not equal the rated machine power (30hp=22.380kW). (10 points):

Upper left	T = _______ N-m	ω = _______ rad/s	P_{mech} = ____ kW	V_s = ________ V
Upper right	T = _______ N-m	ω = _______ rad/s	P_{mech} = ____ kW	V_s = ________ V
Lower left	T = _______ N-m	ω = _______ rad/s	P_{mech} = ____ kW	V_s = ________ V
Lower right	T = _______ N-m	ω = _______ rad/s	P_{mech} = ____ kW	V_s = ________ V

   b) Assume the DC supply can now output between -100 V and +100 V at between -25 A and +25 A. Plot the complete operating envelope (i.e., capability curve) of the drive system's torque-speed operating capabilities on a set of T - ω axes, assuming that the field flux is still constant at its rated value. What are the torque, speed, <u>machine shaft power</u> P_{mech}, and supply voltage V_s at the four corners of the operating envelope? (10 points):

Upper left	T = ________ N-m	ω = ________ rad/s	P_{mech} = ____ kW	V_s = ________ V
Upper right	T = ________ N-m	ω = ________ rad/s	P_{mech}= ____ kW	V_s = ________ V
Lower left	T = ________ N-m	ω = ________ rad/s	P_{mech}= ____ kW	V_s = ________ V
Lower right	T = ________ N-m	ω = ________ rad/s	P_{mech} = ____ kW	V_s = ________ V

   c) Replot the operating envelope in part b) with the same supply specifications but now assuming the field can be weakened. Note the machine constant K is proportional to the field flux, and the value on the datasheet is for rated (100%) flux. Assume the machine can operate no faster than 3500rpm in either direction (i.e., ± 3500rpm). What is the maximum value of torque that can be achieved at the extremes of +3500rpm and -3500rpm, and what are the corresponding values of <u>machine output power</u> P_{out}, machine constant K, and supply voltage V_s? (10 points)

   Hint: what is considered output power for motoring vs. generating scenarios?

ω = +3500rpm

Positive torque	T = ________ N-m	K = ________ N-m/A	P_{out} = ______ kW	V_s = ________ V
Negative torque	T = ________ N-m	K = ________ N-m/A	P_{out}= _______ kW	V_s = ________ V

ω = -3500rpm

Positive torque	T = ________ N-m	K = ________ N-m/A	P_{out}= _______ kW	V_s = ________ V
Negative torque	T = ________ N-m	K = ________ N-m/A	P_{out}= _______ kW	V_s = ________ V

DC Machine Dynamics

2) Calculate the following for two 20hp DC machines, one rated at 3500rpm and the other rated at 500rpm. Use data from the DC machines datasheet on the course website, including "hot" armature resistance value for all calculations. Note the machine constant K is proportional to the field flux, and the value on the datasheet is for rated (100%) flux. Both the load moment of inertia J_L and the viscous friction coefficient B are zero unless stated otherwise. Do not neglect the machine inertia J_m.

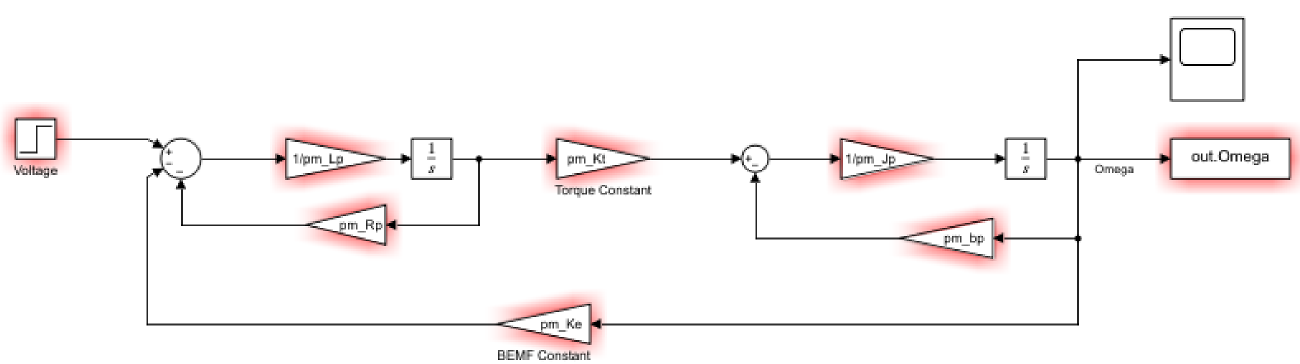
a) Calculate the eigenvalues p_1 and p_2 (real or complex) for operation at rated flux and at 50% of rated flux. (8 points):

		3500rpm Machine		*500rpm Machine*
Rated (100%) Flux	p_1 =	______________ 1/sec	p_1 =	______________ 1/sec
	p_2 =	______________ 1/sec	p_2 =	______________ 1/sec
50% of Rated Flux	p_1 =	______________ 1/sec	p_1 =	______________ 1/sec
	p_2 =	______________ 1/sec	p_2 =	______________ 1/sec

DC Machine Dynamics using MATLAB/Simulink

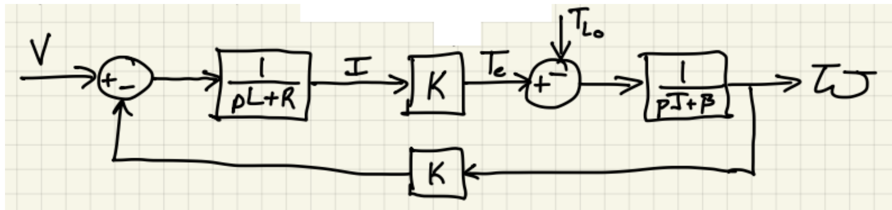
This next section takes the 20hp 500rpm machine and simulates the time dynamics, thus providing an introduction to MATLAB/Simulink for modelling electric machines and drives.

3) Build the block diagram below of an unloaded DC machine in Simulink. Save the filename as "HW_02_DC_Machine_Sim.slx" (4 points)



Description:
We are exciting the DC machine armature terminals with a step in voltage and evaluating what the resultant speed of the machine is.

ECE 411 – Introduction to Electric Drives – Fall 2023



Helpful tips:

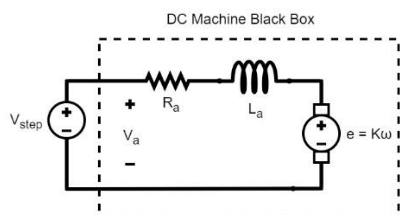
- The variable names (e.g., pm_Lp, pm_Rp) you choose **must** be consistent with what you defined in your MATLAB script… shown later.
- Please see the Appendix on where to find the blocks and how to populate the block with the correct parameters.
- If you see red highlights around your gain and unit step blocks, that's ok. It is because these variables have not been defined yet. When you run the corresponding MATLAB script, the variables will be defined, and these red error highlights will go away.

4) Open the test script "HW_02_DC_Machine_ScriptRunner.m."
   a) Replace the eigenvalues with what you got in part 2a for the 20hp 500 rpm machine:

```
%%%%%%%%%%%% TODO: REPLACE EIGENVALUES HERE %%%%%%%%%%%%%%
p1_fullFlux = -5 + 5*1i;      % Eigenvalues for DC machine at 100% rated flux
p2_fullFlux = -5 - 5*1i;
p1_halfFlux = -10 + 10*1i;    % Eigenvalues for DC machine at 50% rated flux
p2_halfFlux = -10 - 10*1i;
%%%%%%%% END TODO: REPLACE EIGENVALUES HERE %%%%%%%%%%%%%%
```

   b) Run the script.

The test script runs two cases of the DC machine: (i) nominal operating conditions and (ii) field weakening with 50% rated flux.



The purpose is to demonstrate how field weakening can affect DC machine transients.

Full description of machine parameters:

```
% Based off a 20hp, 500 rpm DC machine
Kp_run01 = 4.35;            % machine constant
                            %   (100% rated flux)
Kp_run02 = 0.5*Kp_run01;    % field-weakened machine constant
                            %   (50% rated flux)
pm_Rp = 1.2*0.168;          % [Ohms] Hot resistance
pm_Lp = 0.013;            % [H] DC machine inductance
pm_Jp = 1.34*1.355;        % [kg*m^2] Moment of inertia
pm_bp = 1e-4;       % [N*m/(rad/s)] Damping coefficient
pm_Ke = Kp_run01;   % [V/(rad/s)] machine constant (BEMF)
pm_Kt = Kp_run01;   % [N*m/A] machine constant (torque)
```

ECE 411 – Introduction to Electric Drives – Fall 2023

The machine is excited with a 5V voltage step.

If you built the Simulink block diagram correctly and named the file properly, the script should run without further modification.

5) Screenshot the plot of the time domain waveforms involving speed here. (6 points)

6) Screenshot the plot of your DC machine eigenvalues here. (2 points)

7) For both scenarios, demonstrate how the time domain waveforms give the same information as the complex plane plot of the eigenvalues of the DC Machine in terms of **overshoot.** (16 points)

8) Using both the plot of eigenvalues and time domain waveforms, choose one metric (e.g., natural frequency, overshoot) and describe how the speed response compares between the two operating cases of the DC machine. (4 points)

ECE 411 – Introduction to Electric Drives – Fall 2023

Brushless DC Machine Concepts

9) Name three advantages and two disadvantages of using a brushless DC machine instead of a brushed DC machine. Attach your answer on a separate sheet. (10 points):

10) Why does a brushless DC machine have a trapezoidal back-emf? Explain using physical concepts how it is implemented in the internal construction of the machine. Write your answer using words and diagrams on a separate sheet. Note: you do not need to mathematically model how the construction gives rise to the trapezoidal emf waveform. (10 points):

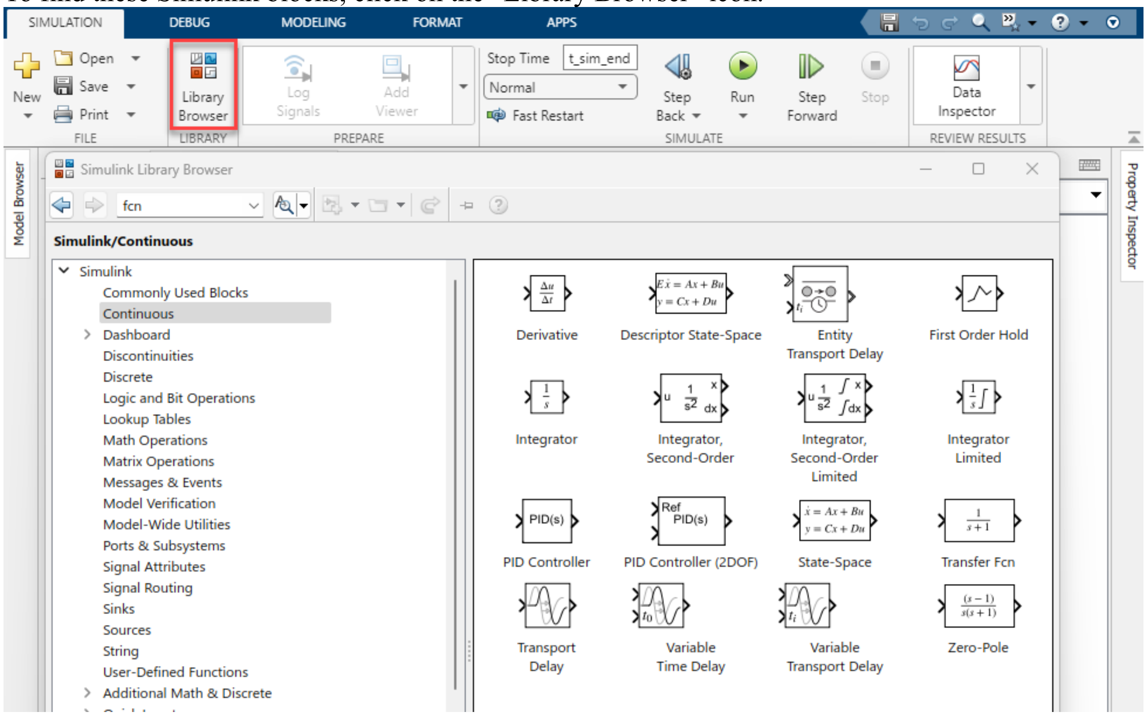
11) On the right-hand column of the table, indicate whether the description applies to a brushed DC machine (BDC), a brushless DC machine (BLDC), neither, or both. Assume that the machine is operating as a motor (10 points).

Externally supplied current is AC	
Externally supplied current is DC	
Externally supplied voltage is AC	
Externally supplied voltage is DC	
Electrical to mechanical energy converter	
Field is stationary	
Field spins	
Can use permanent magnets	
Requires electronic commutator	

ECE 411 – Introduction to Electric Drives – Fall 2023

Appendix for Hints

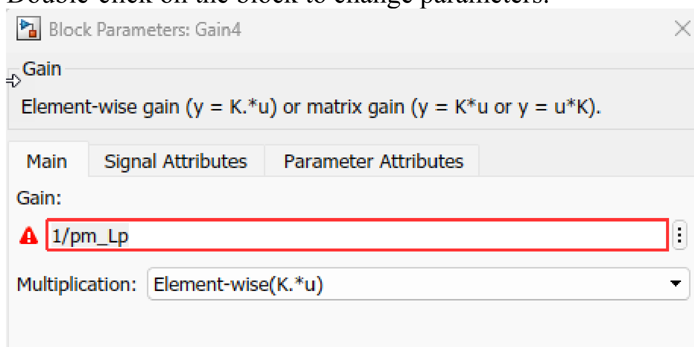
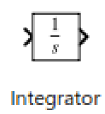
To find these Simulink blocks, click on the "Library Browser" icon.

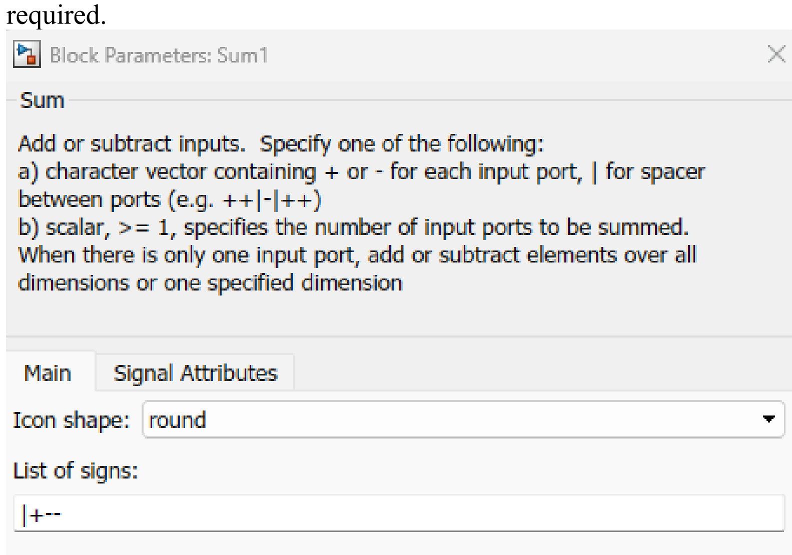


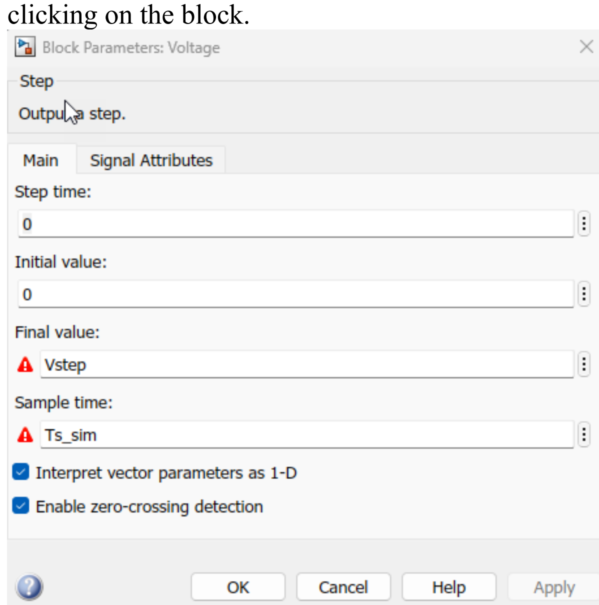
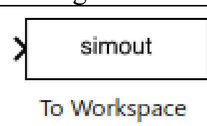
Description of blocks used:

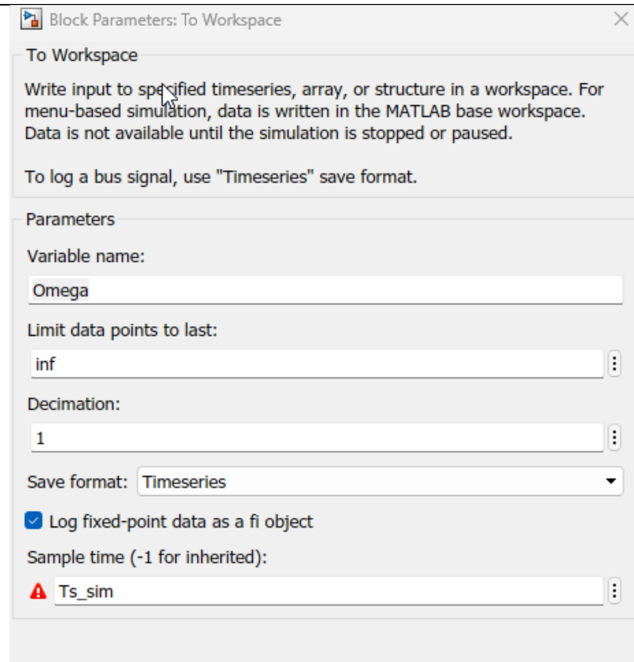
<table>
<tr><th>Name</th><th>Location</th><th>Description</th></tr>
<tr><td>Gain</td><td>Commonly Used Blocks</td><td>Looks like a triangle.


Represents multiplication by a constant.

Double-click on the block to change parameters.

</td></tr>
<tr><td>Integrator</td><td>Continuous</td><td>Represents the 1/s Laplace term

</td></tr>
<tr><td>Sum</td><td>Commonly Used Blocks</td><td>

Double-click on the block to change how many input terminals are required.

</td></tr>
</table>

		Or put successive sum blocks to get the proper addition and subtraction.
Step	Sources	Represents a step function.  Change the step height and time at which the step occurs by double clicking on the block. 
Scope	Sinks	 Plots a selected Simulink signal/waveform. Double click on the scope after running the model to view said waveform.
To workspace	Sinks	 Takes a certain Simulink signal/waveform to MATLAB workspace for post-processing Double-click on the block and change to match these parameters.

		Block Parameters: To Workspace To Workspace Write input to specified timeseries, array, or structure in a workspace. For menu-based simulation, data is written in the MATLAB base workspace. Data is not available until the simulation is stopped or paused. To log a bus signal, use "Timeseries" save format. Parameters Variable name: Omega Limit data points to last: inf Decimation: 1 Save format: Timeseries Log fixed-point data as a fi object Sample time (-1 for inherited): Ts_sim