MSE 312: MECHATRONICS DESIGN II

Electronics/Control Lab 1
Introduction to Simscape Electrical

OBJECTIVES
Become familiar with Simscape Electrical by constructing a DC Motor and a circuit to drive it.

PREREQUISITES
- Matlab/Simulink 2020a or later
  - Other versions may require some modifications or have different results
- Simscape Electrical

REFERENCES
https://www.mathworks.com/help/physmod/sps/ug/example-modeling-a-dc-motor.html
- (Accessed 2020-05-22)
- Title: "DC Motor Model"

ACKNOWLEDGEMENTS
Part B of this tutorial is nearly identical to the referenced MathWorks tutorial (see https://www.mathworks.com/help/physmod/sps/ug/example-modeling-a-dc-motor.html).

PREAMBLE
Simscape is a useful tool for analyzing the design of physical, real-time systems. Simscape Electrical is useful for modeling the electric circuit components within a system. Feel free to search the MATLAB documentation and online videos for other useful tutorials.

PART A: IMPORTANT SIMSCAPE ELECTRICAL BLOCKS
The following tables briefly summarize the types of blocks in Simscape Electrical that can be found in the Library Browser (see Simulation tab):

Table 1: Summary of the most basic Simscape Electrical Blocks

Category	Summary
Simscape → Foundational Library → Electrical	• Electrical elements (ex. Capacitor, Diode, Electrical Reference, Resistor, Rotational Electromechanical Converter, …) • Electrical Sensors (ex. Current Sensor, Voltage Sensor) • Electrical Sources (contains various current and voltage sources)

Table 2: Summary of all Simscape Electrical blocks located in Simscape/Electrical. Some advanced blocks may be left out.

Category	Summary
Connectors and References	• Contains special electrical circuit connection types (ex. busbar, open circuit, phase splitter) • Electrical reference ("ground") block
Control	• Contains many pre-defined control circuits • General control blocks (ex. Low-pass filter, PI controller) • Certain mathematical transforms (ex. Clarke transform) • Measurements (ex. Harmonic distortion) • Observers (ex. Quadrature Shaft Decoder) • Pulse Width Modulation (ex. PWM Generator)
Electromechanical	• Asynchronous (ex. Simplified Induction Motor) • Brushed Motors (ex. DC Motor) • Mechanical (ex. Machine Inertia) • Mechatronic Actuators (ex. Solenoid) • Permanent Magnet (ex. Simplified PMSM Drive) • Reluctance & Stepper (ex. Stepper Motor, Switched Reluctance Machine) • Synchronous (ex. Synchronous Machine Model 2.1)
Integrated Circuits	• Logic (contains binary logic gates, S-R Latch, and Schmitt Trigger) • Various Op-Amps, Comparator, Multiplier, Operational Transconductance Amplifier • Controlled PWM Voltage • Push-Pull Output • Timer • Voltage-Controlled Oscillator
Passive	• Lines (ex. Transmission Line) • RLC Assemblies (ex. Delta-Connected Load, RLC (Three-Phase)) • Thermal (ex. Thermal Resistor) • Transformers (ex. Nonlinear Transformer, Mutual Inductor) • Capacitor, Inductor, Resistor, Winding • Also contains more advanced passive components

Semiconductors & Converters	• Converters (ex. Buck-Boost Converter, DC-DC Converter, H-Bridge, Rectifier (Three-Phase), …) • Current Limiter, Diode • Gate Driver, IGBT (Ideal, Switching), MOSFET (Ideal, Switching) • NPN Bipolar Transistor, PNP Bipolar Transistor • Optocoupler, Thyristor • Several others
Sensors & Transducers	• Accelerometer, Gyro • Current Sensor, Voltage Sensor, Power Sensor, Proximity Sensor • Incremental Shaft Encoder • Inductive Rotor Position Sensor • Photodiode, Resolver, Thermistor • Various others
Sources	• Current Source, Voltage Source • Positive Supply Rail, Negative Supply Rail • Various others
Switches & Breakers	• Relays, Circuit Breaker, Fuse • Various types of special switches (ex. DPDT Switch)
Utilities	• **Environment Parameters** o Controls the temperature and “GMIN” value of the Simscape Electrical components that are compatible with SPICE. • Fault • Fault (Three-Phase)
Additional Components	• SPICE Passives (ex. Current-Controlled Switch, SPICE Resistor, Voltage-Controlled Switch) • SPICE Semiconductors (ex. SPICE Diode, SPICE NPN, SPICE PNP, …) • SPICE Sources (ex. DC Current Source, DC Voltage Source, Pulse Current Source, Pulse Voltage Source, …)

Specialized Power Systems	NOTE: The "**powergui**" block may need be placed somewhere in the model for any of these blocks to work.
	• Fundamental Blocks
	  o Required Block: **powergui**
	  o Electrical Sources (ex. AC Voltage Source)
	  o Elements (ex. Connection Port, Ground, Linear Transformer, Parallel RLC LOAD, Series RLC Load)
	  o Interface Elements (ex. Current-Voltage Simscape Interface)
	  o Machines (ex. Excitation System, Permanent Magnet Synchronous Machine, Stepper Motor, …)
	  o Measurements (ex. Current Measurement, Voltage Measurement,
	  o Power Electronics (contains various pulse & signal generators, converters, switches, MOSFETs, …)
	• Control & Measurements
	  o Additional components (ex. Discrete Variable Time Delay, Discrete Shift Register, Sample and Hold)
	  o Filters (ex. First-Order Filter)
	  o Logic (ex. Edge Detector Off Delay, On Delay, …)
	  o Measurements (ex. Fourier, Mean, …)
	  o PLL ("Phase-Locked Loop")
	  o Pulse & Signal Generators (various PWM generators, sawtooth generator, …)
	  o Transformations
	• Electric Drives
	  o AC drives (ex. Brushless DC Motor Drive, …)
	  o DC drives (ex. Four-Quadrant Chopper DC Drive, …)
	  o Extra Sources (ex. Battery, Fuel Cell Stack, …)
	  o Fundamental Drive Blocks (ex. Active Rectifier, Direct Torque Controller, …)
	  o Shafts and speed reducers (ex. Mechanical Shaft, Speed Reducer)
	• FACTS
	• Renewables

Several other important blocks are used in this tutorial, which are part of Simscape or Simulink:

Table 3: Relevant blocks for this tutorial outside of Simscape Electrical.

Block Name	Function
Simulink-PS Converter **PS-Simulink Converter**	Convert between Simulink and Simscape (PS, or physical signal) domain
Solver Configuration	Connect this to any part of the model to define certain solver configuration parameters (Access related settings via Ctrl + E)
Mechanical Rotational Reference	Reference for rotational mechanical systems
Ideal Rotational Motion Sensor	Measures angle and angular velocity
Scope	Standard tool in Simulink for plotting data

PART B: CREATING A SIMPLE DC MOTOR MODEL

In this section, a simple DC motor will be created using MATLAB 2020a, Simscape, and Simulink:

1. In the MATLAB command terminal, type `ssc_new('DC_motor_model','electrical')`
2. In Simscape, delete the Spectrum Analyzer and the Simulink-PS Converter.
3. Replicate the following screenshot. Add the blocks by double clicking and typing the name of each block. Feel free to rotate and flip each block using Ctrl + R and Ctrl + I:

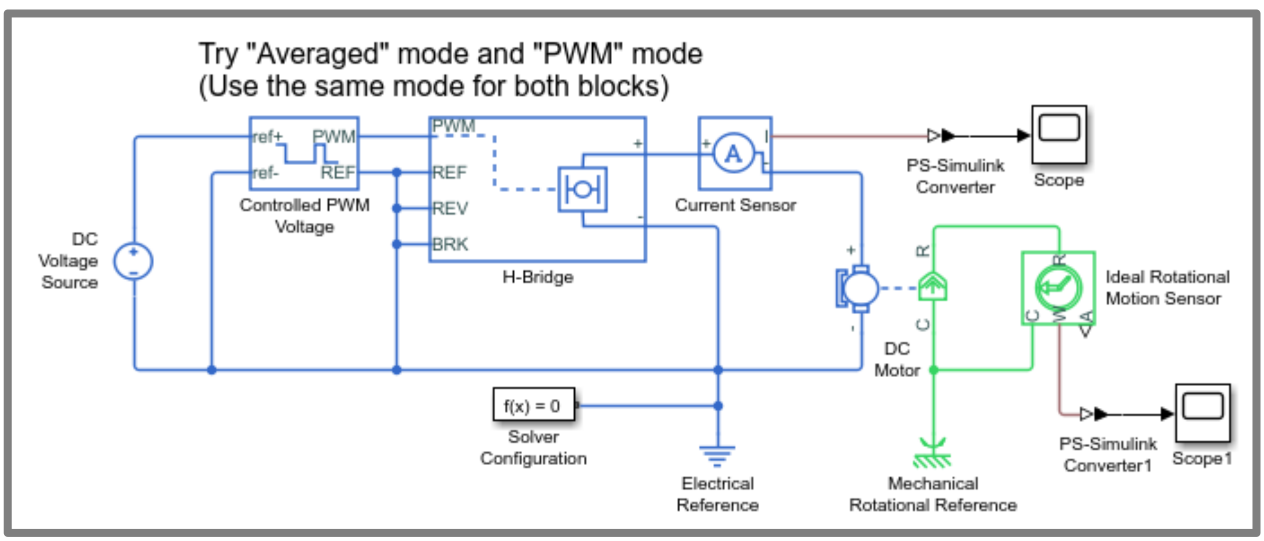

Figure 1: Overall DC Motor Model Layout

4. Set the following parameters:

Table 4: Block Settings

Block	**Settings to Change**
DC Voltage Source	• Constant Voltage: **2.5 V** • Rename the block to "**PWM Reference Voltage**"
Controlled PWM Voltage	• PWM Frequency: **4000 Hz** • Simulation Mode: **Averaged**
H-Bridge	• Simulation Mode: **Averaged**

DC Motor	Electrical Torque:
	• Option 1: Model Parameterization: **By rated load and speed**
	  o Armature Inductance: **0.01 H**
	  o No-load speed: **4000 rpm**
	  o Rated speed (at rated load): **2500 rpm**
	  o Rated load (mechanical power): **10 W**
	  o Rated DC supply voltage: **12 V**
	• Option 2: Model Parameterization: **By equivalent circuit parameters**
	  o Armature resistance: **Ra in Ohms from datasheet**
	  o Armature inductance: **La in Henry from datasheet**
	  o Define back-emf or torque constant: **Specify back-emf constant**
	  o Back-emf constant: **Kb in V/(rad/s) from datasheet**
	  o Rotor damping parameterization: **By damping value**
	
	Mechanical:
	• Rotor inertia: **2000 g*cm^2**
	• Rotor damping: **1e-06 N*m/(rad/s)**

PS-Simulink Converters	Change the units to **A** for the current sensor output and **rpm** for the ideal rotational motion sensor output
Scope blocks	Rename them to "**Current**" and "**RPM**"

5. Configure the solver parameters (Ctrl + E):

Category (Referencing the Left Tabs)	**Values**
Solver	• Solver: **ode15s (Stiff/NDF)** • Max step size: **1**

6. Run the simulation in both "Averaged" and "PWM" modes to get the following plots:

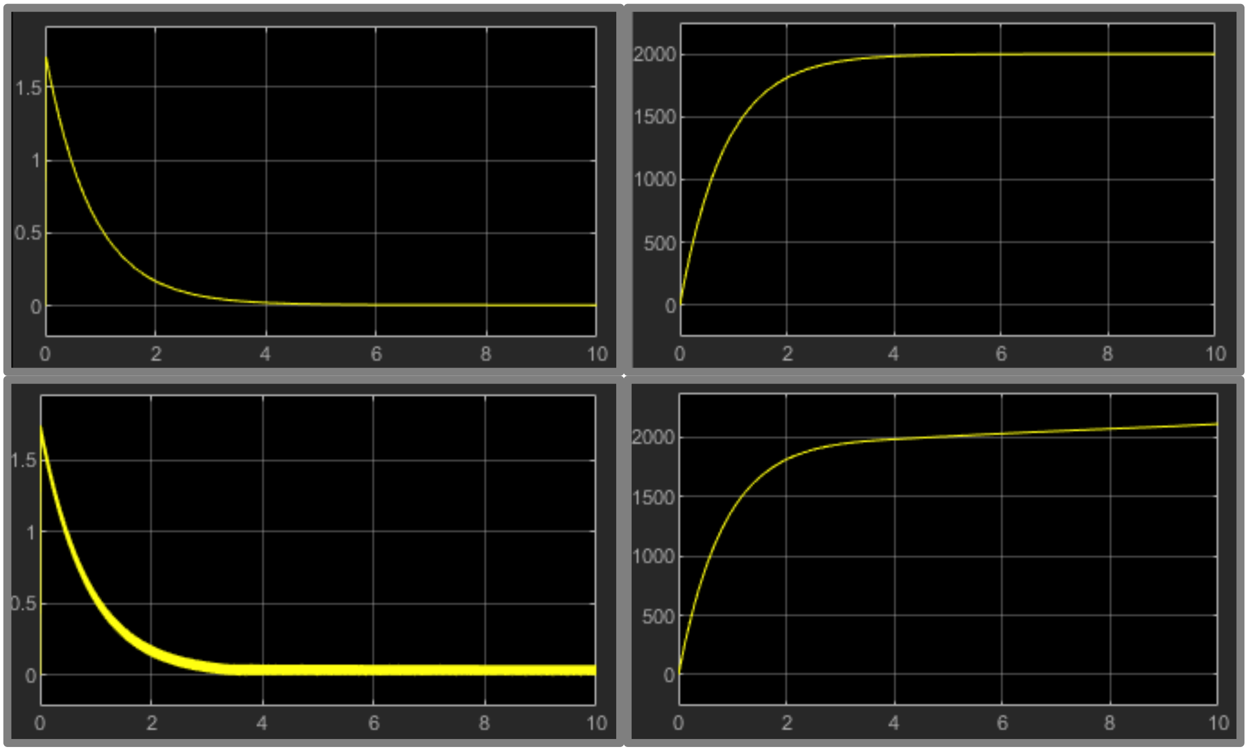

Figure 2: Correct plots for each simulation mode. (Left) Current vs Time. (Right) RPM vs Time. (Top) Averaged mode. (Bottom) PWM Mode. Note that the grey borders are added for aesthetic purposes.

PART C: EXPLAINING THE PURPOSE OF EACH DC MOTOR MODEL COMPONENT

The main role of each component (excluding the most obvious) in part B of this tutorial is summarized below:

Table 5: Main role of each Simscape block used in Part B (excl. the obvious)

Block or Component	**Main Role**
DC Motor	Cause rotational motion based on electrical energy
H-Bridge	Drives the DC motor
Controlled PWM Voltage	Generates a PWM signal based on a reference voltage
Electrical and Mechanical Rotational References	Required (prevents Simscape errors)
Solver Configuration	Must be connected to the Simscape diagram at some location (prevents Simscape errors and configures aspects of solver).

ACTIVITY FOR LAB 1:

Based on the datasheet of a DC motor (e.g., GM8224S009 motor) and an H-bridge chip (e.g., TB6568KQ MOSFET H-bridge), build a Simulink/SimScape model for open-loop simulation of a DC motor driven through a PWM circuit. Please consider the following:

- The simulation should allow operating the DC motor based on a *command voltage* that is within the range -*Vm* to *Vm*, where *Vm* is the supply voltage of the H-bridge. At a later stage of your project, this command signal will be coming from your controller output.
- The simulation should allow rotating the motor in both directions.
- The *command voltage* is to be converted to a sign command and a positive value between 0 and 1 (PWM duty cycle) sent to the H-bridge.
- In the SimScape model of a DC motor, you can use simulation parameters based on either *equivalent circuit* (option 1) or *rated load and speed* (option 2) models.
- The simulation should include power measurements (e.g., voltage and current of the DC motor). Find appropriate blocks in SimScape and include them in the simulation blocks.
- Obtain power dissipation of the bridge under different conditions and design an appropriate heat sink.
- The simulation must include a gear to change the speed/torque provided of the motor.

Observe and record the performance of the circuit by changing different motor and bridge circuit characteristics such as rotor inertia, damping, bridge resistance, PWM frequency, *Vm*, parametrization options 1 and/or 2 for motor model, …

Deliverable: Each group must provide a demo of how they have implemented the system during lab hours. Please check canvas for schedule.

Note: Start writing your lab report at this stage. The results and observations made during this lab should be included in your lab report.