LAB 3: Dynamic Systems Modeling in Simscape

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Section No.	0NA
Group No.	N/A
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Student Name	Signature*	Total Mark
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LAB 3 Grading Sheet

Student First Name: Michael	**Student Last Name:** McCorkell
Part A.1: Build the Model, Set the Component Parameters & Run the Simulation	5 **/5**
Part A.2: Current Circulation in the Active Phase & Freewheel Phase	10 **/10**
Part A.3: Effect of the Duty-Cycle on the Motor Voltage & Motor Speed	10 **/10**
Part A.4: Effect of the Rotor Inertia and Armature Inductance on the Motor Speed	10 **/10**
Post Lab Assignment	8.5 **/10**
General Formatting: Clarity, Writing style, Grammar, Spelling, Layout of the report	5 **/5**
Total Mark	48.5 **/50**

LAB 3: Dynamic Systems Modeling in Simscape

OBJECTIVES

- To model and simulate a buck converter system in Simscape to speed control of a DC motor.
- To understand the circulation of the current in the circuit in active phase and in freewheel phase.
- To visualize and evaluate the effect of the duty cycle, switching frequency and the inductance value on the current, voltage and speed of DC motor.

Simpscape Model of DC Motor Control by Buck Converter

Introduction

A **Buck Converter** is a DC-to-DC power converter, which steps down voltage from its input (source) to output (load). It typically contains two semiconductor switches, a **diode**, and a **transistor**, to control the direction of the current in the circuit. Buck converters enable us to obtain an adjustable DC voltage from a fixed DC voltage, which is particularly used to **speed control** of **DC motors**. Figure 1 shows a typical configuration of a simple buck converter.

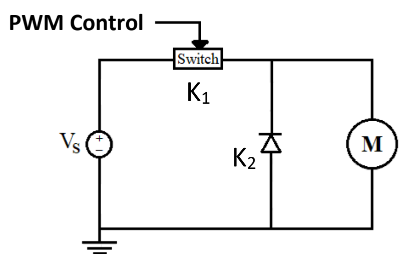
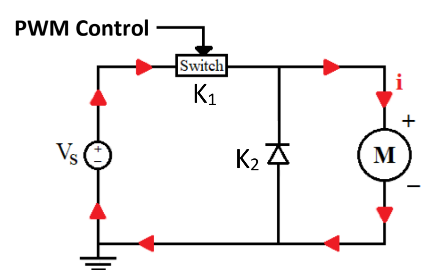


Figure 1: Typical Buck Converter

V_s is a fixed **DC voltage source**. **M** is a **brushed DC motor**. Switch **K_1** is a **power transistor** which can be turned ON and OFF by a PWM control signal. Switch **K_2** is a **diode**, which is called flyback or freewheeling diode.

A PWM controlled buck converter has two phases of operation: **Active phase** and **Freewheel phase**.

In the **active phase**, switch K_1 is **ON**, and K_2 is **OFF**.



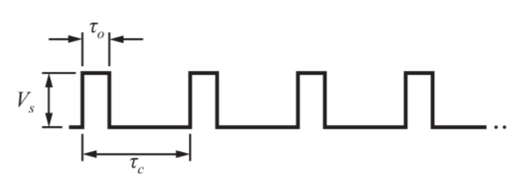
- The current that passes through the motor is identical to that passes through the supply.
- The current in the diode branch is zero.
- The high frequency PWM signal turns ON and OFF the K_1 switch at a fast rate, which allows us to adjust the average or effective value of the applied voltage to the DC motor.
- The average voltage depends on the duty cycle of the PWM signal.
- Duty cycle is the amount of time the PWM signal is ON versus the amount of time the signal is OFF in a single period.

$$\text{Duty} - \text{cycle} = \frac{\tau_o}{\tau_c}$$

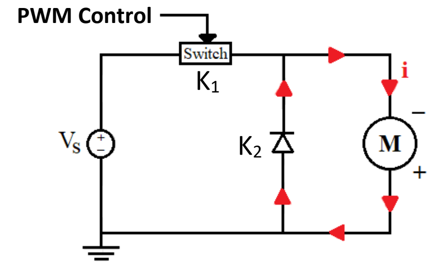
- The effective applied voltage V_e is determined as:

$$V_e = V_s \frac{\tau_o}{\tau_c}$$

which increases by increasing the duty-cycle of the PWM signal.



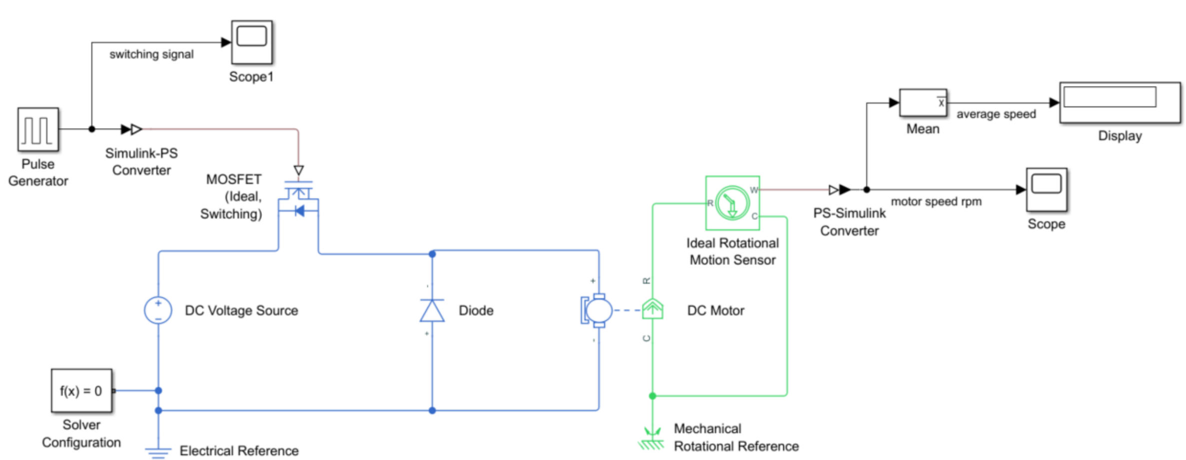
In the **freewheel phase**, switch K_1 is **OFF**, and K_2 is **ON**.



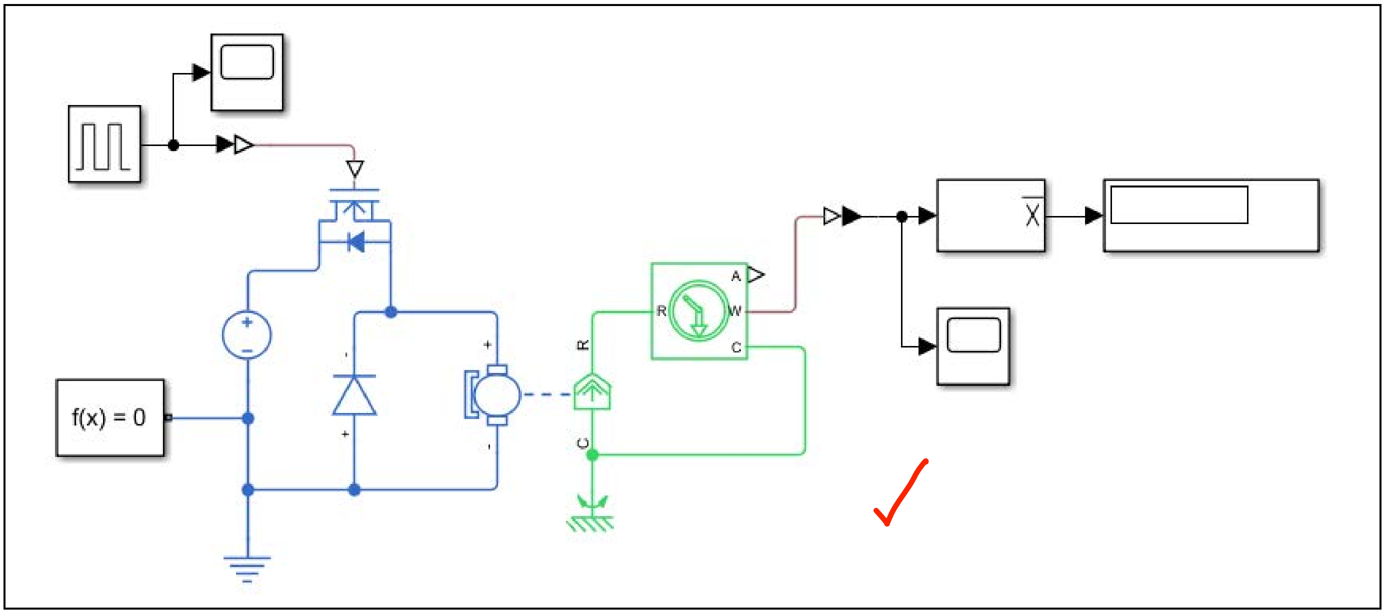
- The current that passes through the motor is identical to that passes through the diode branch.
- The current in the supply is zero.
- Turning OFF the switch K_1 does not immediately stop current in the motor windings.
- The inductive behavior of the DC motor causes current to continue to flow when the switch K_1 is opened suddenly.
- Adding a flyback diode in parallel with the motor provides a path for dissipation of stored energy when the switch K_1 is OFF.

A.1. Build the Model, Set the Component Parameters & Run the Simulation

1. Open a new **Simulink** model page. Find and place the following elements and components from the **Simulink Library Browser**.
   - **Simscape > Foundation Library > Electrical > Electrical Elements > Diode**
   - **Simscape > Foundation Library > Electrical > Electrical Elements > Electrical Reference**
   - **Simscape > Foundation Library > Electrical > Electrical Sources > DC Voltage Source**
   - **Simscape > Foundation Library > Mechanical > Rotational Elements > Mechanical Rotational Reference**
   - **Simscape > Foundation Library > Mechanical > Mechanical Sensors > Ideal Rotational Motion Sensor**
   - **Simscape > Electrical > Semiconductors & Converters > MOSFET (Ideal Switching)**
   - **Simscape > Electrical > Electromechanical > Brushed Motors > DC Motor**
   - **Simscape > Electrical > Specialized Power Systems > Sensors and Measurements > Mean**
   - **Simscape > Utilities > PS-Simulink Converter**
   - **Simscape > Utilities > Simulink-PS Converter**
   - **Simscape > Utilities > Solver Configuration**
   - **Simulink > Sinks > Scope**
   - **Simulink > Sinks > Display**
   - **Simulink > Sources > Pulse Generator**
2. Arrange and connect the blocks as shown below. The model involves the **electrical field** and the **mechanical rotational field**:



3. Provide your final **Simscape** model diagram below:



4. Open the **Block Parameters** by *double-clicking* on the appropriate block. Enter the following values for each component:

   a) Pulse Generator:
   Amplitude = 1, Period = 0.001 sec, Pulse Width = 50 percent, Phase delay = 0 second

   b) DC Voltage Source:
   Constant Voltage = 24 V

   c) MOSFET (Ideal Switch):
   Drain-source on resistance = 0.01 Ohm, Off-state conductance = 1e-6 1/Ohm, Threshold voltage = 0.5 V

   d) Diode:
   Forward voltage = 0.1 V, On resistance = 0.1 Ohm, Off conductance = 1e-8 1/Ohm

   e) DC Motor:
   Armature resistance = 20 Ohm, Armature inductance = 100 mH, Back-emf constant = 9e-4 V/rpm
   Rotor inertia = 0.5 g.cm^2, Rotor damping = 0.001 Nm/(rad/s), Initial rotor speed = 0 rpm

   f) Mean:
   Fundamental frequency = 1000 Hz

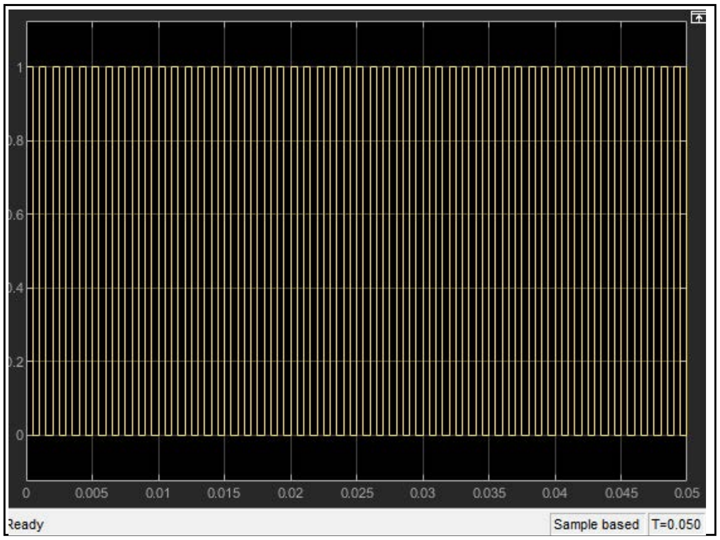
   g) Motion Sensor:
   Deselect the **Position** and **Acceleration** outputs.

   h) PS-Simulink Converter:
   Set the **Output signal unit** to **rpm**.

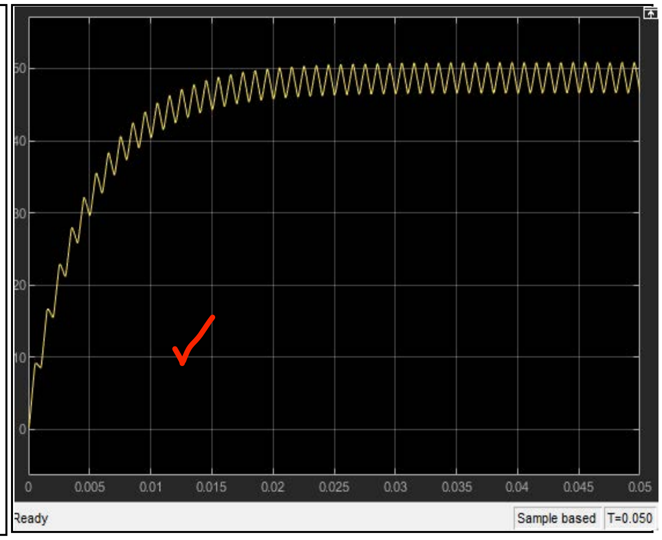
5. Click on the **Model Settings** icon in the **MODELING** tab to open the **Configuration Parameters** window. Click on the **Solver** drop down menu and select the **ode23t** solver. Then click **OK**.

6. **Save** the model file as **Lab3_PartA.slx**. Set the simulation **Stop Time** to **0.05sec** and **Run** the simulation. Open the **Scope** blocks. You will see the **switching signal** with the frequency of **1kHz** and the **rotational speed of the DC motor** in **rpm**. Provide the graphs below:

Switching PWM Signal



DC Motor Speed (rpm)



7. Since the PWM switching frequency is _very fast_ and the load inertia is _very low_, the commutation frequency causes _ripple_ in the motor speed. What is the **average final speed** of the motor?

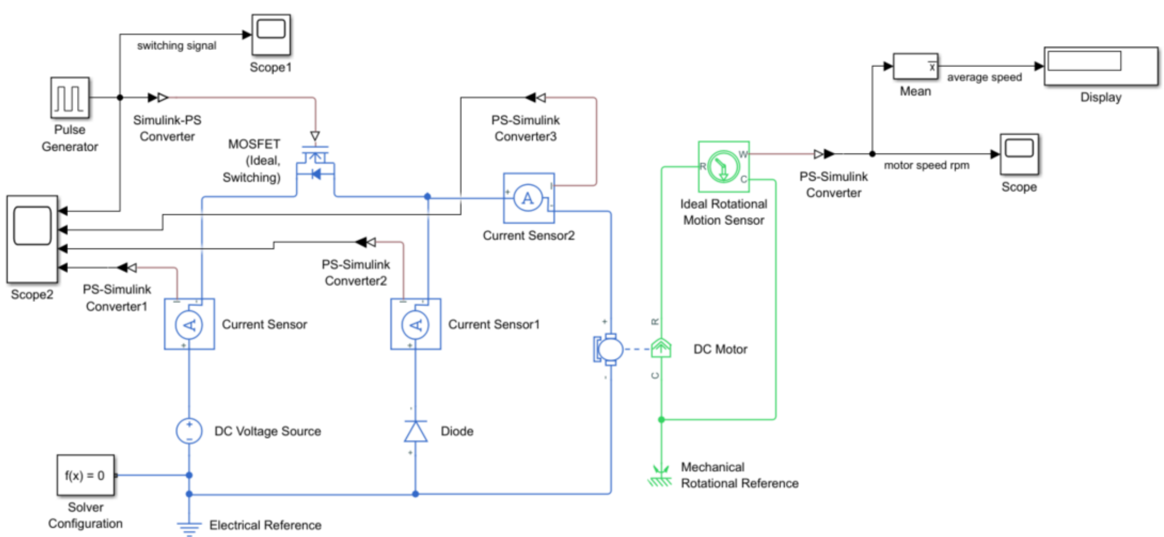
48.72 rpm

A.2. Current Circulation in the Active Phase & Freewheel Phase

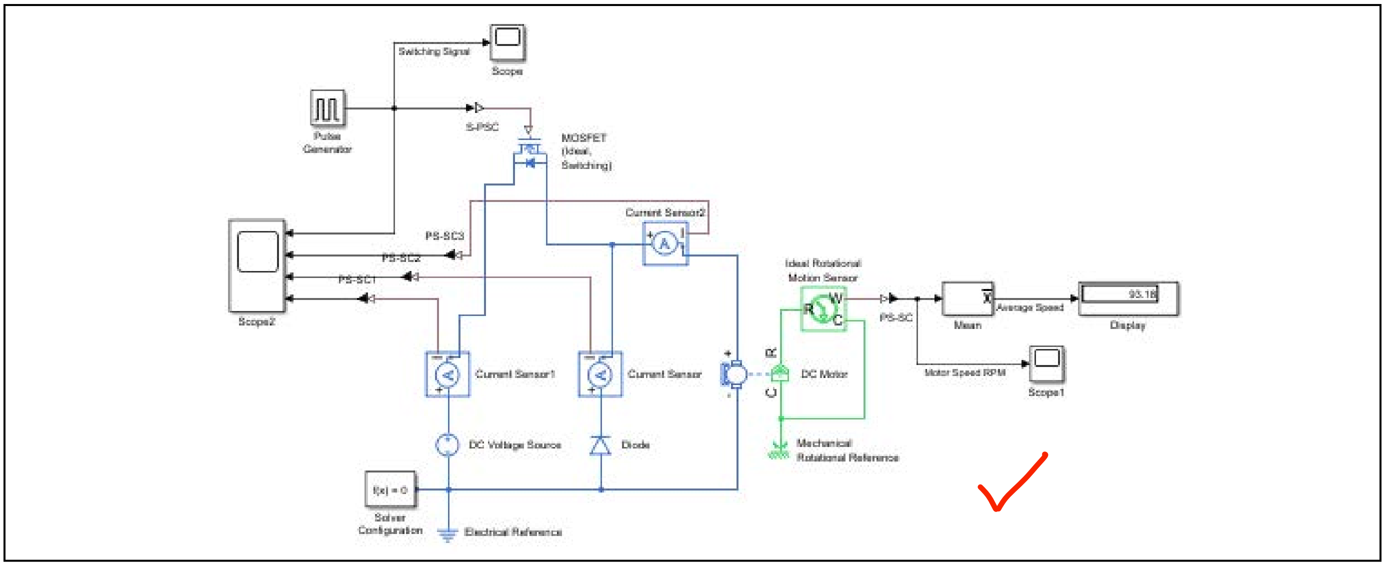
To view the current circulation in the buck converter, we will modify the **Simscape** model by adding the current sensors in each of the circuit branches.

8. Select and place the following blocks from the library and modify the circuit diagram as shown below:

- **Simscape > Foundation Library > Electrical > Electrical Sensors > Current Sensor**
- **Simscape > Utilities > PS-Simulink Converter**
- **Simulink > Sinks > Scope**

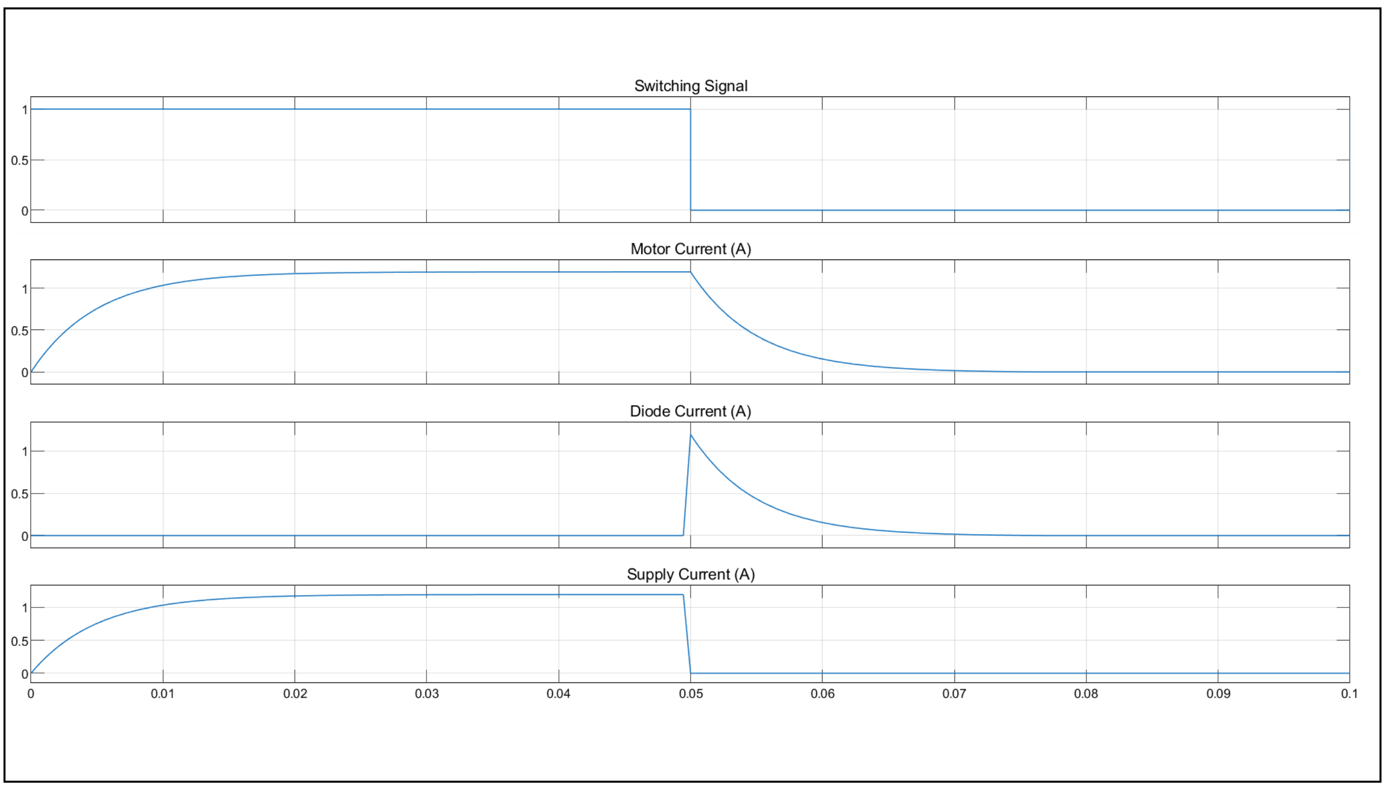


9. Provide your **Simscape** model diagram below:



10. To better understanding the current flow, we set the frequency of the switching signal in **Pulse Generator** to **10Hz**.
11. Adjust the **Fundamental frequency** in **Mean** block to **10Hz** to match with the switching frequency.
12. Set the simulation **Stop Time** to **0.1 sec** and **Run** the simulation.
13. Open the **Scope** block to view the currents waveform of each branch in the circuit.
14. Provide the **currents waveform** graph below. Identify the **active phase** and **freewheel phase** on the graph.

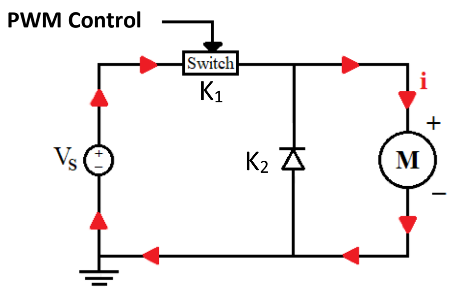
Currents Waveform



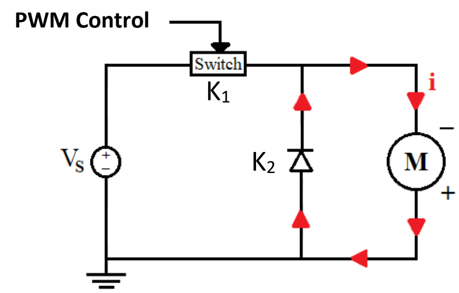
15. Briefly describe the **current waveforms** and the **motor speed** in the *active phase* and the *freewheel phase*.

In the active phase, both motor speed and current increase until they reach their maximum, but during the freewheeling phase, the waveform stops completely since the control frequency is too low to continue functioning.

What about the diode current? [-0.5]



Active Phase



Freewheel Phase

16. To check the effect of the switching frequency on the current waveforms, set the switching frequency to the given values in **Table 1**. Observe the **current waveforms** and collect the **average motor speed** data. Make sure to change the **Fundamental frequency** of the **Mean** block based on the assigned switching frequency.

Table 1

Switching Frequency	10 Hz	20 Hz	40 Hz	80 Hz	200 Hz	500 Hz
Average Speed (rpm)	46.4 rpm	48.72 rpm	48.72 rpm	48.74 rpm	48.72 rpm	48.72 rpm

17. Briefly describe the effect of increasing the ***switching frequency*** on the **current ripples** and the **motor speed**.

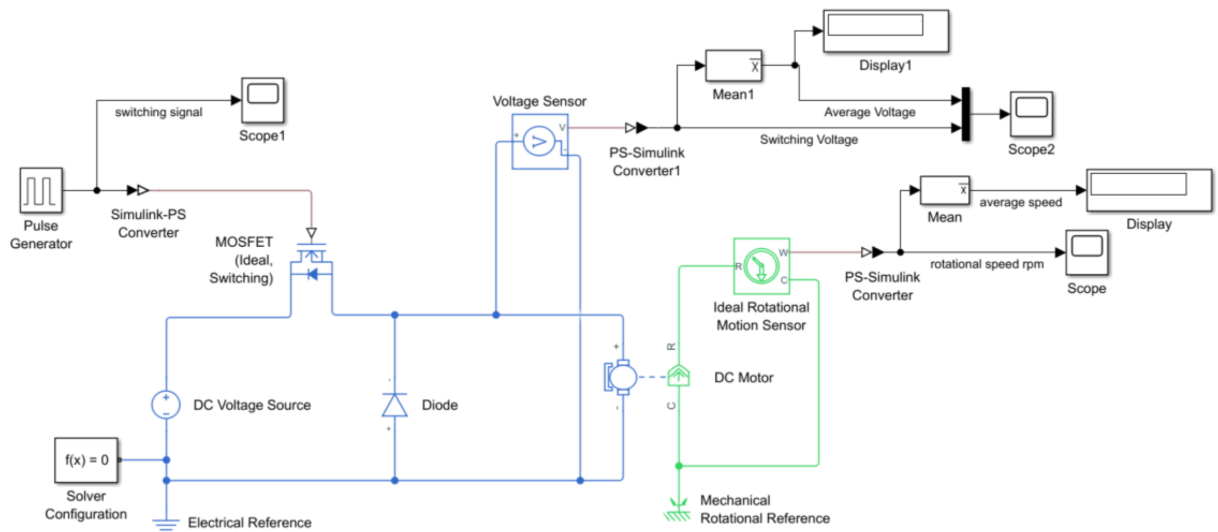
Raising the switching frequency reduces current variations while keeping motor speed relatively constant.

A.3. Effect of the Duty-Cycle on the Motor Voltage & Motor Speed

In this step the goal is to observe the variation of the average applied voltage and speed of the DC motor by changing the duty-cycle of the PWM signal.

18. Modify the **Simscape** model from previous part by adding the following components as shown below:

- **Simscape > Foundation Library > Electrical > Electrical Sensors > Voltage Sensor**
- **Simscape > Electrical > Specialized Power Systems > Sensors and Measurements > Mean**
- **Simscape > Utilities > PS-Simulink Converter**
- **Simulink > Sinks > Scope**

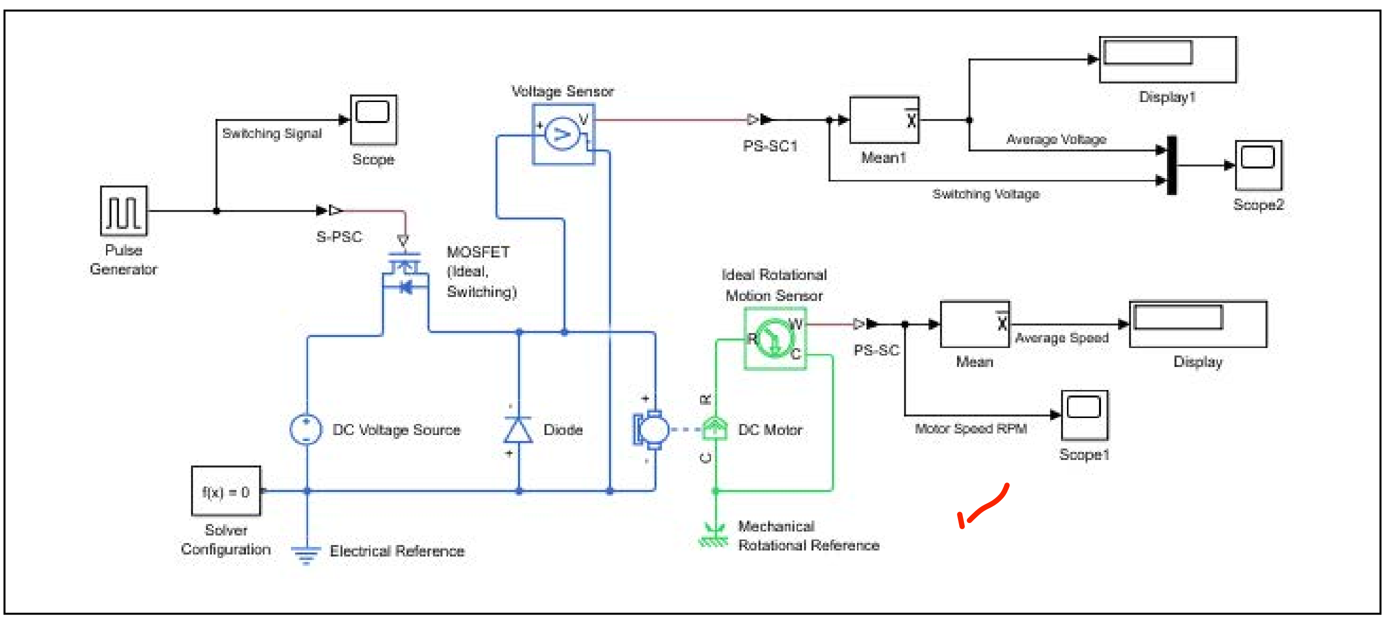


19. Set back the **Pulse Generator** parameters to the give *original values*.

Amplitude = 1, Period = 0.001 sec, Pulse Width = 50 percent, Phase delay = 0 second

20. Set the **Fundamental frequency** of the **Mean** blocks to **1000 Hz**.

21. Provide your **Simscape** model diagram below:



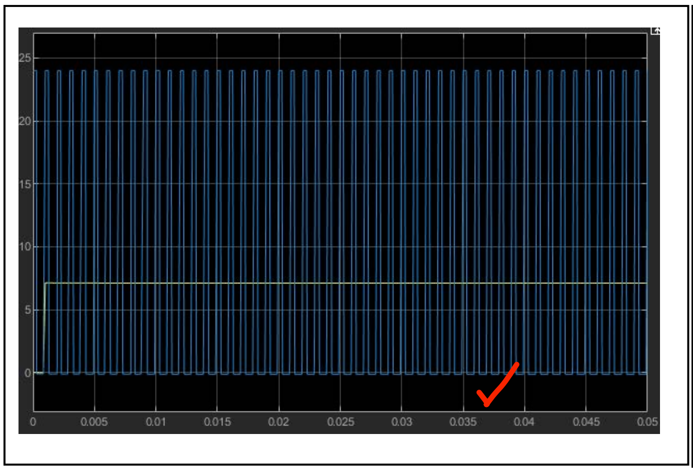
22. Change the **duty-cycle** of the PWM switching signal in the **Pulse Generator** block for each of the given values in **Table 2**. **Run** the simulation for **0.05sec** in each case. Provide the required graphs, calculations, and data from the simulation and complete **Table 2**.

Table 2

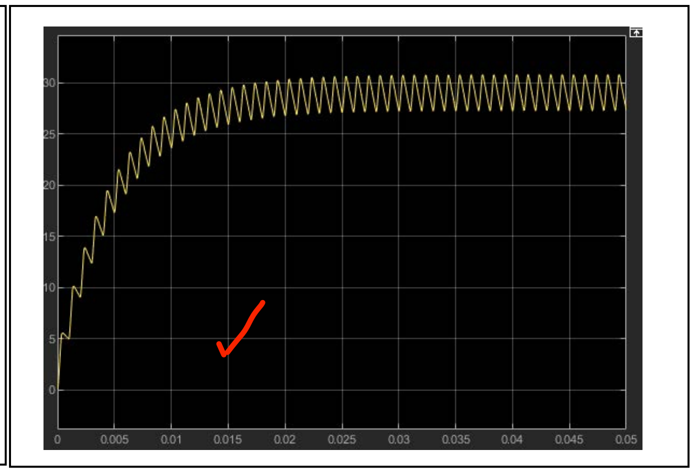
Duty-Cycle	10%	30%	50%	70%	90%	99%
Average Speed (rpm)	9.401 rpm	29.04 rpm	48.72 rpm	68.43 rpm	88.18 rpm	97.08 rpm
Average Voltage (V)	2.3 V	7.104 V	11.92 V	16.74 V	21.57 V	23.75 V

Provide required samples of simulation graphs below:

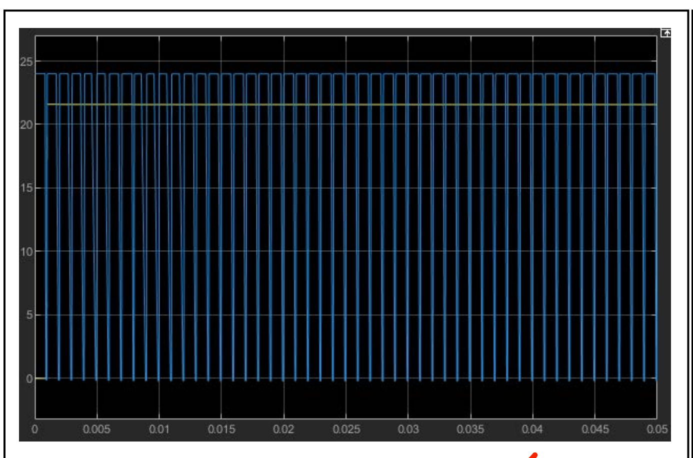
Applied Voltage (V) (Duty-cycle = 30%)



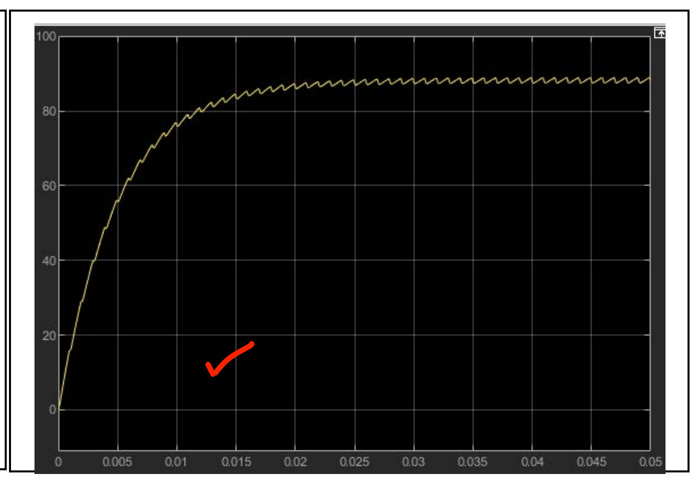
DC Motor Speed (rpm) (Duty-cycle = 30%)



Applied Voltage (V) (Duty-cycle = 90%)



DC Motor Speed (rpm) (Duty-cycle = 90%)



23. Briefly describe the effect of increasing the ***duty-cycle*** on the **ripples**, the **average motor speed**, and the **average voltage** applied to the motor.

As the duty cycle increases, the average motor speed and voltage rise, while the ripple effect diminishes.

A.4. Effect of the Rotor Inertia and Armature Inductance on the Motor Speed

In this part, the goal is to observe the effect of the **rotor inertia** and the **armature inductance** on the **average motor speed** and the **ripple**.

24. Set back the **Pulse Generator** parameters to the *original values*.

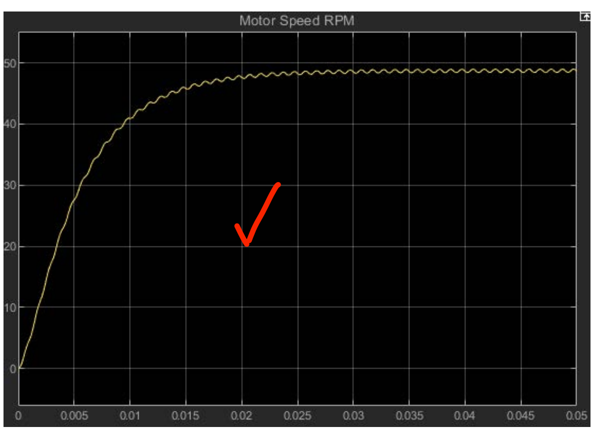
    Amplitude = 1, Period = 0.001 sec, Pulse Width = 50 percent, Phase delay = 0 second

25. *Double-click* on the **DC Motor** block and change the **Rotor inertia** first to **10 g.cm^2** and then to **0.001 g.cm^2**

26. **Run** the simulation for **0.05sec** and open the **Scope** block and check the motor speed for each case. Provide the speed graphs and the average final speed below.

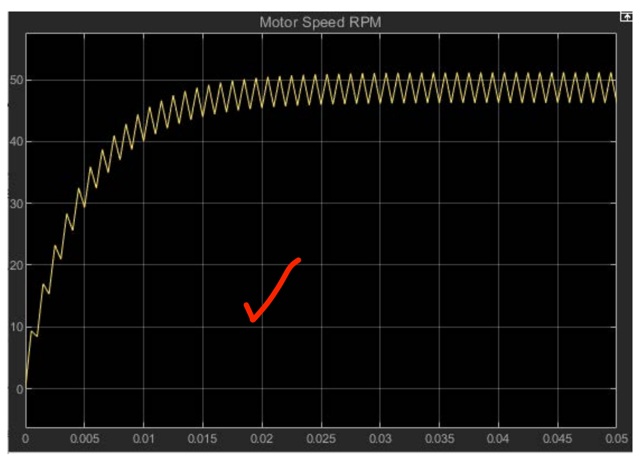
DC Motor Speed (Rotor Inertia = 10 g.cm^2)

Average Final Speed (rpm): 48.72 rpm



DC Motor Speed (Rotor Inertia = 0.001 g.cm^2)

Average Final Speed (rpm): 48.72 rpm



27. Explain the effect of variation of ***rotor inertia*** on the **ripple**, **time constant** and the **average speed** of the motor.

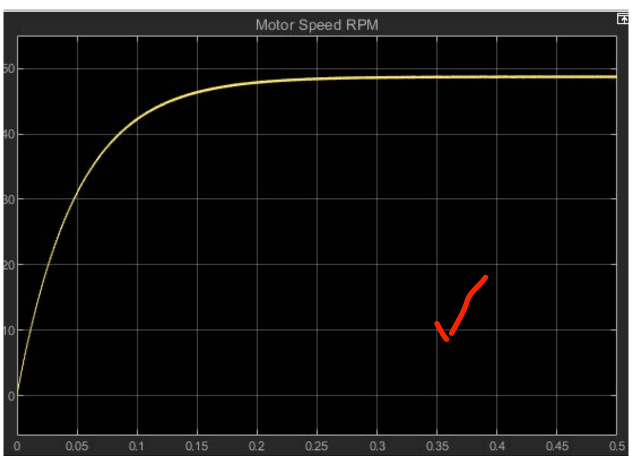
> When the rotor inertia was adjusted to 10, the ripples decreased, but the time constant and average speed stayed unchanged. Conversely, reducing the rotor inertia to 0.001 caused an increase in ripples, while the time constant and average speed remained unaffected.

28. Set back the **Rotor inertia** to the *original value* of **0.5 g.cm²**.
29. *Double-click* on the **DC Motor** block and change the **Armature inductance** first to **1 H** and then to **10 mH**.
30. **Run** the simulation and open the **Scope** block and check the motor speed for each case. Provide the speed graphs below.

NOTE: *For* L_a ***= 1H*** *set the simulation time to* ***0.5 sec*** *and for* L_a ***= 10mH*** *set the simulation time to* ***0.02 sec*** *to capture the full speed response graph.*

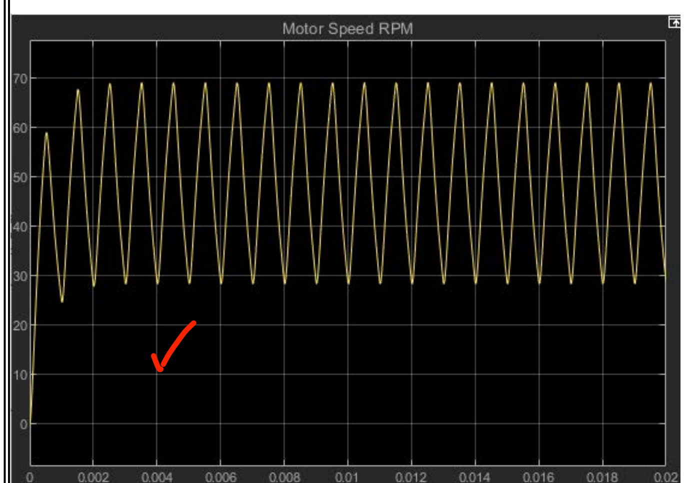
DC Motor Speed (L_a = 1 H)

Average Final Speed (rpm): 48.72 rpm



DC Motor Speed (L_a = 10 mH)

Average Final Speed (rpm): 48.73 rpm



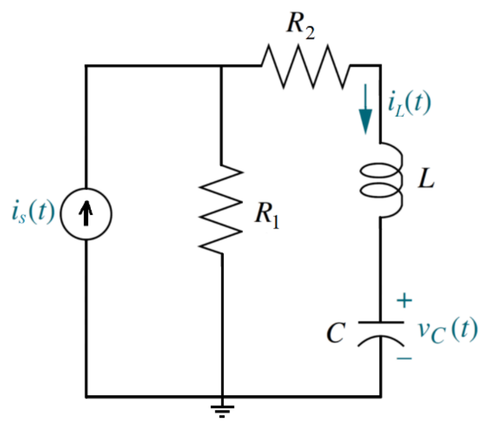
31. Explain the effect of changing the ***Armature inductance*** on the **ripple**, **time constant** and the **average speed** of the motor.

> Setting the armature inductance to 1 H considerably eliminates ripples, decreases the time constant, and keeps the average speed virtually constant. When the inductance is increased to 10 mH, the ripples rise significantly, the time constant accelerates, but the average speed remains essentially constant.

Post Lab Assignment

1. Build the Simscape physical diagram for the following electric circuit.

$$R_1 = 0.2\ \Omega,\ \ R_2 = 1\ \Omega,\ \ \ C = 0.01\ F,\ \ \ L = 0.1\ H$$



   a) Provide your Simscape model diagram.

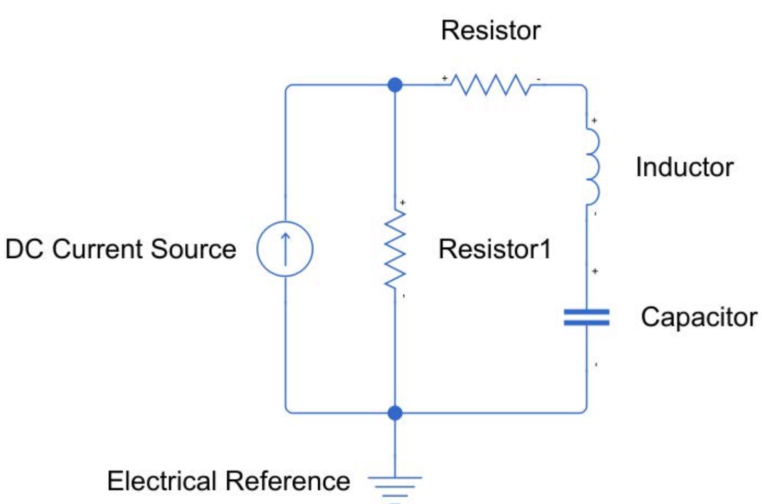
   b) Select an appropriate simulation time and plot the voltage across the capacitor $v_c(t)$ and current through the inductor $i_L(t)$ if the input signal is $i_s(t) = 0.5\ A$ and all initial conditions are $v_c(0) = 0$ and $i_L(0) = 0$. Provide the graphs.

   c) What is the final voltage of the capacitor? What is the final current of the inductor?

   d) Set the initial conditions to $v_c(0) = 2\ V$ and $i_L(0) = 0.5\ A$. Plot the voltage $v_c(t)$ and current $i_L(t)$ graphs. Provide the graphs?

   e) What is the final voltage of the capacitor? What is the final current of the inductor?

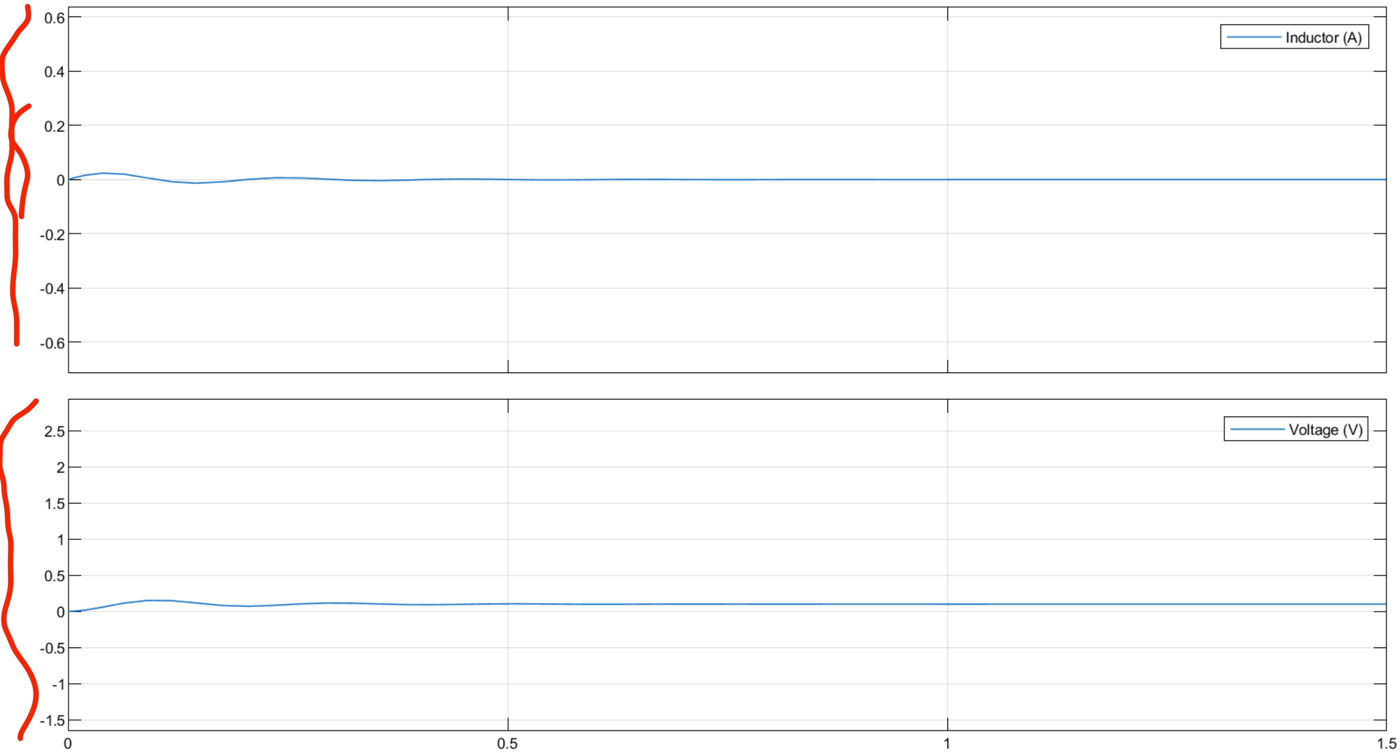
A)



The required ammeter, voltmeter, scopes and PS-Simulink converters are missing. [-1]

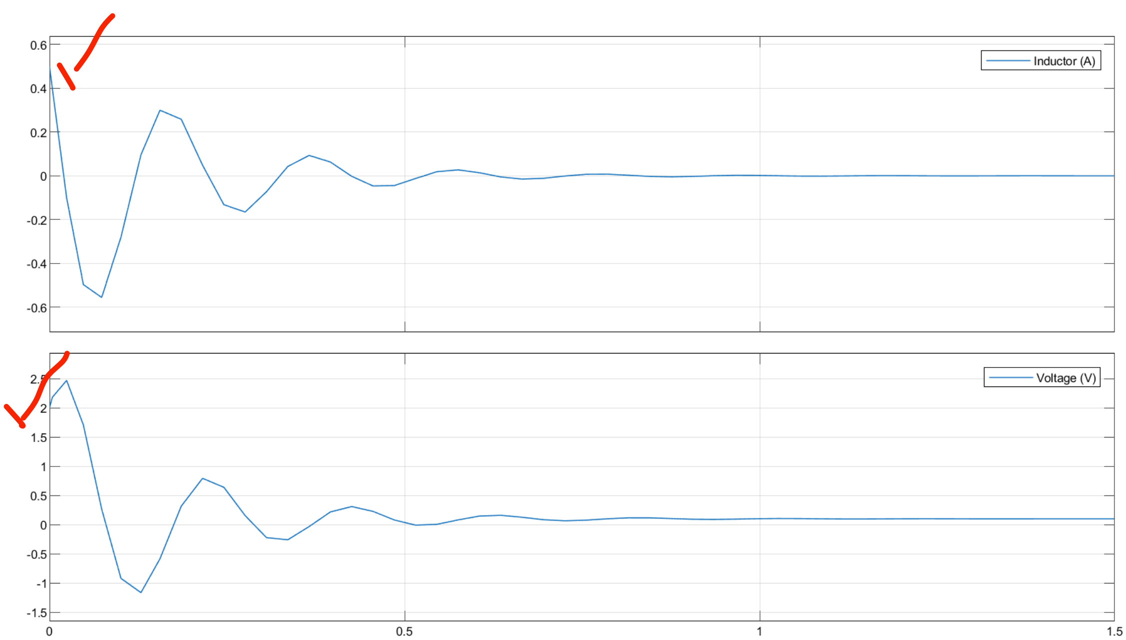
B) Time set was 1.5 seconds

The selected range for y-axis is not appropriate. [-0.5]



How did you plot

C) Final Value
Inductor: 0 A
Voltage: 0.1 V
D)



E)Final Value Tagged at 1 sec
Inductor: 1.725 mA
Voltage: 102.323 mV