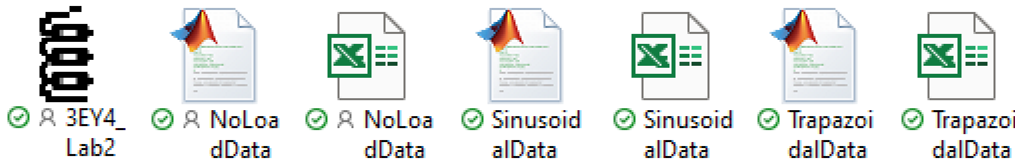
Brushless DC Motor Control

McMaster University
EE3EY4 Electrical Systems Integration Project - Winter 2021

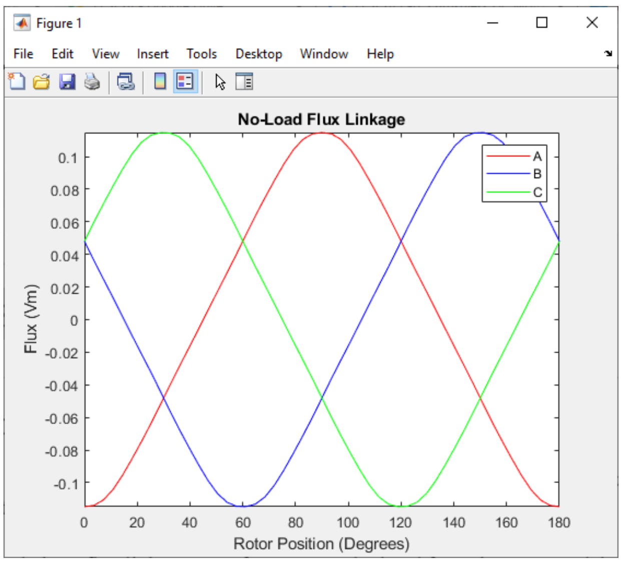
Pre-Lab

NoLoadData.m will take the previous lab's FEM model and save data in excel. This excel file then will be used for this lab.

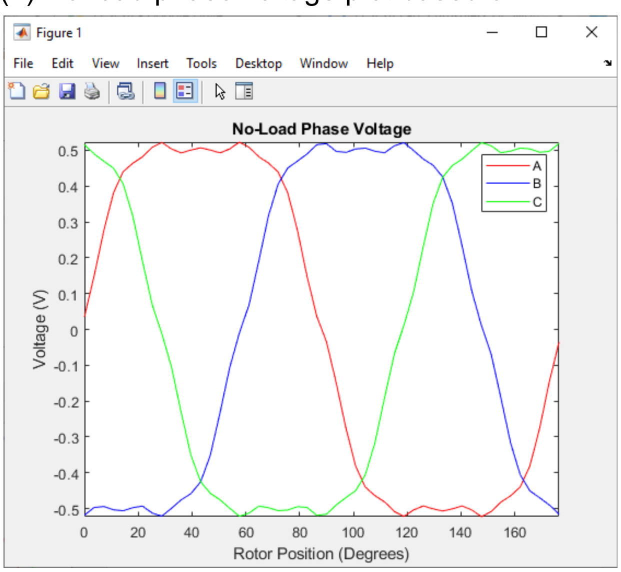


Part 1

(1) No-load flux linkage plot based on FEA model



(2) No-load phase voltage plot based on FEA model

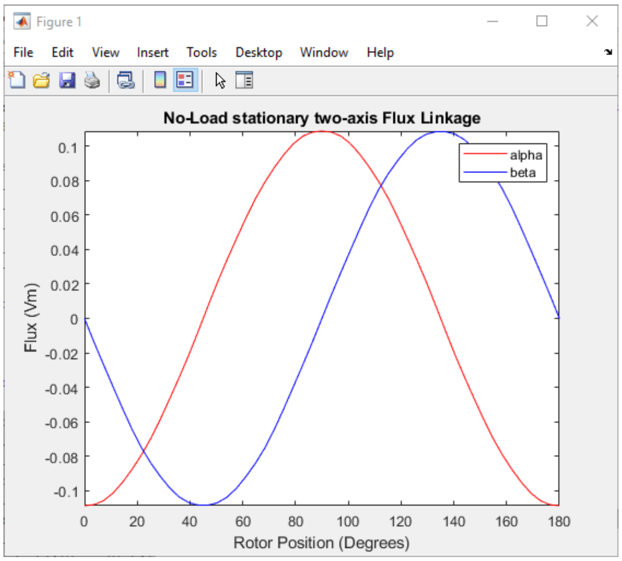


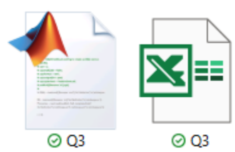
The induced voltage was calculated using Faraday's Law.

$$\varepsilon = \frac{d\lambda}{dt} = \frac{d\lambda}{d\theta}\frac{d\theta}{dt} = \frac{d\lambda}{d\theta}\omega \qquad\qquad \varepsilon_{calc} = \frac{\lambda_2 - \lambda_1}{\theta_2 - \theta_1}$$

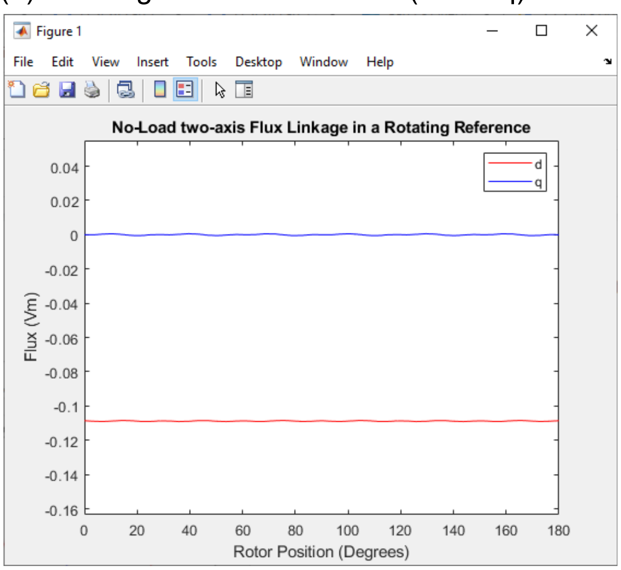
EMF = change in flux over the change in degrees times the angular speed
However, since FEMM was only able to provide discrete values of flux and position, it was necessary to find the slope between adjacent values to calculate the induced voltage

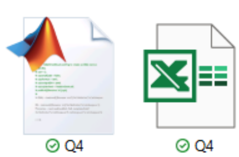
(3) Stationary reference two-axis (alpha and beta) no-load flux linkage plot





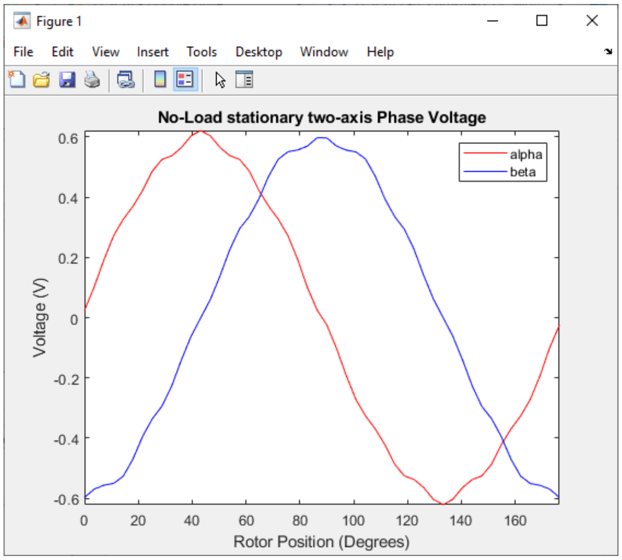
(4) Rotating reference two-axis (d and q) no-load flux linkage plot

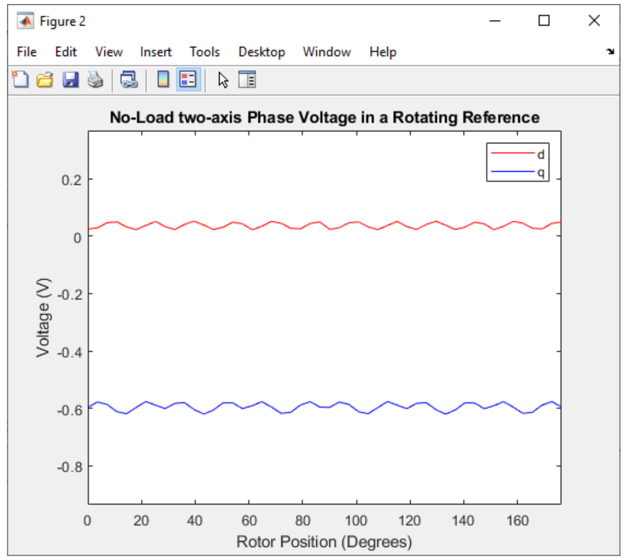




The difference between a stationary two-axis reference frame and a rotating two-axis reference frame is that the rotating reference frame gives DC values that correspond to torque and EMF. Assuming the negative signs matter, the q-axis has a higher value at around 0Vm, whereas d-axis has -0.104Vm. This is because the q-axis corresponds to torque production due to flux linkage, which in this case is zero. The flux linkage from permanent magnets, in the rotating reference frame, is the d-axis.

(5) The plots of stationary 2-axis and rotating 2-axis reference frames for phase voltage






Q5


Q5

The difference between a stationary two-axis reference frame and a rotating two-axis reference frame is that the rotating reference frame gives DC values that correspond to torque and EMF. Assuming the negative signs matter, the d-axis has a higher value at around 0V, whereas q-axis has -0.6V. This is because the q-axis corresponds to the induced voltage due to the rotation of permanent magnets, which in this case is nonzero. The d-axis represents the induced voltage from the flux linkage of permanent magnets.

(6) Calculated motor speed in RPM

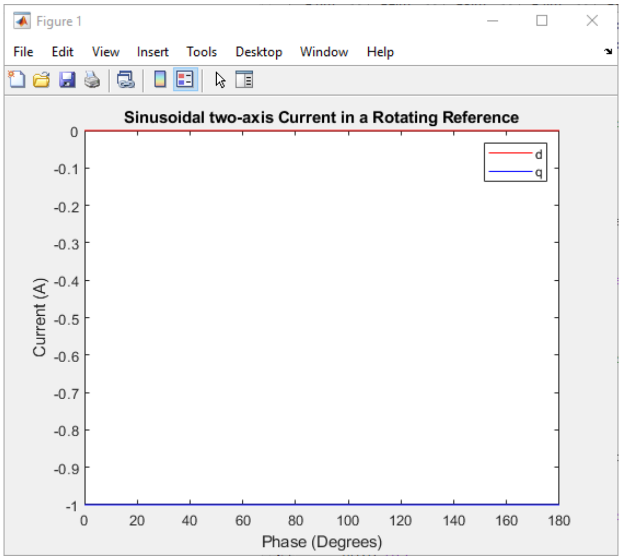
```
wd_RPM =

   -8.9729


wq_RPM =

  -1.4994e+03

fx >>
```

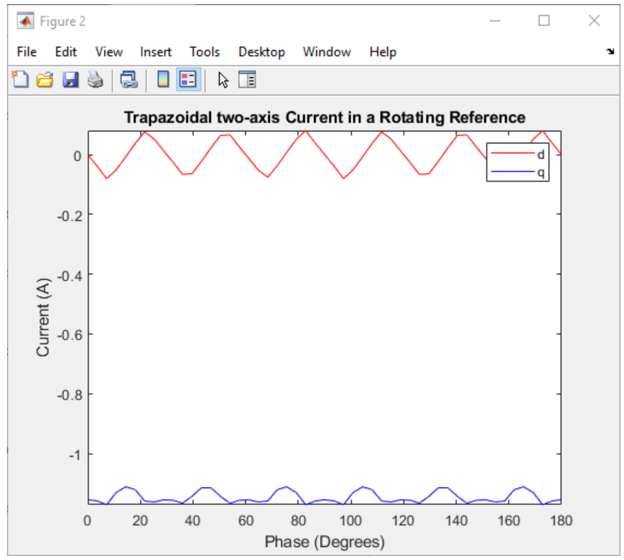

Q6

The ω_q is the angular speed of the motor that was calculated Using the no-load flux linkage and voltage waveforms in the rotating reference frame. The calculated value of 1499.4 RPM is close to the value of 1500 RPM used in the analysis.

Part 2

(7) The transformed sinusoidal and trapezoidal current waveforms





Q7 Q7

The d-axis is the excitation of the current due to the flux linkage of the permanent magnets, which in this case is zero. The q-axis is the torque-generating current, which is why it is nonzero. D-axis value is zero because the flux linkage does not oppose or aid the current in any way.

(8) The calculated average torques

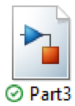
Using the torque equation in rotating reference frame, along with the stationary reference frame for comparison, for both sinusoidal and trapezoidal waveforms:

```
avgTorque =

  2×3 table

    axis      sin        trap
    ____    _______    _______

    ABC     0.32482    0.37953
    dq      0.32482    0.37973

fx >>
```

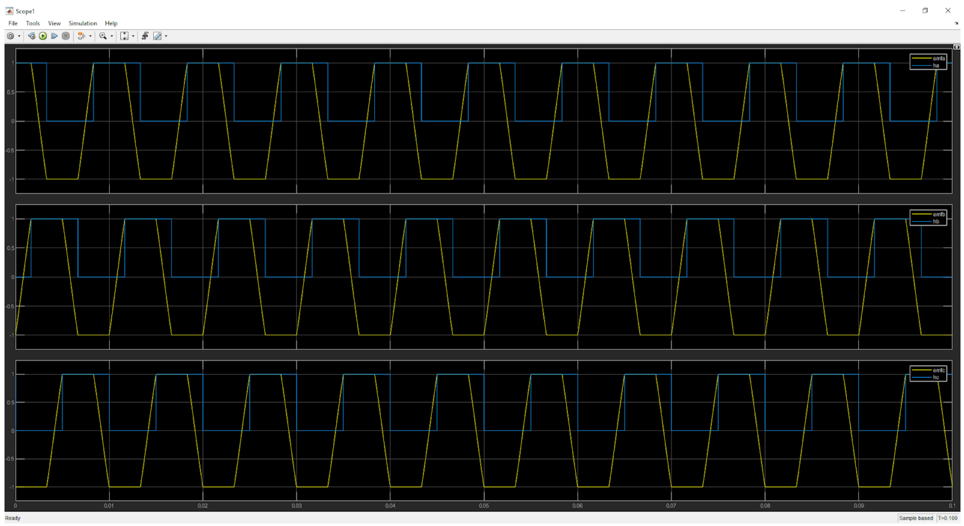
Q8

Comparing both sets of values, the calculated torques are close to the FEA model's average torque.

Part 3

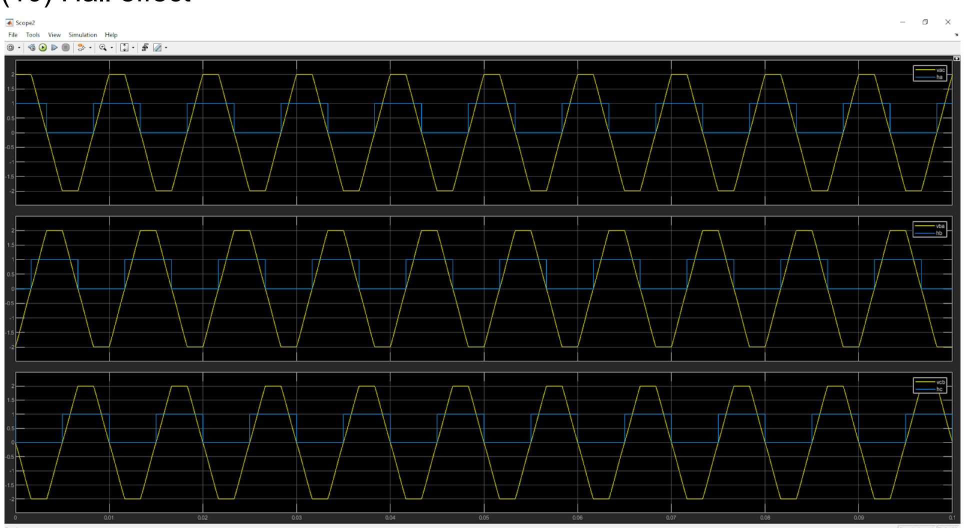


(9) BLDC motor in Simulink with calculated model parameters
Set the back emf waveform parameterized as trapezoidal, additional parameters based on the reference frame transformations results, phase resistance as 8ohms, and phase inductance as 5.68mH.



The magnitude of the induced EMF waveform does not match with the magnitude of the induced EMF waveform of the FEA model. In fact, the FEA model's magnitude of induced EMF is half of the phase voltage magnitude of the Simulink model. This mismatch is due to the difference in the ratio used in the Simulink model.

(10) Hall effect



The induced phase voltages are not in phase with the hall effect sensor outputs. However, the line-to-line voltages are in phase with the hall effect sensor outputs.

(11) Induced phase voltages after hall effect

To develop a model for the induced phase voltage using the hall effect, We treated the hall effect as inputs and induced voltage as outputs. Using k-maps, We developed a relationship between the two. Also, since -1 is just the negative of 1, I can essentially ignore the negative and add it back in later to the appropriate k-map.

ha	hb	hc	emfa	emfb	emfc
0	0	0	0	0	0
0	0	1	0	-1	1
0	1	0	-1	1	0
0	1	1	-1	0	1
1	0	0	1	0	-1
1	0	1	1	-1	0
1	1	0	0	1	-1
1	1	1	0	0	0

<u>K-map for emf of a</u>

a\bc	00	01	11	10
0	0	0	-1	-1
1	1	1	0	0

emfa = ab’-a’b = ha&hb’-ha’&hb

<u>K-map for emf of b</u>

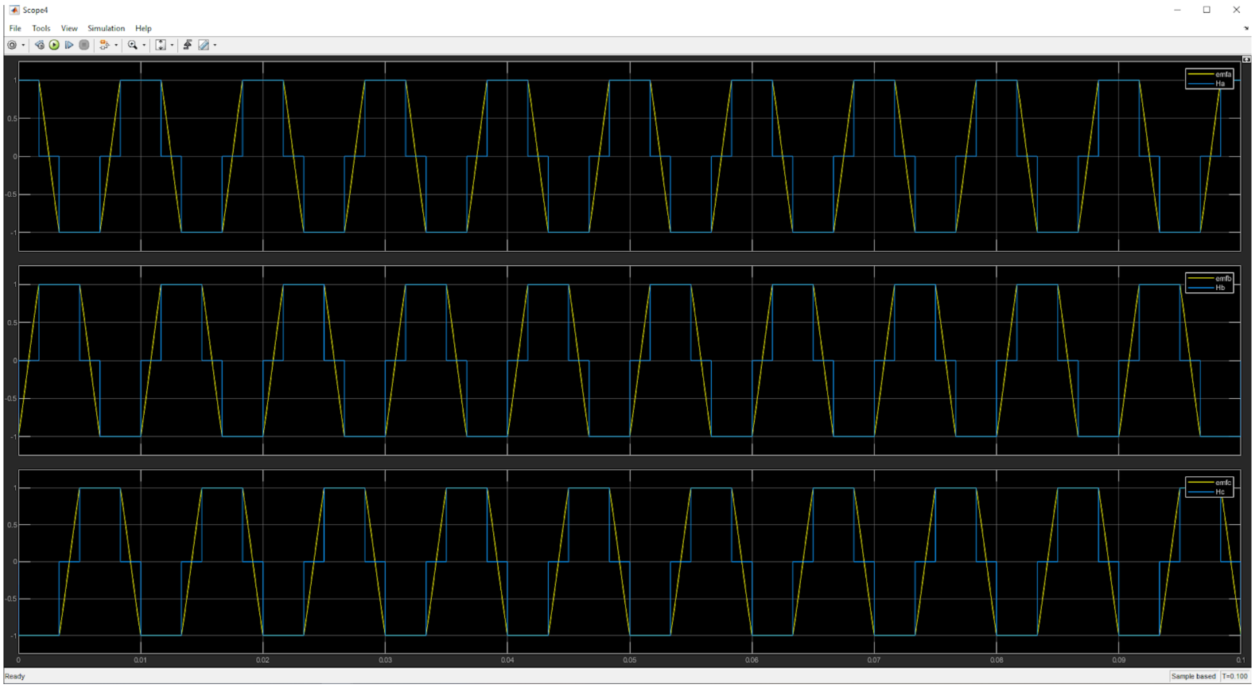
a\bc	00	01	11	10
0	0	-1	0	1
1	0	-1	0	1

emfb = bc’-b’c = hb&hc’-hb’&hc

<u>K-map for emf of c</u>

a\bc	00	01	11	10
0	0	1	1	0
1	-1	0	0	-1

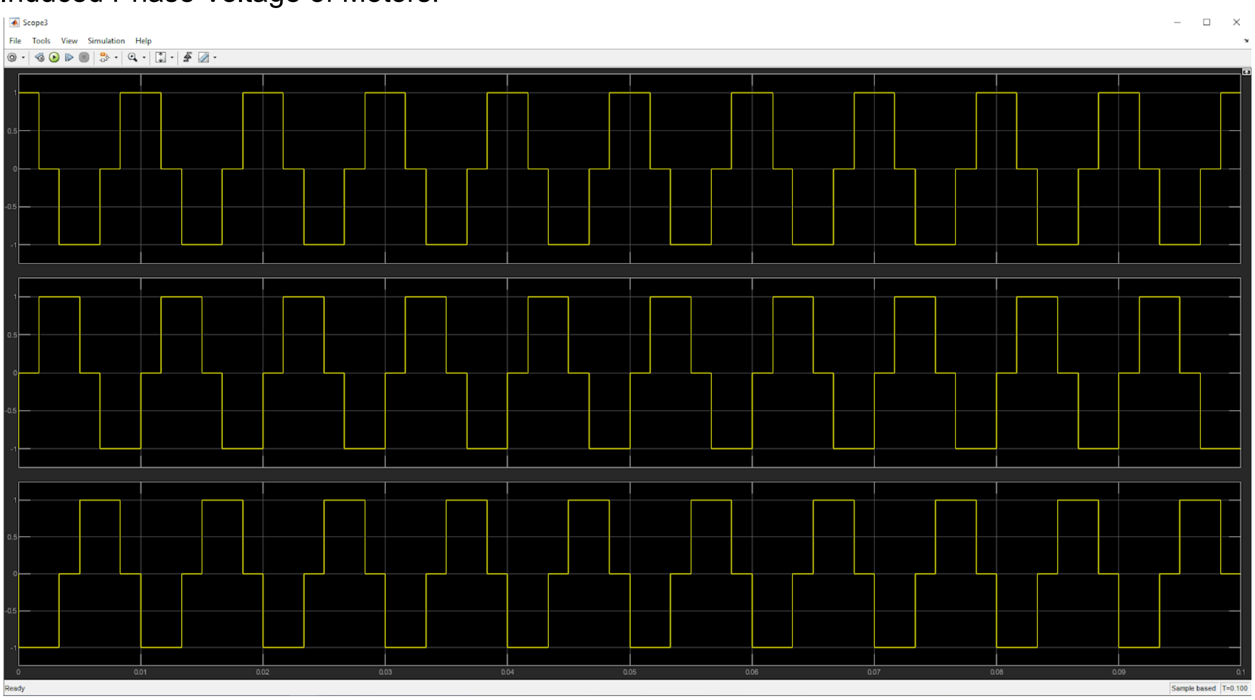
emfc = a’c-ac’ = ha’&hc-ha&hc’



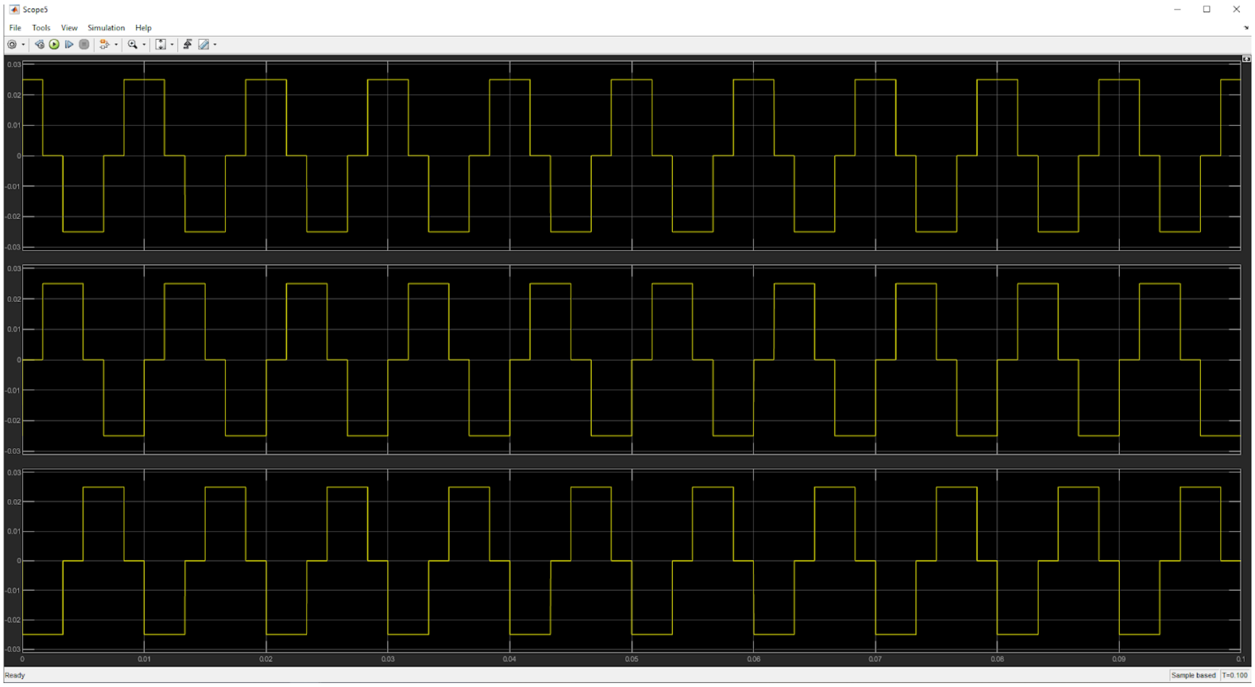
(12) Three-phase inverter

To apply the hall effect signals appropriately, we used MOSFETS. The idea of using MOSFETs as a voltage-controlled switch was taught to us in previous years. This enabled us to create a circuit to control when the hall effect signals are 1 or 0 individually, as needed.

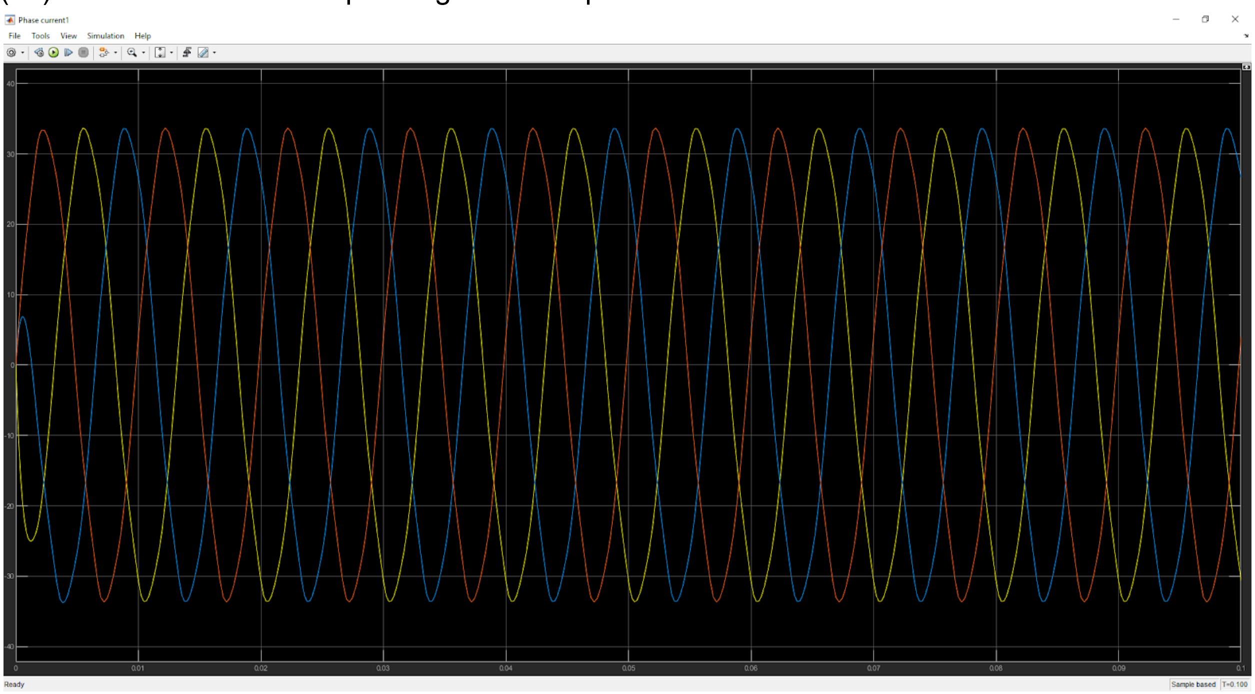
Induced Phase Voltage of Motors:

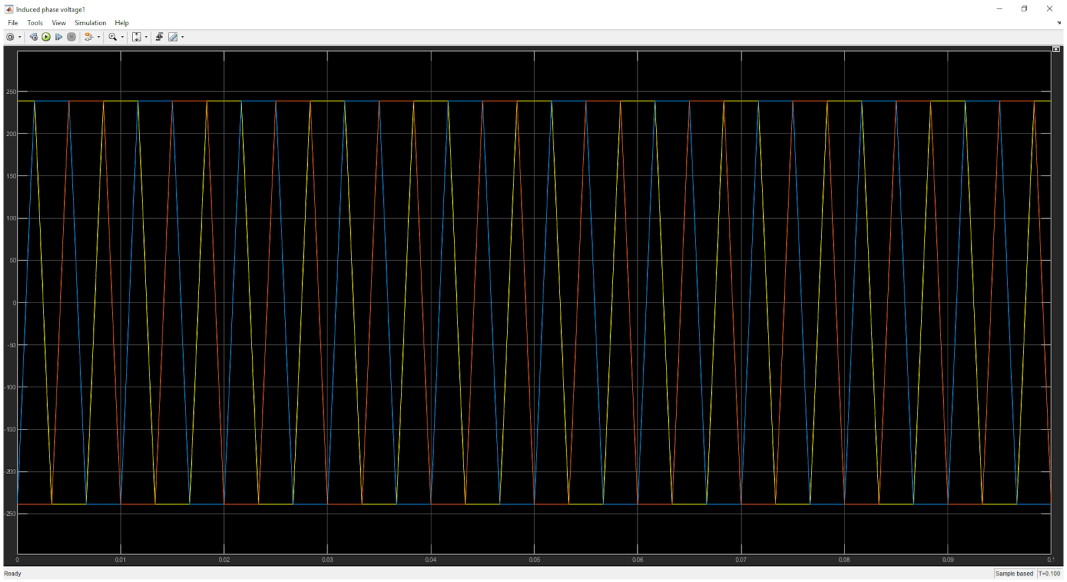


Three Phase Inverter Phase Voltage:

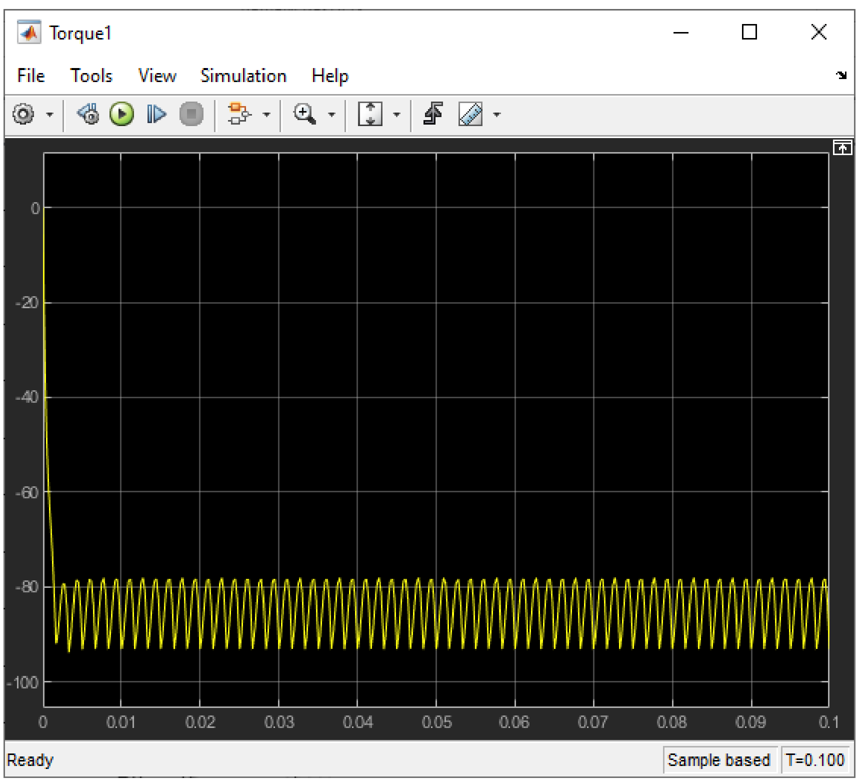


(13) Waveforms after incorporating the three-phase inverter





The current waveform is sinusoidal while the induced voltage is trapezoidal. This is exactly what we got in lab 2 where when we calculated the induced voltage for a sinusoidal current we achieved a trapezoidal result.



Torque is negative, this is because the ω is 1500RPM clockwise. If we set ω to negative, we can see that we get the exact same torque but on the positive side of the y-axis. This makes sense since τ=Jω and changing the polarity of angular speed should change the polarity of torque.