MIDDLE EAST TECHNICAL UNIVERSITY

ELECTRICAL & ELECTRONICS ENGINEERING DEPARTMENT

EE-361

Homework #6

Submission Date: 31.01.2021

Group no: 99

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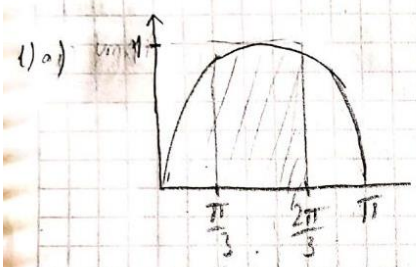
Part I

1.

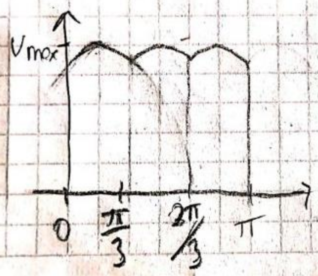
a.

1) a)



$$\text{Area} = \int_{\pi/3}^{2\pi/3} \sin\theta \, d\theta = -\cos\theta \Big|_{\pi/3}^{2\pi/3} = 1$$

$$V_{AV} = \frac{1}{\pi}$$



$$V_{AV\,dc} = \frac{3}{\pi} V_{max} = \frac{3\sqrt{2}}{\pi} V_{rms}$$

$$V_{AV\,dc} = \frac{3\sqrt{2} \cdot 400}{\pi} = 540.19\ V$$

b.

$$P = \frac{V^2}{R} \Rightarrow R = \frac{V^2}{P} = \frac{(540.19)^2}{3000} = 97.26\ \Omega$$

c.

$$V_{ripple} = V_{max} \times 0.134 = 400\sqrt{2} \times 0.134 = 75.8\ V$$

d.

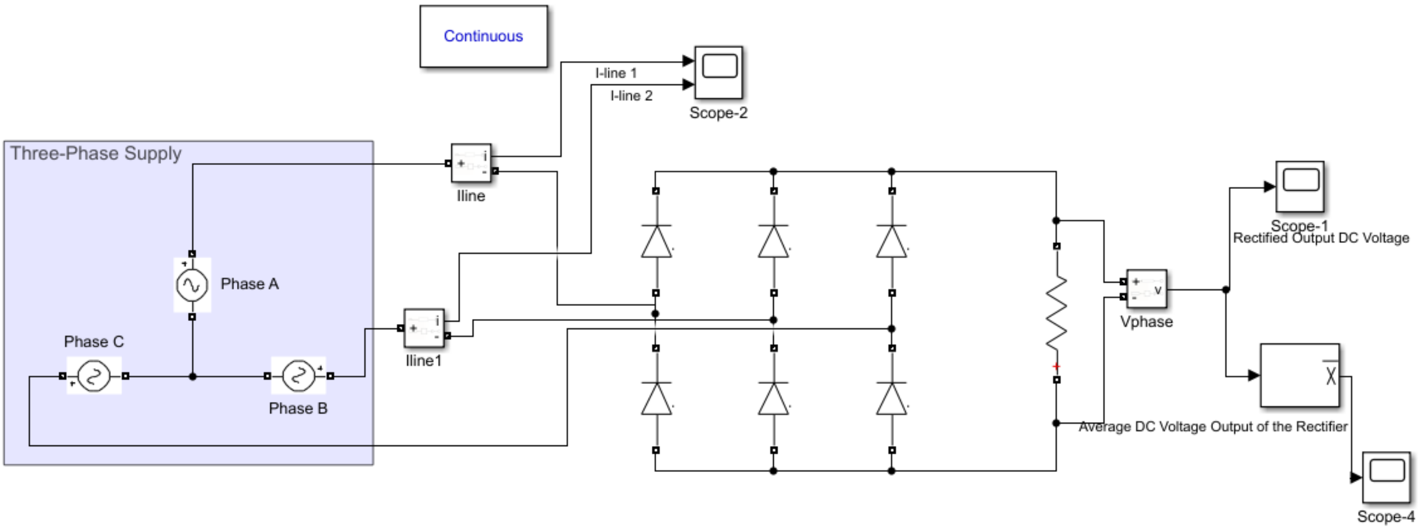


Figure 1:Schematic of Simulated 3-Phase Full-Wave Rectifier

e.

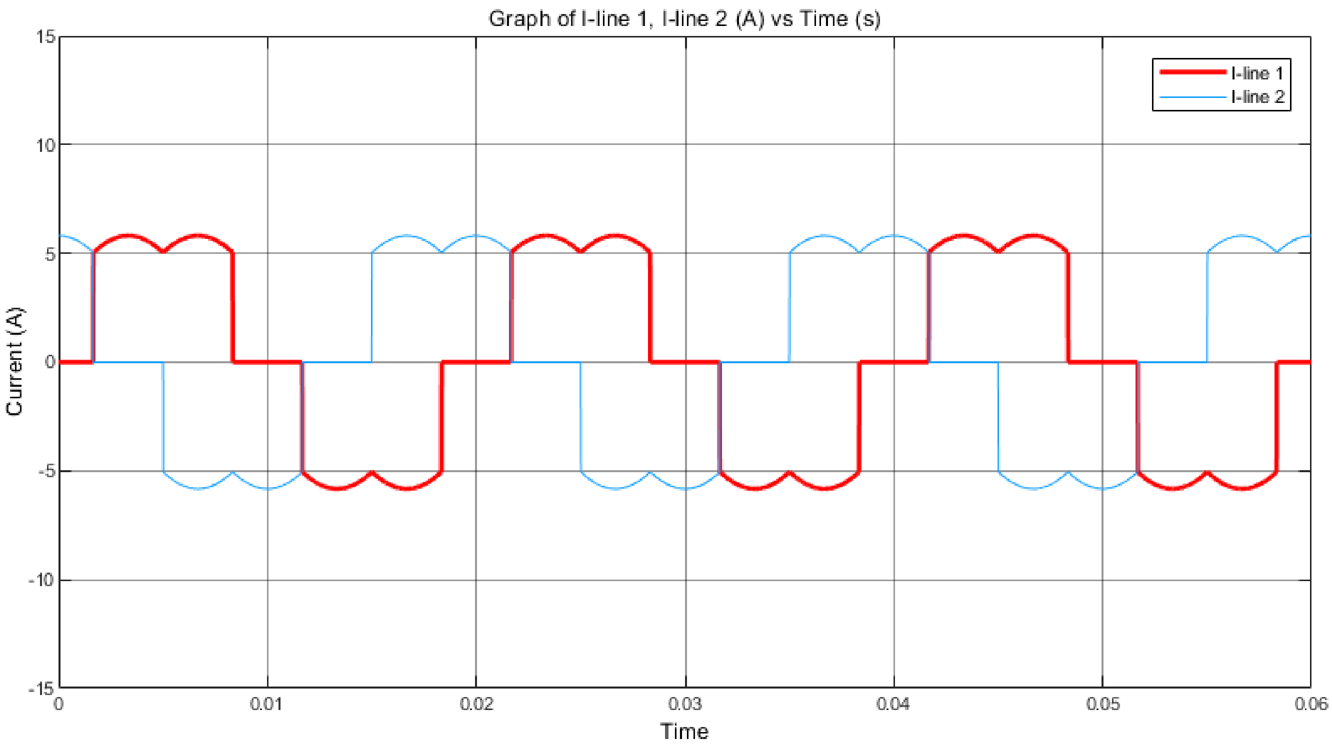


Figure 2: Graph of I_{line-1} (A) & I_{line-2} (A) vs Time (s)

f.

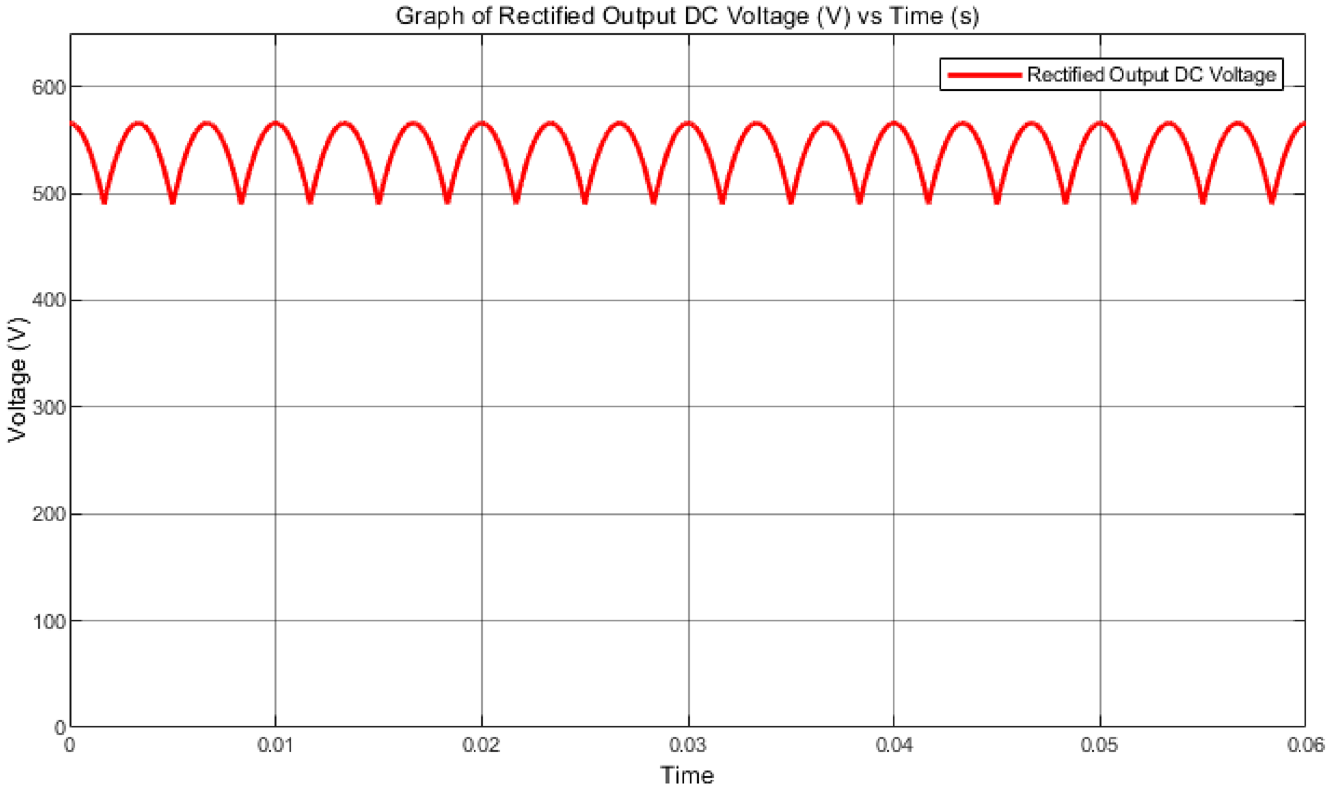


Figure 3: Graph of Rectified Output Voltage (V) vs Time (s)

g.

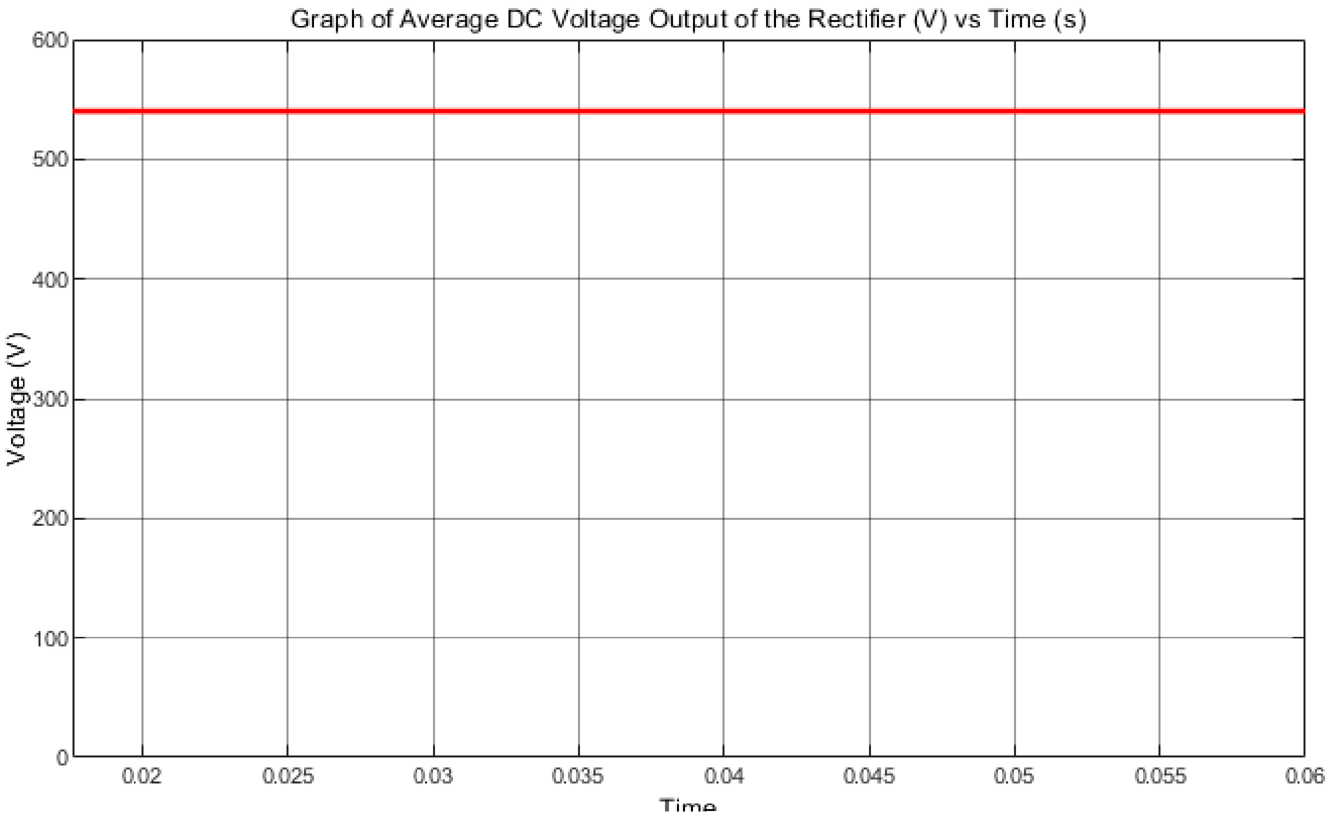


Figure 4: Graph of Average Rectified Output Voltage (V) vs Time (s)

Comment: Analytical calculation of average voltage output is almost same with simulation result. We found average DC voltage as 540.19 V. As we can see from figure 4, the average DC voltage in simulation result is around 540V.

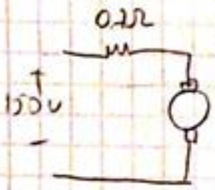
h. In order to reduce ripple voltage of rectifier, we can connect capacitor parallel to resistor. Connected capacitor should be large enough so that it can eliminate ripple voltages and give smoother output.

Part II

2.

a.

c) $V_o = V_{in} D_s \Rightarrow V_o = 150V$



$E_A = K_a\phi \, \omega_{mech}$

$T = K_a\phi I_A \Rightarrow I = 0.0026\omega^2/2$

$E_A = 150 - 0.2 \times 0.0013\omega^2 = 2.\omega$

solve the equation $\boxed{\omega = 72.6 \frac{rad}{sec}}$

$T = 0.0026\omega^2 = \boxed{13.7\ Nm} \Rightarrow I_a = \frac{T}{K_a\phi} = \boxed{6.85\ A}$

b.

b) $P = w_{mech} T_{mech} = 0.0026\, w^3 = 3000$

$w = 104.89$ rad/sec. $\Rightarrow E_A = 209.77\, V$

$T = 0.026\, w^2 = 28.6\ Nm \Rightarrow I_a = 14.3\, A$

$V_T = E_A + R_A I_A = 209.77 + 14.3 \times 0.7 = 219.77 V$

$$\text{duty cycle} = \frac{219.78}{300} \times 100 = \%\,73.26$$

c.

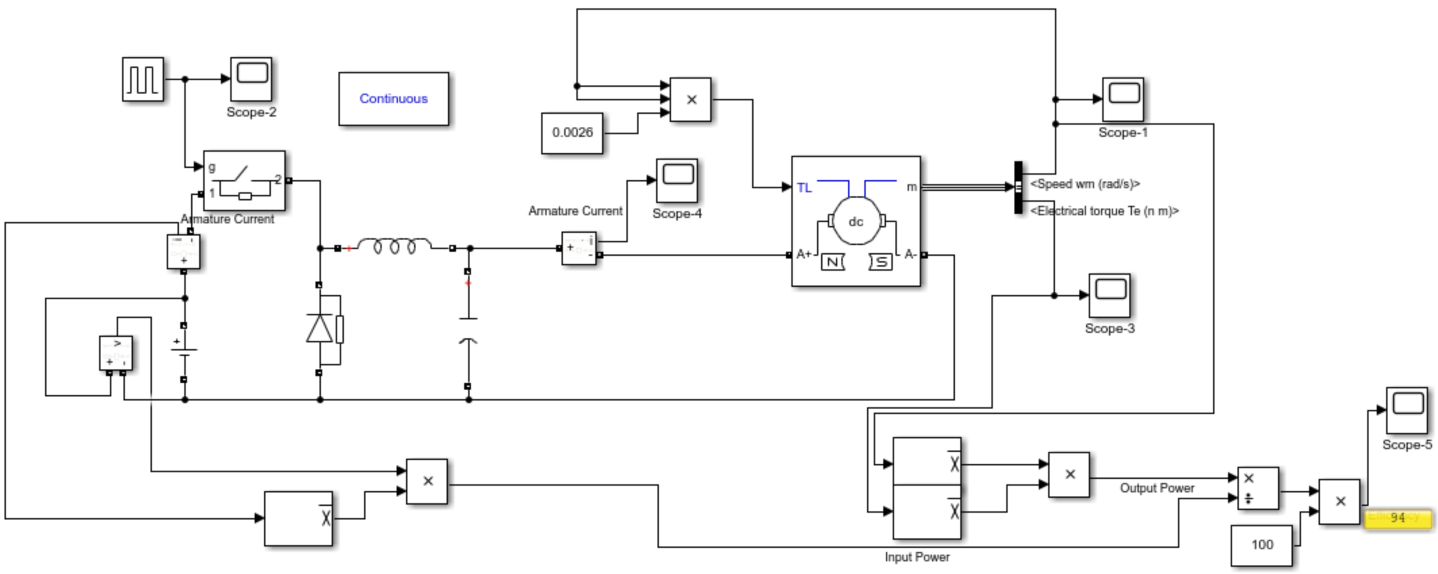


Figure 5: Schematic of Simulated Permanent Magnet DC Motor Driven by a Buck Converter

1- %50 Duty Cycle

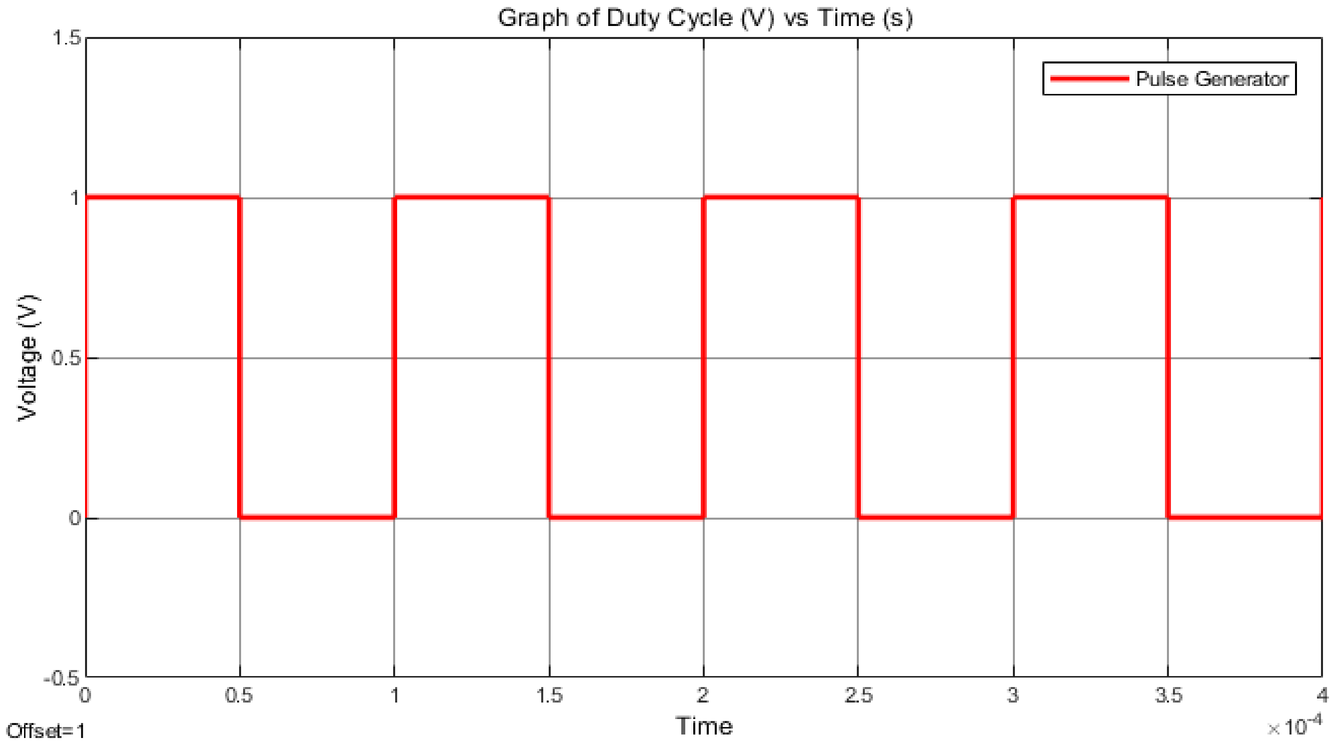


Figure 6: Graph of Duty Cycle (V) vs Time (s) (%50 Duty Cycle)

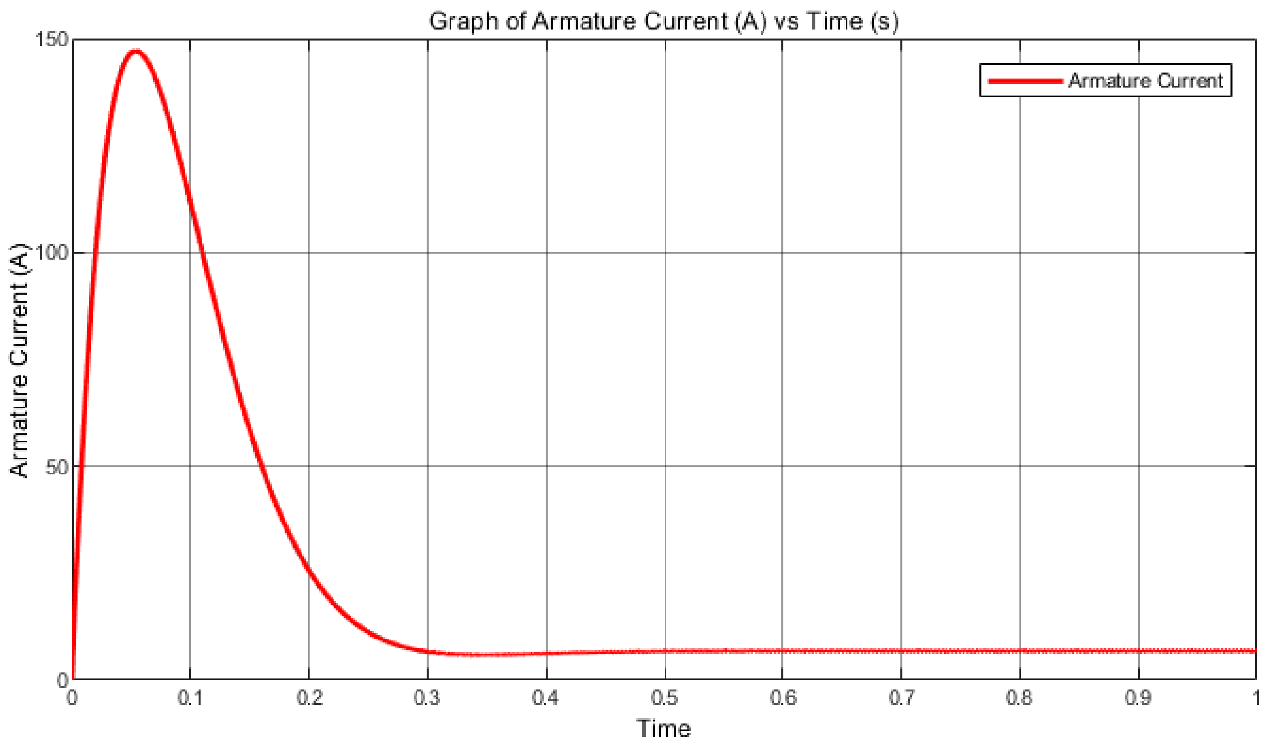


Figure 7: Graph of Armature Current (A) vs Time (s) (%50 Duty Cycle)

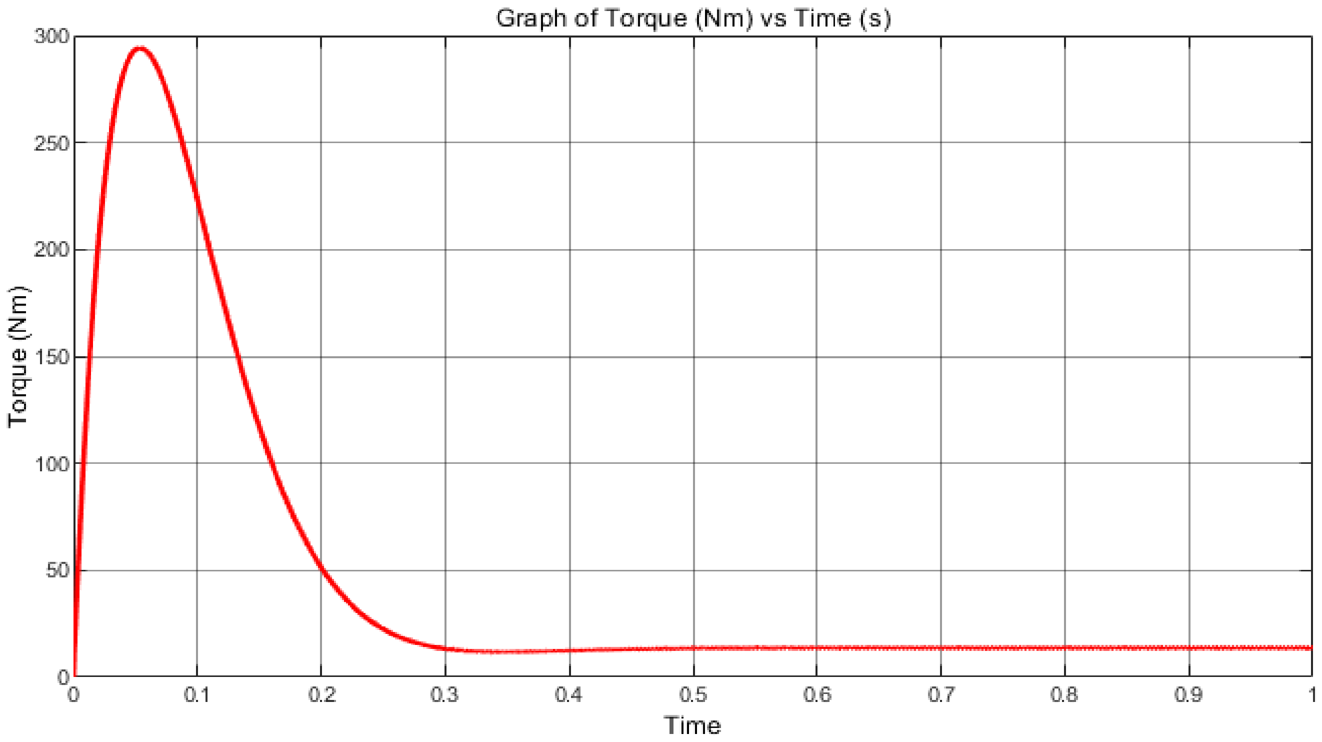


Figure 8: Graph of Torque (N.m) vs Time (s) (%50 Duty Cycle)

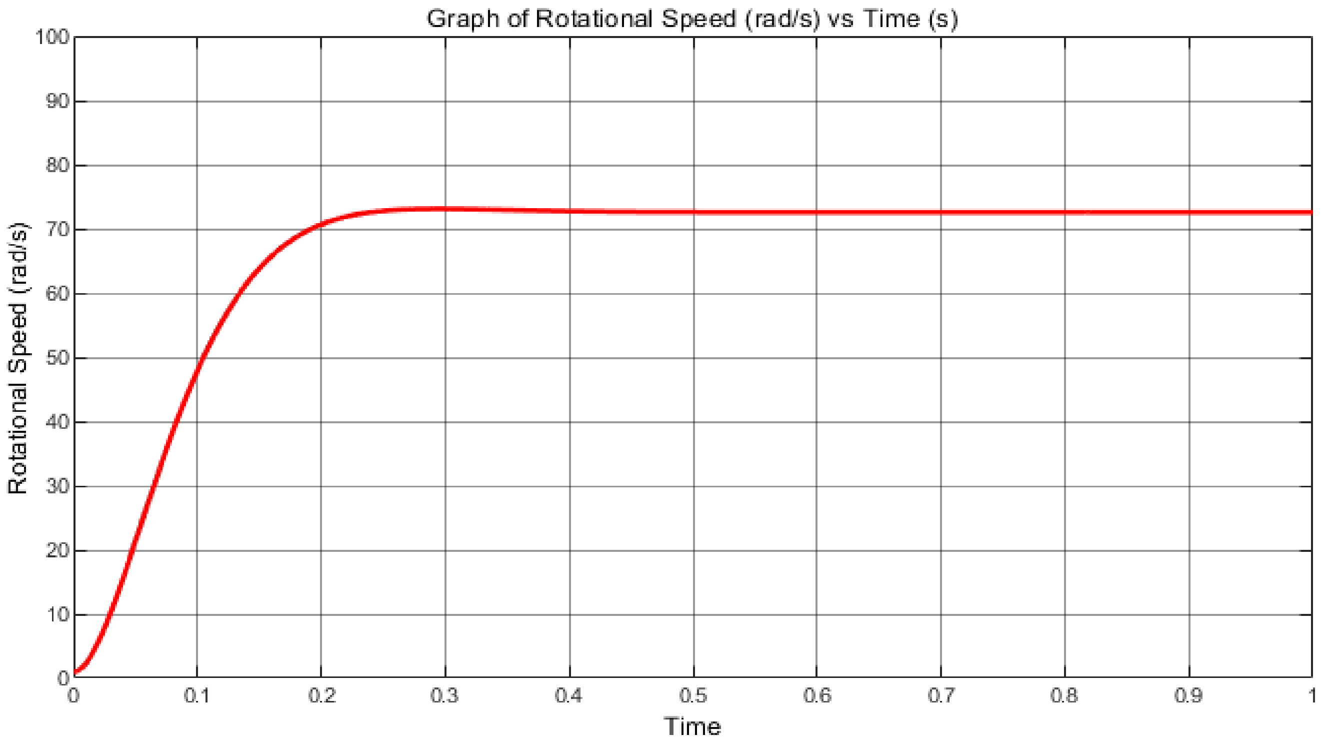


Figure 9: Graph of Rotational Speed (rad/s) vs Time (s) (%50 Duty Cycle)

2- %75 Duty Cycle

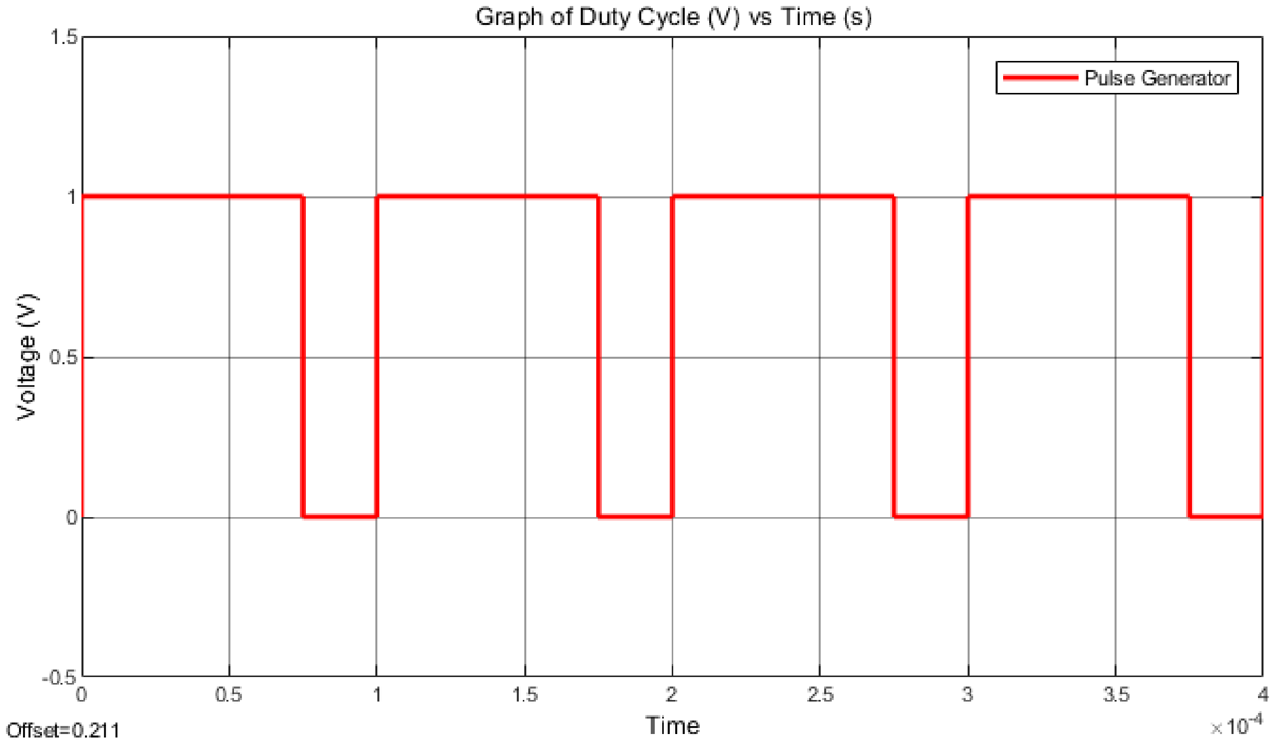


Figure 10: Graph of Duty Cycle (V) vs Time (s) (%75 Duty Cycle)

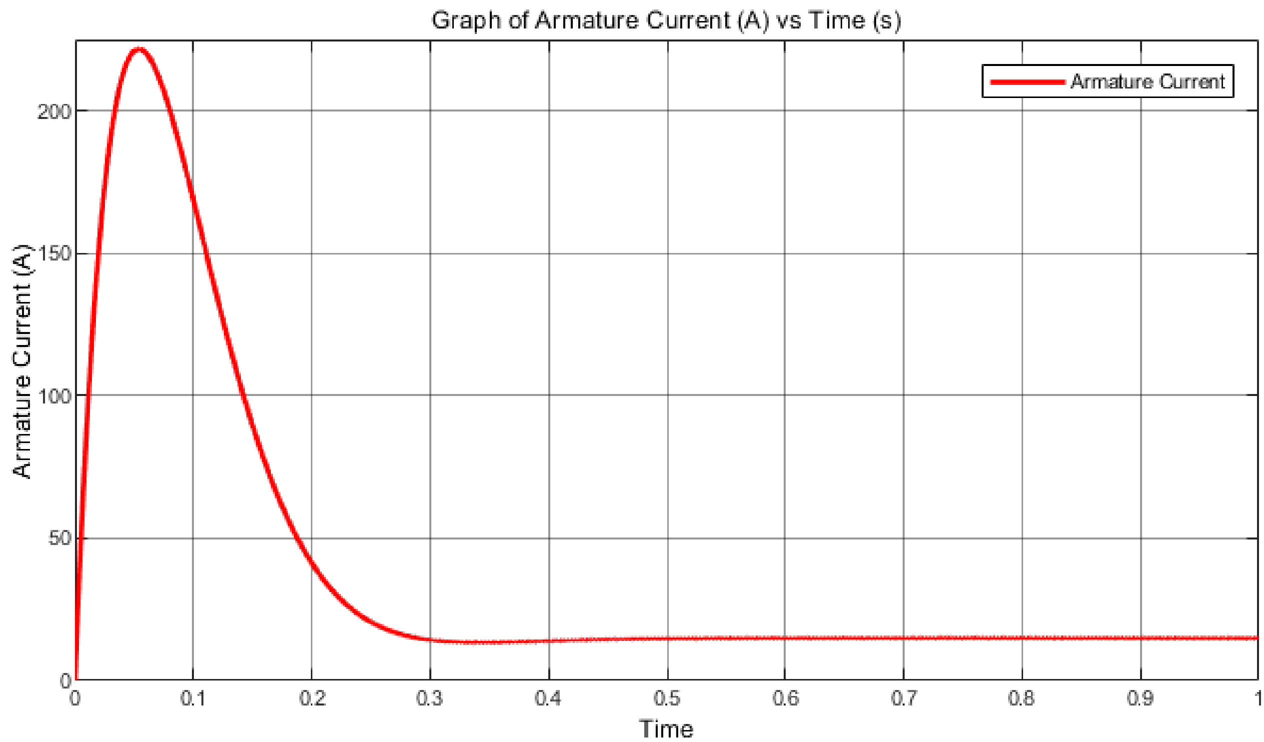


Figure 11: Graph of Armature Current (A) vs Time (s) (%75 Duty Cycle)

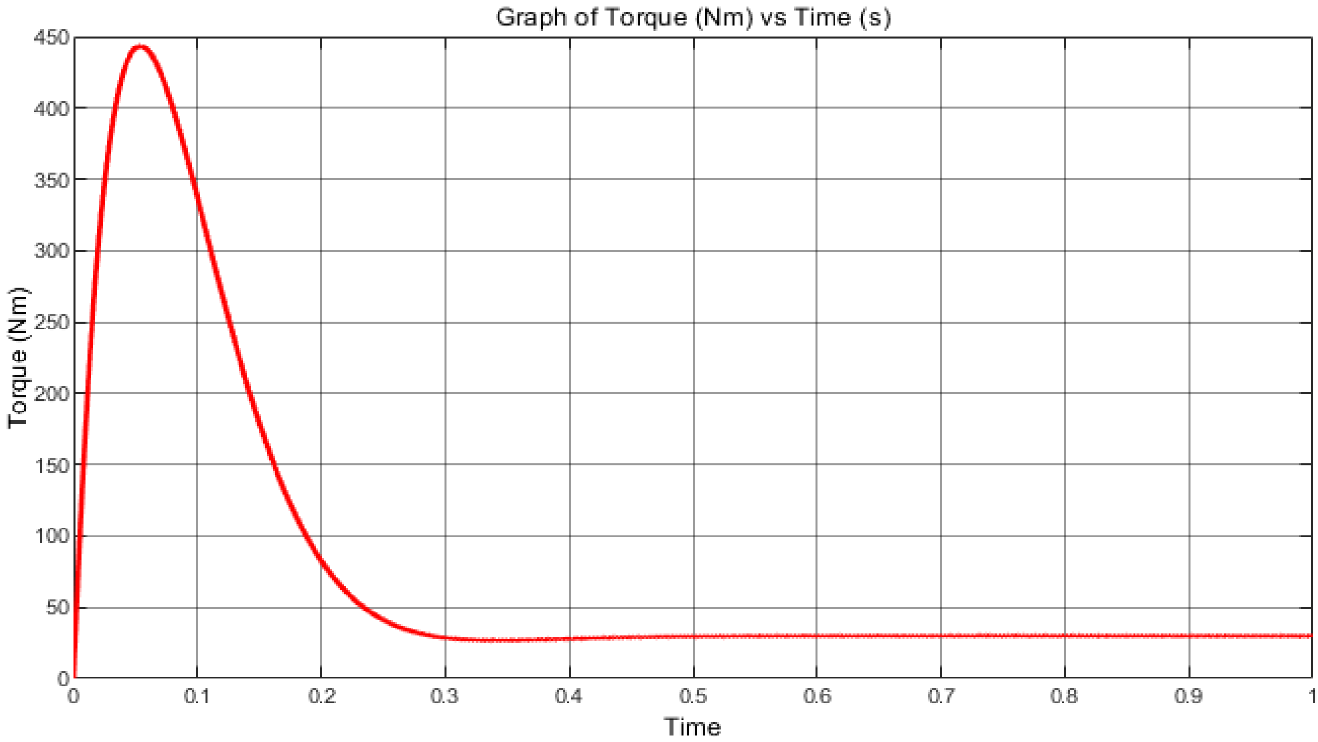


Figure 12: Graph of Torque (N.m) vs Time (s) (%75 Duty Cycle)

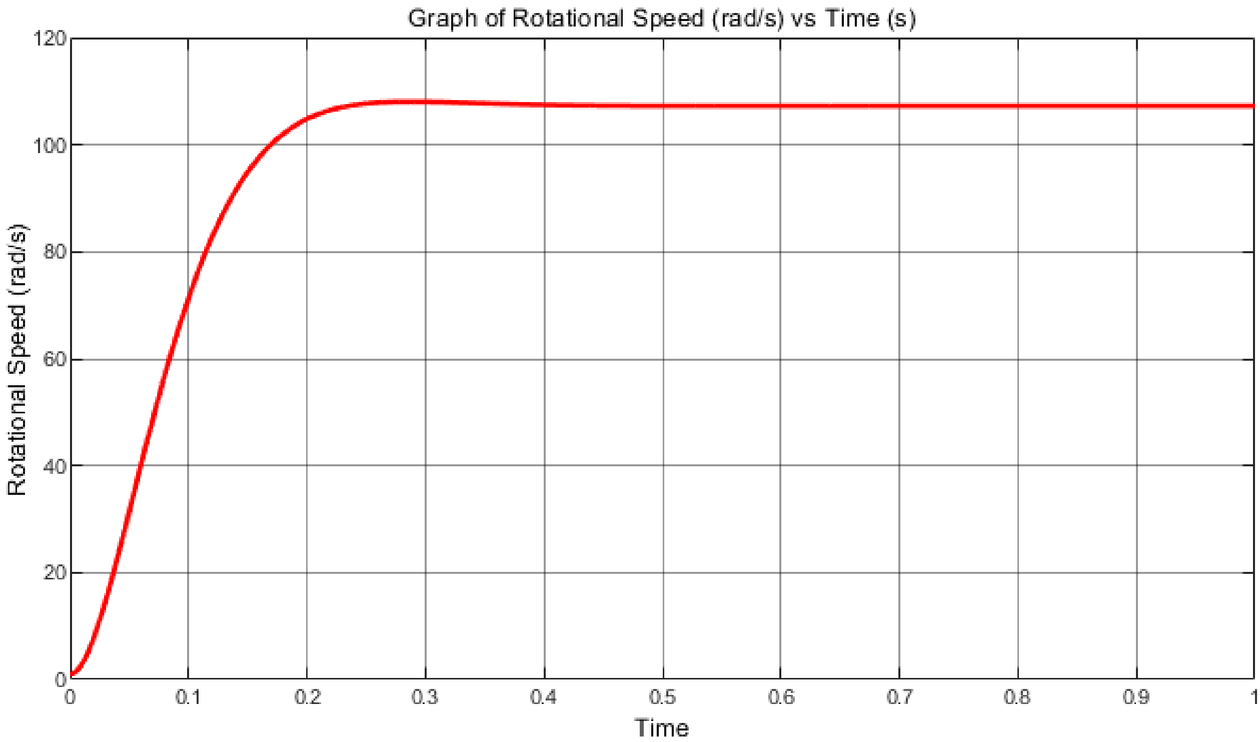


Figure 13: Graph of Rotational Speed (rad/s) vs Time (s) (%75 Duty Cycle)

3- %100 Duty Cycle

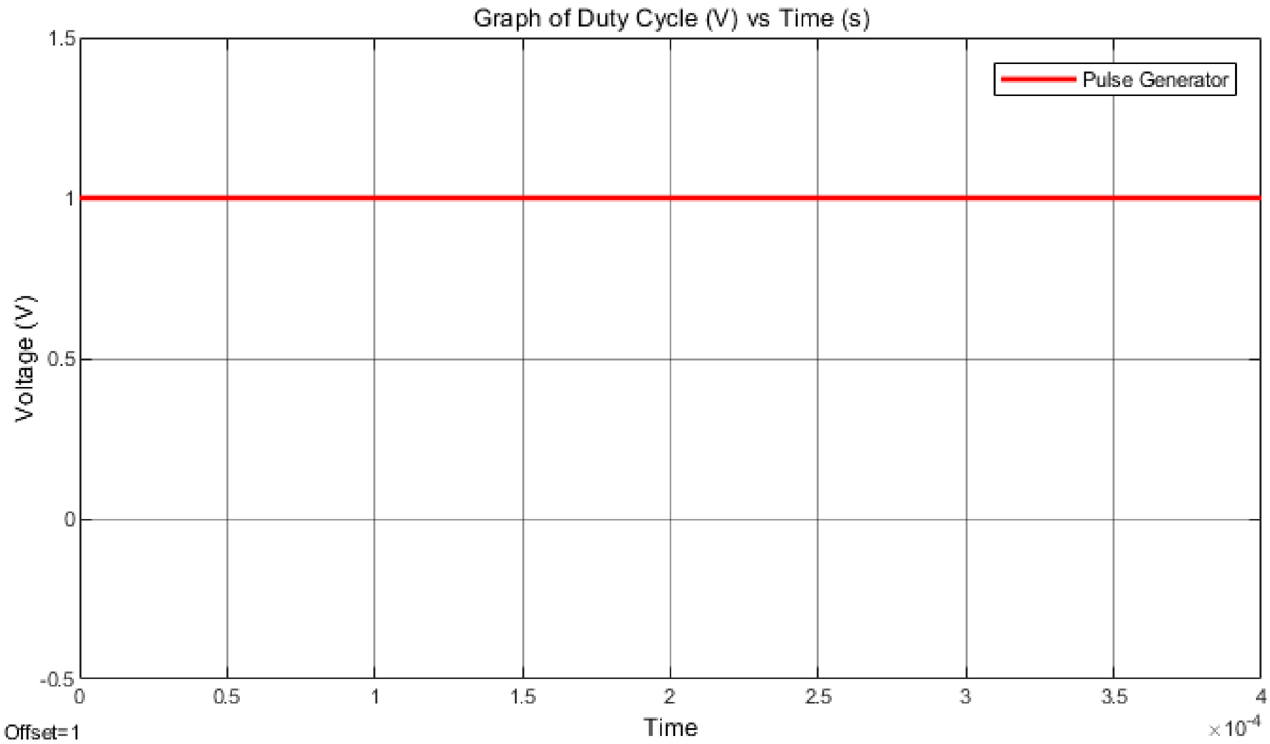


Figure 14: Graph of Duty Cycle (V) vs Time (s) (%100 Duty Cycle)

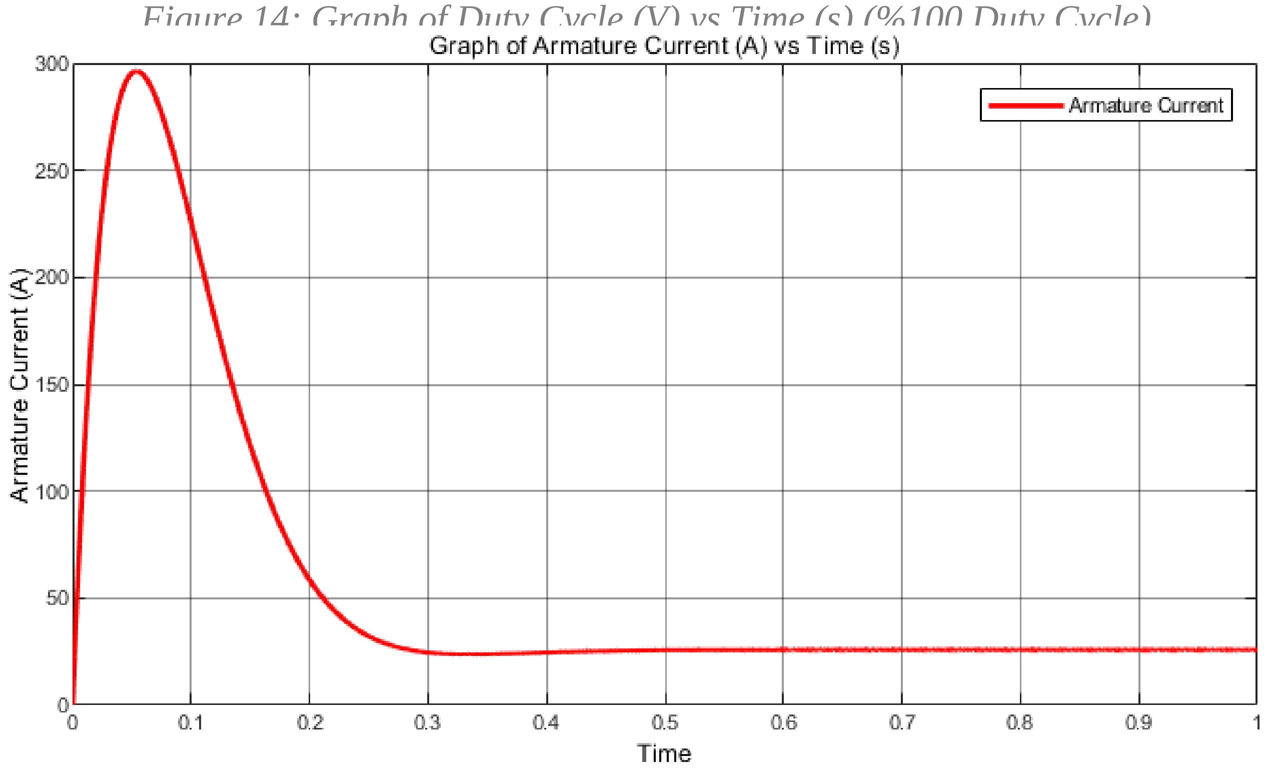


Figure 15: Graph of Armature Current (A) vs Time (s) (%100 Duty Cycle)

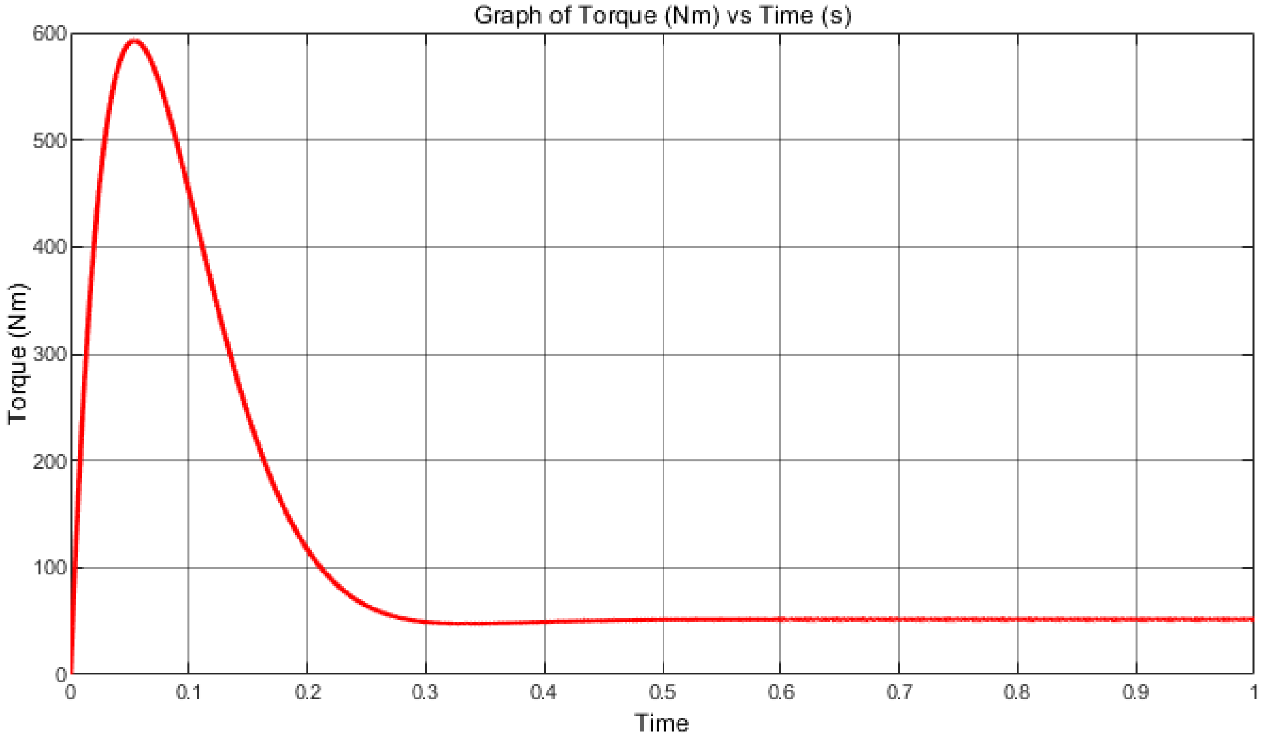


Figure 16: Graph of Torque (N.m) vs Time (s) (%100 Duty Cycle)

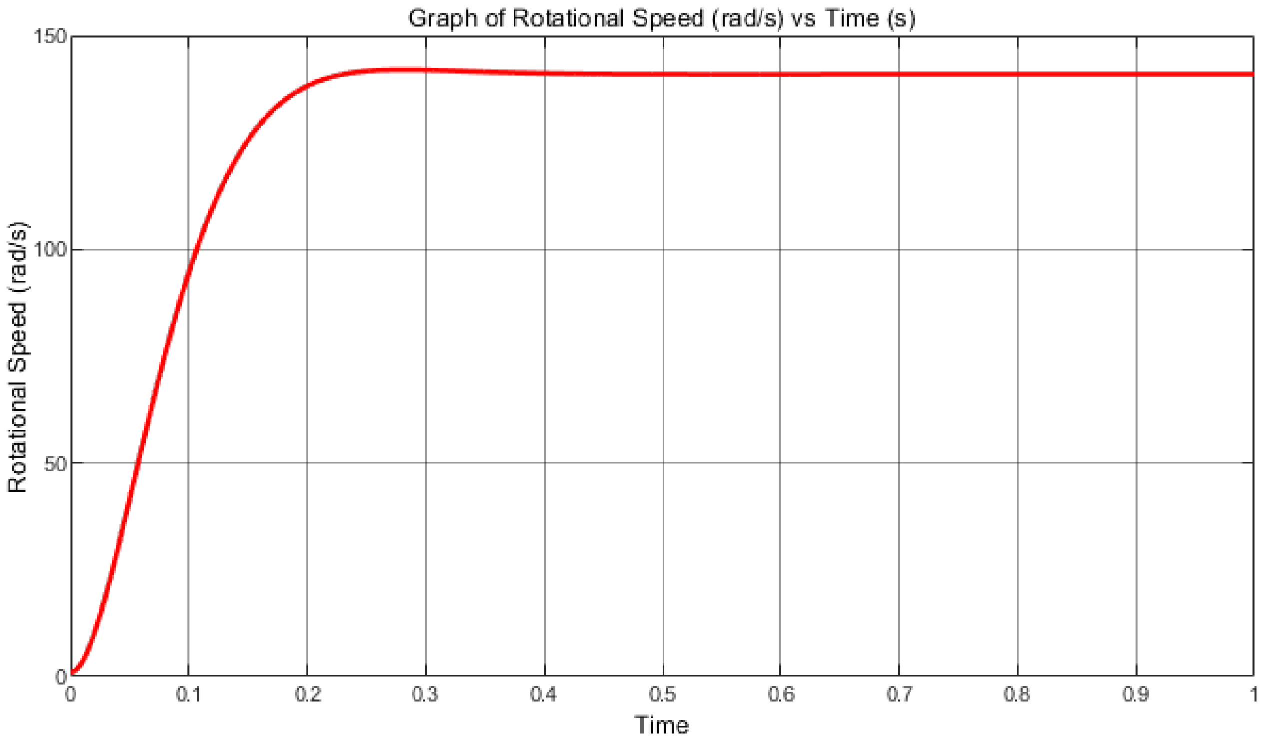


Figure 17: Graph of Rotational Speed (rad/s) vs Time (s) (%100 Duty Cycle)

Comment: When we increase the duty cycles, armature terminal voltage increases as we expected. Increase in armature terminal voltage causes increase in rotational speed of the DC motor because back EMF is direct proportional with rotational speed from equation 12 in figure 18. Also, we are given that load torque is proportional with speed of the motor. That's why, when duty cycle goes up, load torque also increases. Moreover, as we can easily see from figures 8, 12 and 16, the torque of the motor sharply increases and just after sharply decreases before reaching the steady state since back EMF of the DC motor initially is zero. It's known that armature current is calculated as (Vt – Ea)/Ra from equation 14 in figure 18. This explains why armature current and also torque sharply increase before reaching steady state.

The back emf equation:

$$E_a = K_a \phi_p \omega_m \tag{12}$$

The torque equation:

$$T = K_a \phi_p I_a \tag{13}$$

Terminal voltage equation:

$$V_t = E_a + r_a I_a \tag{14}$$

Figure 18: DC Motor Equations

d.

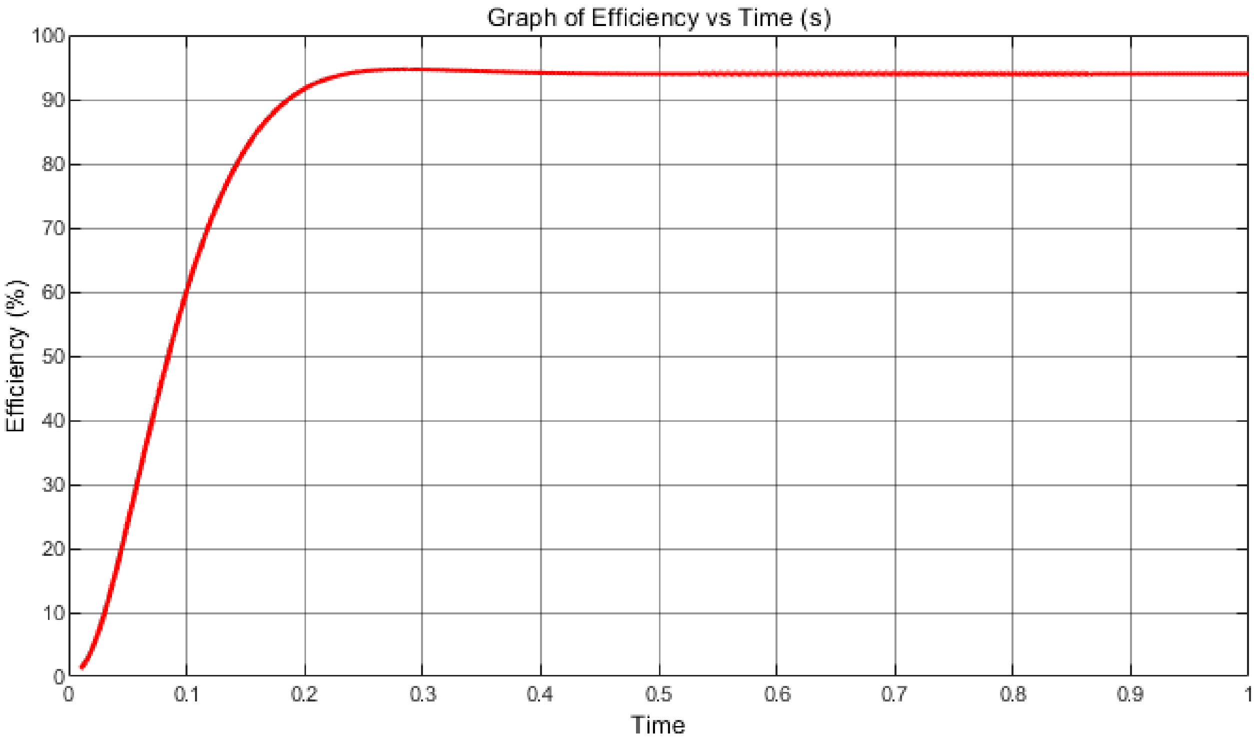


Figure 19: Graph of Efficiency vs Time (s)

Comment: Efficiency of motor is too low before reaching steady state. This is caused by high armature current that results in high copper losses. Motor doesn't generate enough back EMF at low speed, this explains why armature current makes peak. As it can bee seen from figure 19, DC motor has efficiency of around %93.

e.

Comment: Because inductive effect of the DC motor balances the power factor.

3.

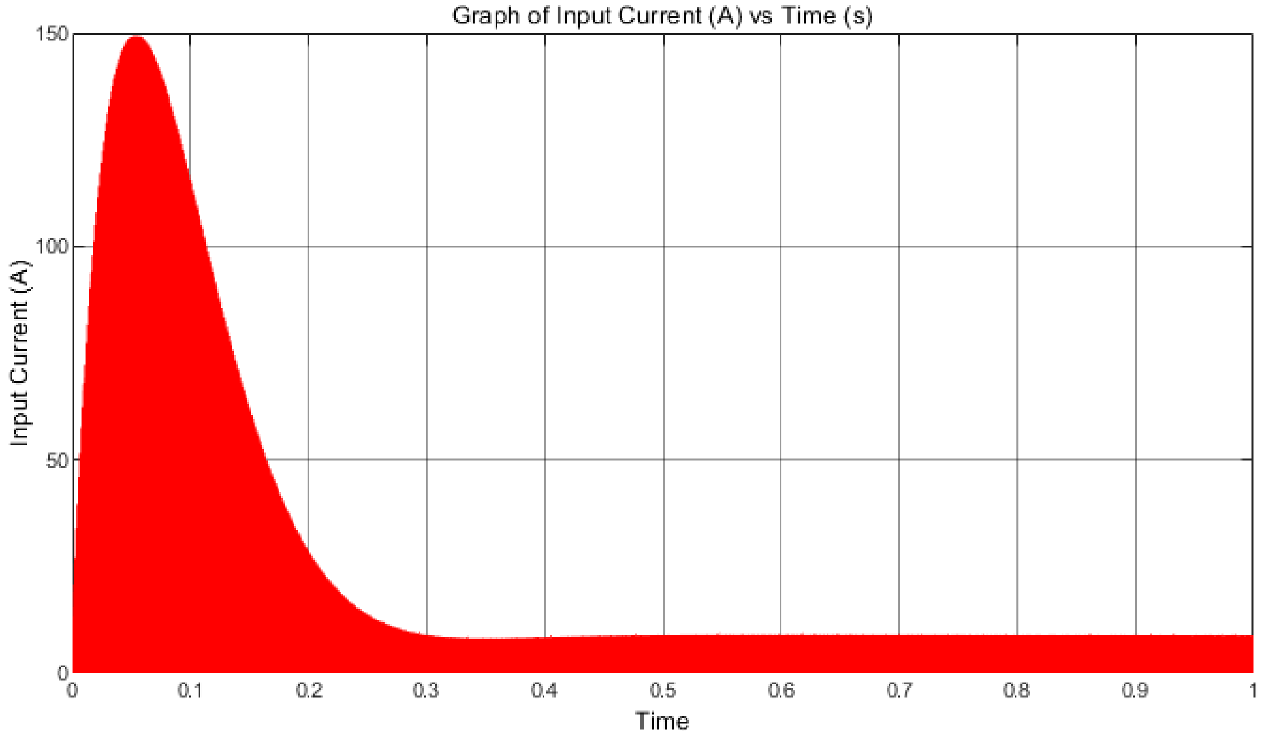


Figure 20: Graph of Input Current (A) vs Time (s) with 25kHz switching frequency and %50 duty cycle

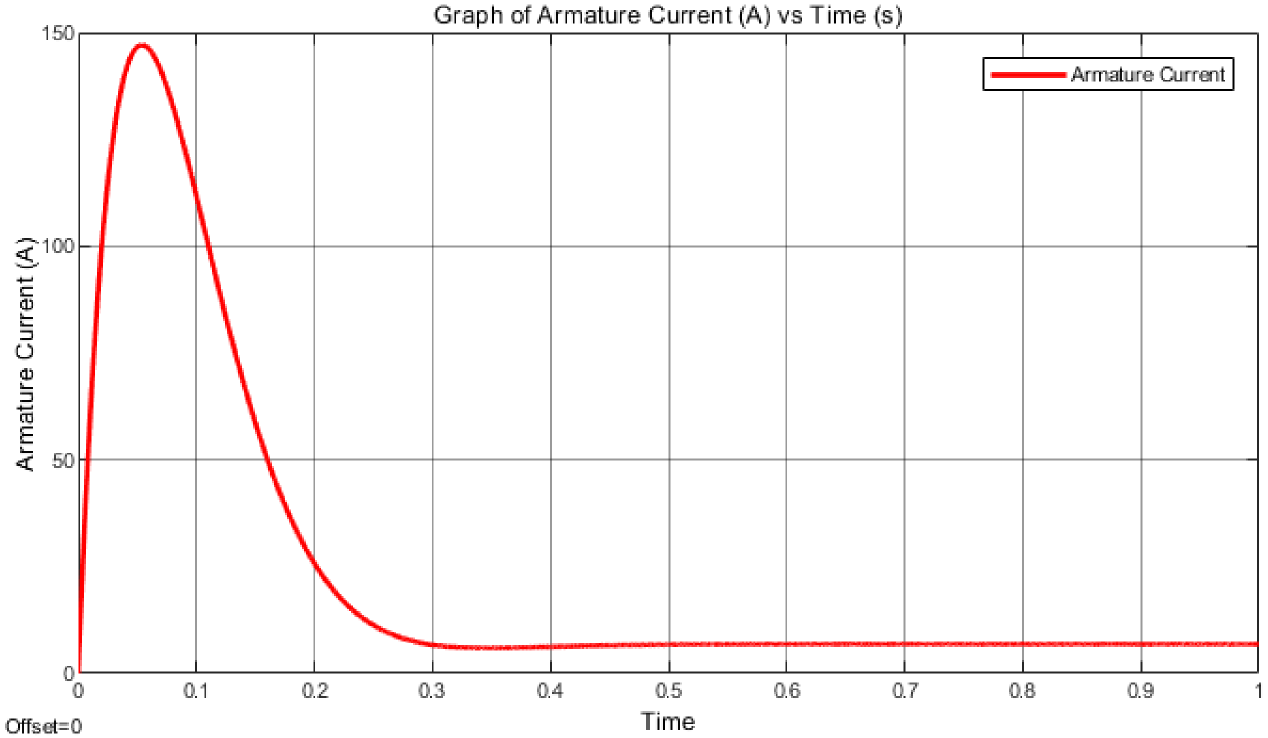


Figure 21: Graph of Armature Current (A) vs Time (s) with 25kHz switching frequency and %50 duty cycle

Comment: There is no explicit difference between 10kHz and 25kHz switching frequency because 10kHz is already high enough. As it can be seen from Figure 22 & 23, when switching frequency increases ripple armature current decreases as we expected. Also, efficiency of the system rises slightly.

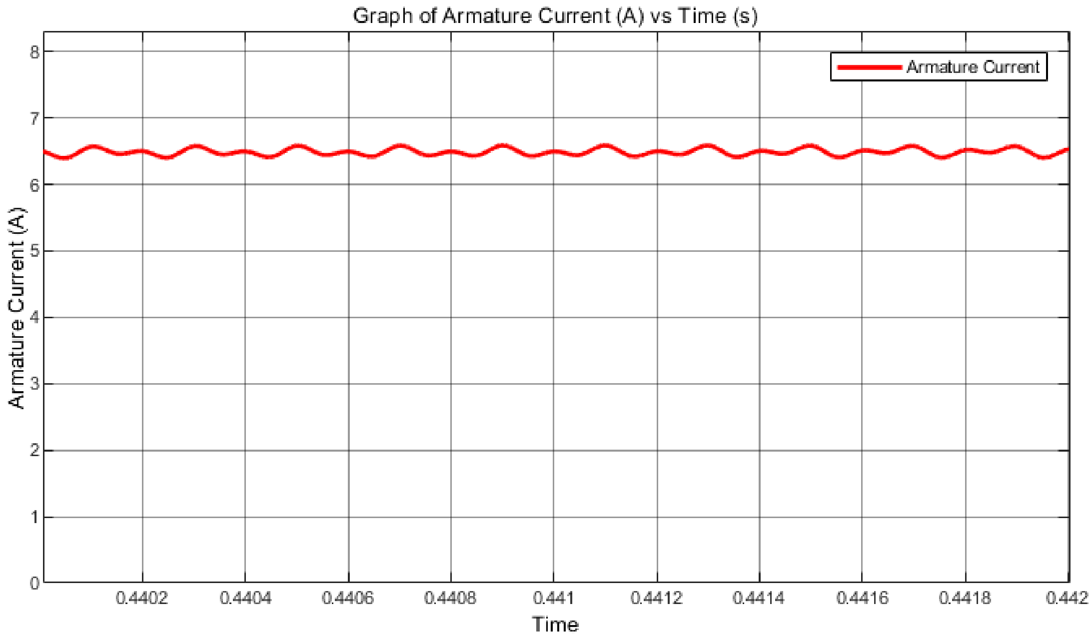


Figure 22: Graph of Input Current (A) vs Time (s) with 10kHz switching frequency

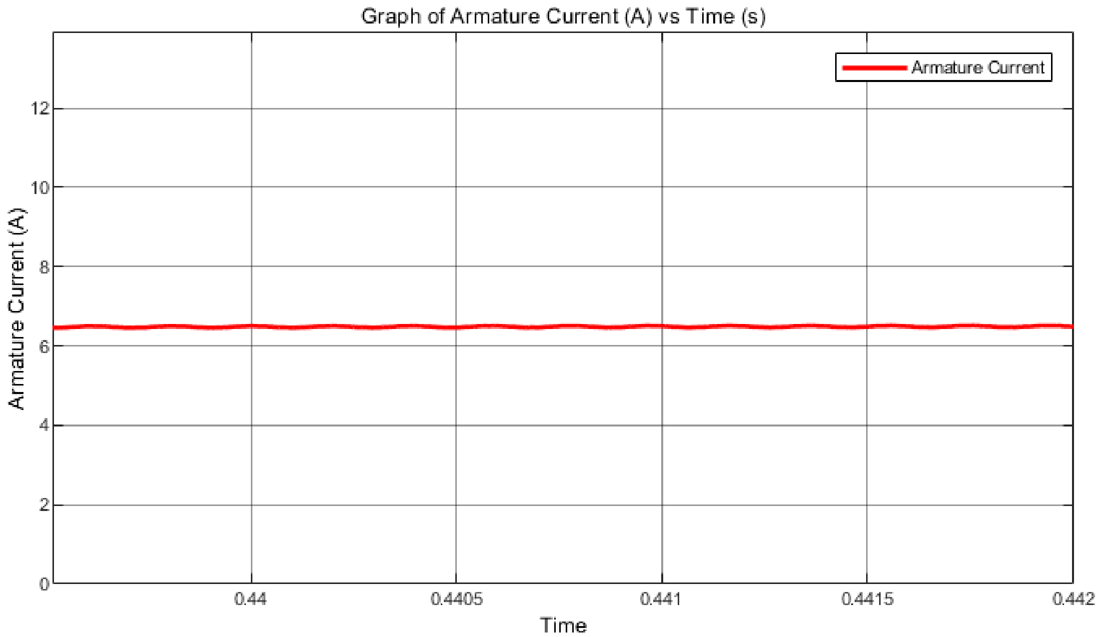


Figure 23: Graph of Input Current (A) vs Time (s) with 25kHz switching frequency