EE463 Static Power Conversion I -Simulation Project II

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Introduction

In this simulation project, we investigated single phase and three phase controlled rectifier topologies. The differences, pros and cons of fully controlled and hald controlled single phase rectifier topologies discussed Q1. First part of the Q2 we used 3 phase full wave rectifier for driving DC motor. The speed, torque and armature current of rectifier investigated. We propose 2 methods for improving torque ripple. Then, the efficiency and components of power losses showed. Selection of diode and rectifier module be explained part 2. At Q3 we examined an alternative rectifier topology, 12 pulse rectifier, describe its operation and application areas and we showed the differences between full wave diode rectifier.

Abbreviations

THD	Total Harmonic Distortion
Qx	x'th question
FFT	Fast Fourier Transform **PCC**
Point of Common Coupling	
l-l	Line to Line
pf	Power Factor
RMS	Root Mean Square

Question 1

Part a

Single Phase Fully Controlled Rectifier

Analytical calculations are following;

$$\frac{1}{T}\int_{\alpha}^{\pi+\alpha} v_d dt = \frac{r_d}{T}\int_{\alpha}^{\pi+\alpha} i_d dt + \frac{L_d}{T}\int_{I_d(\alpha)}^{I_d(\pi+\alpha)} di_d$$

In the steady state waveforms with time period T, $I_d(\alpha) = I_d(\pi+\alpha)$ then we can say;

$$v_d = r_d I_d = 160V$$

$$v_d = \frac{1}{\pi}\int_{\alpha+u}^{\pi+\alpha} 230\sqrt{2} sin(\omega t) d\omega t = 160V$$

$$cos(\alpha+u) - cos(\alpha+\pi) = 1.545$$

$$cos(\alpha+u) = 0.772$$

$$\alpha+u = 39.40°$$

$$A_u = \int_{\alpha}^{u+\alpha} V_m sin(\omega t) d\omega t = \omega L_s I_d$$

$$cos(\alpha) - cos(\alpha+u) = \frac{\omega L_s I_d}{V_m}$$

$$cos(\alpha) = 0.772 + \frac{(2\pi 50)(0.5)10^{-3}(40)}{230\sqrt{2}} = 0.7913$$

$$\alpha = 37.63°$$

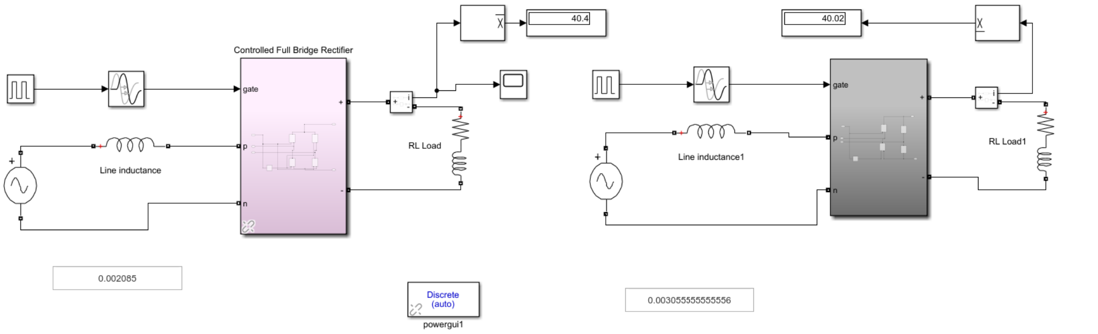


Figure 1: Simulink simulation results

Single Phase Half Controlled Rectifier

$$v_d = \frac{1}{\pi}\int_{\alpha+u}^{\pi} 230\sqrt{2}sin(\omega t)d\omega t = 160V$$

$$cos(\alpha+u) - (-1) = 1.545$$

$$cos(\alpha+u) = 0.545$$

$$\alpha + u = 56.95^{\circ}$$

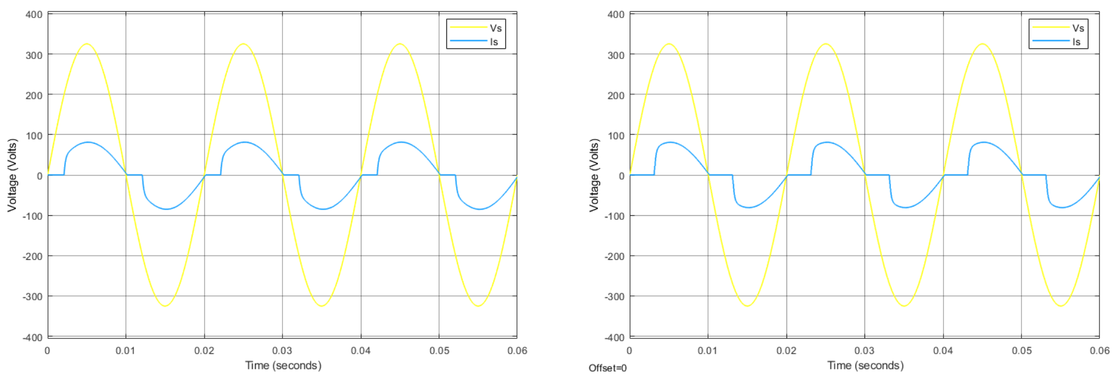
$$A_u = \int_{\alpha}^{\alpha+u} V_m sin(\omega t)d\omega t = \omega L_s I_d$$

$$cos(\alpha) - cos(\alpha+u) = \frac{\omega L_s I_d}{V_m}$$

$$cos(\alpha) = 0.545 + 0.0193 = 0.5646$$

$$\alpha = 55.625^{\circ}$$

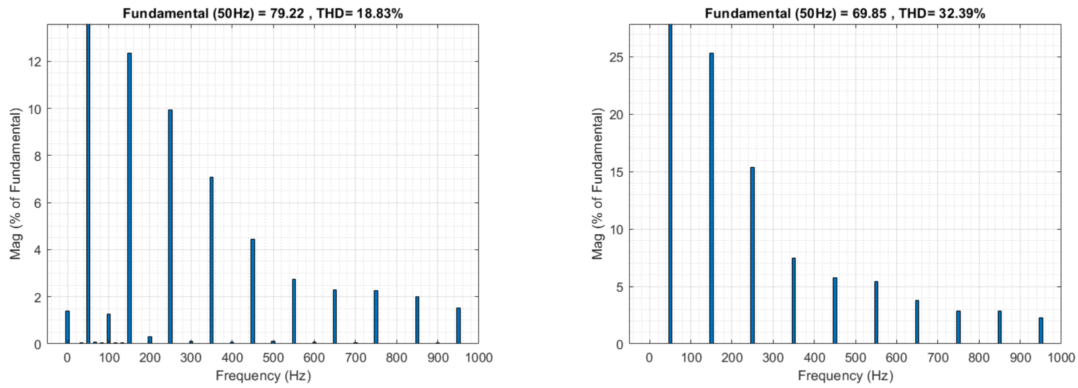
Part b



(a) Fully controlled single phase rectifier

(b) Half controlled single phase rectifier

Figure 2: Source side voltage and current waveform of both topologies



(a) Fully controlled single phase rectifier

(b) Half controlled single phase rectifier

Figure 3: Line current THD comparison of two topologies

Part c

Fully Controlled Rectifier	Half Controlled Rectifier
It provide negative output voltages at output	It can not provide negative output voltage
It can work both rectifier and inversion modes	It has less thyristors, less gate driver
	Diodes are working as free wheeling dioded so there is no need for extra diodes

Table 1: Comparison of half and full controlled rectifier

Question 2

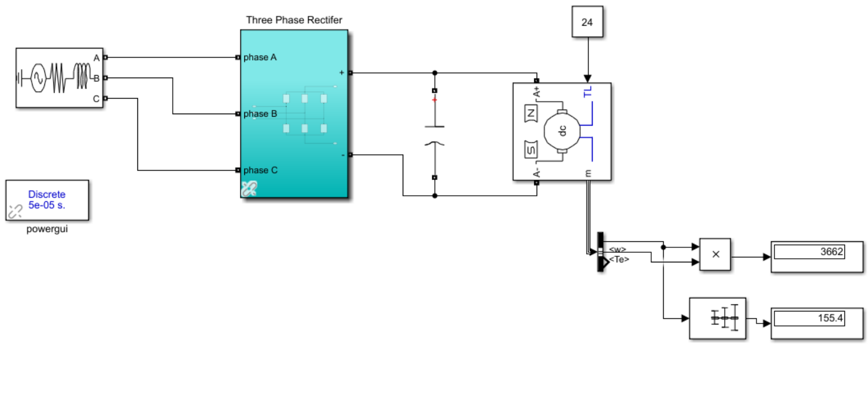
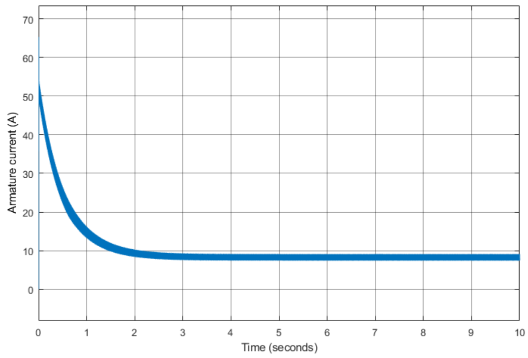
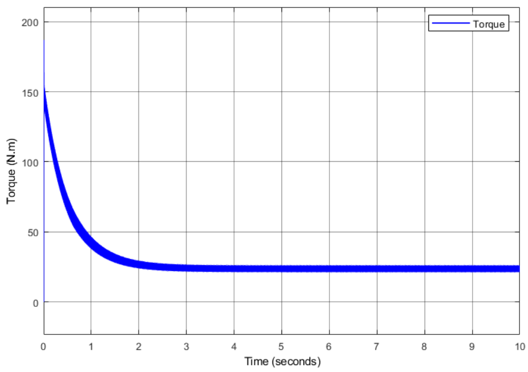


Figure 4: Simulink model for Q2

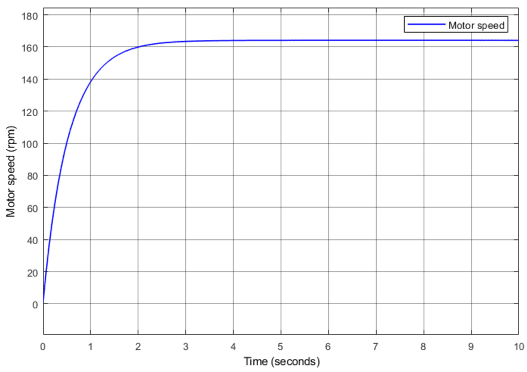
Part 1



(a) Armature current



(b) Torque



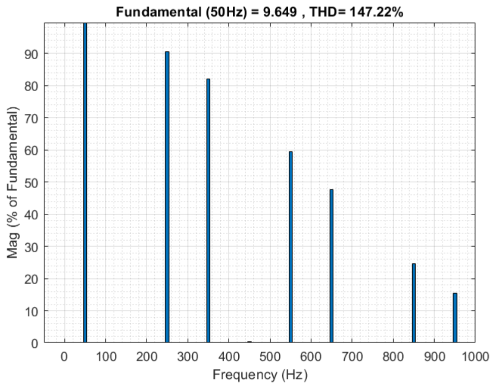
(c) Motor Speed

Figure 5: DC motors output characteristics

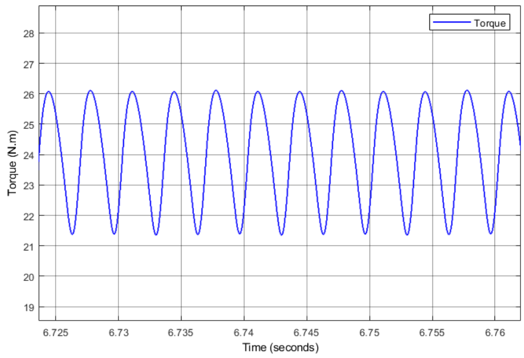
Part 2

The frequency of torque ripple is 300 Hz. The reason is that the torque of DC motor is directly related with armature current. Since the output ripple of 3 phase diode rectifier is 300 Hz and the load is simply RLC (load can not change frequency, only the magnitude and phase of the ripple can be effected by load.) armature current has same ripple frequency, 300 Hz. The magnitude of the torque ripple is 4.5 N.m when DC bus capacitor is 470 μF.

THD of line current is % 144.22. When we analyze the FFT of line current, we didn't see any third harmonics components (3rd,9th..) since we have balanced three phase system.



(a) THD of line current

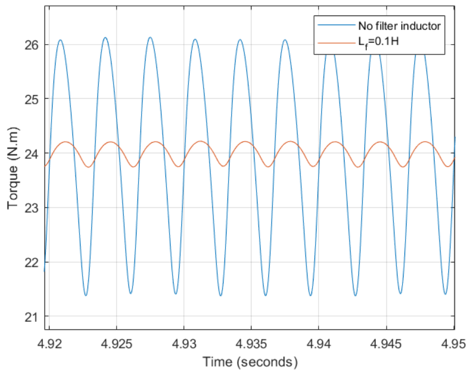


(b) Torque ripple at steady state

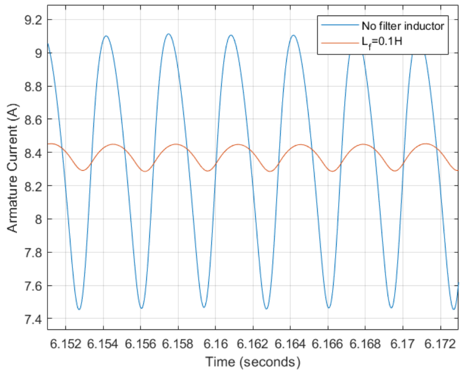
Figure 6: THD of line current and torque ripple at the output

Part 3

Adding line inductor armature side



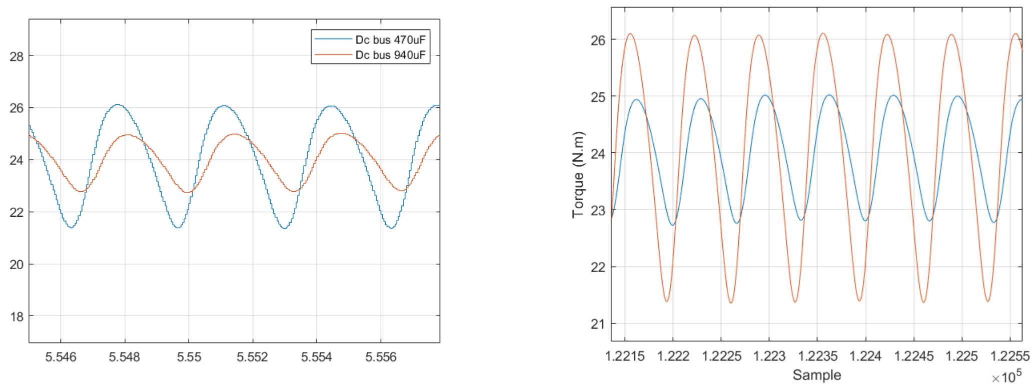
(a) Torque



(b) Armature current

Figure 7: The effect of adding filter inductor to armature side

Improving DC bus capacitor



(a) THD of line current (b) Torque ripple at steady state

Figure 8: THD of line current and torque ripple at the output

Pros	Cons
It significantly reduce armature current ripple, thus torque ripple	Bulky inductor and DC bus capacitor increases driver volume drastically.
More robust when we think closed loop system control as alternative	Power density of driver decreased

Table 2: Pros and Cons of adding passive filtering elements to the output

Part 4

$$\eta = \frac{P_{mech}}{P_{elec}} = \frac{T\omega}{3V_{rms}I_{rms}pf} = \frac{3939.36}{4692} = 0.8395$$

Cupper losses

Cupper losses can happen on armature resistance,r_a ,source resistance,r_s or diode on resistance,r_{on}. Passive elements like capacitors and inductors have also parasitic resistance components, but since we didn't model them in simulation we didn't calculate their losses.

$$P_{r_a} = I_{a_{rms}}^2 r_a$$
$$P_{r_{on}} = I_{d_{rms}}^2 r_{on}$$
$$P_{r_s} = I_{s_{rms}}^2 r_s$$

Switching losses

Mechanical losses

When we calculating overall efficiency, we also look at mechanical losses like friction. However, we didn't model viscous friction at DC Machine model (B = 0 N.m.s).Therefore, there is no mechanical loss in this model.

Question 3

References