MIDDLE EAST TECHNICAL UNIVERSITY

ELECTRICAL AND ELECTRONICS ENGINEERING DEPARTMENT

EE463 STATIC POWER CONVERSION-I

EXPERIMENT #3

SINGLE-PHASE FULL-BRIDGE THYRISTOR RECTIFIER

EXPERIMENT DATE: 07.12.2018

FRIDAY MORNING

Team Members

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EQUIPMENT LIST

- Resistive Load Bank 1 3ϕ, each resistor 192 Ω, 250W
- Inductive Load Bank 1 3ϕ, each inductor 0.61H, 250VAR
- Autotransformer 1 3ϕ, 240 V, 8 A
- Oscilloscope 1 TPS2024 with four isolated channels
- Thyristor Based Converter Module 1 Semikron, SemiTeach Module; Thyristor: 1200V 55A, Diode: 1200V 47A.
- DC Power Supply 1 GW Instek, 40V 5A

INTRODUCTION

In this experiment, we examined the single phase rectifier under different firing angles and different types of load. First part of experiment, we observed some waveform of single phase thyristor rectifier with resistive load. In second part, we changed the load type to R-L. Again, we obtained some waveforms and we observed their differences. In third part, to observe commutation effect of single phase rectifier, we added inductor to source side and we observed commutation effect on input current. Finally, we used this rectifier with freewheeling diode. Freewheeling diode effect is that single phase did not go to negative region and we eliminate the inverter operation.

Single-Phase Full-Bridge Fully-Controlled Thyristor Rectifier Feeding a Resistive Load

Laboratory Data and Graph

		AC SIDE (INPUT) MEASUREMENTS						DCSIDE (OUTPUT) MEASUREMENTS			
		V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	Q_{IN} (VAR)	P.F	Φ	I_{IN} THD-F (%)	V_{OUT} (V_{AVG})	$V_{O,RIPPLE}$ (V_{P-P})	I_{OUT} (A_{AVG})	P_{OUT} (W)
R Load	$\alpha=0^\circ$	150	2.83	425	28.5	0.99	3.88	1.68	135	216	2.19	379
	$\alpha=60^\circ$	150	2.51	340	170	0.89	26.5	36.6	102	212	1.60	303

Table 1: Measurements taken during the experiment

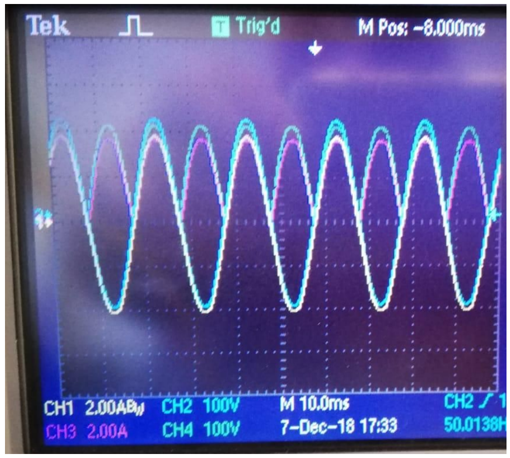

Figure 1: Output voltage, output current, line voltage and line current for α =0°

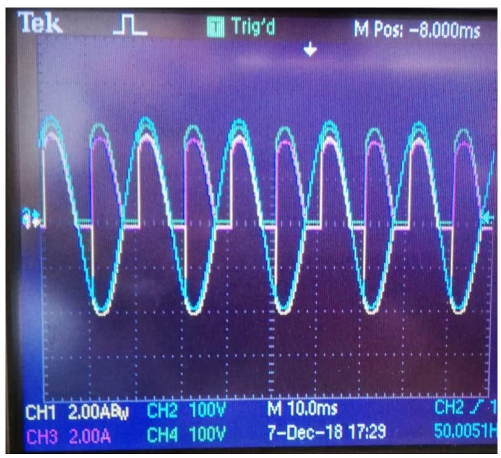

Figure 2: Output voltage, output current, line voltage and line current for α =60°

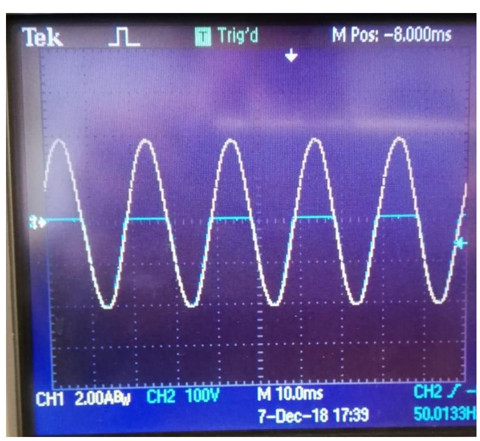

Figure 3: Thyristor voltage and line current for α =0°

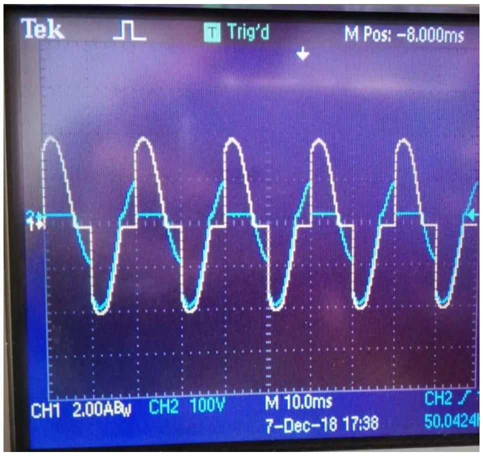

Figure 4: Thyristor voltage and line current for α=60°

Simulation Graphs

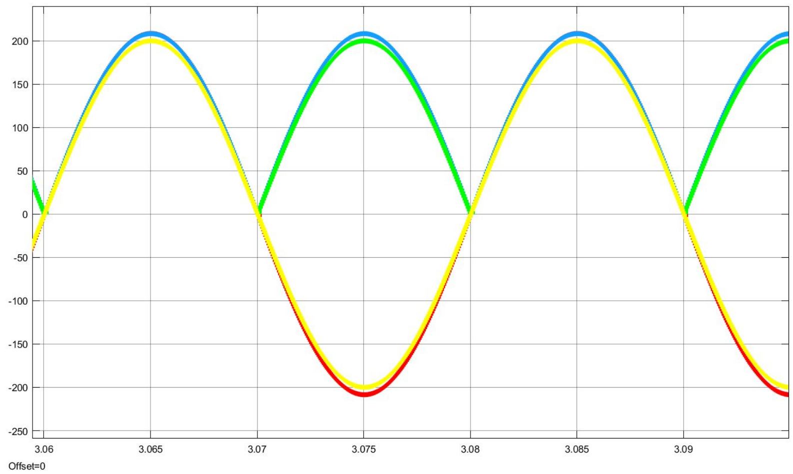

Figure 5: Simulated output voltage (green), output current (x50, blue), line voltage (yellow) and line current (x50, red) for α=0°

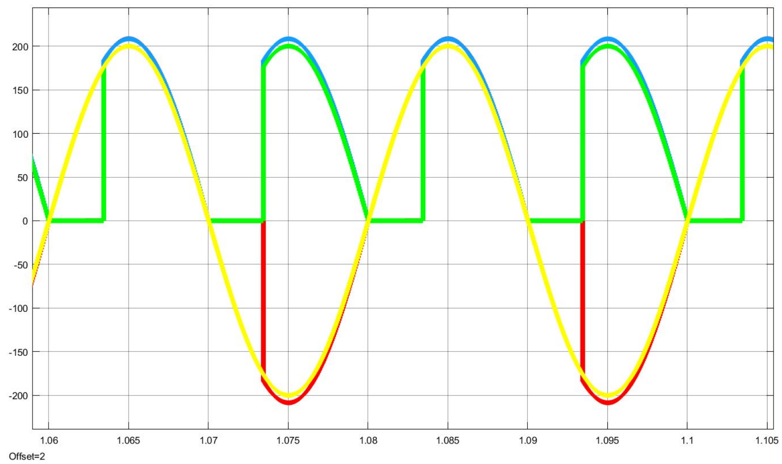

Figure 6: Simulated output voltage (green), output current (x50, blue), line voltage (yellow) and line current (x50, red) for $\alpha = 60^{\circ}$

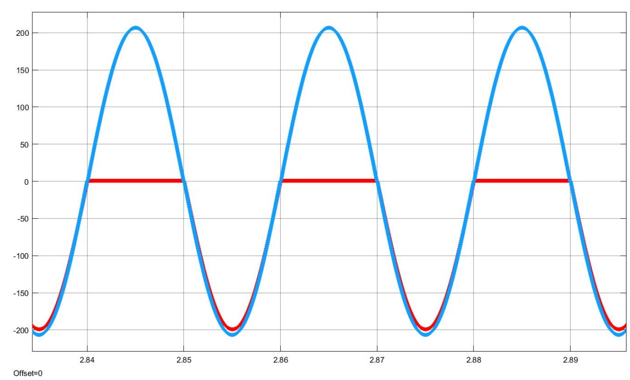

Figure 7: Simulated input current (x50, blue) and thyristor voltage (red) for $\alpha = 0^{\circ}$

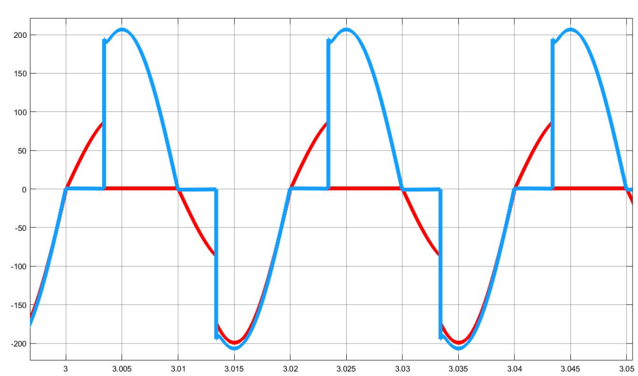

Figure 8: Simulated input current (x50, blue) and thyristor voltage (red) for $\alpha = 60^{\circ}$

Theoretical Approach

$$V d = \frac{1}{\pi}\int_{a}^{\pi} V m * sin(wt)dwt = \frac{V m}{\pi}[- cos(\pi) \ - \ (- cos(\alpha))]$$

$$V d = \frac{V m}{\pi}(1 \ + \ cos(\alpha) \ )$$

Theoretically, Vm=200 V for $\alpha = 0$ degree. Hence, Vd=127.234 V.

for $\alpha = 60$ degree. Hence, Vd=95.493 V.

Similarly Vripple is founded as 200 V.

The Average output current, Id= $\frac{V d}{R}$

Where R=48 ohm. for $\alpha = 0$ degree. Hence, Id=2.65 A.

for $\alpha = 60$ degree. Hence,Id=1.99 A.

- **Comment of part 1.3.1 R load**

at $\alpha = 0$ degree

Because of R(pure resistive) load, Distortion factor on sinusoidal current does not exist.Therefore total distortion factor, THD of input current is approximate 0. Moreover, as expected, we approximately found zero phase angle , then unity power factor.

at $\alpha = 60$ degree

As seen figure x, when we set firing angle as 60 degree, 0-60 and 180-240 degree, current is discontinuous because of distortion factor. Therefore there exists phase difference,then input current of waveform shift , hence displacement power factor decreases. Moreover, because of discontinuity between 0-60 and 180-240 degree, average voltage (R*Id) and output power(Id*Id*R) decrease.

Single-Phase Full-Bridge Fully-Controlled Thyristor Rectifier Feeding an R-L Load

Laboratory Data and Graph

		AC SIDE (INPUT) MEASUREMENTS							DCSIDE (OUTPUT) MEASUREMENTS			
		V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	Q_{IN} (VAR)	P.F	Φ	I_{IN} THD-F (%)	V_{OUT} (V_{AVG})	$V_{O,RIPPLE}$ (V_{P-P})	I_{OUT} (A_{AVG})	P_{OUT} (W)
R-L Load	$\alpha=0^{\circ}$	143	3.55	457	217	0.9	25.45	41.8	127	208	3.23	412
	$\alpha=60^{\circ}$	144	3.01	327	282	0.75	40.6	36.6	107	312	2.65	287

Table 2: Measurements taken during the experiment

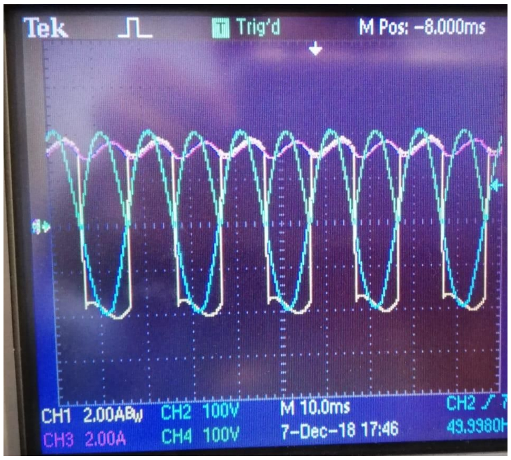

Figure 9: Output voltage, output current, line voltage and line current for $\alpha=0^{\circ}$

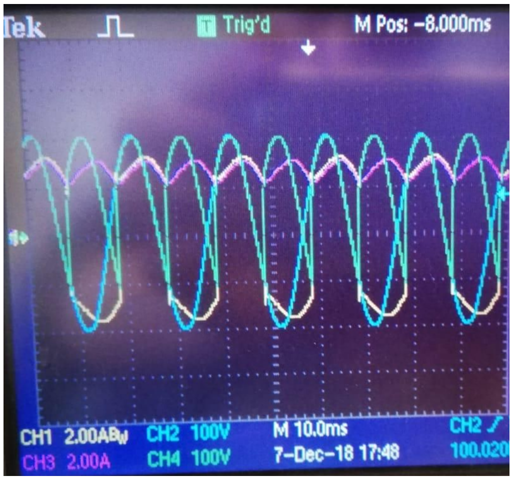

Figure 10: Output voltage, output current, line voltage and line current for $\alpha = 60^{\circ}$

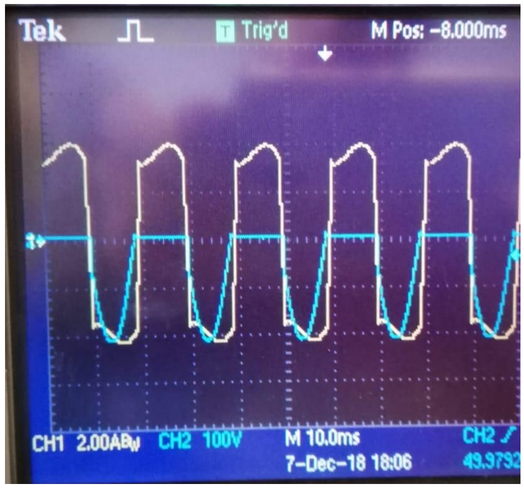

Figure 11: Thyristor voltage and line current for $\alpha = 0^{\circ}$

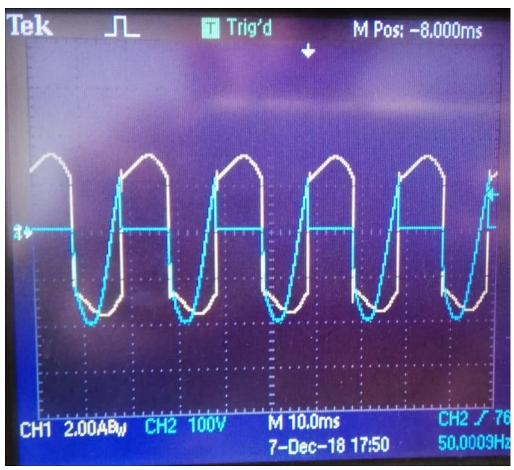

Figure 12: Thyristor voltage and line current for $\alpha = 60^{\circ}$

Simulation Graphs

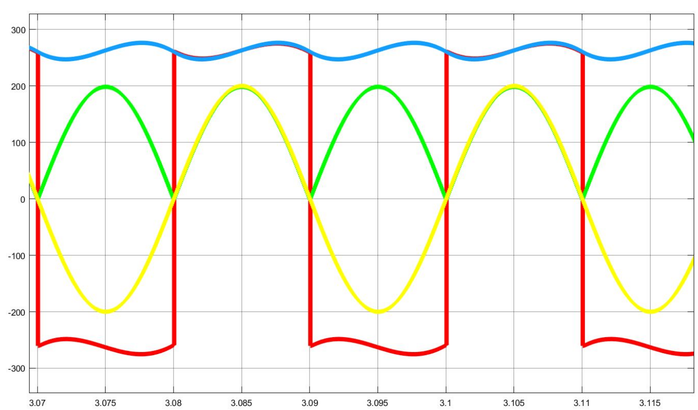

Figure 13: Simulated output voltage (green), output current (x50, blue), line voltage (yellow) and line current (x50, red) for $\alpha = 0^{\circ}$

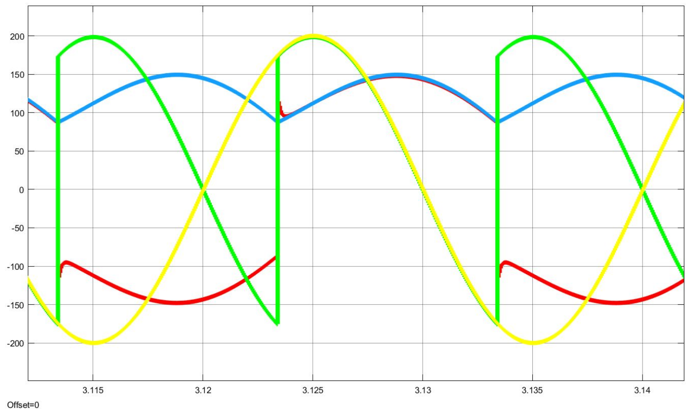

Figure 14: Simulated output voltage (green), output current (x50, blue), line voltage (yellow) and line current (x50, red) for $\alpha = 60^{\circ}$

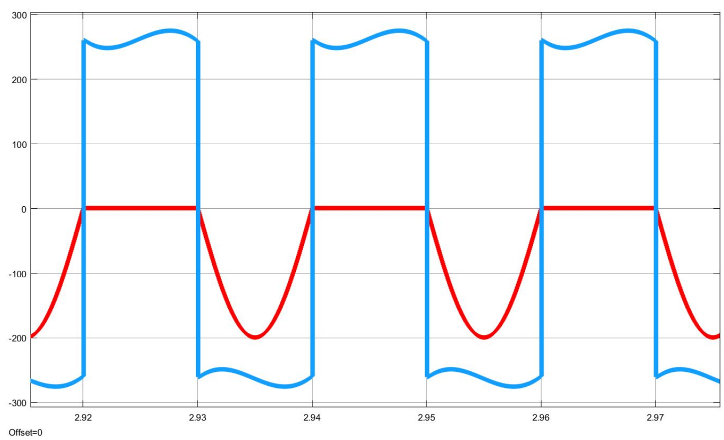

Figure 15: Simulated input current (x50, blue) and thyristor voltage (red) for $\alpha = 0^{\circ}$

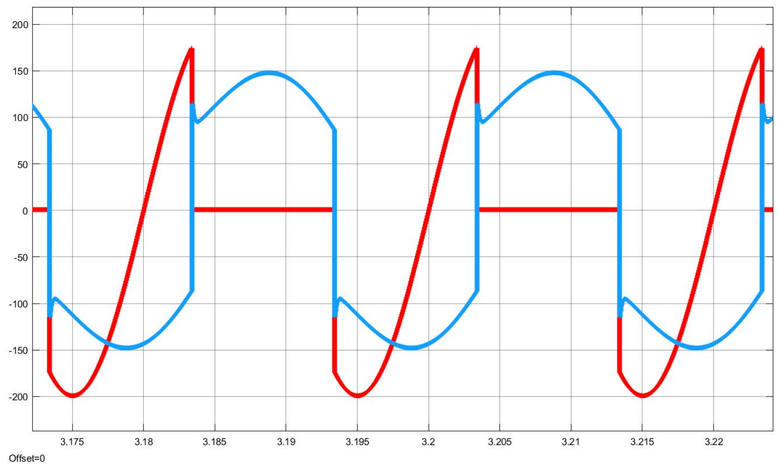

Figure 16: Simulated input current (x50, blue) and thyristor voltage (red) for α =60°

Theoretical Approach

$$Vd = \frac{1}{\pi}\int_{a}^{\pi+a} Vm * sin(wt)dwt = \frac{Vm}{\pi}[-cos(\pi + a) - (-cos(\alpha))]$$

$$Vd = \frac{2Vm}{\pi}cos(\alpha)$$

Theoretically, Vm=200 V for α = 0 degree. Hence, Vd=127.234 V.

for α = 60 degree. Hence, Vd=63.662 V.

for α = 0 degree. Hence, Vripple=95.493 V.

for α = 60 degree.Hence,Vripple=200+sin(60) V

Vripple=373.2 V

Load have also serie connected 0.5 H highly inductive load.Because of this reason, The average output current approximately equal to Rload average output current The Average output current, Id= $\frac{Vd}{R}$

Where R=24 ohm. for α = 0 degree. Hence, Id=5.3 A.

for α = 60 degree. Hence,Id=3.978 A.

- **Comment of part 1.3.2 R-L load**

Comparison between α = 0 degree and α = 60 degree

Average voltage related to cos(α), Then,when α = 60 degree, average voltage decreases. Because of Id rating with Vd, then average current also decreases. Output ripple is increases in α = 60 degree condition, related to this condition, output voltage ripple is also increases. On the other hand, ripples make input current waveform more sinusoidal. Therefore, Total Distortion Factor (THD) decreases at α = 60 degree .

Comparison between part 1.3.1(L load) and part 1.3.2 (R-L load)

In R-L load part, inductive loads tend to prevention instant change in current. Therefore, shape of input current is more similar like sinusoidal shape.Then, distortion factor decreases, Total Harmonic Distortion (THD) increases and power factor (pf) decreases.

Single-Phase Full-Bridge Fully-Controlled Thyristor Rectifier Feeding an R-L Load with AC Line Reactor

Laboratory Data and Graph

		AC SIDE (INPUT) MEASUREMENTS							DCSIDE (OUTPUT) MEASUREMENTS			
		V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	Q_{IN} (VAR)	P.F	Φ	I_{IN} THD-F (%)	V_{OUT} (V_{AVG})	$V_{O,RIPPLE}$ (V_{P-P})	I_{OUT} (A_{AVG})	P_{OUT} (W)
R-L Load and L_{AC}	α =0°	153	3.64	502	239	0.9	25.43	35.9	133	228	3.37	455
	α =60°	154	3.19	373	318	0.76	40.36	35.2	115	328	2.84	330

Table 3: Measurements taken during the experiment

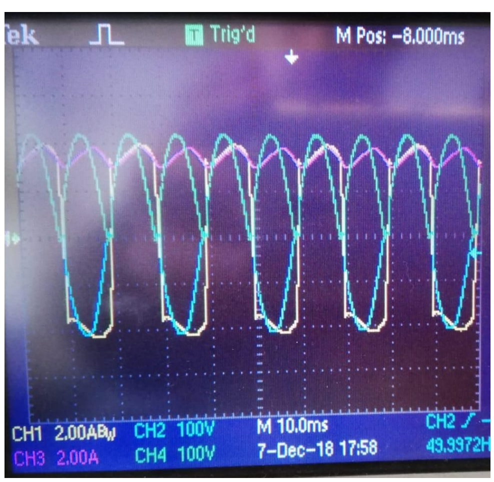

Figure 17: Output voltage, output current, line voltage and line current for $\alpha = 0^{\circ}$

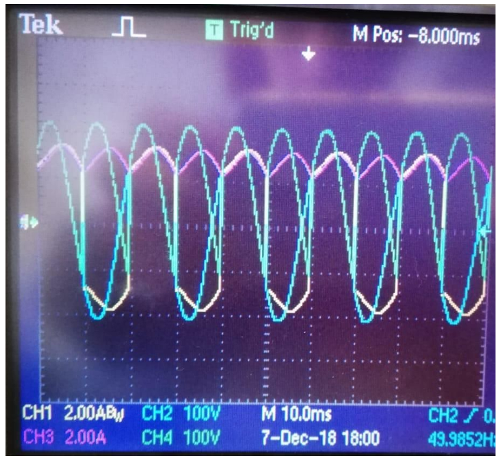

Figure 18: Output voltage, output current, line voltage and line current for $\alpha = 60^{\circ}$

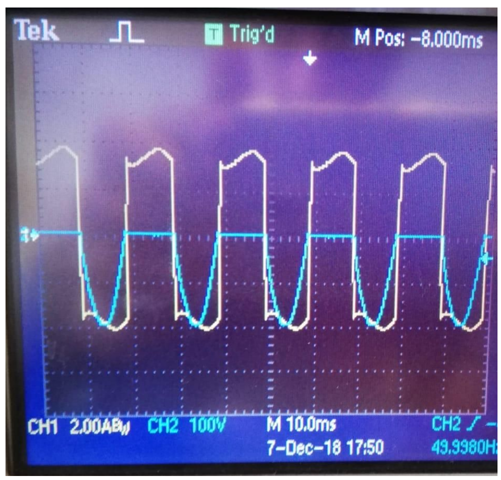

Figure 19: Thyristor voltage and line current for $\alpha = 0^{\circ}$

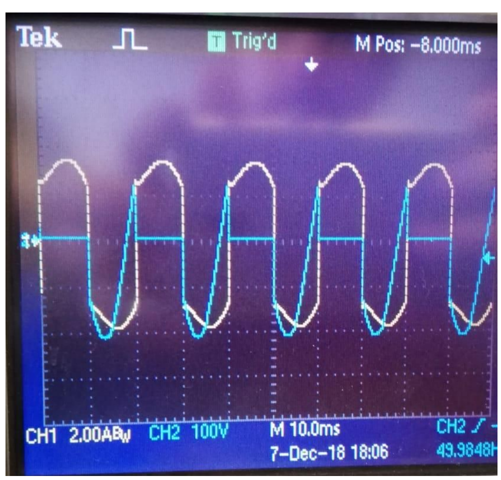

Figure 20: Thyristor voltage and line current for $\alpha = 60^{\circ}$

Simulation Graphs

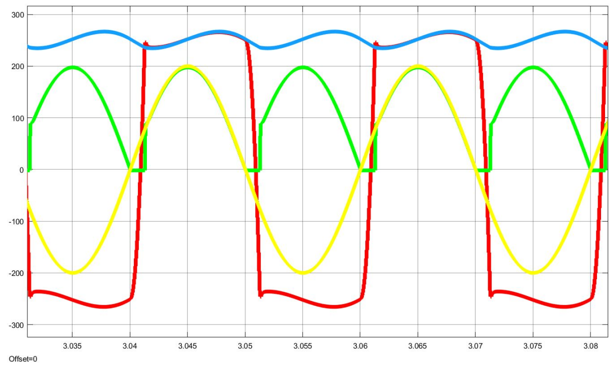

Figure 21: Simulated output voltage (green), output current (x50, blue), line voltage (yellow) and line current (x50, red) for $\alpha = 0^{\circ}$

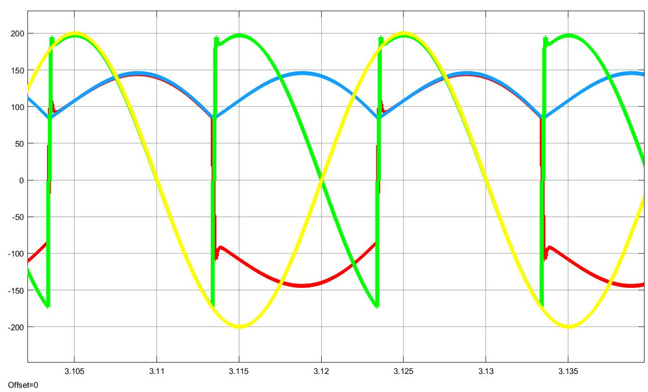

Figure 22: Simulated output voltage (green), output current (x50, blue), line voltage (yellow) and line current (x50, red) for $\alpha = 60^{\circ}$

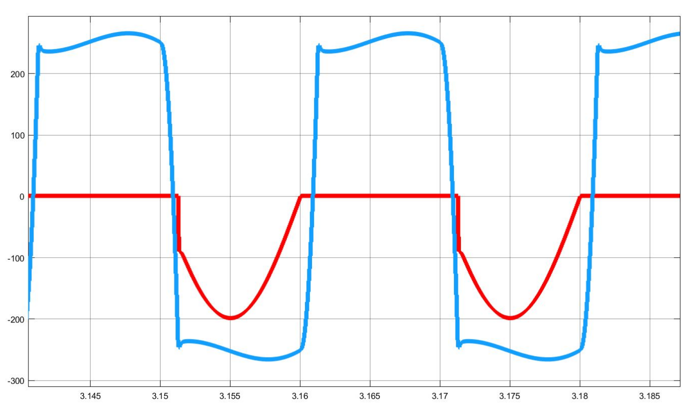

Figure 23: Simulated input current (x50, blue) and thyristor voltage (red) for α =0°

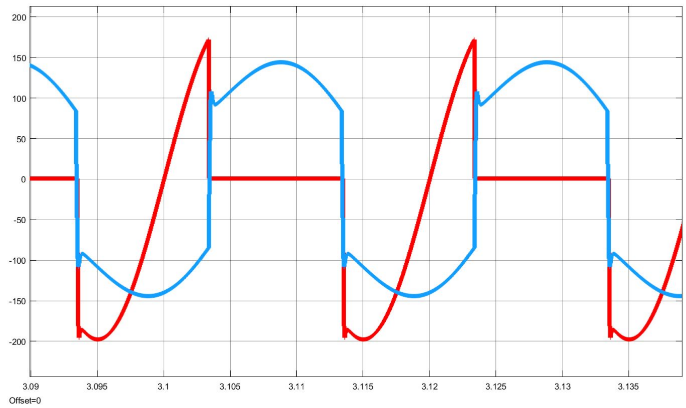

Figure 24: Simulated input current (x50, blue) and thyristor voltage (red) for α =60°

Theoretical Approach

$Vd = \frac{2Vm}{\pi}cos(\alpha) - \frac{2wLsId}{\pi}$, Au= $\frac{2wLsId}{\pi}$ is result from commutation.

- **Comment of Part 1.3.3 (with Line inductor(LS))**

with respect to equation, decreasing line inductance values, average voltage increases.Also with increasing frequency , output average voltage decreases. Because of the commutation,output voltage also decrease. Moreover, due to effect of line inductor(Ls), Input current tent to be more sinusoidal current.Because, line reactor prevent to instant change on input current.Therefore Total Distortion Factor (THD) decreases. In α = 0 degree , commutation is higher than α = 60 degree case. Because, in α = 0 degree case, voltage difference on itself.

Single-Phase Full-Bridge Thyristor Rectifier Feeding an R-L Load with AC Line Reactor and Free-Wheeling Diode (Half-Controlled)

Laboratory Data and Graph

		AC SIDE (INPUT) MEASUREMENTS							DCSIDE (OUTPUT) MEASUREMENTS			
		V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	Q_{IN} (VAR)	P.F	Φ	I_{IN} THD-F (%)	V_{OUT} (V_{AVG})	$V_{O,RIPPLE}$ (V_{P-P})	I_{OUT} (A_{AVG})	P_{OUT} (W)
R-L Load and L_{AC}	α =0°	153	3.60	497	236	0.9	25.37	35.2	133	216	3.34	447

with F.W.D	$\alpha = 60^{\circ}$	153	3.12	414	234	0.87	29.63	23.8	121	216	3	366

Table 4: Measurements taken during the experiment

Figure 25: Output voltage, output current, line voltage and line current for $\alpha = 0^{\circ}$

Figure 26: Output voltage, output current, line voltage and line current for $\alpha = 60^{\circ}$

Figure 27: Thyristor voltage and line current for $\alpha = 0^{\circ}$

Figure 28: Thyristor voltage and line current for $\alpha = 60^{\circ}$

Simulation Graphs

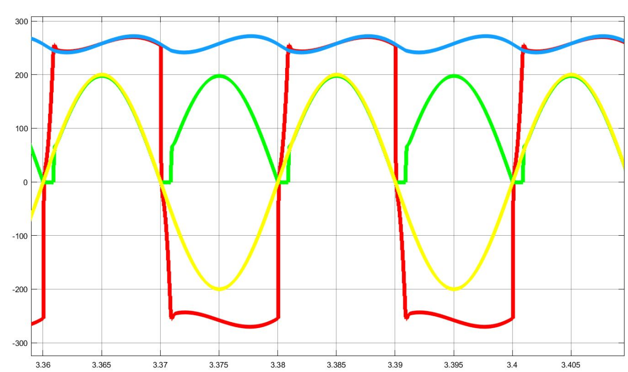

Figure 29: Simulated output voltage (green), output current (x50, blue), line voltage (yellow) and line current (x50, red) for $\alpha=0^{\circ}$

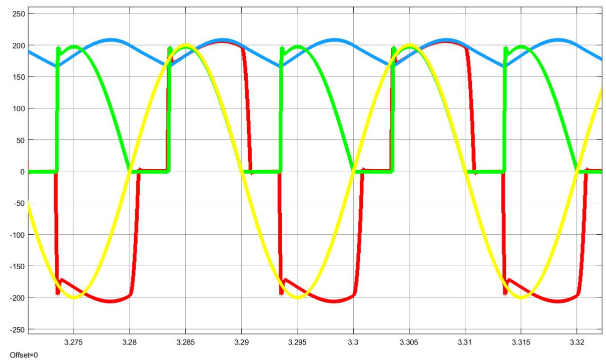

Figure 30: Simulated output voltage (green), output current (x50, blue), line voltage (yellow) and line current (x50, red) for $\alpha=60^{\circ}$

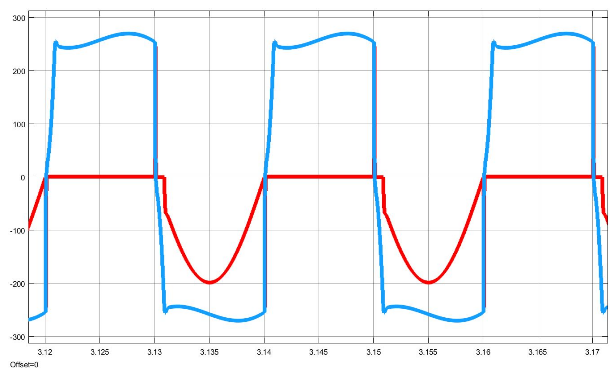

Figure 31: Simulated input current (x50, blue) and thyristor voltage (red) for $\alpha=0^{\circ}$

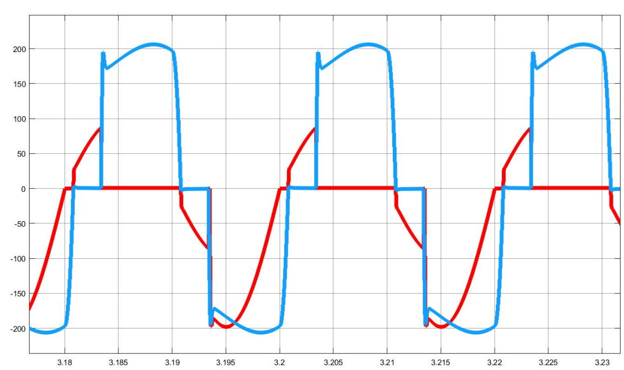

Figure 32: Simulated input current (x50, blue) and thyristor voltage (red) for $\alpha=60^{\circ}$

Theoretical Approach

$V d = \frac{1}{\pi} \int_{a+u}^{\pi} V m * sin(wt) dwt$ = $\frac{V m}{\pi}[-cos(\pi) - (-cos(\alpha + u))]$

$V d = \frac{V m}{\pi}(1 + cos(\alpha + u))$

u is result of commut

Vripple=200 V ,   R= 24ohm

-**Comment of Part 1.3.4 (freewheeling diode)**

Thanks to freewheeling, output voltage does not located below zero. Because when it try to get below zero, freewheeling diode is opened. Therefore we observe higher average output current,output voltage and output power.

if freewheeling diode is opened ,input current equal to zero.Then we get more sinusoidal shape of output current.Therefore Total Distortion factor(THD) of input current decreases.

CONCLUSION

In this report we have presented our laboratory results along with simulations results related to the experiment 3 which was about single phase controlled rectifiers. Moreover we have made the required calculations in order to analyze the converter behaviour. Also, we have provided comments on the variables that we have changed between the parts of the experiment.