MIDDLE EAST TECHNICAL UNIVERSITY
ELECTRICAL AND ELECTRONICS ENGINEERING DEPARTMENT

EE463 STATIC POWER CONVERSION-I

EXPERIMENT #4

THREE-PHASE FULL-BRIDGE THYRISTOR RECTIFIER

EXPERIMENT DATE: 14.12.2018

FRIDAY MORNING

Team Members

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EQUIPMENT LIST

- Resistive Load Bank 1 3ϕ, each resistor 192Ω, 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

Notes Before Results and Conclusions: Unfortunately, the simulated waveforms below had a 230 Vrms source voltage while in this experiment, our source voltage was 140 Vrms. But the shapes and behaviors are the more important part here.

Other than this issue, CH1,CH2,CH3,CH4 waveforms on the experimented waveforms are respectively Source Voltage(Vs), Source Current(Is), Output Voltage(Vout), Output Current(Iout).

INTRODUCTION

In this experiment, we examined the three phase rectifier under different firing angles and two types of load which are resistive and resistive - inductive. Firstly, we observed input and output waveforms of three phase thyristor rectifier with resistive load. In second part, we changed the load type to R-L. Again, we obtained input and output waveforms and we observed when load types changed, input and output waveforms changed. In third part, to observe commutation effect of three phase rectifier, we added ac line reactor to source side and we observed commutation effect. Finally, we used this rectifier with freewheeling diode. Freewheeling diode effect is that three phase did not go to negative region and we eliminate the inverter operation.

Three-Phase Full-Bridge Controlled Thyristor Rectifier Feeding a Resistive Load

Laboratory Data and Graph

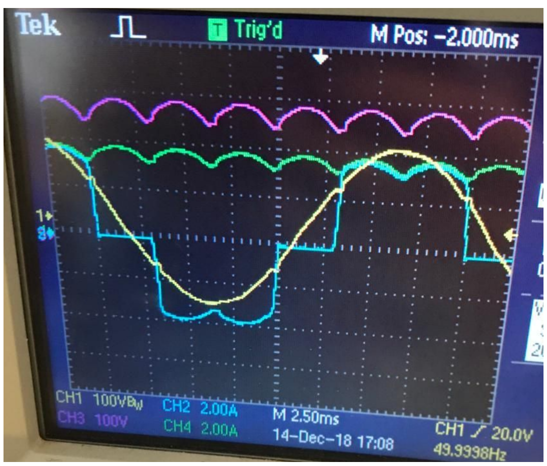


Figure 1. R-Load with Firing Angle = 0°

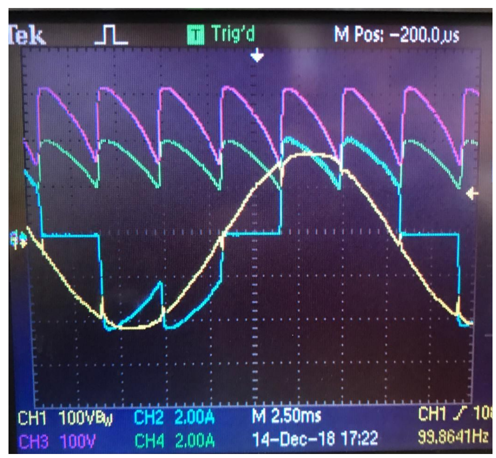


Figure 2. R-Load with Firing Angle = 60°

Simulation Graphs

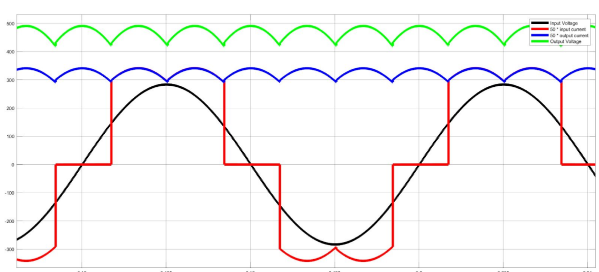


Figure 3.Simulated R-Load with Firing Angle = 0°

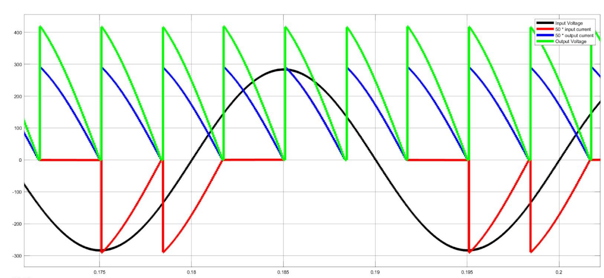


Figure 4.Simulated R-Load with Firing Angle = 60°

Theoretical Approach

When firing angle is zero, characteristics of the 3-phase thyristor system is same as a 3-phase diode full-bridge rectifier as it can be seen from all the simulations and experimental waveforms below. Because this is a simply resistive load, Vout and Iout are just a multiplication of each other. Simulation and experimental results are close to each other.

<u>Differences when Firing Angle Switched from 0 to 60:</u>

- At zero angle, output voltage’s ripple value is 50 Volts approximately and at sixty degrees, output ripple increases to 172 Volts. This is due to thyristor’s off state effect as the voltage output value gets past voltage value when the time where neutral voltages of 2 phase sources are equal to each other, instead of taking the higher neutral voltage’s value, Vout continues to decrease until thyristors are fired again thus decreasing the Vmin value of of the output voltage. All of these events shows that Vavg,out will decrease when firing angle increases.
- When firing angle goes to 0 from 60, THD increases and Is deteriorates. Power factor decreases and Reactive power increases.

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

Laboratory Data and Graph

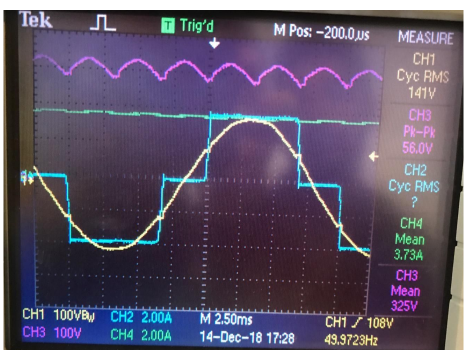


Figure 5. RL-Load with Firing Angle = 0°

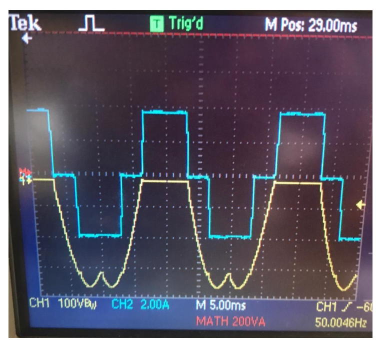


Figure 6. Thyristor Voltage and Line Current for Firing Angle = 0°

Figure 7. RL-Load with Firing Angle = 60°

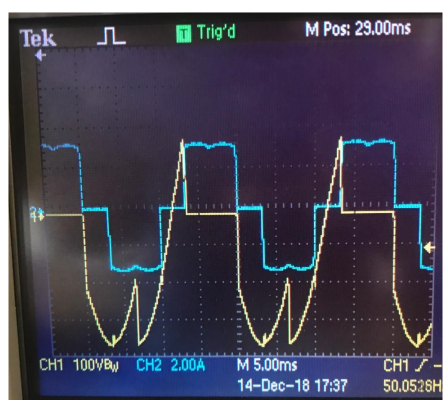


Figure 8. Thyristor Voltage and Line Current for Firing Angle = 60°

Simulation Graphs

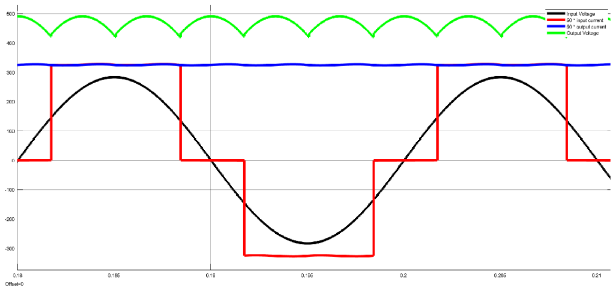


Figure 9. Simulated RL-Load with Firing Angle = 0°

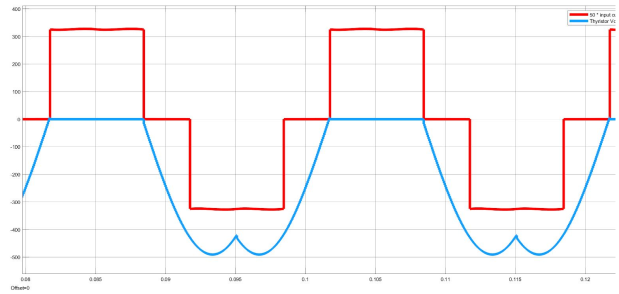


Figure 10. Simulated Thyristor Voltage and Line Current for Firing Angle = 0°

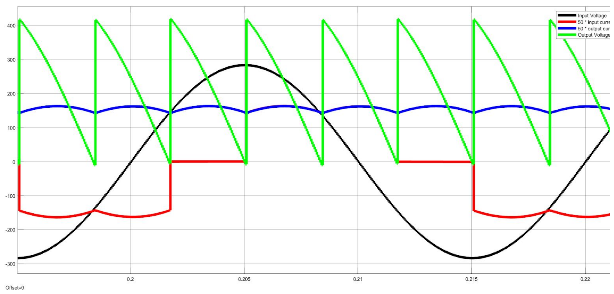


Figure 11. Simulated RL-Load with Firing Angle = 60°

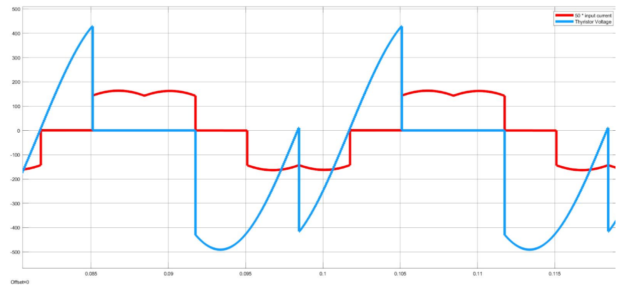


Figure 12. Simulated Thyristor Voltage and Line Current for Firing Angle = 60°

Theoretical Approach

Simulation and experimental results are close to each other. For R-L and R case differences, see below:

<u>Differences Between R and R-L Load:</u>

- Output current ripple decreased significantly as compared to R load case and average current decreased.
- THD of the line current in R-L case is lower than the R case for firing angle = 60 degrees.
- With RL, Reactive power increases and P.F. decreases.
- Shape of the voltage output of the R case and RL case does not differ much but average voltage decreases with the RL case. This due to fact that even with just R load, output current still acts as good current source but not just good as the RL case.

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

Laboratory Data and Graph

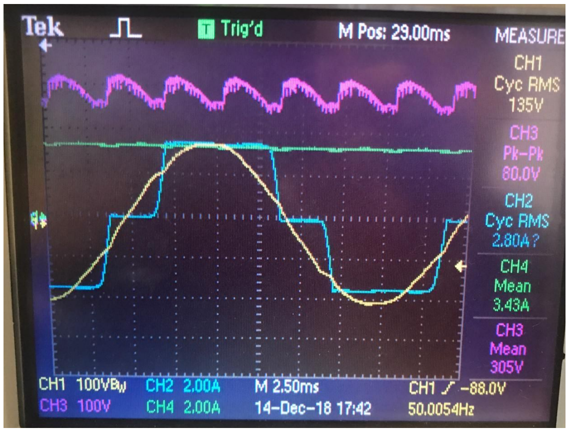


Figure 13: Experimental results for Firing Angle = 0°

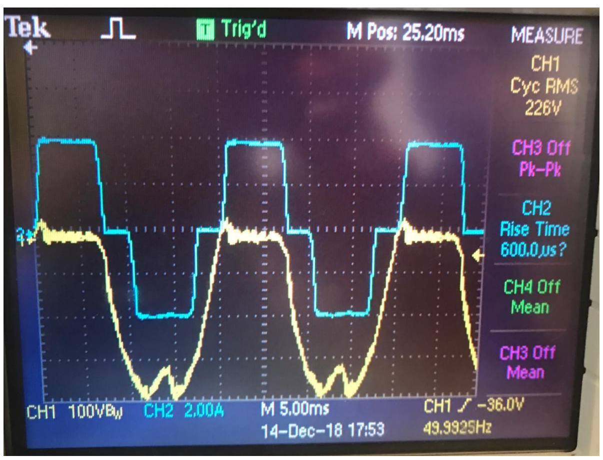


Figure 14: Thyristor voltage and line current for Firing Angle = 0°

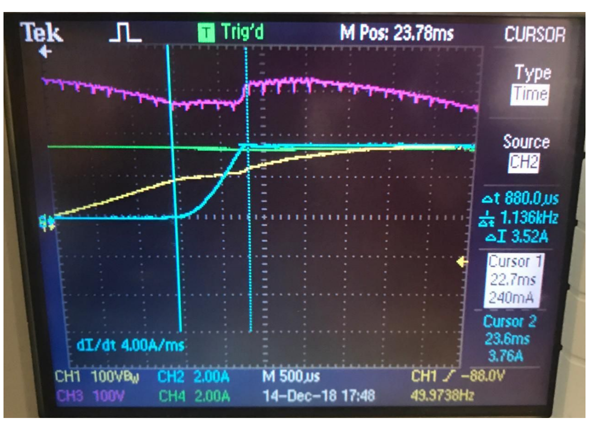


Figure 15: Commutation period for Firing Angle = 0°

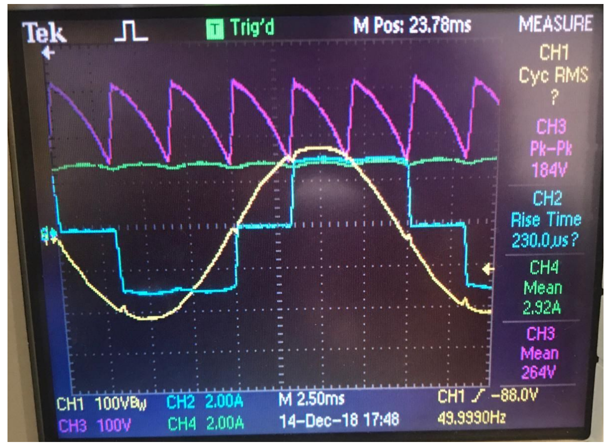


Figure 16: Experimental results for Firing Angle = 60°

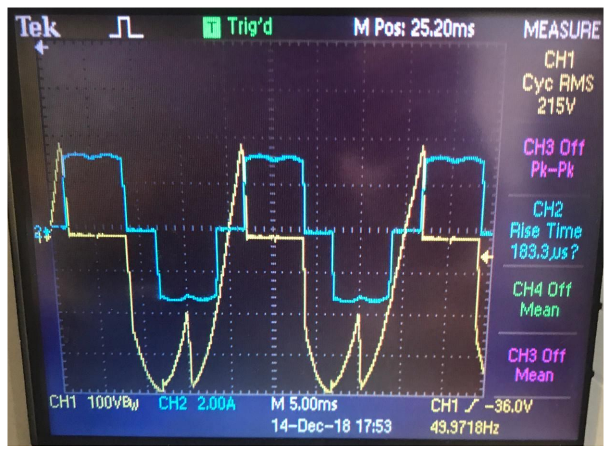


Figure 17: Thyristor voltage and line current for Firing Angle = 60°

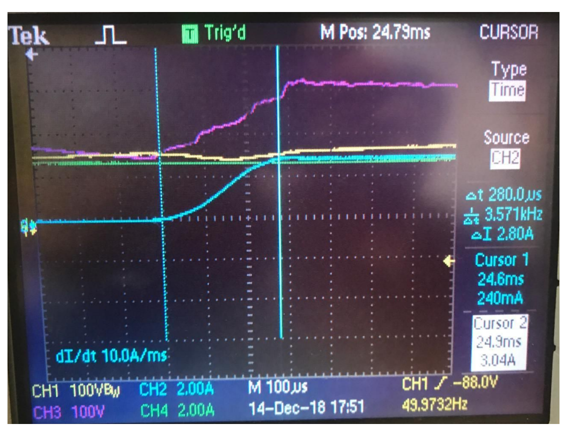


Figure 18: Commutation period for Firing Angle =60°

Simulation Graphs

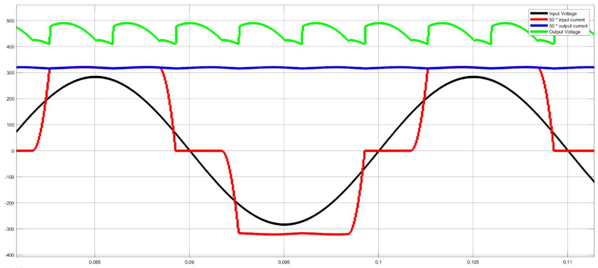


Figure 19: Simulation results for Firing Angle = 0°

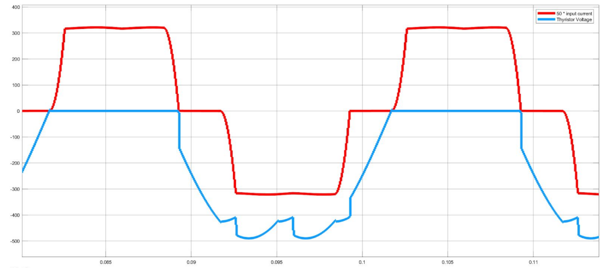


Figure 20: Simulation result for thyristor voltage and line current for Firing Angle = 0°

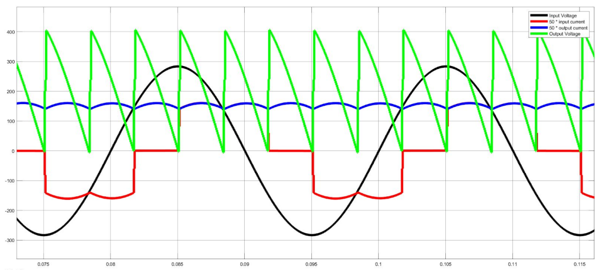


Figure 21: Simulation results for Firing Angle =60°

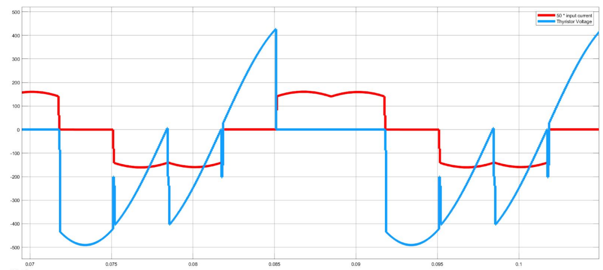


Figure 22: Simulation result for thyristor voltage and line current for Firing Angle =60°

Theoretical Approach

Inserting the AC line reactor changed our results significantly at some points. Commutations are not instantaneous due to the presence of source inductances.This means that input current does not change instantaneously. For some interval, three thyristors continue to conduct. This interval is called overlap. Due to the conduction of two devices during commutation either from the top group or the bottom group, the output voltage during the overlap period drops resulting in reduced average voltage. This means that commutation overlap reduces average output voltage. Moreover,we observed that harmonic amplitudes of the input current are reduced during the overlap period.Thus, this results in lower THD. Like the other cases, when firing angle increased, average output voltage decreases and also, THD increases. Moreover, we observed that as the firing angle is increasing, commutation period is decreasing. When we compared our experimental and simulation results,we obtained the nearly same results.

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

Laboratory Data and Graph

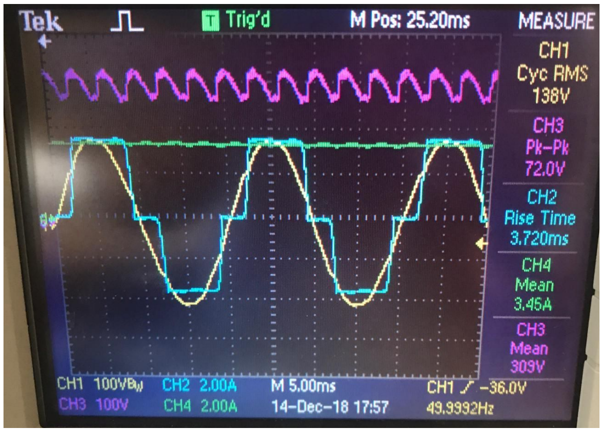


Figure 23: Experimental results for Firing Angle = 0°

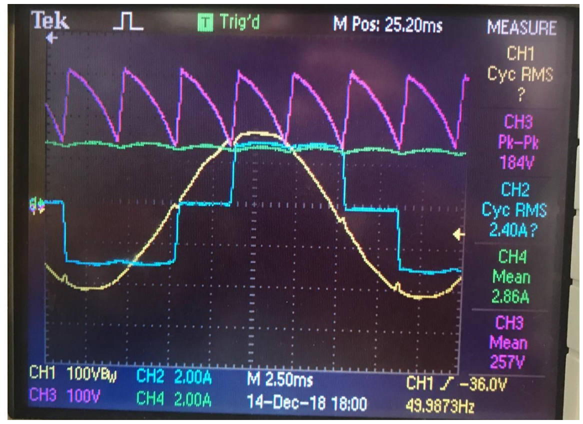


Figure 24: Experimental results for Firing Angle = 60°

Simulation Graphs

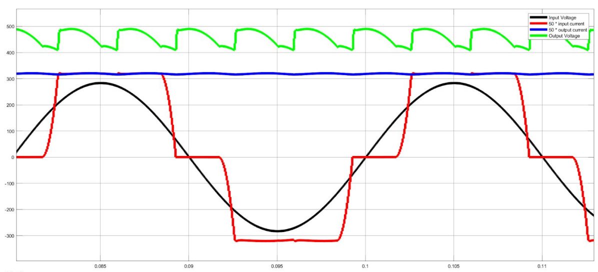


Figure 25: Simulation results for Firing Angle = 0°

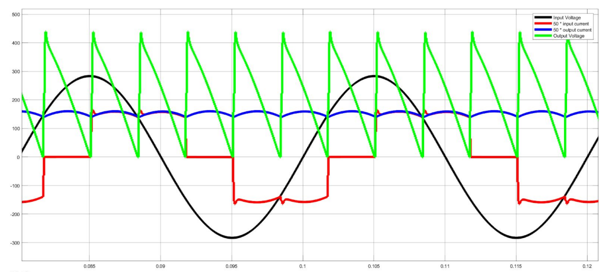


Figure 26: Simulation results for Firing Angle = 60°

Theoretical Approach

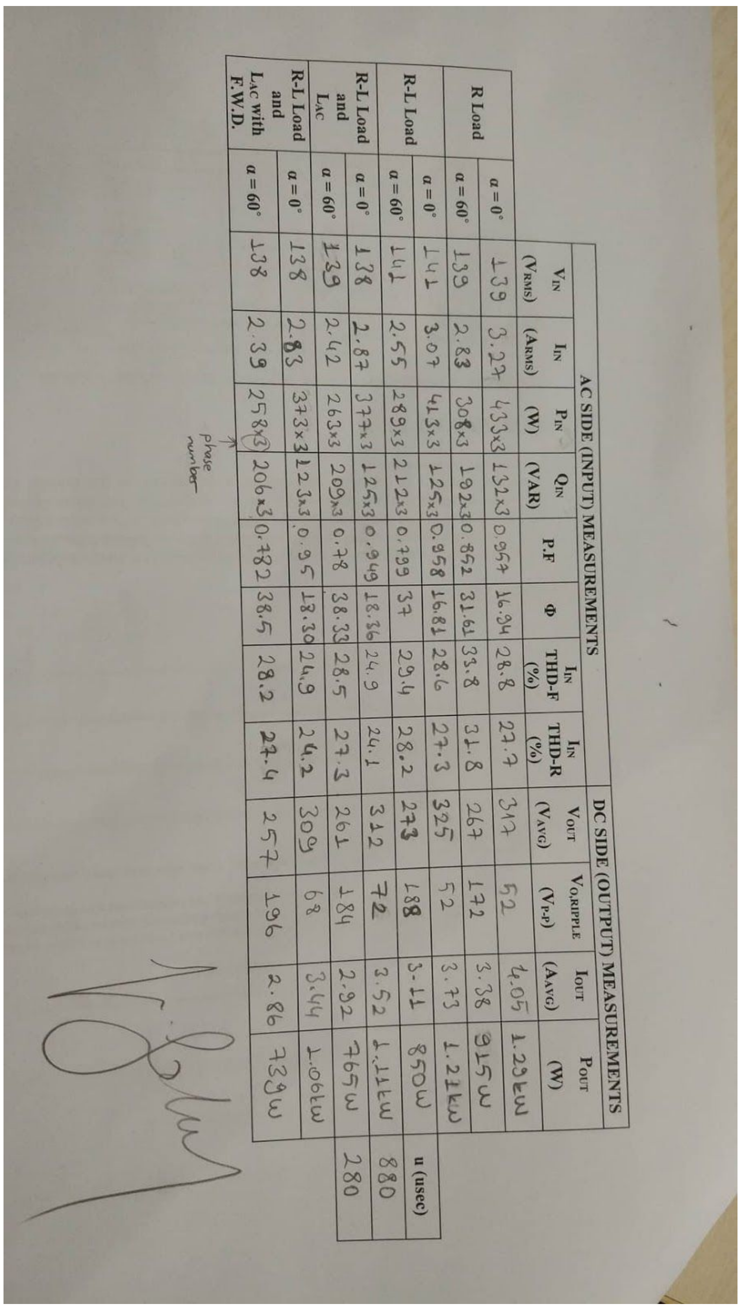
Adding a freewheeling diode did not change our previous case (R-L Load with L_{AC}) results significantly. The circuit operates like a three phase fully controlled rectifier when firing angle is less than 60°. However, for firing angle between 60° and 120°, the free wheeling action of the diode does not permit negative excursions of the instantaneous voltage. In the experiment, when we changed the firing angle between 60° and 120°, we observed that output voltage could not be negative because the free-wheeling diode is conducting within this period.As in previous cases, while firing angle increases, average output voltage decreases because of formula given below. Moreover, as firing angle is increased, distortion in the current waveform also increases. This results in higher THD and also, displacement power factor for thyristor rectifier is cos a, hence total power factor will be low. As the firing angle is increasing , minimum value of output voltage decreases and hence, ripple of output voltage increases. When we compared our experimental and simulation results,we obtained the nearly

$$V_{avg} = \frac{3\sqrt{2}}{\pi} \times V_{l-l} \times \cos a$$

same results.

CONCLUSION

Subject of this experiment is three phase thyristor rectifier with two different firing angle, different type load. In the first part of experiment, we observed input and output current and voltage waveform with two firing angle. Hence, we observed output voltage decreases and THD of input current increases with increasing firing angle. In the second part of experiment, we added inductive load. Hence, load close to current source with adding inductor. Because of that, input current looks like square wave. In the third part, we added inductor to source side in order to observe commutation effect. Therefore, input current changes smoothly. Finally, we added freewheeling diode. We observed this effect in the laboratory.



		AC SIDE (INPUT) MEASUREMENTS								DC SIDE (OUTPUT) MEASUREMENTS				
		V_{IN} (V_{RMS})	I_{IN} (A_{RMS})	P_{IN} (W)	Q_{IN} (VAR)	P.F	Φ	I_{IN} THD-F (%)	I_{IN} THD-R (%)	V_{OUT} (V_{AVG})	$V_{O,RIPPLE}$ (V_{P-P})	I_{OUT} (A_{AVG})	P_{OUT} (W)	u (usec)
R Load	$\alpha = 0°$	139	3.27	433x3	132x3	0.957	16.94	28.8	27.7	317	52	4.05	1.29kW	
	$\alpha = 60°$	139	2.83	308x3	192x3	0.852	31.61	33.8	31.8	267	172	3.38	915W	
R-L Load	$\alpha = 0°$	141	3.07	413x3	125x3	0.958	16.81	28.6	27.3	325	52	3.73	1.21kW	
	$\alpha = 60°$	141	2.55	289x3	212x3	0.799	37	29.4	28.2	273	188	3.11	850W	
R-L Load and L_{AC}	$\alpha = 0°$	138	2.87	377x3	125x3	0.949	18.36	24.9	24.1	312	72	3.52	1.11kW	880
	$\alpha = 60°$	139	2.42	263x3	209x3	0.78	38.33	28.5	27.3	261	184	2.92	765W	280
R-L Load and L_{AC} with F.W.D.	$\alpha = 0°$	138	2.83	373x3	123x3	0.95	18.30	24.9	24.2	309	68	3.44	1.06kW	
	$\alpha = 60°$	138	2.39	258x3	206x3	0.782	38.5	28.2	27.4	257	196	2.86	739W	

phase number