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Design and testing of 1 phase semi-controlled rectifier circuit (experiment scale): a part of green laboratory project

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Abstract. This paper discussed design and testing of one (1) phase semi-controlled full wave rectifier circuit (experiment scale) as a part of green laboratory project. The research method was divided by two stages: design and testing. The design stage included: component selection and calculation, conceptual design and circuit physical implementation. The three main components included 2 diodes, 2 thyristors (SCR), resistive (R) and inductive (L) load with varying values. The testing stage was physical rectifier circuit operation with R (220; 580; 1,500 ohm) and R-L (L=2.37 H) load. The voltage waveform, voltage and current were observed during this stage. The testing results (voltage and current) in rms value were compared with theoretical calculation for validation. The testing results showed that the rectifier circuit working optimally. The testing results were differed by small percentage with theoretical calculation. The output voltage was differed by 1.085%. The output current for R and R-L load were differed by 4.590% and 6.457%, respectively.

1. Introduction

Generally, power electronic circuit is applied to power conversion both in large or small scale [1]. In large scale, application of power electronics equipment can be found at electrical power transmission/distribution and also at electrical motors control in industry. The transmission and distribution of electrical power itself, requires good and reliable power quality [2, 3]. For small scale, this circuit can be found at electronic equipment chargers and UPS.

The power source waveform can be converting from one form to another. For example, from sinusoidal alternating current (AC) waves to direct current (DC) waves or vice versa. This converting waveform can be performing through a power electronics circuit based on power semiconductors. Based on the desired performance, power semiconductors in a circuit can be used for controlling, conversion and switching [4]

The controlled and uncontrolled power electronics circuit is classified based on the components it used [5]. If the circuit only uses diode, it is classified as an uncontrolled circuit. If the circuit uses components such as thyristor, MOSFET, IGBT then it is classified as a controlled circuit [6]. If the circuit uses uncontrolled and controlled combined components, it is called a semi-controlled circuit. Controlled is a condition that circuit can be arranged to produce a specific output by triggering an angle at its gate.



For example, thyristor silicon-controlled rectifier (SCR) has a gate, so it can be subject to a trigger angle. This is different with diodes that have not a gate. Diodes have a cathode and anode only, so they cannot be triggered at certain angles. Triggering in a controlled circuit requires characteristics understanding of each component. This is related to the amount of triggering current [6].

This research discussed about design and testing of 1 phase semi-controlled rectifier circuits using diodes and thyristors (SCR). Specifically, the testing aim was to observe output waveforms and output voltage and current values for different types and load values. This circuit was produced on laboratory scale and for experiment needs.

2. Theory

Thyristor can be used as a controlled phase angle rectifier. The controlling is done by giving a trigger signal to gate. As a switch, if anode voltage is more positive compared to cathode voltage and the positive pulse current flows at gate terminal, the thyristor (SCR) is active position or (on). Triggering is a process that occurs when there is a current flowing at gate. The commutation process is a condition of termination (off) from condition (on) before [6]. Controlled rectifier applications can be found widely on VSD for induction motors. The characteristics of thyristor (SCR) are shown in Figure 1 [7].

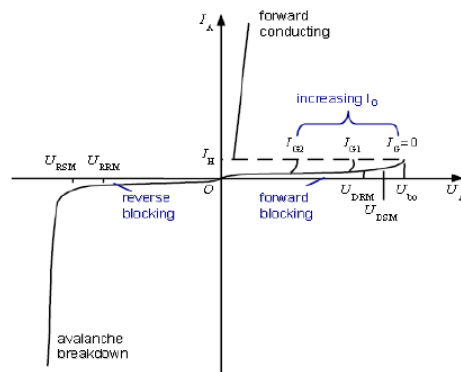


Figure 1. Thyristor (SCR) characteristics [7]

Diodes are formed from crystals and have two regions called P and N region. Diode with electronic switch function is able to flow current in one direction only. The diode characteristics are shown in Figure 2 [8].

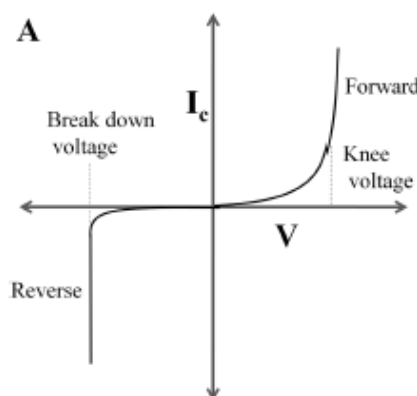


Figure 2. Diode characteristics [8]

Trigger DIAC (AC diode) changes input signals in random waves form into square waves at the output signal [9]. DIAC is also used for triggering TRIAC [10]. TRIAC must use a bidirectional

trigger diode because it does not have a symmetrical trigger character which results in a lack of sensitivity and opposite current flow at the gate. The trigger circuit is shown in Figure 3 [10].

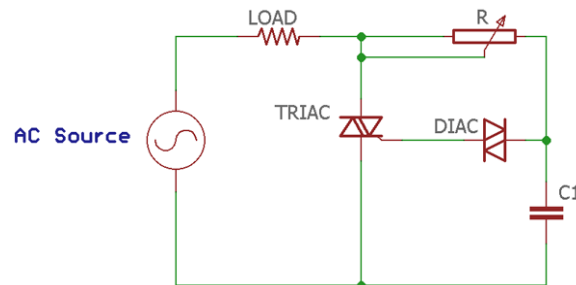


Figure 3. DIAC and TRIAC trigger circuits [10]

At non-linear loads, the output waveform is not same with input waveform. There is a distortion that occurs in wave. This will result in harmonic in currents and voltages [11]. At nonlinear loads, the output waveform is not linear with the voltage at each half cycle [12].

3. Circuit design and construction

The rectifier circuit design was consisted of three main components:

- Diode
- Thyristor (SCR)
- Resistive load (R) and inductive load (L)

The materials and equipment for circuit manufacturing are shown in Table 1

Table 1. Materials and tools for circuit construction

No	Material / Tools Name
1	Diode
2	Thyristor (SCR)
3	Resistor
4	Capacitor
5	Board
6	Resistive Load
7	Inductive Load
8	Lead
9	Ferrite Solution
10	Cable
11	DC Power Supply
12	Voltage Regulator
13	Oscilloscope
14	PCB Drill
15	Solder
16	Electrical Multimeter

In this research, full wave rectifier circuit used 2 diodes and 2 thyristors (SCR). Diodes function as rectifiers, while thyristors function as controllers. To adjust the output signal, thyristor gate is connected to trigger circuit which also functions as a gate trigger. Capacitor mounted on circuit output

side has a function as filter. The single line diagram of circuit is shown at Figure. 4. The physical circuit is shown at Figure 5.

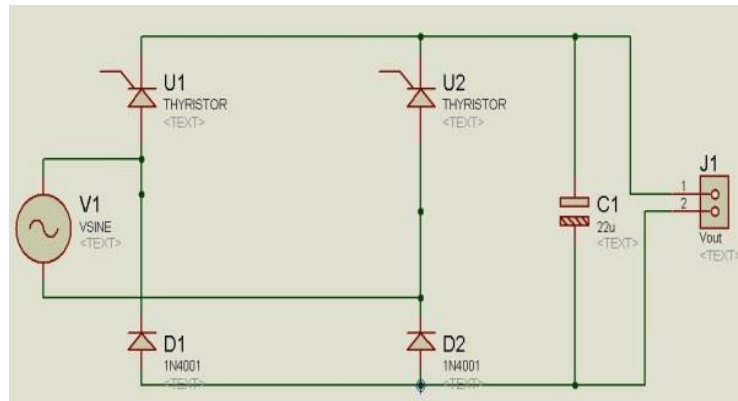


Figure 4. Single line diagram of circuit

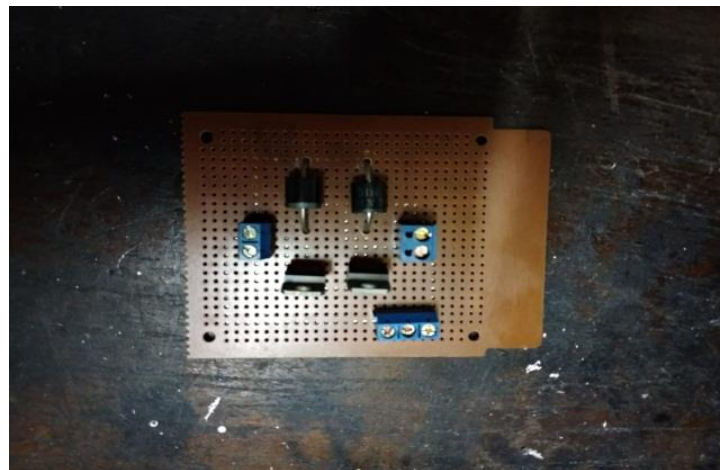


Figure 5. Rectifier physical circuit

4. Theoretical Calculation

The theoretical calculation was carried out using data below:

- $V_{\text{input-rms}} = 30 \text{ V}$
- Frequency = 50 Hz
- SCR trigger angle = 60°
- Resistor load: 220 Ohm/250 W; 680 Ohm/100 W; 1,500 Ohm/50 W
- Inductor load 2.37 H serialized with resistor load

The theoretical calculation described as below:

1. Calculation of $V_{\text{dc-avg}}$

$$V_{\text{dc-avg}} = \frac{V_m}{\pi} (1 + \cos \alpha)$$

$$V_{dc-avg} = \frac{30\sqrt{2}}{\pi}(1 + \cos 60)$$

$$V_{dc-avg} = 20.257 \text{ V}$$

2. Calculation of V_{dc-rms}

$$V_{dc-rms} = V_m \left[\frac{\pi - \alpha}{2\pi} + \frac{\sin 2\alpha}{4\pi} \right]^{\frac{1}{2}}$$

$$V_{dc-rms} = 30\sqrt{2} \left[\frac{\pi - \frac{1}{3}\pi}{2\pi} + \frac{\sin 2 \cdot \frac{1}{3}\pi}{4\pi} \right]^{\frac{1}{2}}$$

$$V_{dc-rms} = 26.908 \text{ V}$$

3. Calculation of I_{dc-rms} for R (220 Ohm) load

$$I_{dc-rms} = \frac{V_{dc-rms}}{R}$$

$$I_{dc-rms} = \frac{26.908}{220}$$

$$I_{dc-rms} = 0.122 \text{ A}$$

4. Calculation of impedance for R (220 ohm) and L (2.37 H) load

$$Z_L = \sqrt{(R)^2 + (X_L)^2}$$

$$Z_L = \sqrt{(220)^2 + (2\pi \cdot 50 \cdot 2.37)^2}$$

$$Z_L = 776.380 \text{ Ohm}$$

5. Calculation of I_{dc-rms} for R (220 ohm) and L (2.37 H) load

$$I_{dc-rms} = \frac{V_{dc-rms}}{Z_L}$$

$$I_{dc-rms} = \frac{26.908}{776.380}$$

$$I_{dc-rms} = 0.0347 \text{ A}$$

Based on above calculation, V_{dc-rms} and I_{dc-rms} for R and R-L load were shown at Table 2 and Table 3, respectively.

Table 2. Voltage and current calculation results with R load

No	R load	V_{dc-rms} (Volt)	I_{dc-rms} (A)
1	220 Ohm	26.908	0.122
2	680 Ohm	26.908	0.049
3	1,500 Ohm	26.908	0.018

Table 3. Voltage and current calculation results with R-L load

No	R-L load	V_{dc-rms} (Volt)	I_{dc-rms} (A)
1	220 Ohm -2.37 H	26.908	0.035
2	680 Ohm -2.37 H	26.908	0.027
3	1,500 Ohm -2.37 H	26.908	0.016

5. Circuit testing

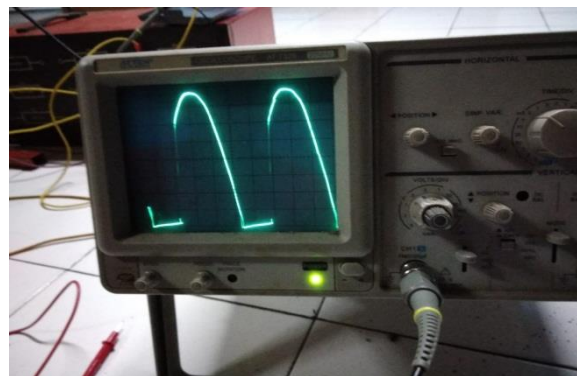
At this stage, the testing was carried out using R and RL loads with varying values. The input voltage ($V_{input-rms}$) was set on 30 Volt from voltage source/power supply. The SCR trigger angle was set on 60° with trigger circuit. The oscilloscope parameters were set at 5v div and 2ms/div. The load output voltage and current were measured in its rms value.

5.1. Testing with resistive loads (R)

The voltage and current testing results of three types of R load are shown in Table 2. The output waveform is shown in Figure 6.

Table 4. Testing results with R load

No	R load (Ohm)	V_{dc-rms} (Volt)	I_{dc-rms} (A)
1	220	27.2	0.127
2	680	27.2	0.051
3	1,500	27.2	0.019

**Figure 6.** Voltage output waves for R load

5.2. Testing with series RL loads

The testing results of three R load types: connected in series with L are shown in Table 5. The output waveform is shown in Figure 7.

Table 5. Testing results with R-L load

No	R-L load	V_{dc-rms} (Volt)	I_{dc-rms} (A)
1	220 Ohm -2.37 H	27,2	0.037
2	680 Ohm -2.37 H	27,2	0.029
3	1,500 Ohm -2.37 H	27,2	0.017

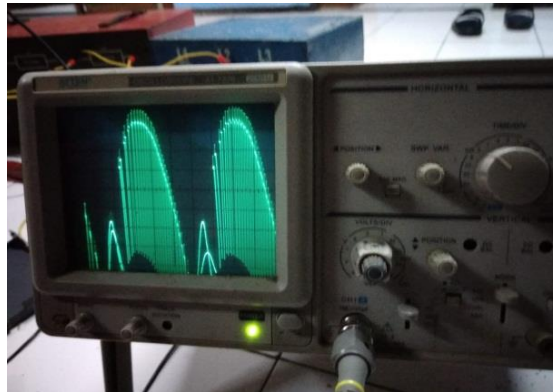


Figure 7. Voltage output waves for R-L load

6. Comparison between theoretical and testing result

The voltage comparison results between theoretical and testing is shown at Table 6. The current comparison results for R and R-L load are shown at Table 7 and 8, respectively. The comparison graphic of output voltage, output current for R load and output current for R-L load are shown at Figure. 8; 9; and 10, respectively.

Table 6. Voltage comparison results for R and R-L load

No	R and R-L load	V_{dc-rms} theoretical (Volt)	V_{dc-rms} testing (Volt)	ΔV_{dc-rms} (Volt)	ΔV_{dc-rms} (%)
1	R=220 Ohm; L= 2.37 H	26.908	27.2	0.292	1.085
2	R=680 Ohm; L= 2.37 H	26.908	27.2	0.292	1.085
3	R=1,500 Ohm; L= 2.37 H	26.908	27.2	0.292	1.085
				Average	1.085

Table 7. Current comparison results for R load

No	R and R-L load	I_{dc-rms} theoretical (A)	I_{dc-rms} testing (A)	ΔI_{dc-rms} (A)	ΔI_{dc-rms} (%)
1	R=220 Ohm	0.122	0.127	0.005	4.098
2	R=680 Ohm	0.049	0.051	0.002	4.082
3	R=1,500 Ohm	0.018	0.019	0.001	5.556
				Average	4.590

Table 8. Current comparison results for R-L load

No	R and R-L load	I_{dc-rms} theoretical (A)	I_{dc-rms} testing (A)	ΔI_{dc-rms} (A)	ΔI_{dc-rms} (%)
1	R=220 Ohm, L= 2.37 H	0.035	0.037	0.002	5.714
2	R=680 Ohm, L= 2.37 H	0.027	0.029	0.002	7.407
3	R=1,500 Ohm, L= 2.37 H	0.016	0.017	0.001	6.25
				Average	6,457

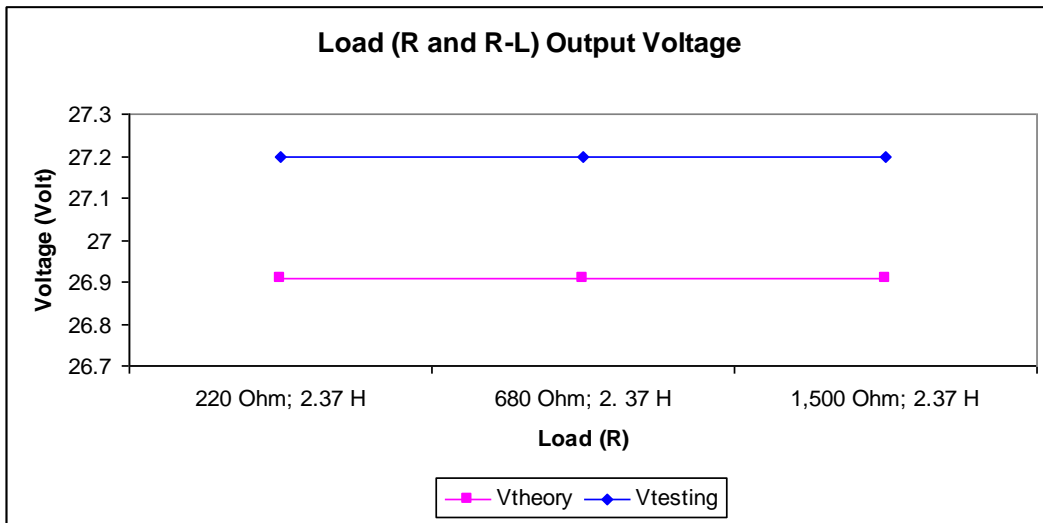


Figure 8. Load (R and R-L) output voltage

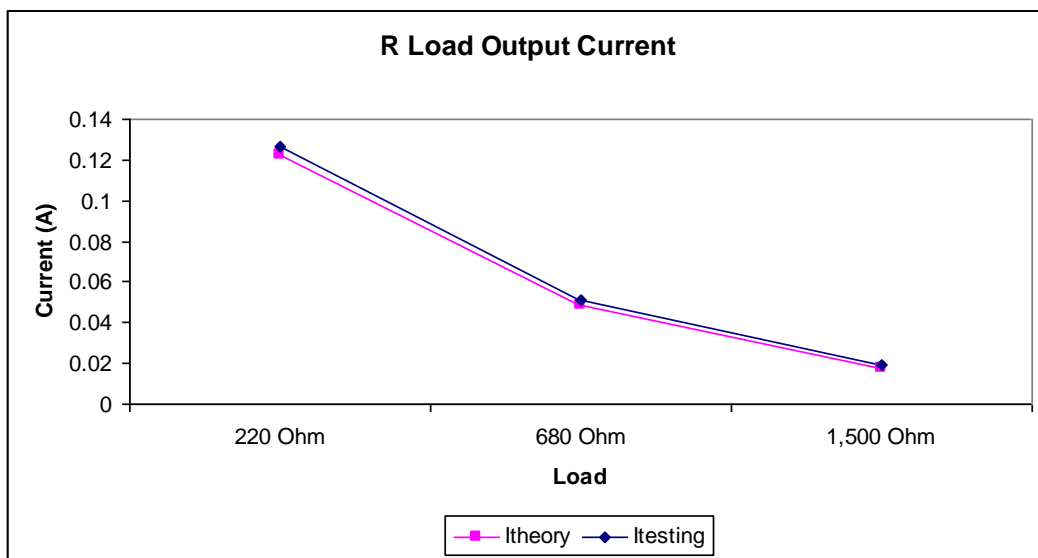


Figure 9. Load (R) output current

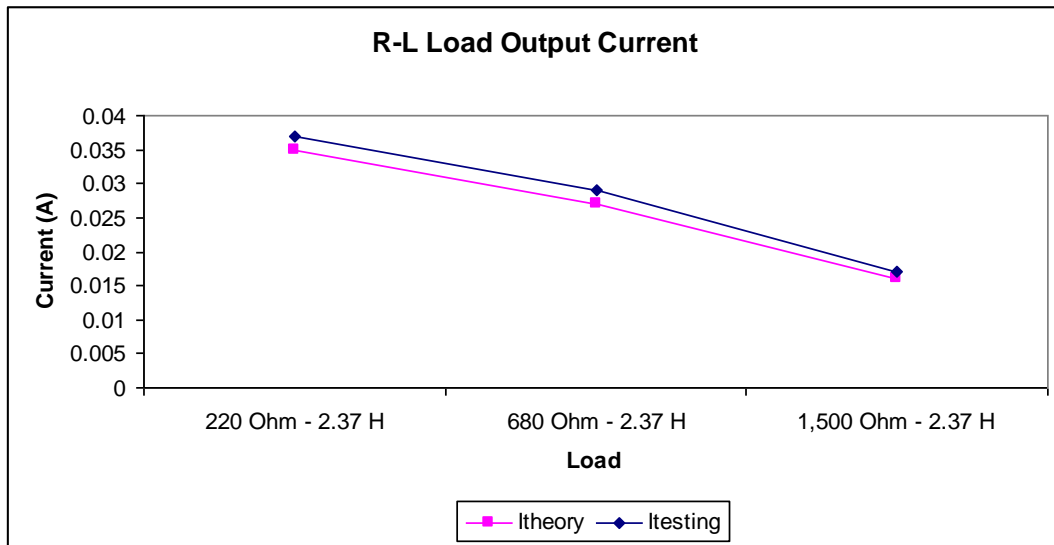


Figure 10. Load (R-L) output current

7. Conclusion

One (1) phase semi-controlled full wave rectifier circuit using diodes and thyristors (SCR) were successfully designed and tested in this research. The voltage output for R and R-L load was 27.2 Volt. It was differed by 1.085% (average) with the theoretical calculation result. The current output for R load is differed by 4.59% (average) with the theoretical result. For RL load, the current output was differed by 6.457% (average) with the theoretical result. The circuit testing result indicate that the rectifier still needs further refinement to overcome its deficiencies.

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