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Design and Application SCR Trigger Circuit for Three-phase Half-wave Controlled Rectifier with Resistive Load

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ABSTRACT

Power electronics is a field of science that studies and discusses electronics applications related to large-power electrical equipment's, one of the sub-subject that studied is the AC to DC converter such as three-phase half-wave controlled rectifier with a resistive load in which output voltage can be controlled by adjusting the triggering delay angle of gate SCR. The components that used include a three-phase step down transformer where the output used as a reference signal to determine the starting point (30°) and the end point (150°) of triggering delay angle, it also used as a power source for the system, LM393 used as a comparator between three-phase rectifier (Vd) with DC voltage (Vreference), likewise to compare triangular waves with DC voltages that resulting from changes in the voltage on the potentiometer in order to controlling the triggering delay angle (α) of SCR. The first step that must be taken to make measurements using an oscilloscope is to determine the t_{on} and t_{off} values for each angle by rotating the potentiometer on the comparator circuit and then measuring the average output voltage (Vo), determination the triggering angle in this research is still done manually so that the measurement results compared to the calculation has a difference this is due to the level of accuracy in observing the oscilloscope, on the other hand the three-phase transformer and sources used are not in ideal conditions.

I. Introduction

Power electronics is a field of science that studies and discusses electronics applications related to high-power electrical equipment such as industrial heaters, light control, reactive power control and starting as well as speed control of AC and DC motors [1-6]. One of the subjects that studied in power electronics is the AC to DC converter which can be controlled using an electronic component in the form of an SCR. Controlled rectifier is a power electronics circuit that used to change the alternating current source voltage in the form of a sine into a direct voltage that can be controlled by adjusting the triggering angle of the SCR [1-3].

In this research the authors designed and applied the SCR trigger circuit for the purposes of a controlled three-phase half-wave rectifier with a resistive load where the SCR trigger angle changes have a range greater than 30° and less than 150°. Changes in the trigger angle can be controlled by using an electronic component in the form of a potentiometer which is rotated manually and then observing the changes in t_{on} and t_{off} on the output wave in the oscilloscope manually.

Rectifier that uses a three-phase input voltage source will produce a larger average output voltage compared to a rectifier that uses a single-phase voltage, thus the need for electronic components that used to filter current and voltage on the load side will be simpler, this reason makes three-phase rectifiers widely used in high-power variable speed drive systems [1-2].

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II. The Proposed Method

2.1. Principle Of Three-Phase Half-Wave Converter

The circuit topology of a three-phase half-wave controlled rectifier that using three Thyristors (SCR) as shown in Figure 1 [7], where the transformer and source voltage are considered ideal to facilitate mathematical analysis, the output voltage at the load side can be controlled by using three SCRs which are arranged in the form of common cathode and the triggering angle can be adjusted as needed. the three-phase source voltage Van, Vbn, and Vcn can be expressed mathematically by using equations (1), (2), and (3) where Vm is the peak voltage that measured from the phase side to the neutral on the secondary side of the transformer [1-2, 7], the frequency of the voltage source that used in this research is 50 Hz.

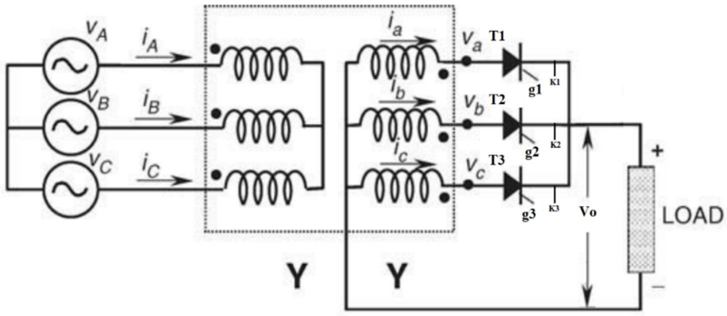

Fig. 1. Power circuits

$$V_{an} = V_m \sin(\omega t) \tag{1}$$

$$V_{bn} = V_m \sin\left(\omega t - \frac{2\pi}{3}\right) \tag{2}$$

$$V_{cn} = V_m \sin\left(\omega t + \frac{2\pi}{3}\right) \tag{3}$$

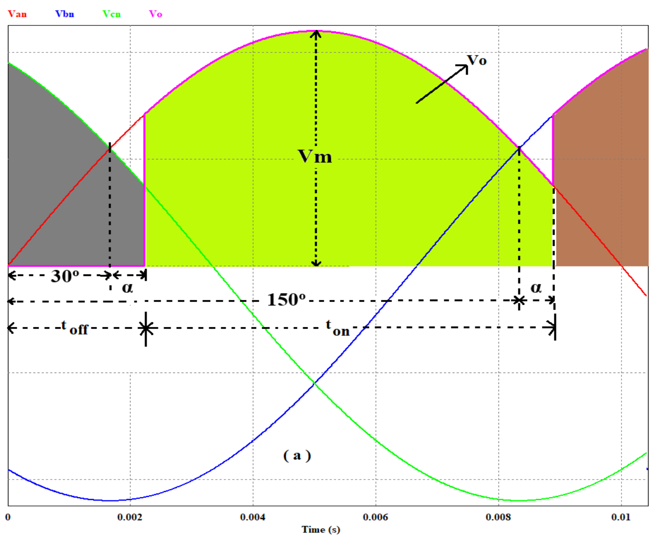

Fig. 2. Output for continuous current

By using equations (1), (2), and (3), the point of intersection between the Van and Vcn sources is obtained at an angle of 30° while the intersection of Van and Vbn occurs at an angle of 150° from the starting point of the voltage source[2][7] as shown in Figure 2. The SCR will work (on state) when the gate of each SCR is triggering with a delay angle (α). The pulse delay angle (α) can be adjusted in order to triggering the gate of SCR with variations angle as needed so that it will produce an average volage (Vo) at the load side according to the angle that has been set, for a continuous current as shown in Figure 2, the average output voltage Vo can be found by using equation (4) while for a non-continuous current as shown in Figure 3 using equation (5)[1][2][7].

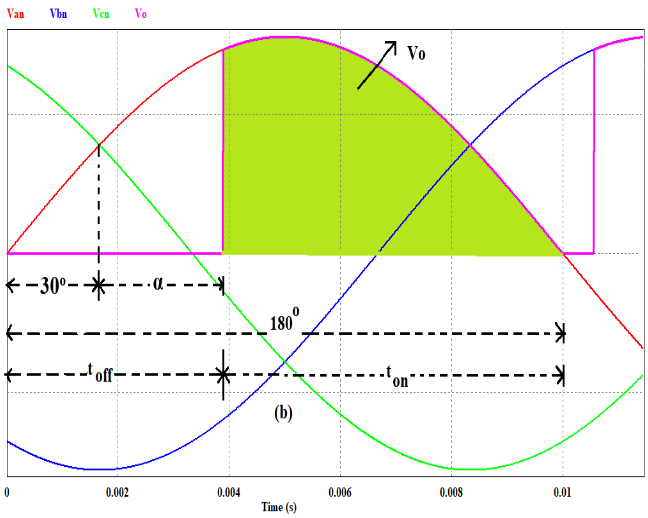

Fig. 3. Output for non-continuous current

$$V_o = \frac{3}{2\pi}\int_{\pi/6+\alpha}^{5\pi/6+\alpha} V_m \sin \omega t \, d(\omega t) \quad (4)$$

$$V_o = \frac{3}{2\pi}\int_{\pi/6+\alpha}^{\pi} V_m \sin \omega t \, d(\omega t) \quad (5)$$

2.2. SCR Triggering Block Diagram

The proposed SCR triggering circuit in this research was built using basic electronic components such as Op-Amp, diode, capacitor, and etc, in a diagram block this system can be seen in Figure 4 below.

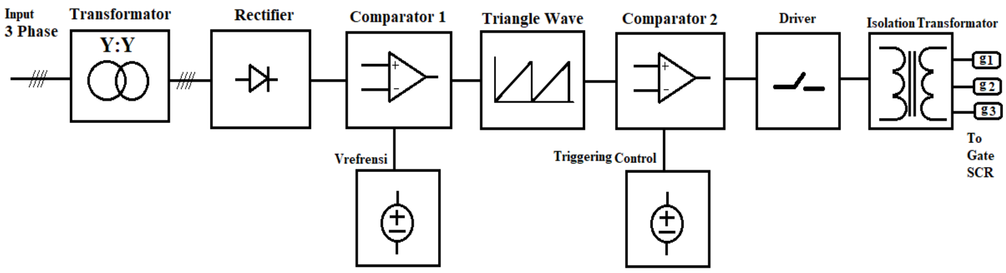

Fig. 4. SCR triggering block diagram

2.3. Three Phase Step Down Transformer

The transformer in this research was conducted by using step down transformers (three pieces) that connected in a Y system on the primary and secondary sides as shown in Figure 5[8][9]. It is needed because this system requires a low voltages three-phase power source which is used as a reference for electronics control circuits and also for power supply's system.

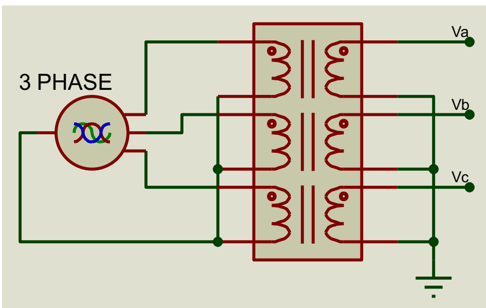

Fig. 5. Transformer connection

2.4. Half Wave Uncontrolled Rectifire

The three-phase half-wave uncontrolled rectifier circuit as shown in Figure 6 is used to convert the voltage wave in form of AC (alternating current) to a DC (Direct Current) voltage where this rectifier circuit is not connected with a filter circuit, the result of the intersection between Van and Vcn is located at angle of 30°, and it becomes the starting point of reference for the triggering circuit and then intersection between Van and Vbn which is located at an angle of 150° becomes the end of reference point for triggering. The output voltage (Vd) of this circuit is then connected to the comparator 1 circuit.

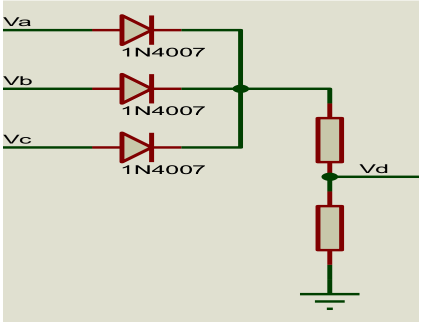

Fig. 6. Uncontrolled rectifier circuit

2.5. Comparator 1 Cicuit

The comparator 1 circuit in this system was built using the LM393 IC as shown in Figure 7 where the system uses a 12 Volt DC power supply, this comparator used to compare the voltage waves that comes from the rectifier circuit (Vd) with the DC voltage (Vreference) that obtained by adjuste potentiometer (20 KΩ) rotation, the output of this circuit (Vcom1) is then connected to a triangular wave generator circuit.

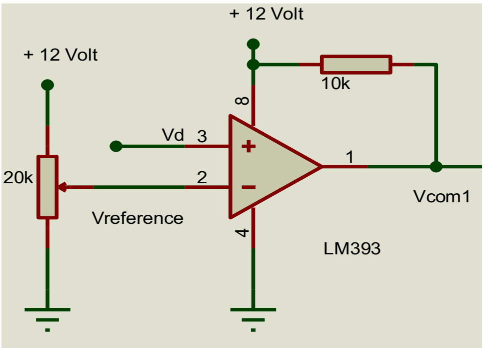

Fig. 7. Comparator 1 circuit

2.6. Triangle Wave Generator

Output wave from comparator 1 circuits is then connected to a triangular wave generator circuit which is composed of several electronic components as shown in Figure 8 The output of this circuit (Vtri) is in the form of a triangle wave which is then connected to comparator 2 circuit.

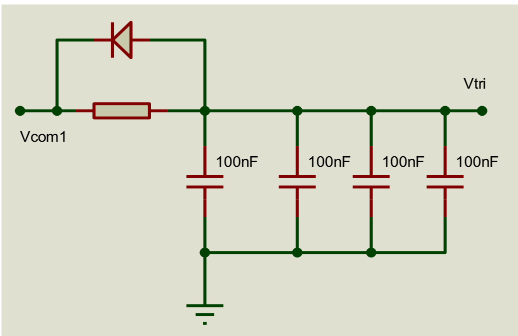

Fig. 8. Triangle wave circuit

2.7. Comparator 2 Circuit

This comparator 2 circuit is used to compare the triangular waveform with the DC voltage which produced from the change in rotation of the potentiometer as shown in Figure 9. The change in the voltage on the potentiometer is used as a controlling the triggering delay angle of the SCR circuit. The output of this circuit (Vcom2) is then connected to the drive circuit and isolation transformer.

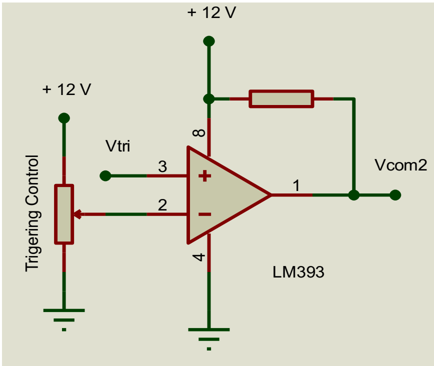

Fig. 9. Comparator 2 circuit

2.8. Drive Circuit and Isolation Transformer

The driving circuit is built using MOSFET IRF3205 Component where the gate is connected to the output of the comparator 2 circuit, this circuit used to drive the transformer so that the output of this transformer can be used to control the SCR triggering angle (g1, g2, and g3) as shown in figure 10. The ratio of the number of turns on the primary and secondary sides of the transformer in this research is 1:1:1:1.

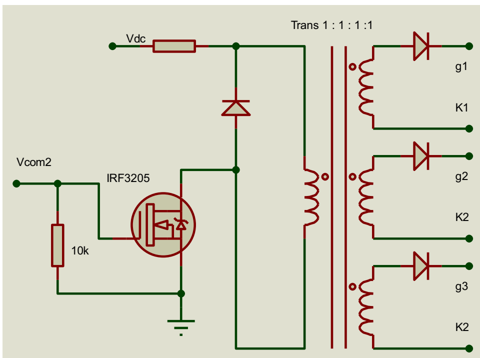

Fig. 10. Drive circuit and isolation transformer

2.9. The Controlling Circuits System

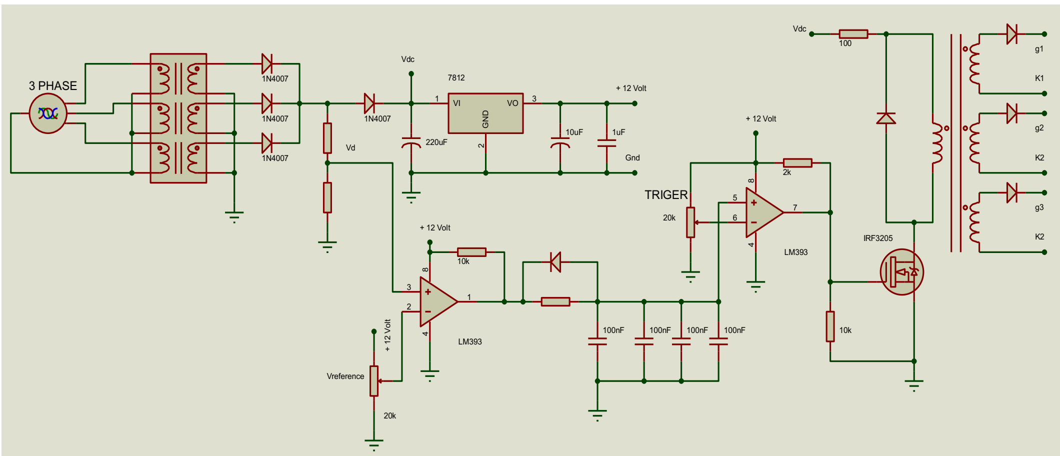

Fig. 11. Controlling circuits system

The controlling circuits system in this research in general can be divide into two parts, the circuit system for the power supply and the SCR triggering circuit as shown in Figure 11. The power supply circuit is built using the LM7812 regulator IC component and several capacitors used as voltage filters.

III. Results and Discussion

Measurements in this system circuit are divided into two parts, that is measurement's part by part on the side of the electronics control circuits system and then measurements on the power circuit side, the load that used in this research is a resistive with value 100 Ω/20 Watt, the reasons to used the low voltage three phase source that used in this research is due to the limitations of the measuring equipment in the laboratories.

3.1. Measurements on Transformer Circuit

The three-phase output waves in the transformer which it's circuit was arranged in a Y connection can be seen in Figure 12, where the maximum voltage from each source has a different value where Van = 18 Volts, Vbn = 17.6 Volts, and Vcn = 18.8 Volt.

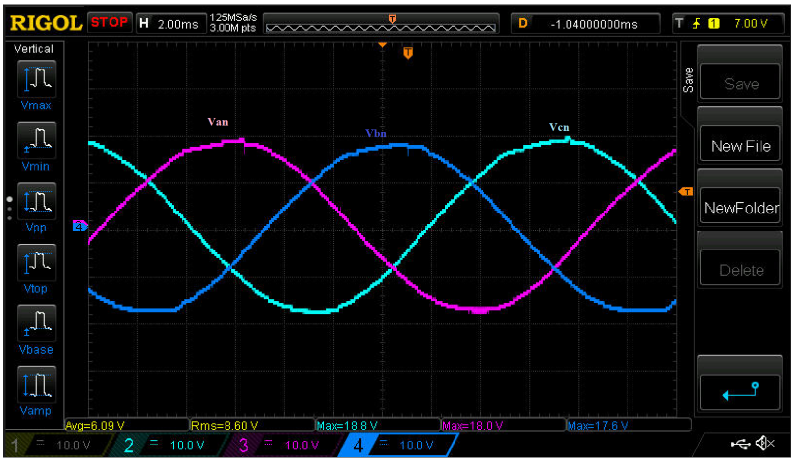

Fig. 12. Transformer output wave

3.2. Measurment on Uncontrolled Rectifier

The output waveform (Vd) of the three-phase half-wave uncontrolled rectifier circuit in this research can be seen in Figure 13, where the maximum voltage generated is 16.2 Volts, the Vd wave will start moving from the point of intersection of the phase and will stop at the point of intersection another phase and never touch the neutral point.

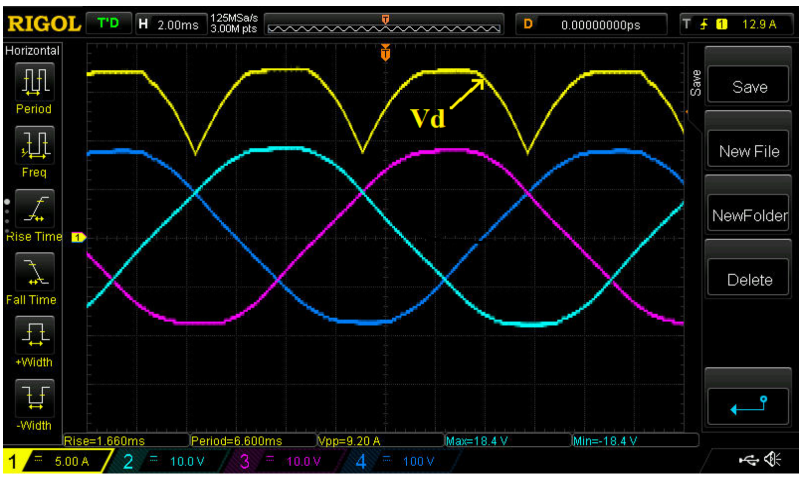

Fig. 13. Uncontrolled rectifier wave

3.3. Testing on the Comparator Circuit 1

The output waveform in the comparator 1 circuit can be seen in Figure 14, the Vcom 1 wave will be on starting from the point of intersection of the Van phase with Vcn to the point of intersection of the Van with Vbn phase.

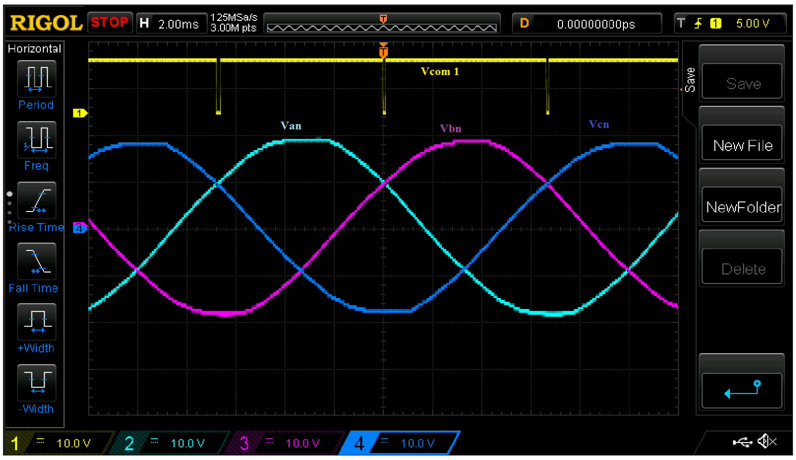

Fig. 14. Output waveform of comparator 1

3.4. Testing on the Triangular Wave Generator Circuit

The Vcom1 wave that has been connected to a triangular wave generator circuit will produce a triangular output waveform (Vtri) as shown in Figure 15.

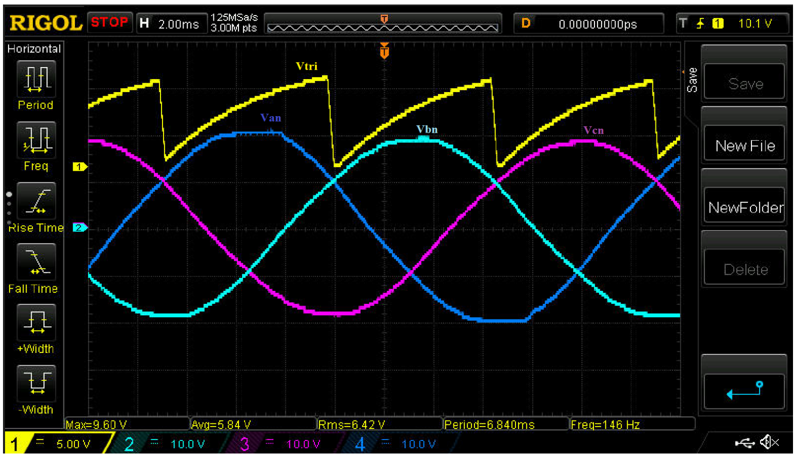

Fig. 15. Output wave form of triangular generator circuit

3.5. Testing on the Comparator Circuit 2

The output waveform that generated in the comparator 2 circuit can be seen in Figure 16, where the delay angle can be adjusted by comparing the Vtri voltage with a varying DC voltage, while the SCR will be active at tons, in Figure 16 (a) the SCR will conduct when the smallest delay time, Figure 16 (b) show that The SCR will conduct when delay angle of 50 percent, while Figure 16 (c) show The SCR in this research will conduct at maximum point of delay angle.

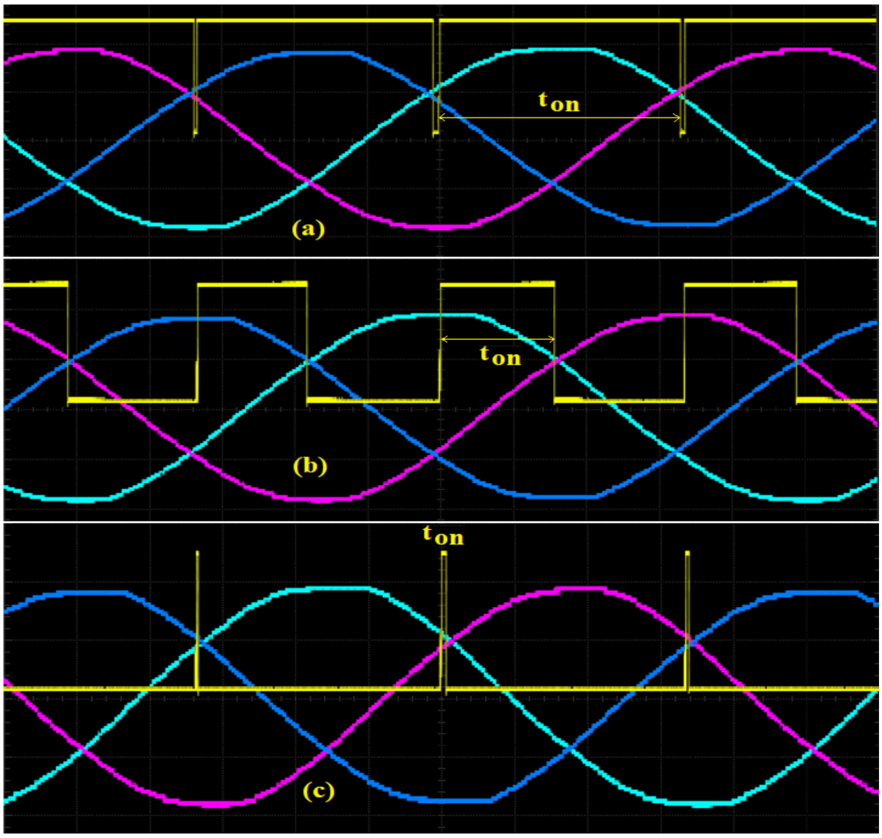

Fig. 16. Output waveform of comparator 2

3.6. Testing on Power Circuits with Resistive Loads

The output waveform and the average voltage value (Vo) in the power circuit that uses a resistive load can be seen in Figure 17 (a) to Figure 17 (h), while the display of the overall testing tool can be seen in Figure 18. The three-phase source in this research use AC voltage at low power. The average output voltage that measures using oscilloscope (Vo Osc) of each change in the delay angle (α) can be seen in Table 1 where the measurement starts at the delay angle (α) of 40º, 50º, 60º, 70º, 80º, 90º, 100º to 110º, to get each delay angle is done by turning the potentiometer on comparator 2 and observing the t_{off} and t_{on} displays on the oscilloscope manually.

Tabel 1. Measurement and calculations data

No	Delay angle (α)	toff (mS)	ton (mS)	Van max (Volt)	Vbn max (Volt)	Vcn max (Volt)	Vo Osc (Volt)	Vo Calc (Volt)	ΔVo (Volt)
1	40°	3,89	6,11	16,80	16,80	16,80	10,50	10,32	0,18
2	50°	4,44	5,56	17,60	17,20	17,20	8,87	9,33	0,46
3	60°	5,00	5,00	18,00	17,60	17,60	7,48	8,14	0,66
4	70°	5,56	4,44	18,00	17,60	17,60	6,14	6,72	0,58
5	80°	6,11	3,89	18,40	17,60	18,00	4,88	5,44	0,56
6	90°	6,67	3,33	18,40	18,00	18,00	3,29	4,16	0,87
7	100°	7,22	2,78	18,40	18,00	18,00	2,23	2,97	0,74
8	110°	7,78	2,22	18,40	18,00	18,00	1,57	1,95	0,38

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Fig. 17. Output waveform with resistif load

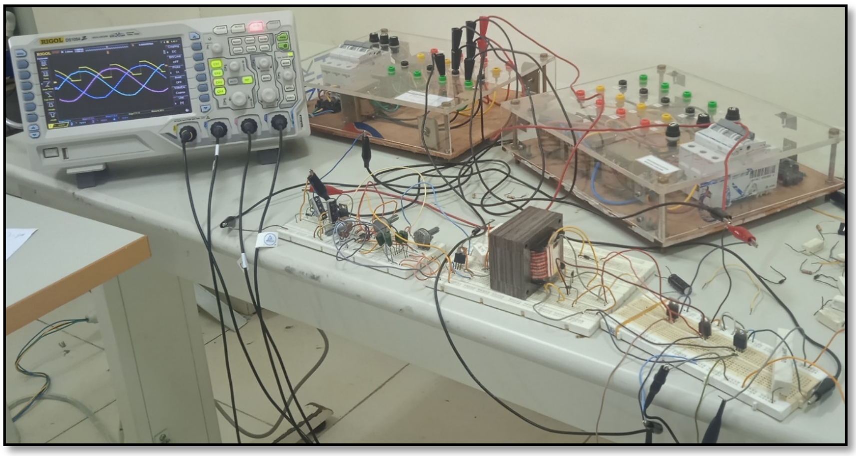

Fig. 18. Overall system testing mechanism

3.7. Discussion

The maximum voltage of the three-phase source used in this study has a value that varies and changes from one measurement to another, this is due to several factors including the transformer windings used are not identical to one transformer with another transformer, on the other hand the three-phase source before being lowered has an unbalanced load so that the voltages Van, Vbn, and Vcn are not the same values. For the first time equation (6) must be rearranged into part by part according to the conditions of the maximum voltage of each phase that not identically, so that to get the average DC voltage value at the load should take into account the voltage drop of 0.7 Volts for each SCR used, the results of mathematically calculations using the formula (Vo Calc) can be seen in table 1. The measurement and calculation results have differences (ΔVo) as shown in Table 1, this matter because the observations of oscilloscope still carried out manually, on the other hand the components and voltage three phase sources that used in this research are not in ideal condition.

IV. Conclusion

Overall the SCR trigger circuit design that is applied to a three-phase controlled rectifier with a resistive load in this research can be operated and work properly, where the average output voltage on load measurements that using an oscilloscope compared to mathematical analysis does not have too much differences for the first step that must be taken to taking measurements using an oscilloscope is determining the ton and toff values for each angles, then adjusting the potentiometer in the comparator 2 circuit so that the output waveform has t_{on} and t_{off} on the oscilloscope according to the calculation above, because the observations of oscilloscope still carried out manually, the results the measurement of one person with another person may be different because of the level of accuracy in observing the oscilloscope, on the other hand the components and voltage three phase sources that used in this research are not in ideal condition.

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