DESIGN AND CONSTRUCTION OFA LIGHT DIMMER

BY

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JANUARY, 20[illegible]

DECLARATION

I hereby declare that this project work "Design and construction of a light dimmer" was carried out by me for the award of Bachelor of Engineering Degree in the Department of Electrical and Computer Engineering and has never been presented elsewhere.

....	16th August, 2010
Agoh .A. Yakubu	Date

CERTIFICATION

This is to certify that the project work titled "Design and construction of a light dimmer" was carried out by Agoh .A. Yakubu with Registration Number 2004/18758EE, under the supervision of Engr. (Dr.) M. N. Nwohu and submitted to the Electrical and Computer Engineering Department, Federal University of Technology, Minna in partial fulfillment for the award of Bachelor of Engineering (B. Eng.) degree in Electrical and Computer Engineering.

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DEDICATION

This project is dedicated to my heavenly father, the most merciful God and to Elder Agoh M.A.

ACKNOWLEDGEMENT

My thanks go to all those who have contributed to the success of this project.

My sincere thanks go to my parents for giving birth to me and for their moral and financial support.

I wish to express my profound gratitude to my project supervisor, Engr. (Dr.) M. N. Nwohu who despite his tight schedule had time to go through my project.

My thanks go to Inikpi, Onojo, Ojoma, Mamuda, Agoh (Jnr.), Unekwu, Aunty Leah, Mal. Agoh, Jonathan, Stephen, Joshua, Mabel and all the Audu Family for their encouragement to my academic career.

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Finally, my thanks go to Elder. Agoh M.A. for showing me the light and bringing out the best in me.

ABSTRACT

This project presents the construction of a light dimmer circuit that utilizes the current-regulating properties of a triac. Prior to being triggered, the triac provides a barrier in the circuit, preventing current flow from a 200V ac source through the light bulb. During this time, voltage across a capacitor within the circuit builds up until it exceeds the breakover voltage of a zener diode. Once the breakover voltage is exceeded, the triac is fired into a conducting state and current flows through the light bulb. The amount of voltage seen over the light bulb is determined by the firing angle of the triac which is set by the RC time constant of the circuit. This process then repeats every half cycle, and thus is the illumination of the light bulb regulated. However, the switching of the triac introduces high order harmonics into the system.

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CHAPTER ONE

GENERAL INTRODUCTION

1.1. INTRODUCTION

This project presents the construction, testing and operation of a light dimmer using simple devices such as zener diode and triac. Power flow is regulated to a lamp. Light dimming can be used to adjust the brightness of lighting system. It minimizes the consumption rate of energy by the lamp. A light dimmer is designed to control the magnitude of voltage supplied to a lamp which consequently varies the intensity of light in the lamp.

Light dimmers are becoming very popular among the residential buildings. They are taking the place of regular light switches and are being widely used for lighting control. Light dimmer has many advantages over conventional light switches. The modern light dimmers offer convenience and flexibility. One of the most important features of newer light dimmer is to offer 'presets'. This feature lets the user to set the light intensity according to the mood or need. It provides a real convenience in homes, hotels or restaurants where the glare of the atmosphere can be adjusted at the turn of a knob of a potentiometer.

1.2. MOTIVATION

It could be observed that in some residential buildings where the glare of light could bring discomfort to the user, light dimmers can be used. Light dimmer brings the comfort by adjusting light intensity that would otherwise be unfavourable to the eyes of the user. Furthermore, incandescent lamp is characterized by enormous heat dissipation and this heat can be reduced with the use of a light dimmer.

1.3 AIMS AND OBJECTIVES

Some of the objectives as related to this project include:

- To develop an affordable and cost effective way of regulating light intensity to our convenience.
- To demonstrate the idea of the use of light dimmer in the case of some people with eye problem whose eyes get irritated when exposed to bright light.

1.4 PROJECT OUTLINE

This project outlines the procedures, techniques and design that are involved in the construction and implementation of this project and the amount of research work done on the subject matter.

Chapter one gives an introduction of the project, the motivation and its objectives.

Chapter two gives a brief history of previous work done (literature review) that culminates to the present day concept of the device under study.

Chapter three discusses the principle of operation of the device. While Chapter four deals with the circuit construction, testing and encasing. Finally, chapter five depicts conclusion and recommendation.

CHAPTER TWO

LITERATURE REVIEW OF A LIGHT DIMMER

2.1. INTRODUCTION

Light dimming is based on adjusting the voltage which gets to the lamp. Light dimming has been possible for many decades by using adjustable power resistors and adjustable transformers. These light controlling methods have been used in movie theatres, stages and other public places. The problem of those light controlling methods have been that they are big, expensive, have poor efficiency and they are hard to control from remote location [1].

Dimmers were first introduced by Granville Woods in 1892 for theatres. The early dimmers were made for commercial purposes such as theatres and halls and were produced using heavy transformers and resistors. The quality of these early dimmers was not very good and they created electrical noise in the circuit. In the 1960`s, Lutron made the first electronic solid state dimmer. The dimmer was made from solid state components which were more efficient and reliable. The wear and tear of the dimmer circuitry dramatically dropped and the life of dimmers changed from months to years. After continued progress in the electronics world the whole concept of dimmers changed. Instead of large heavy dimmers, small and light dimmers were introduced and began to dominate the market [2].

The advent of power electronics since 1960 paved way to high efficiency of light dimmer and its versatility. Between 1960-1970 thyristors and triacs came into market. Using those components, it was quite easy to make small and inexpensive light dimmers which have good efficiency. Electronics control also made them easily controllable from remote location.

This type of electronic light dimmers became available after 1970 and are nowadays used in very many locations like homes, restaurants, conference rooms and in stage lighting [2].

Solid-state light dimmers work by varying the "duty cycle" (on/off time) of the full a.c. voltage that is applied to the lights being controlled. For example, if the voltage is applied for only half of each a.c. cycle, the light bulb will appear to be much less bright than when it gets the full a.c. voltage, because it receives less power to heat the filament. Solid-state dimmers use the brightness knob setting to determine at what point in each voltage cycle to switch the light on and off.

A typical light dimmer is built using thyristor and the exact time when the thyristor is triggered relative to the zero crossings of the a.c. power is used to determine the power level. When the thyristor is triggered it keeps conducting until the current passing though it goes to zero (exactly at the next zero crossing if the load is purely resistive, like light bulb). By changing the phase at which you trigger the triac you change the duty cycle and hence the brightness of the light [3]. Figure 2.1, is an example of normal a.c. power you get from the receptacle.

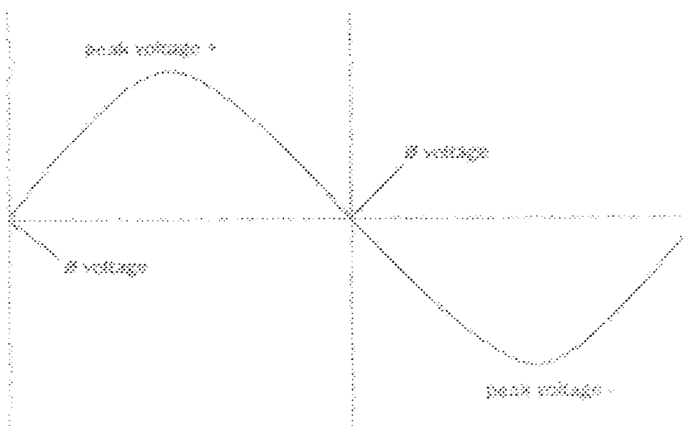

Fig.2.1: Normal a.c. voltage you get from the receptacle (sine wave)

And in figure 2.2 shows what gets to the light bulb when the triac fires on the middle of a.c. phase:

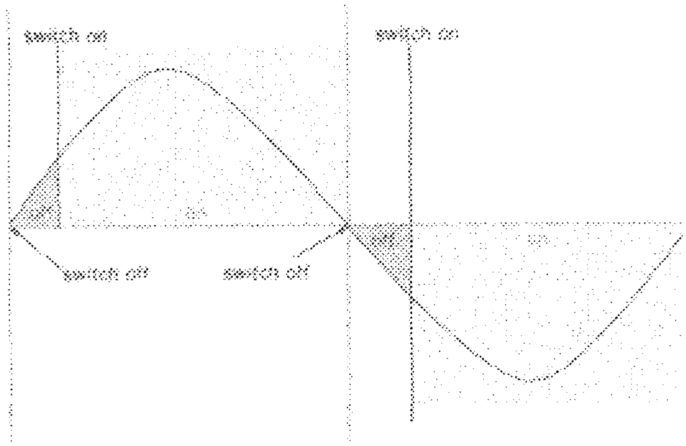

Fig.2.2: The on-state of the triac when fired.

As you can see, by varying the turn-on point, the amount of power getting to the bulb is adjustable, and hence the light output can be controlled.

The advantage of thyristors over simple variable resistors is that they (ideally) dissipate very little power loss when they are either fully on or fully off.

2.2. HISTORICAL ACCOUNT OF COMPONENTS

2.2.1. THE TRIAC

A dimmer switch rapidly turns a light circuit on and off to reduce the energy flowing to the switch. The central element in this switching circuit is a triode alternating current switch, or triac.

The triac, or bidirectional triode thyristor, is a device that can be used to pass or block current in either direction. It is therefore an a.c. power control device. It is equivalent to two thyristors in anti-parallel with a common gate electrode. However, it only requires one heat sink compared to the two heat sinks required for the anti-parallel thyristor configuration. Thus the triac saves both cost and space in a.c. applications [14].

A triac is a small semiconductor device, similar to a diode or transistor. Like a transistor, a triac is made up of different layers of semiconductor material. This includes N-type material, which has many free electrons, and P-type material, which has many "holes" where free electrons can go [3].

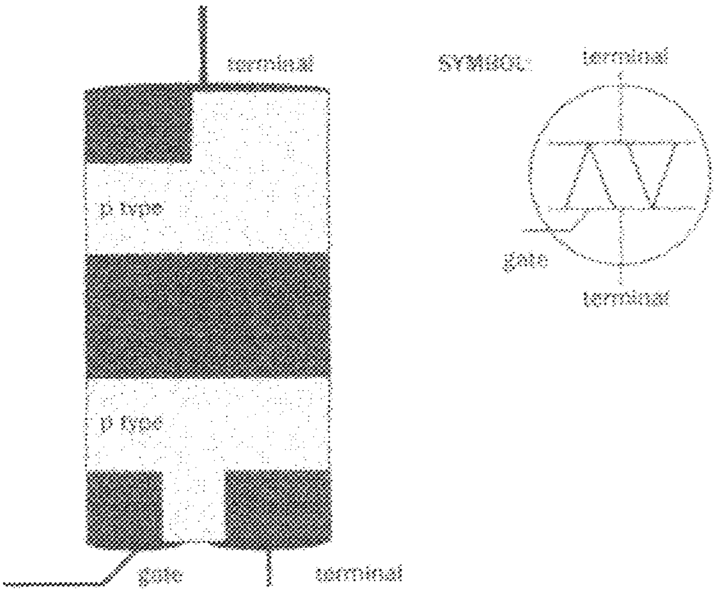

Fig.2.3: Arrangement of n-type and p-type materials in a triac.

You can see that the triac has two terminals, by which connections are made. There is always a voltage difference between the two terminals, but it changes with the fluctuation of the alternating current. That is, when current moves one way, the top terminal is positively charged while the bottom terminal is negatively charged, and when the current moves the other way the top terminal is negatively charged while the bottom terminal is positively charged.

2.2.2 ZENER DIODE

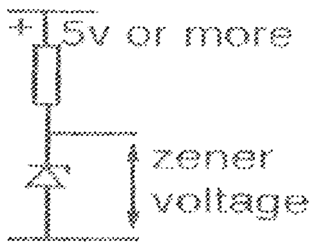

Fig. 2.4. Voltage across the zener diode

A zener diode allows current to flow in both directions. In the "forward" direction, no current will flow until the voltage across the diode is about 0.7 volts (as with a normal diode). In the reverse direction (cathode more positive than the anode) no current will flow until the voltage approaches the "zener" voltage, after which a lot of current can flow and must be restricted by connecting a resistor in series with the zener diode so that the diode does not melt.

Within a certain supply voltage range, the voltage across the zener diode will remain constant. Values of 2.4 volts to 30 volts are common. Zener diodes are not available in values above around 33 volts but a different type of diode called an AVALANCHE diode works in a similar way for voltages between 100V and 300V. (These diodes are often called "zener" diodes since their performance is so similar.)

Zener diodes are used to "clamp" a voltage in order to prevent it from rising higher than a certain value. This might be to protect a circuit from damage or it might be to "chop off" part of an alternating waveform for various reasons. Zener diodes are also used to provide a fixed "reference voltage" from a supply voltage that varies. They are widely used in regulated power supply circuits [13].

CHAPTER THREE

DESIGN AND CONSTRUCTION

3.1. METHODOLOGY

Simple devices such as zener diode and triac are used in the operation of the light dimmer. Power flow is regulated to a load (100W light bulb) by intermittently applying a 200V a.c. source across the load during each half cycle. The intensity of the light is determined by the proportion of the sine wave that is applied across the load.

3.2. LIGHT DIMMER DESIGN

This section describes and analyzes the theoretical background of each module in the block diagram of the light dimmer. The light dimmer circuit is made up of a.c. power supply, dimming operation section, firing circuit and the display as shown in figure 3.1.

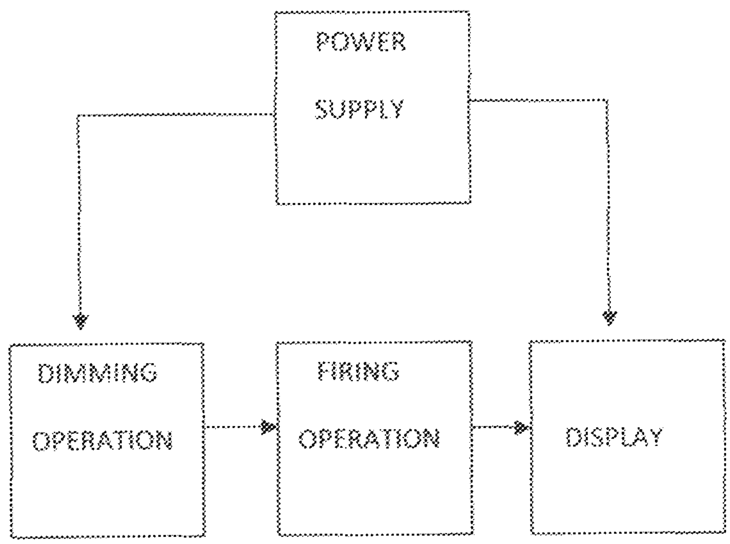

Fig. 3.1: Block diagram of a light dimmer circuit

3.2.1 POWER SUPPLY

The power source of the device is an alternating current (ac). It does not need any signal modification. The device can work with the voltage range from 200V to 240V rms value. However, due to the low voltage in our environment, this voltage (240V) is unattainable. A voltage of 220V is obtained and used in most of the time.

Table 3.1: Input specifications of the dimmer

Voltage (V)	Frequency (Hz)	r.m.s Voltage (V)	Peak Voltage(V)	Peak-To-Peak Voltage (V)
200	50	200	282.2	565.6

3.2.2 DIMMING OPERATION

This operation is basically the regulation of the input voltage via a potentiometer into the zener diode that triggers the triac gate. A potentiometer with a high value, say 500kΩ, to vary over a wide range of voltages is need.

By ohm's law,

$$V = IR \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

At maximum voltage, 200V

Then, $$I = \frac{200}{500K\Omega} = 0.0004A = 0.4mA\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

At the minimum voltage, 0V

Then, $$I = \frac{0}{500K\Omega} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

3.2.3 FIRING OPERATION

The firing operation is accomplished by controlling the rate at which the capacitor charges, and is determined by the RC time constant of the series potentiometer and capacitor. Note: In an RC circuit, the value of the time constant (in seconds) is equal to the product of the circuit resistance (in ohms) and the circuit capacitance (in farads), i.e.

$$\tau = R \times C \text{ .... (4)}$$

It is the time required to charge the capacitor through the resistor, to 63.2 (≈ 63) percent of full charge; or to discharge it to 36.8 (≈ 37) percent of its initial voltage. The values are derived from the mathematical expression, specifically $1-e^{-1}$ and e^{-1} respectively [16].

Using equation 4 and figure 3.2,

$$\text{Time constant } (\tau) = (820K\Omega + 500K\Omega)100nF$$

$$(820K\Omega + 500K\Omega) = 1320K\Omega = 1320000$$

$$100nF = 100\times10^{-9} = 0.0000001$$

$$\text{Time constant } (\tau) = 1320000 \times 0.0000001 = 0.132$$

$$\text{Time constant} = \frac{0.132}{60\min s} = 0.0022\sec$$

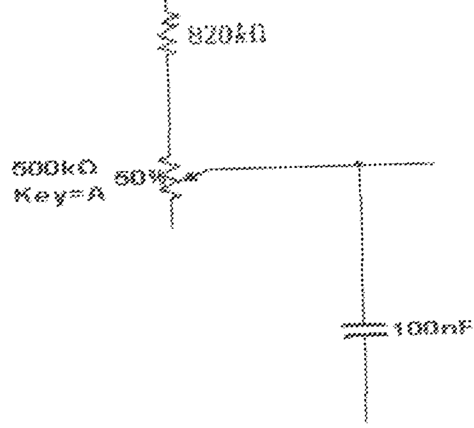

Fig.3.2: Series connection of potentiometer and capacitor

Thus, to control the intensity of the light, one simply controls the value of the resistance on the potentiometer, which determines the rate at which the capacitor reaches the breakover voltage. The smaller the RC time constant, the quicker the capacitor reaches the breakover voltage, and thus the more of the 50Hz sine wave that is applied to the light bulb. The greatest intensity of the light can be seen when the resistance of the potentiometer is set to zero, while the greatest of the sine wave is applied to the bulb [4].

Initially, before the zener diode conducts, the triac is in a non- conducting state. In this configuration, the circuit appears as in Figure 3.3 below. As one can see, there is no conduction through the light bulb, and thus the light remains off.

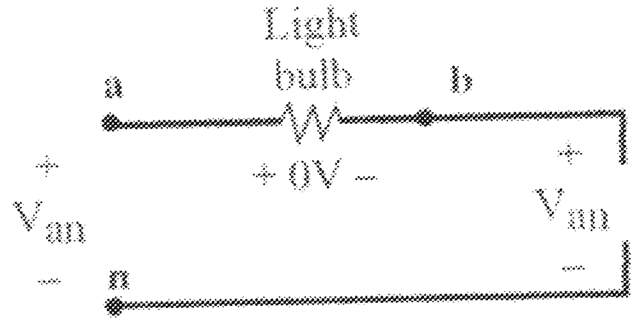

Fig.3.3: Before firing - Triac non-conducting

Once firing occurs, the triac is in its conducting state, and appears as a closed switch. As shown in Figure 3.4, this then causes the voltage, Van, to appear across the light bulb.

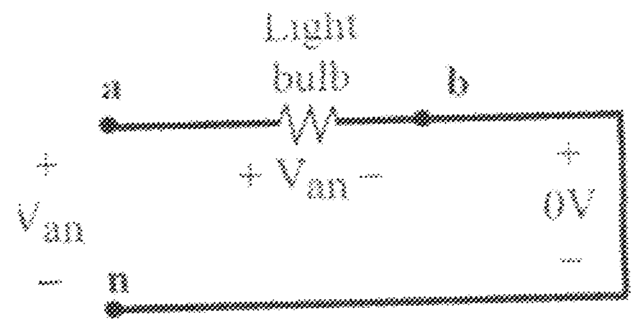

Fig.3.4: After firing - Triac conducting

NOTE: The quick change between conducting and non-conducting states of the triac, goes unnoticed by the human eye. The eye cannot detect the change of states, and thus one cannot see the light flickering on and off.

RESISTOR

The resistor performs two functions, to block current that would have flowed back into the circuit, and to contribute to the time constant that controls the firing circuit. The voltage across the resistor is calculated from:

$$V_1 = V_T \frac{R_1}{R_T} \quad \text{..(5)}$$

$$V_1 = 200 \times \frac{820}{1320} = 124.24V$$

The value of the current is the output current of the triac at maximum value of the time constant (

i.e, the maximum time the capacitor charges through the resistor at a higher percentage)

TRIAC

Since 240V is required for the circuit, a triac with appropriate voltage and current rating is selected. BT138-G is chosen because not only does it have a maximum voltage capacity of 800V and current rating of 12A, it has a maximum operating junction temperature of 125°C.

ZENER DIODE

The zener diode whose $V_Z = 1.5V$ is used to channel the pulsating voltage that is produced as a result of R and C in the circuit to triac. Usually the zener diode has to be connected in the reverse biased direction for proper conduction.

Also, when selecting this device, a high avalanche breakdown voltage greater than the negative pulse by RC is selected. Since the maximum triggering voltage of the triac (V_{max}) = 2.5V and V_z = 1.5V, therefore, for the zener diode to function properly V_{max} must be greater than V_z.

The current applied through the zener diode should be less than the I_{zmax}. Also, for proper conduction, V_z must be less than the voltage applied.

3.2.4 DISPLAY

The display is a light bulb of 100W 50Hz rating. The choice of this display is because of the low voltage in the test area. It is capable of showing a considerable brightness of the light.

3.3. Complete schematic diagram of a light dimmer

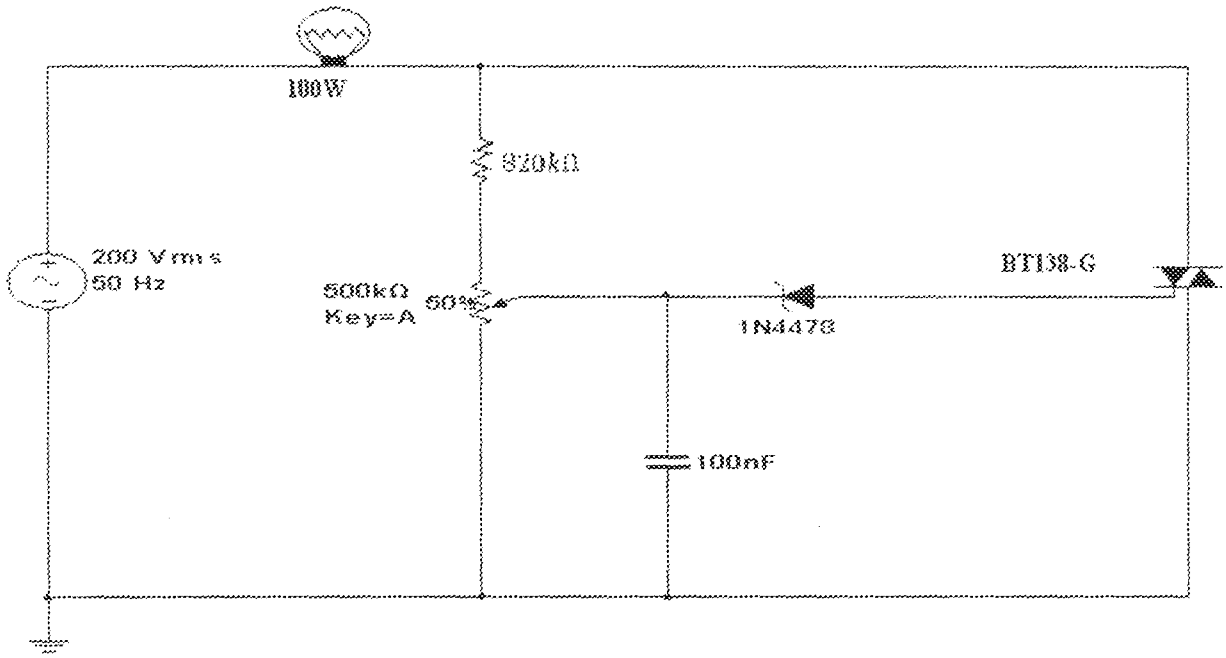

Fig. 3.5: Complete Schematic Diagram of a Light Dimmer

3.4 CONSTRUCTION

The circuit diagram was drawn from the block diagram, unit by unit first. The light dimmer circuit was constructed and tested on the bread board, after which the circuit was transferred to the veroboard. The triac was first connected and followed by other components. Connections were made on the circuit to put the circuit in the best operating conditions and to ensure they do not over-heat due to excessive current.

The light dimmer circuit components were scraped to remove impurities so as to be firmly soldered. Thereafter, it was soldered on a Vero board. The scraping encouraged smooth and neat soldering of the components on the board.

added or removed with ease without soldering. The complete circuit was housed in a plastic casing and the lamp holder was screwed on a ply-wood. The plastic case and the ply wood on which the lamp dimmer was mounted were rectangular in shape.

Some soldering precautions taken are outline below;

- Little but enough soldering lead was applied to any joint to ensure proper contact of the components.
- Care was taken to ensure proper soldering of each joint.
- All components and connecting wires were inserted in place before soldering.

3.5. DIFFICULTY ENCOUNTERED

Difficulties encountered during the construction of the project were:

- Erratic power supply in the university and the city of Minna slowed down the pace at which the project was done.
- The specified components were not easily found in Minna local markets.

CHAPTER FOUR

TESTS, RESULTS AND DISCUSSION OF RESULT

4.1. TESTS

The circuit was initially constructed on a bread board and found to be working properly. It was then dismantled and transferred to the Vero-board and connections were made as appropriate continuity test was carried out with a multimeter.

4.2. RESULTS

For proper result documentation, the following steps were taken

1. With the aid of a voltmeter, the voltage across the lamp was measured at minimum resistance (0%)and maximum resistance (100%).
2. Measurement of voltage across the capacitor.

Measurement of voltage across the lamp to get the triac firing angle was determined by varying the resistance of the potentiometer at minimum and maximum percentage.

DETERMINATION OF FIRING ANGLE

In order to determine the firing angle α, a plot of Voltage vs time had to be made using an osciloscope as shown below in Figure 4.1.

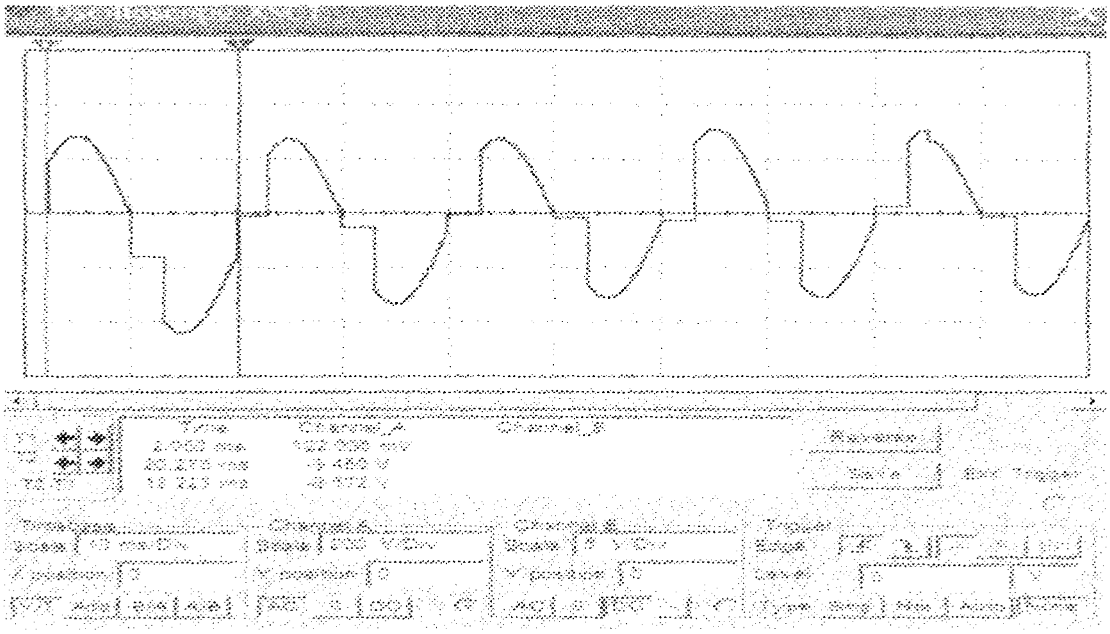

Fig.4.1: minimum firing angle

To determine the firing angle in degrees, it was first measured in milliseconds using the oscilloscope along with the period of the wave. Then, using equation 6, the firing angle in degrees was found. The firing angle in degrees was computed as;

$$\alpha = \frac{T_{off}}{T_{period}} \times 360° \text{...} (6)$$

In this equation T_{off} is the firing time in milliseconds and α is the firing angle in degrees[9].

From the above graph, T_{period} =18.223, T_{off} =3.645.

This gives the firing angle $\alpha = \frac{3.645}{18.223} \times 360 = 72.00 = 72°$

NOTE: All values were obtained from my stimulated circuit.

Therefore, firing angle in degrees is equal to 72 degrees. When the voltage across the light bulb was measured, it was found to be 190.43Vrms via an osilloscope and 182.19Vrms via a meter.

VOLTAGE ACROSS THE LAMP WITH 90% RESISTANCE

The potentiometer was set at 90% of its resistance as shown in the plot in Figure 4.2. below,

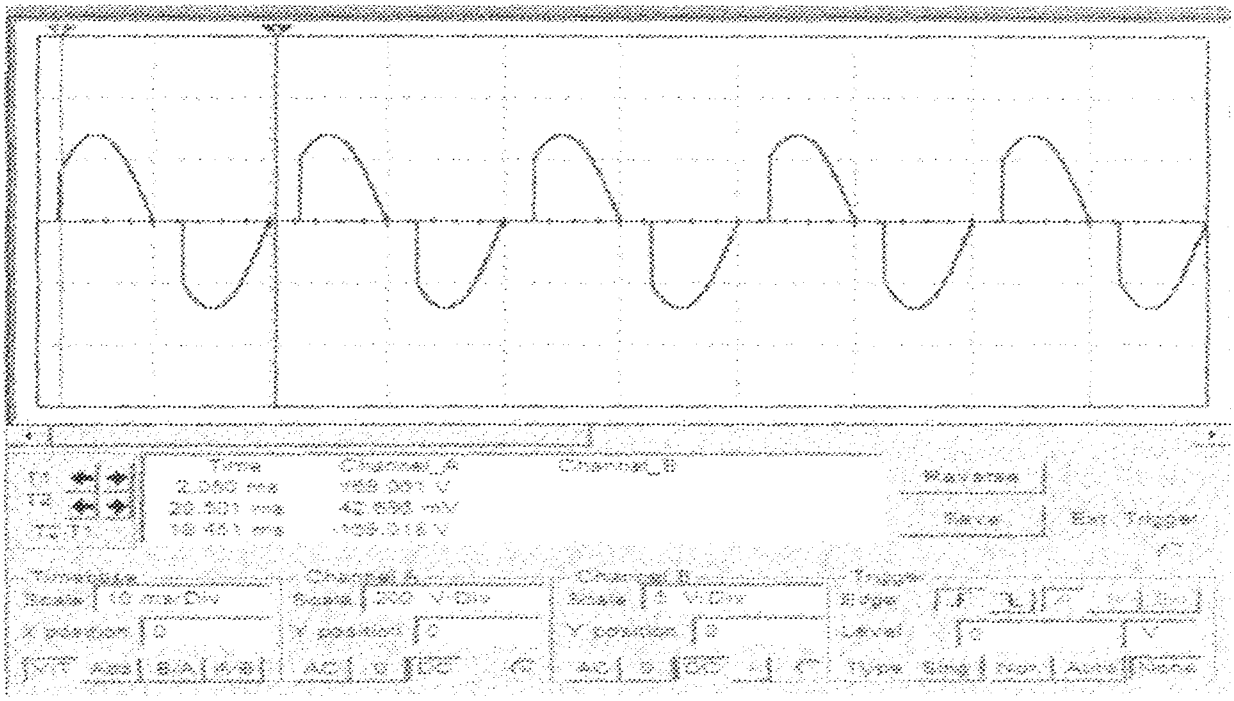

Fig.4.2: Firing angle at 90% resistance

From the above graph in figure 4.2 the total period of the wave form T_{period} is equal to 18.415ms and the firing angle was T_{off} equal to 2.506ms.

Therefore the firing angle in degrees is given as:

$$\alpha = \frac{2.506}{18.451} \times 360 = 48.89^{\circ}$$

When the voltage across the light bulb is measured on oscilloscope, it gave 144Vrms while using a multimeter, it is measured to be 135V.

Since the maximum voltage applied to the load is 200Vrms, therefore the theoretical voltage value of the load at firing angle $\alpha = 48.89°$ is $\frac{200V}{\sqrt{2}} = 141.42V$ which is close to the value measured on the oscilloscope.

VOLTAGE ACROSS THE LAMP AT MAXIMUM RESISTANCE

The potentiometer was set at maximum resistance of 100 percent. This plot is shown in Figure 4.3.

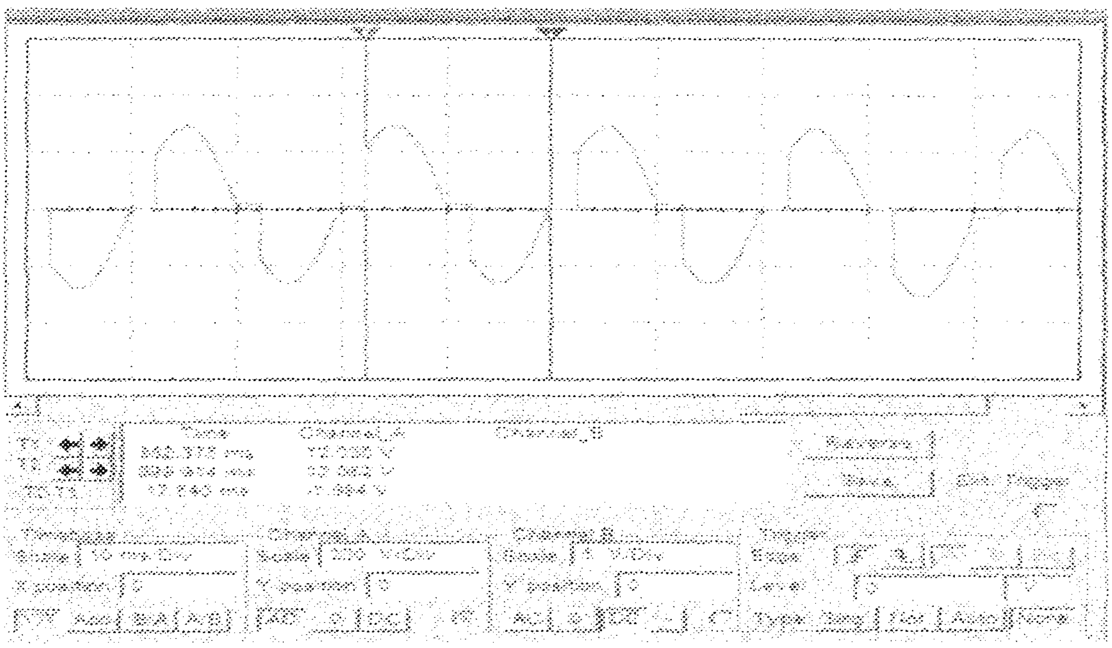

Fig. 4.3: Firing angle = 46°

From the plot, the period of wave $T_{period} = 17.54ms$ while $T_{off} = 2.28ms$.

$$\text{Therefore } \alpha = \frac{2.28}{17.54} \times 360 = 46°$$

Furthermore, the voltage across the load using a multimeter was 141.2Vrms and 150Vrms using an oscilloscope. However it was noted that beyond this firing angle, the capacitor would never be fully charged before discharging during the negative cycle. For this reason, the circuit would fail to conduct.

4.2.2 MEASUREMENT OF VOLTAGE ACROSS THE CAPACITOR

VOLTAGE ACROSS CAPACITOR

In the plot of the oscilloscope shown (figure 4.4) it was notice that, one can see the capacitor charging up to the point where the break over voltage is reached, and then a quick discharge is observed through the gate of the triac (figure 4.5).

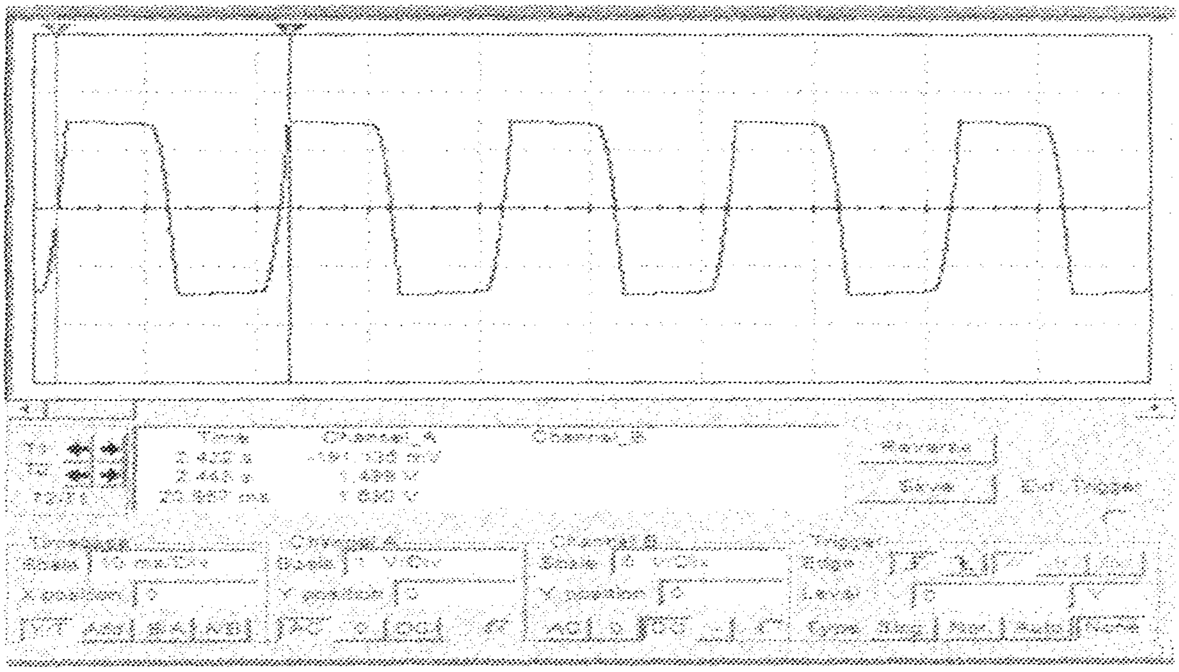

Fig. 4.4: Voltage across capacitor

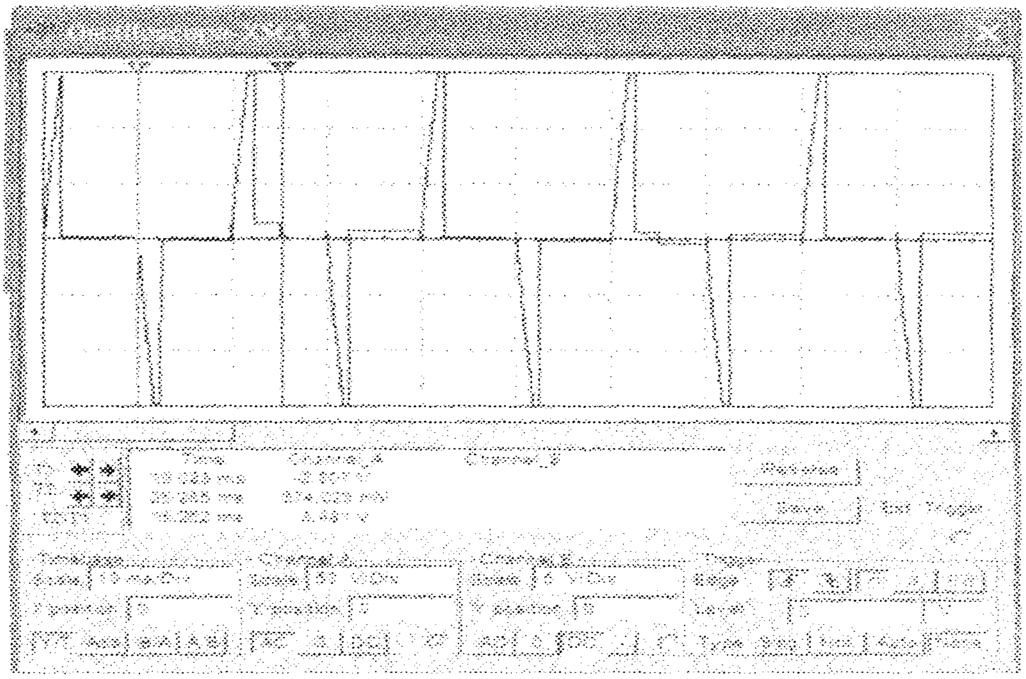

Fig. 4.5: Voltage across the triac

In figure 4.5, there were harmonic components introduced into the light bulb voltage as a result of the switching operation of the triac in the circuit.

4.3. DISCUSSION OF RESULTS

During this experiment several observations were made. It was noticed that the rms voltage levels measured with the multimeter were not in agreement with those observed using the oscilloscope. It was determined that this discrepancy is caused by the multimeters` tendency to average the rectified wave and make a sine wave assumption. It is for this reason that as the firing angle was increased, and the voltage across the light deviated further and further from a true sine wave, that the multimeter reading became less and less accurate.

The smaller the RC time range, the quicker the capacitor reaches the break over voltage, and thus the more of the 50Hz sine wave that is applied to the light bulb. This plot can be seen in figure 4.6.

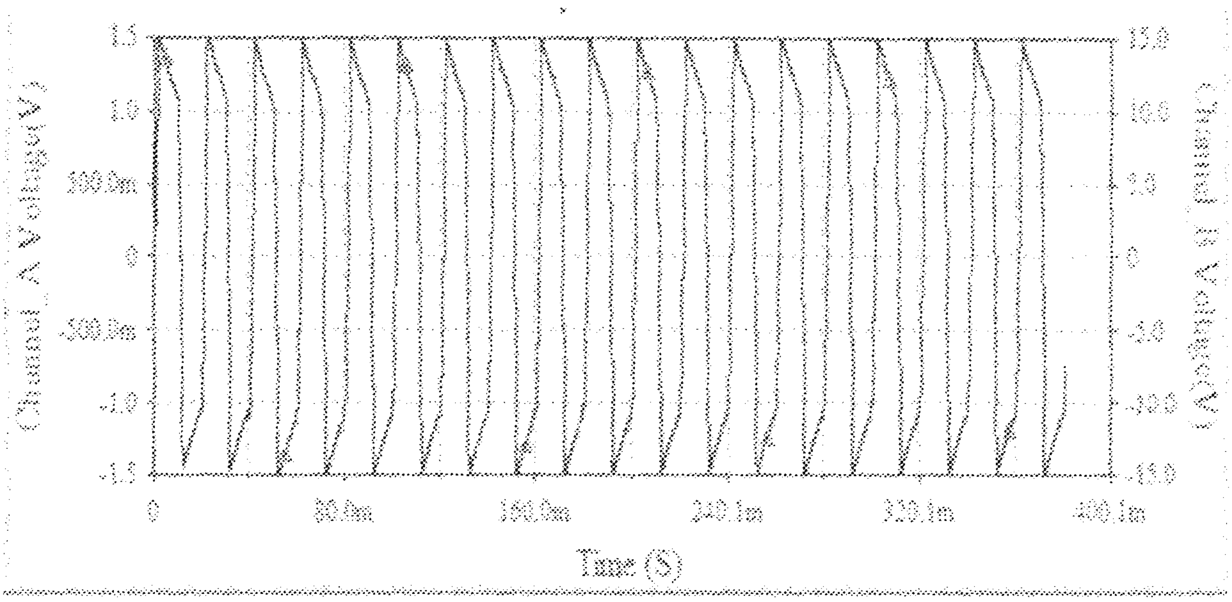

Fig. 4.6: Voltage across capacitor

The greatest intensity of the light can be seen when the resistance of the potentiometer is set to zero, and the full sine wave is applied to the bulb. The graph can be viewed in figure 4.7.

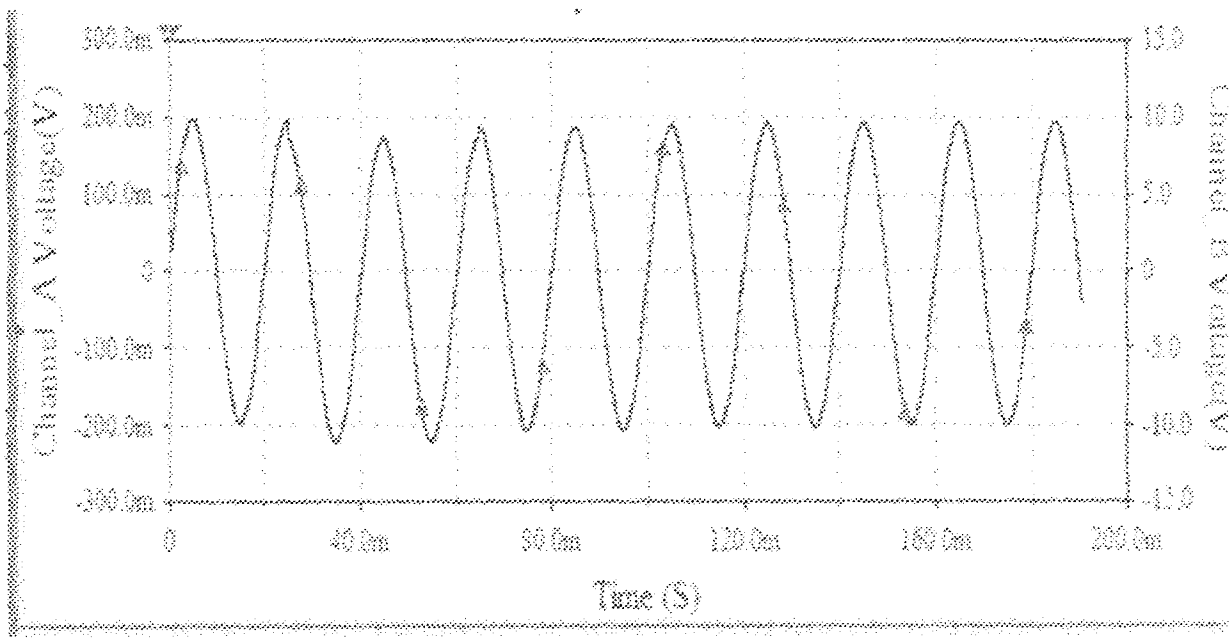

Fig. 4.7: Sine wave applied to the bulb

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

The variation of the potentiometer brought about variation in firing angle that yielded the variation in voltage value across the load. It also causes variation in the intensity of the light.

For the circuit to conduct, the breakover voltage must be overcome by the capacitor.

As a result of switching, harmonics are found in the wave form of the power at the load.

5.2. RECOMMENDATIONS

1. The circuit can be designed using a microcontroller.
2. A printed circuit board can be used in place of a veroboard to reduce the circuit complexity and enhance easy understanding of the circuit.

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