DESIGN AND CONSTRUCTION OF OVERLOAD PROTECTION SYSTEM USING SOLID STATE RELAY

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DEDICATION

In loving memory of my late father: MR. Daniel Abolaji Balogun. May his soul rest in perfect peace, AMEN.

DECLARATION

I BALOGUN OLUBUNMI MARGARET declare that this project work was done by me and has never been presented elsewhere for the award of a degree. I also hereby relinquish the copyright to the Federal University of Technology, Minna.

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ABSTRACT

This project design is an overload protection system. The project is design in order to provide an automated way of disconnecting load from A.C supply. The purpose of this project was realized via current detector (current transformer), sensor comparators, timer circuit, switching circuit, regulated power supply. The current transformer senses the load current and then generates a much reduced magnitude of the load current in the secondary winding. A voltage proportional to the load current developed across the power resistor connected in parallel to the secondary winding of the current transformer. This current rectified and then used as the control input to the base of an NPN transistor that triggers a monostable circuit, whenever the load voltage is greater than the v0. preset voltage. The monostable output goes high for a time period determined by $1.1R_TC_T$ after which it switch low to reconnect the load. The monostable output sense current through the led internal to the opto-triac switch on or off the power triac, thereby controlling the load at over current condition.

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CHAPTER ONE

INTRODUCTION

The use of over load protection unit in our day to day lives, either at home or laboratory cannot be over emphasized. One of the versatility of overload protection unit is to enable an alternating current circuit to be interrupted in case of malfunction, it protects against abnormal conditions for satisfactory and reliable operation, it acts to prevent mechanical damage, fires, explosion, and electrocution also allow the circuit to be operated within it rating.

Danger arises only when the rating of the protection exceeds that of the circuit protected. For example, three (3) 15A loads have been connected to a 15A circuit, blowing the fuse. A misguided handyman may replace the use and find that it blows again, use a 60A fuse. The overload current will not blow the fuse but will certainly overload the circuit conductor, rapidly aging the insulation and causing over heating or insulation failure. Therefore, a special device is needed called overload relay which closes the circuit at overload in the case of external failure.

In most industrial process overload protection is achieved using solid state electronic devices instead of electromechanical devices for their many advantages. Solid state devices have not changed the basics of the industrial process but have provided more precise control of industrial process. For example, electromechanical relays must consist of devices which are closed by some type of magnetic effect which makes maintenance of contact expensive and introduces time delay. Solid state devices, by no contrast, have no contacts and switch entirely by electronic devices.

1.1 OBJECTIVES

The objectives of this project are:

1. To acquire a deeper insight into the use of solid state electronic device as a switching device in an overload protection circuit.

2. To realize a simple design that can be put to use even in the laboratory as well as in industrial process.

3. To put into practice the various theories learnt in the school. Such course includes analogue electronic and laboratory practice.

1.2 PROJECT OUTLINE

This project set out to present an orderly account of work done. It consists of five chapters:-Chapter 1:- This chapter gives an insight into the project from an introductory point of view and presents the stated objectives of the project.

Chapter 2:- This chapter gives an historical review of the project and also expatiate on some of the fundamentals which are applied in carrying out the task.

Chapter 3:- This chapter shows all the steps carried out in setting up the circuit element and report on the construction and listing of the circuit.

Chapter 4:- This chapter contains steps taken to test the work. Short comings or limitations of the work are also explained.

Chapter 5:- This chapter gives the conclusion of the work. Summary of the work is presented and result obtained and problems encountered are summarized.

1.3 SCOPE OF THE PROJECT

For simplicity, the project is sectioned into three (3) parts:- Current sensing (Detection), Rectification and control unit.

CHAPTER TWO

LITERATURE REVIEW

2.1 BRIEF HISTORY OF OVERLOAD PROTECTION DEVICES.

In application of alternating current circuits there is a requirement for a reliable, efficient and economical means for sensing alternating current levels or flow rates and for protecting the alternating current circuit from damage in the event of overload which result in excessively high current drawn by the circuit. There are several devices and methods for the protection of alternating current circuit. Among these are fuses, circuit breaker to mention but a few.

2.2 FUSES AS A PROTECTIVE DEVICE

Fuse is defined in the IEEE regulation as "a device for opening a circuit by means of a conductor designed to meet when an excessive current flows". A fuse opens when the current through it exceeds its current rating for a period of time. Fuses have three important rating, or characteristics that need to be considered when specifying fuses. These ratings apply to all fuses regardless of size, shape or styles, these three (3) characteristic are:-

2.2.1 CURRENT RATINGS

It is given for specific condition of air circulation and temperature. Therefore, fuses are usually operated well below their rated current. This practice avoids unnecessary blowing of fuses while still providing short-circuit protection.

2.2.2 VOLTAGE RATINGS

Voltage ratings of fuses are based on a power source capable of providing 10,000A of current when dead-shorted. A 250V fuse protects nay 250-v power source that can provide no more than 10,000A. Of course, the current rating of a fuse must be less than the current capabilities, of the power source. Many power source (small batteries and transformers) can provide only a few amperes of current when short circuited. With limited-current power sources, the voltage ratings of fuses are often exceeds. It is fairly common for electronic circuits with more than 400V to be fused with 250-V fuses.

2.2.3 BLOWING CHARACTERISTICS

This characteristics of a fuse indicate how rapidly the fuse blows (open) when subjected to specific overloads. There are three general categories of blowing characteristics of fuses. These are fast-blow, medium-blow and slow-blow, these categories are sometimes referred to as short-time lag, medium-time lag and long-time lag respectively. All three categories respond rapidly (about 1ms) to extreme overloads (more than 10 times the rated current). All three categories respond about the same to very small overloads at 1.35times (135 percent) the rated current, they all take a minute to open.

2.3 CIRCUIT BREAKERS AS A PROTECTIVE DEVICE

The IEEE regulations define a circuit breaker as a mechanical device for making a circuit both under normal conditions and under abnormal conditions such as those of a short circuit, the circuit being broken automatically. It is an automatic switch, which opens in the event of excess current. The switch can be closed again when the current returns to normal, because the device does not damage itself during normal operation. The contacts of a circuit breaker are closed by a latch arrangement. The small movement of the latch will release the contact which will open quickly under spring pressure to break the circuit.

There are two (2) basic methods by which excess current can operate or trip the latch, either by thermal tripping or magnetic tripping

2.4 THERMAL TRIPPING OF A PROTECTIVE DEVICE

In thermal tripping the load current is passed through small heater, the temperature of which depends on the current it carries. This heater is made of two different metals which are securely riveted or wheeled together along their length. The rate of expansion of the metal is different, so that as the strip is warm, it will bend and will trip the latch. The bimetallic strip and heater are so arranged that normal current will not heat the strip top tripping point. If the current increases beyond the rated value, extra power is dissipated by the heater ($P = I^2R$) and the bimetallic strip is raised in temperature to trip the latch.

2.5 MAGNETIC TRIPPING OF A PROTECTIVE DEVICE

The principle used here is the force of attraction which can be set up to the magnetic field of a coil carrying the load currents. At normal current the magnetic field is not strong enough to attract the latch, but overload currents operates the latch and trip the main contact. There is always some time delay in the operation of thermal trip, since the neat produced by load current must be transferred to the bimetal strip. Thermal tripping is thus best suited to small overloads of comparatively long duration. Magnetic trips are fast acting for heavy overloads but uncertain in operation for high overload.

The two methods are thus combined to take advantage of best characteristic of protecting high-current loads that is thermal and magnetic mechanisms. The thermal trip opens when the overload is small and quick in the circuits not needed. A large rush of current, however causes the breaker to open quickly via magnetic trip mechanism.

2.6 SOLID STATE ELECTRONIC OVERLOAD PROTECTION

Although the most common method used before for overload protection was overload heater, but in recent decade, electronic overload is becoming increasingly popular. The electronic overload function on the same basic principle as mechanical and electromechanical principles, but due to solid state electronic declining cost, high reliability and immense capability, solid state devices have begun replacing many devices which operate on mechanical and electromechanical principles. To be able to explain the difference between these devices, there must be examination of both devices capabilities and their switching devices.

Electromechanical relays and solid state relays are both designed to provide a common purpose of switching each accomplishing this final result in different ways. Basically, the electromechanical relay provides switching through the use of electromagnetic devices and set on contacts, while the solid state relay depend upon electronic devices such as silicon controlled rectifier (SCR), Transistors and Triac to switch without contacts.

2.7 COMPARISONS OF ELECTROMECHANICAL RELAYS WITH SOLID STATE RELAYS

Differences arise almost immediately both in the terminology used to describe the devices and in their overall ability to perform certain functions.

2.7.1 INPUT SIGNALS

It takes more voltage and current to pull in the coil than to hold it in, due to the initial air gap between the magnetic coil and the armature in electromechanical relay. Because of these operating characteristics, four different specifications are used to describe the energizing and de-energizing process of an electromagnetic device, namely, coil voltage, coil current, hold current and drop out voltage. By contrast, solid state relay has neither coil nor contacts and requires only minimum value of voltage and current to turn it on and turn it off, only two specifications are needed to describe the input signal for a solid state relay, namely: - control voltage and control current. Many solid state relays are available with minimum control voltages of three (3) volts and control currents as low as one milliampere, making them ideal for variety of current state-of-the-art logic circuits.

2.7.2 RESPONSE TIME

One of the significant advantages of the solid state relay over the electromechanical relay is its response time, or ability to "turn on" and "turn off" where the electromechanical relay may be able to respond hundreds of time per minute, the solid state relay is capable of switching in thousands of time per minute with no chattering or bounce. D.C switching times for a solid state relay are in the micro-seconds range, while A.C switching time, with the use of zero-voltage turn on , is less than nine (9) milliseconds. The reason for this advantage is that solid state relay may be "turned on" and "turned off" electronically much more rapidly than relay may be electromagnetically "pulled in" and "dropped out".

2.7.3 VOLTAGE AND CURRENT RATINGS

When comparing the voltage and current ratings of an electromechanical relay and solid state relay in the load circuit, you are ain effect comparing the maximum safe switching capability of a set of contacts to that of an electronic device such as a SCR or TRIAC. The obvious advantages of solid state relays in this case, however, are that they have a capacity for arc less switching, have no moving parts to wear out, and are totally enclosed, thus being able to be operated in potentially explosive environments without special enclosures.

2.7.4 VOLTAGE DROP

When a set of contacts of an electromechanical relay closes, the contact resistance will usually be quite low unless the contacts are pitted or corroded. The solid state relay, however, being constructed of semiconductor materials, opens and closes circuit by increasing or decreasing its ability to conduct. Even at full conduction, the device presents some residual resistance which can create a voltage drop up to approximately 1.5 Volts in the load circuit. Since this voltage drop is quite small in relation to the load voltage, it is usually considered insignificant and in a majority of cases, presents no problems. When load voltages are quite small, however, this unique feature may have to be taken into consideration.

2.7.5 ZERO CURRENT TURN OFF

Another unique characteristic of solid state relays is the capacity for zero current turn off. Semi conductors by nature will automatically turn-off. When the AC load current is crossing the zero axis. This property of a solid state relay is especially important when switching inductive loads.

2.8 CIRCUIT CAPABILITIES OF SOLID STATE RELAY

The solid state relay can be used to control most of the same circuits that the electromechanical relay is used to control. Because the solid state relay differs from the electromechanical relay in function, the control circuits for solid state relays will differ from those of the electromechanical. This difference will be in how the relay is connected into the circuit and not on the application of the circuit. The solid state relay will perform the same circuit requirements as the electromechanical only with a slightly different control circuit. Following are the basic control circuits that are typical of many circuits requirements:-

2.8.1 TRANSISTOR CONTROL

In this control circuit, solid state relays are capable of being controlled from electronic control signals from integrated circuits and transistors. In this circuit, a solid state relay is controlled through an NPN transistor which receives its signal (IC logic gate for example) and the resistors are used as current limiting resistors.

2.8.2 PARALLEL AND SERIES CONTROL OF SOLID STATE RELAY

Solid state relay can be connected in series or parallel to obtain multi contacts that are controlled by one input device. This can be used to control the three phase circuit, in this case three solid state relay control inputs is connected in parallel so that when the switch is closed all three will be actuated. In this particular application, the DC control voltage across each solid state relay would equal the DC supply voltage. This is because they are connected in parallel. To connect the solid state relays in series to control the same three-phase circuit.

Here the DC supply voltage will divide across the three solid state relays when the switch is closed. For this reason, the DC supply voltage must be at least three times greater than the minimum operating voltage of each individual relay.

CHAPTER THREE

DESIGN AND CONSTRUCTION

The block diagram below of over load protection system is shown below

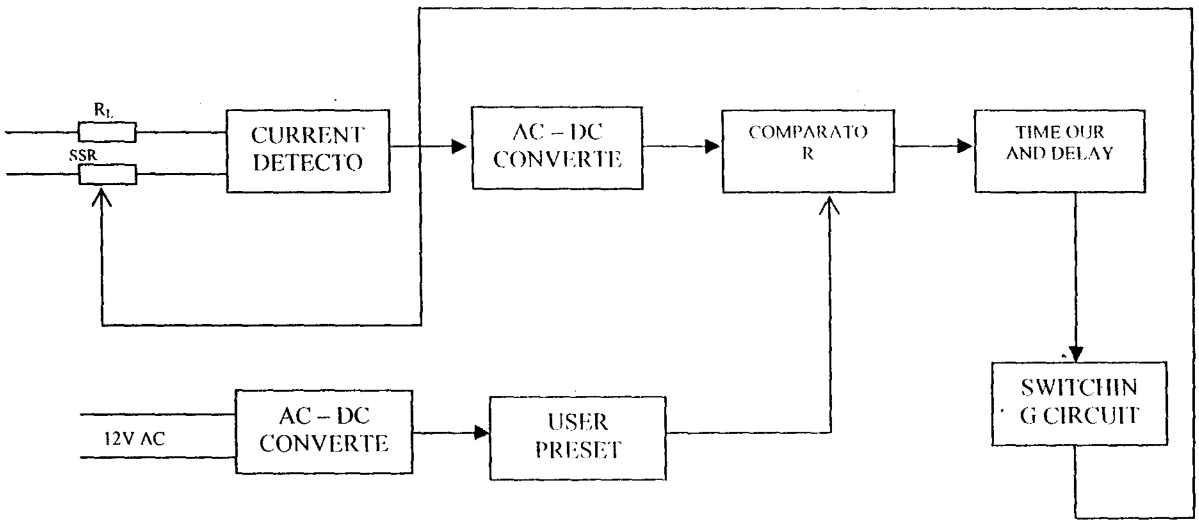

Fig 3.1: Over load protection subsystem.

3.1 SYSTEM CIRCUIT DESIGN

3.1.1 DETECTOR CIRCUIT MODULE COMPONENT

3.1.2 DESIGN OF A CURRENT TRANSFORMER

The primary winding of a transformer is designed to be connected in series to the circuit to be measured. The primary winding is usually of a high voltage winding and the ratio of the secondary winding is usually those of which produce 5A as a 1A at the secondary turns. The current is very important in terms of main circuit carrying full load current. In this project design, the following data will be used.

Primary current Ip = 14A

Secondary current Is = 1.4A

Primary turns, Np = 20 turns

Secondary turns Ns = unknown

By using the transformer formula,

$$\frac{N_s}{N_p} = \frac{I_p}{I_s}$$

$$N_s = N_p \times \frac{I_p}{I_s}$$

$$N_s = \frac{20 \times 14}{1.4}$$

$$N_s = 200 \text{ turns}$$

Thus, the ratio of the primary turn to the secondary turns is 1:10. Therefore, for every 1A of current flow in the primary winding, 0.1A flows in the secondary winding. The current is converted to voltage by a 10Ω, 20W resistance. (RS).

3.2 AC – DC CONVERTER

The AC voltage from Rs is rectified and converted to DC by a full-wave bridge rectifier, the rectified voltage is smoothened by a 470μF capacitance in parallel with a 220Ω resistance. The RC combination provides a delay time of

Td = RC

$= 220 \times 460 \times 10^{-6}$

$= 0.1$ second

The rectified Voltage is fed into a comparator based on the LM 358 dual operational amplifier where it is compared with a reference Voltage derived from a potential divider connected to +12V.

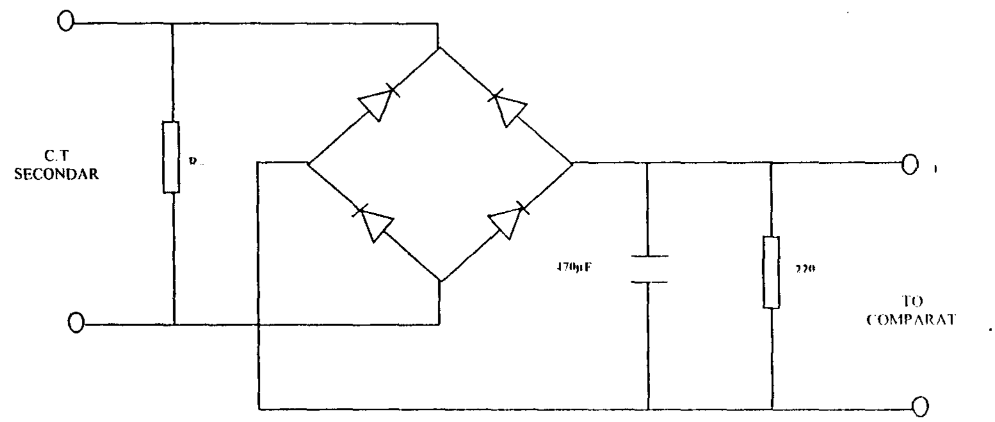

Fig 3.2:Power unit subsystem.

3.3 SENSOR COMPARATOR MODULE COMPONENTS

3.3.1 SELECTION OF RESISTOR VALUES FOR THE OP-AMP

Resistor selection for the op-amp was based on :

Presetting the least loading on the voltage sources.

Limiting input drive into the op-amp

The bias current for the LM358 (from manufactures datasheet) is typically 500mA. The resistors were chosen to pass a current of

$$I = \frac{V}{R}$$

$$= \frac{12}{10000}$$

= 1.2 x 10-3 A

I = 1.2mA into the inputs of the op-amp. If too low current is used, the op-amp becomes unstable if too high current is used, the input stages of the op-amp will be destroyed.

3.3.2 SELECTION OF CURRENT LIMITING RESISTOR FOR LIGHT EMITTING DIODE

The operating voltage for led, $V_{LED} = 2V$

LED minimum operating current, $I_{LED} = \frac{5mA}{20mA}$

Thus, limiting resistor $R_{LED} = \frac{V_{IN} - V_{LED}}{I_{LED}}$

Where, VIN = Voltage supply from the regulator for 5mA,

$$R_{LED} = \frac{12-2}{0.005} = \frac{10}{0.005}$$

$$R_{LED} = 2k\Omega$$

For 20mA,

$$R_{LED} = \frac{12-2}{0.02} = \frac{10}{0.02} = 500\Omega$$

A high efficiency LED was used, hence a higher current limiting resistor of 3.3KΩ was used.

3.4 SWITCHING CIRCUIT MODULE COMPONENTS

3.4.1 DESIGN OF TRANSISTOR BIASING RESISTORS

The transistor selected has the following features

Type: NPN silicon

Functions: Audio and frequency amplification and switching.

Collector to base voltage V_{CBO} = 60Volts

Base to emitter voltage V_{EBO} = 60 Volts

Collector to emitter voltage V_{CEO} = 40 Volts

Maximum collector current I_C = 150mA

Maximum device power dissipation, P_D = 0.5W; (temperatures 25oC)

Current gain, H_{FE} = 300A

Base-emitter Voltage = 0.7V

Since V_{CC} = 12V

To trigger the monostable, the voltage on pin 2 must go lower than 1/3Vcc that is

$V_{PIN} = 2 \leq 4V$

For minimum heat generation in the CB junction of the transistor, $V_{CC} \approx 0V$

Using $V_{CE} = V_{CC} - I_C R_C$

$0 = V_{CC} - I_C R_C$

$V_{CC} = I_C R_C$

$R_C = \frac{V_{ccx}}{R_c}$ limiting IC to 50mA to prevent thermal runaway, RC was chosen as 10KΩ

(recommended value ranges from 1kΩ - 100KΩ).

$$I_C = \frac{V_{CC}}{R_C} = \frac{12}{10000} = 1.2mA$$

$$V_C = \beta I_B$$
Where $\beta = 300$

$$I_B = \frac{I_C}{\beta} = \frac{1.2 \times 10^{-3}}{300} = 4 \times 10^{-6} = 4\mu A$$

V_b = output of LM 358 at positive saturation is 6V on 12V

$$R_b = \frac{V_b - V_{be}}{I_b}$$

$$R_b = \frac{6 - 0.7}{4 \times 10^{-6}} = \frac{5.3}{4 \times 10^{-6}} = 1.33 \times 10^6 \Omega$$

Using the value of the calculated resistance, a high heat dissipation in the transistor may be produced. The base resistance is to be reduced to a value that produce the least amount of heat. The value 3.3KΩ for base resistance was used.

3.5 TIMER CIRCUIT MODULE COMPONENTS

3.5.1 MONOSTABLE

A monostable is an electronic circuit that produces an output pulse whose duration is determined by the values of the Rc timing components connected to it. It is wired as shown below

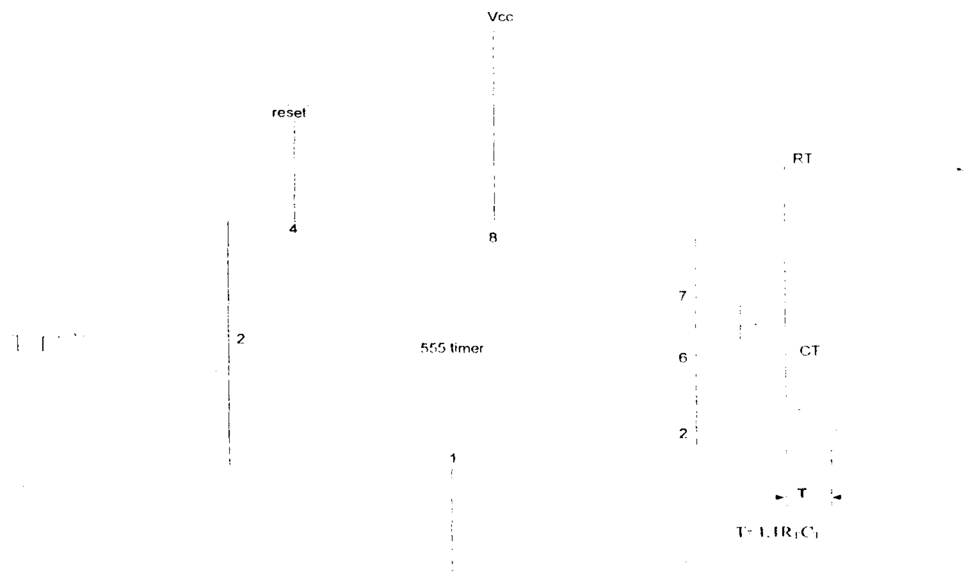

Fig 3.3: A monostable circuit subsystem.

The monostable is triggered when the voltage on pin2 goes below 1/3Vcc. The Output pulse width generated is given by the relationship $T = 1.1R_TC_T$

Where;

R_T = resistance VCC and Pin 6,7

C_T = Capacitance between Pin, 6,7 and ground

$T = 1.1 \times 100K\Omega \times 100\mu f$

$T = 11$seconds

With pin 2 returned to a logic high, pin3 goes low after the time-out period of $1.1R_TC_T$

3.6 REGULATING POWER SUPPLY MODULE COMPONENTS

3.6.1 VOLTAGE TRANSFORMER

For a 220v/12v step down transformer, by applying the transformer formular.

$$\frac{\textit{Total}\text{ emf in the secondary}}{\textit{Total}\text{ emf induced in the primary}} = \frac{\textit{Number}\text{ of turns in secondary}}{\textit{Number}\text{ of turns in primary}}$$

From the supply , the emf induced in the primary side of the transformer is 200v and the desired secondary AC voltage is 12V

From the transformer formular

$$\frac{N_s}{N_p} = \frac{E_s}{E_p}$$

Where;

N_s = number of turns in the secondary winding

N_p = number of turns in the primary winding

E_s = secondary voltage in volts

E_p = primary voltage from supply in volts.

Thus, from the above equation, ratio of primary turns to secondary turns will inverse the equation as

$$\frac{N_s}{N_p} = \frac{E_s}{E_p} = \frac{220}{12} = 18.33$$

The ratio of primary turns to the secondary turn will be 18:1. The voltage transformer to be selected will be 220V/12V transformer of 500mA current rating.

3.6.2 RECTIFIER DIODE SELECTION

The maximum value of the transformer secondary voltage,

$$V_{in} = V_{rms}\sqrt{2}$$

$$V_{in} = \frac{12}{\sqrt{2}} = 16.97V$$

For the silicon diode, biasing voltage = 0.7V

Two diodes conduct at a time, so the voltage drop by the conducting diode for each cycle is

$$V_D = 2 \times 0.7 = 1.4V$$

Therefore maximum output voltage from rectifier

$$V_{LM} = V_{rms} - V_D = 16.97 - (2\times0.7)$$

$$= 16.97 - 1.4 = 15.57V$$

For full wave bridge rectifier, mean value of load voltage,

$$V_{dc} = \frac{2V_{LM}}{\pi}$$

$$V_{dc} = \frac{2 \times 15.57}{3.142}$$

$$V_{dc} = 9.91V$$

RMS value of ac component of the output voltage.

$$V_{rms} = \frac{V_{LM}}{\sqrt{2}}$$

$$V_{rms} = \frac{15.57}{\sqrt{2}} = 11V$$

Also, peak voltage (PRV) for bridge rectifier = 16. 97V.

Hence, the diode with the following specifications is selected

Type: packaged rectifier containing IN5392 rectifier diodes.

Peak voltage rectifier 1,000V.

Average rectifier forward current: 2.5 (max)

Forward voltage drop: 0.8V at 1A.

3.6.3 SELECTION OF FILTER CAPACITOR

The peak to peak voltage, $V_p = \frac{V_{rms}}{\sqrt{2}}$

$$V_p = 12 \times \sqrt{2}$$

$V_p = 16.97V$

The expected output V_{dc} for a bridge rectifier is given as;

$$V_{dc} = \frac{2V_p}{\pi}$$

$$V_{dc} = \frac{2 \times 15.57}{3.142} = 9.91V$$

The essence of the capacitor is to remove the ripples.

The ripple factor, $r = \frac{rms \text{ value of ac components}}{Dc \text{ value}}$

$$r = \frac{V_L(ac)}{V(dc)}$$

$$V_L(ac) = \sqrt{(v_L(rms))^2 - (V_L(dc))^2}$$

$$V_L = \sqrt{(11)^2 - (9.91)^2}$$

$$V_L = \sqrt{22.79} \quad = 4.8$$

Therefore, ripple factor, r,

$$r = \frac{V_L(ac)}{V(dc)}$$

$$r = \frac{4.8}{9.91}$$

$$r = 0.484$$

For a full wave capacitive we filter, the ripple factor is given as

$$r = \frac{I(dc)}{4\sqrt{3}Fcv_p}$$

Where;

F = frequency of supply = 50Hz

VP = peak rectifier voltage = 9.91V

I_{dc} = mean current

C = capacitor voltage

But mean current,

$$I_{dc} = \frac{2I_m}{\pi}$$

Where; I_m = maximum rectifier current = 2.6AA

$$I_{dc} = \frac{2 \times 2.5}{\pi} = 1.592A$$

To calculate the capacitor value, C is made the subject of the formula

$$C = \frac{I(dc}{4\sqrt{3}FV_{pr}}$$

$$C = \frac{1.592}{4\sqrt{3} \times 50 \times 9.91 \times 0.484} = 9.58 \times 10^{-4} F = 958\mu F$$

Thus, a standard 2200μf value of smoothening capacitor is selected in the circuit design for minimum AC ripple on the DC supply.

3.6.4 FIXED POSITIVE VOLTAGE IC REGULATOR

The 7812 IC selected is rated 1A, 12V with power rating of 12W

3.7 SELECTION OF POWER SWITCH

The A.C power switch selected was BT 138 12A triac. The triac is to be connected in series with the load and due to the series connection, the load can be commanded on or off by commanding the power triac on or off.

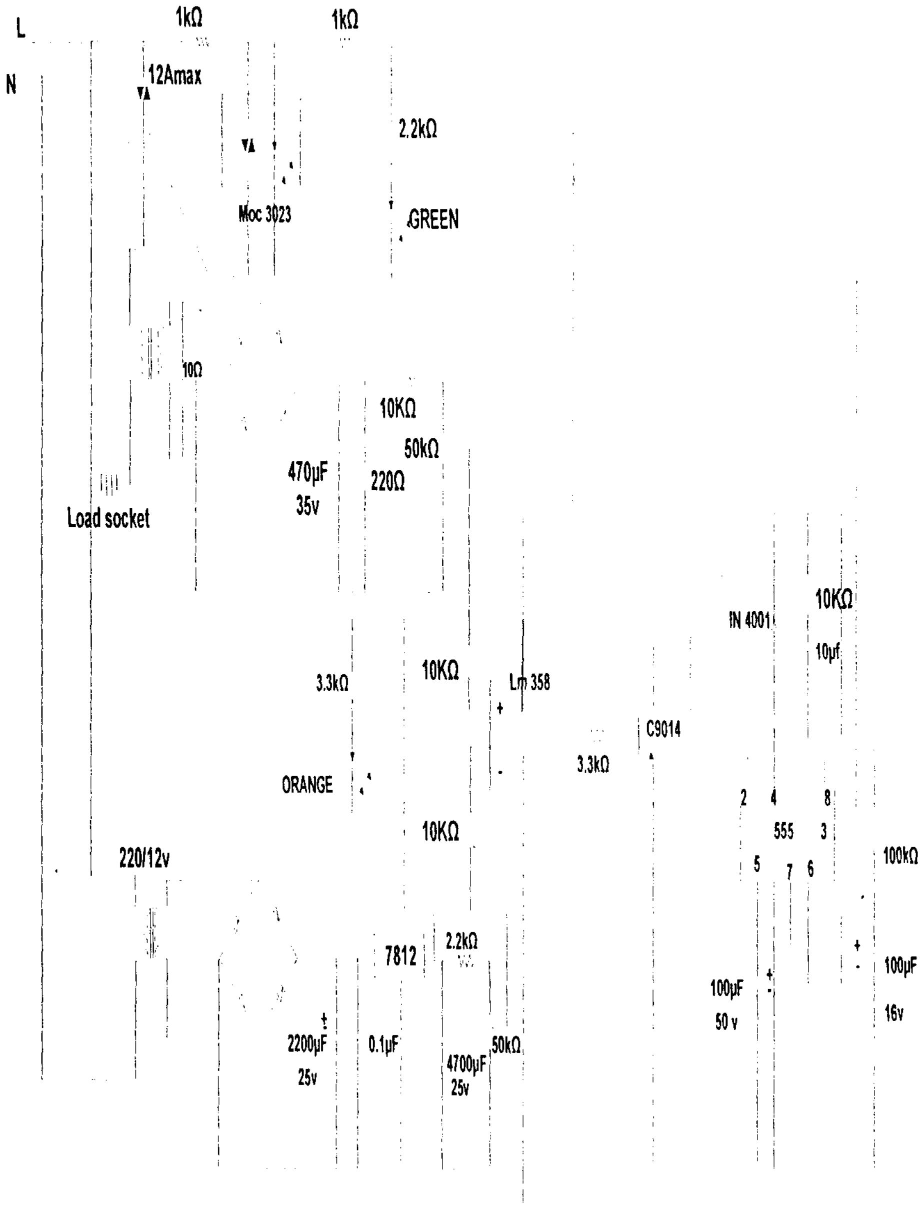

Fig 3.4: The Circuit Diagram Of Over load Protection System Using Solid State Relay.

CHAPTER FOUR

TESTING AND DISCUSSION

4.1 TESTING

During testing two appliance of different rating were used, which gave reasonable result. A water heater of 1200W/240V which has a current rating of 5A was connected to the system and the reference point was presetted to 4A. Since the load current is greater than the load current, the load automatically switched off from the power supply but, if the presetted current is equal to the load current, there will be supply to the load.

The above procedure was also used for a water heater of 500W/240V which has a current rating of 2A and it gives a reasonable result.

4.2 DISCUSSION

For the results gotten the project was able to justify it aims and objective by using solid state electronic device as a switching device in overload protection circuit.

MANUAL OF OPERATION

[1] Preset the reference voltage.

[2] Plug the load to the load socket.

[3] Plug the system to the A.C. socket.

[4] If the load voltage is greater than the presetted reference voltage, the load will automatically switch off from the A.C. supply.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The project was a successful one with achievement in the construction and design. The components used were few and there were considerations in the packaging to give compactness and fault tolerance. The excessive temperature is contained by the perforated case which provides ventilation for the design.

The project has shown that possibility of designing and constructing a low cost device which can be used to protect electrical/electronics appliances against overloading condition.

5.2 RECOMMENDATION

It is recommended that device should be used along with all household equipments to prevent reduction of their useful life time.

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