DESIGN AND CONSTRUCTION OF AN OVER VOLAGE AND UNDER VOLTAGE PROTECTION

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DEDICATION

I dedicate this project work to God and to the family of late Justus Asogwa.

DECLARATION

I, Asogwa, Ikechukwu declare that this 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 and Construction of an Over voltage and under voltage protection, aims at serving as a protector for electronic and electrical appliances against over voltage or under voltage condition.

For problems of over voltage and under voltage conditions, the project could be used to curb the problems.

The project employs a zener diode, two transistors and a relay. The zener diode in conjunction with the transistors energizes and de-energizes the relay during normal and over/under voltage conditions respectively.

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CHAPTER ONE

Introduction

This project, Design and Construction of an Under voltage and Over voltage protection, is an electronic device that protects electronic and electrical appliances during under voltage or over voltage condition by cutting of supply. It automatically restores power to the appliance when the voltage condition returns to normalcy.

Under voltage is a sudden drop in voltage caused by a starting engine or other heavy loads. This condition may occur when there is a fault or breakdown in transmission system; or when the demand for electricity reaches its peak. This condition is dangerous as it could lead to loss of memory in GPS navigation system and crashes in mobile computer systems. [1]

Over voltage is when the voltage in a circuit or part of it is raised above its upper limit. It equally means a sustained voltage that exceeds normal steady state limits. For instance, in a 12 volt system, this is defined as any voltage that exceeds 15 volts. This condition my be hazardous to electronic and electrical appliances, as they are designed to operate at a certain maximum supply voltage, and considerable damage can be caused by voltage that is higher than that for which they are rated. [1]

1.1 Historical background

After the discovery of electricity by Michael Faraday, voltage drop and resistance losses on the voltage d.c distribution circuit were the first set of problems encountered in its utilization. For electronic equipment to perform well, they need a certain stability of the power supply. As a solution to these problems, however, remarkable landmark was made by

George Westinghouse by introducing the a.c transformer. From this idea of the transformer, came out many approaches of voltage regulations. [2]

1.2 Project's aims and objectives

In order to maintain durability of electronic and electrical devises, by avoiding over voltage or under voltage condition, this project, as the title implies, protects these devices from being damaged by switching off automatically whenever it experiences any one of these abnormal conditions. In summary, it serves as a protector to electronic and electrical appliances against under voltage and over voltage conditions.

1.3 Project's layout/ outline

This project's report comprises of five chapters and reference, with each having its own role to play towards a successful completion of the report. Below is a layout of the chapters:

Chapter one: this forms the project's introduction, objectives, methodology and scope. Also included are sources of materials used, constraints, and involvement of others and cited relevant literature

Chapter two: it forms the project's literature re view. It contains the necessary theoretical and historical backgrounds, previous works of others and difficulties that limit performance. Referenced literature is also cited.

Chapter three: this forms the project's design and implementation. Steps taken in the design are carefully laid out. Modular design is strongly recommended; that is, circuit diagram of each module, of which a collection of them forms the entire circuit diagram, is carefully drawn and explained. Also, selection of materials is justified and that the chapter is broken into sub headings.

Chapter four: it makes up the project's tests, results and discussion. It contains the steps taken to test the work; test and measurement methods are properly documented. Results obtained are tabulated or plotted and that signals could be photographed and the photographic plates pasted on the work. Results obtained are discussed I. e results obtained are explained and its relevance to the aim of the project is highlighted. Shortcomings/limitations of work are explained and possible remedy suggested.

Chapter five: this forms the project's conclusion. A summary of the work is to be presented (not repeating abstract). The results obtained and problems encountered are summarized. Open issues (I. e possible improvements/additions to the work that could give rise to further work scheduled for the future is discussed here. Recommendations (if any) are also accepted.

Reference: references cited in the report are listed at the end with font size of 10 [3].

1.4 Project's methodology

The design and construction of this project requires the employment of a step- down transformer. diodes. resistors. capacitor. variable resistor. transistors. zener diode and relay. Also induced in the construction are bread boards. vero board. soldering iron. soldering leads etc.

This project employs two transistors. in conjunction with a zener diode. to energize and de-energize a relay during normal voltage and under voltage/over voltage conditions respectively.

1.5 Project's sources of materials used and constraints.

With the assistance of friends inside and outside the department, most of the materials used for this project were purchased from the market and a few of them was obtained from old electronic panels / printed circuits.

It was not easy getting the whole project's components at a time, as they were not readily available at the first attempt of purchase, and not easily getting the suitable components for the project, from the old electronic printed circuits.

CHAPTER TWO

Literature review

The problem of voltage fluctuations became more pronounced when the transmission and distribution stations were so far from the consumers. However, as a solution to these problems, one of the earliest attempts of obtaining regulated voltage, employed a motorized system controlled by a control circuit to change the taps of the secondary windings of the auto-transformer so as to step up when the input voltage is low or step down when the input voltage is high. Some of the shortcomings are that: it is costly, bulky and the mechanical parts easily wear out, resulting to improper contacts between taps of the transformer. [4]

2.1 Historical background

Electricity was discovered by Michael Faraday (1791- 1867). After its discovery, voltage drop and resistance losses on the voltage d.c distribution circuit were the first set of problems encountered in its utilization. For electronic equipment to perform well, they need a certain stability of the power supply. As a solution to these problems, however, a remarkable landmark was made by George Westinghouse by introducing the a.c transformer. From this idea of the transformer, came out many approaches of voltage regulations. [2]

2.2 Previous works of others

The present technological dispensation has changed voltage stabilization and protection techniques greatly. It came up with an approach known as Regulated d.c Inversion. This uses the principle of switch-mode power supply. The regulated d.c output from the power supply is inverted, using pus-pull inversion and stepped up to the required constant a.c output voltage using a transformer. It uses zener diodes and potentiometers for voltage protection. The output of the system is a square wave a.c voltage which could be filtered to obtain a pure sinusoid. This method produces good regulation and protection. The system is usually not bulky but very expensive to construct than other systems. [4]

Another approach was the Resonant Circuit Voltage Regulator in which the voltage regulator involves few components in the form of inductance of a transformer, coupled with parallel inductive and capacitive circuits. When the line voltage falls below the rated values, less current is drawn by the inductance, and the parallel circuit combination becomes capacitive. The capacitive current drawn through the transformer raises the output voltage. If the line voltage rises above the rated value, the parallel circuit becomes less capacitive and the output voltage falls below the line voltage. Its demerits are that: it is heavy, bulky and frequency dependent. [4]

Phase-Controlled Voltage Regulator is one of the attempts towards realizing a good regulated voltage. In this system, the load is connected in series with the voltage controlling-device which is usually a Silicon Controlled Rectifier (SCR). Voltage control is achieved by triggering the SCR at a phase angle determined by the control circuit in such a way that the voltage across the load, connected to the output terminals is regulated to the desired value. This method is very fast in response to voltage fluctuations at the input. This system is not bulky and expensive but its demerit is that: its output waveform is distorted. [4]

Another method to be considered is that of voltage regulation by transistors, known as Transistorized Voltage Regulator. This approach is an improvement on motorized voltage regulator's method. The pure mechanical tap was replaced by miniature electromechanical relay. The major component of this approach is the auto-transformer whose turn ratio (referred to as taps) can be varied to give the desired regulation. Most system of this kind uses two relays. The positions of the relay contacts on the taps of the transformer are dictated by the control circuit. The control circuit determines whether the low supply voltage is to be stepped up to the rated value or the high supply voltage is to be stepped down to the rated value of the output. [4]

The advances in fabrication of discrete electronic components have led to reduction in their costs and sizes which give better switching performance than the electromechanical switches earlier considered. One of the latest developments is the use of Under voltage and Over voltage Protection's circuit which uses discrete components to protect electrical and electronic appliances from voltage surge. [4]

CHAPTER THREE

3.1 Theory of design/ principle of operation of the system unit.

Under normal working voltage condition, the voltage is greater than the breakdown voltage of the zener diode (Z_1) and this turns on transistor (TR2). Collector current (I_C) flows and relay (RY) is activated. The normally open contacts are closed while the normally close contacts are opened. Power supply from the mains is passed across to the load via the normally open contacts. Under this condition, transistor (TR1) is biased such that it is cut off.

This is achieved through the potential divider bias of the base of TR1, consisting of R!, R2, R3 and RV1. R_B is assumed to be the series combination of R_1 and R_2 and (i.e RB = $R_1 + R_2$). At normal operation, the variable resistor, in series with R_1, is adjusted such that voltage drop across RB (i.e base voltage) is less than 0.6V. This keeps TR1 cut off and so the collector–emitter junction of TR1 behaves as an open circuit such that current only flows through R4 and R5 to turn on TR2. TR2 remains turned on so long as the voltage supply is greater the breakdown voltage of the zener diode. Under this condition, the relay is activated. The normally open contacts become closed. Power supply is passed across to the load.

As the mains voltage begins to rise above normal (over voltage), the voltage drop across RB is high enough to turn on TR1 and drive it into saturation. This causes the input voltage to the zener diode to drop to about zero, which is not sufficient enough to break Z_1 and so TR2 is cut off. Collector current of TR2 seizes to flow. RY is deactivated since Ic is zero and as a result, the normally open contacts become closed

3.2 Modular representation of each circuit diagram/justification of component's selection/ block diagram.

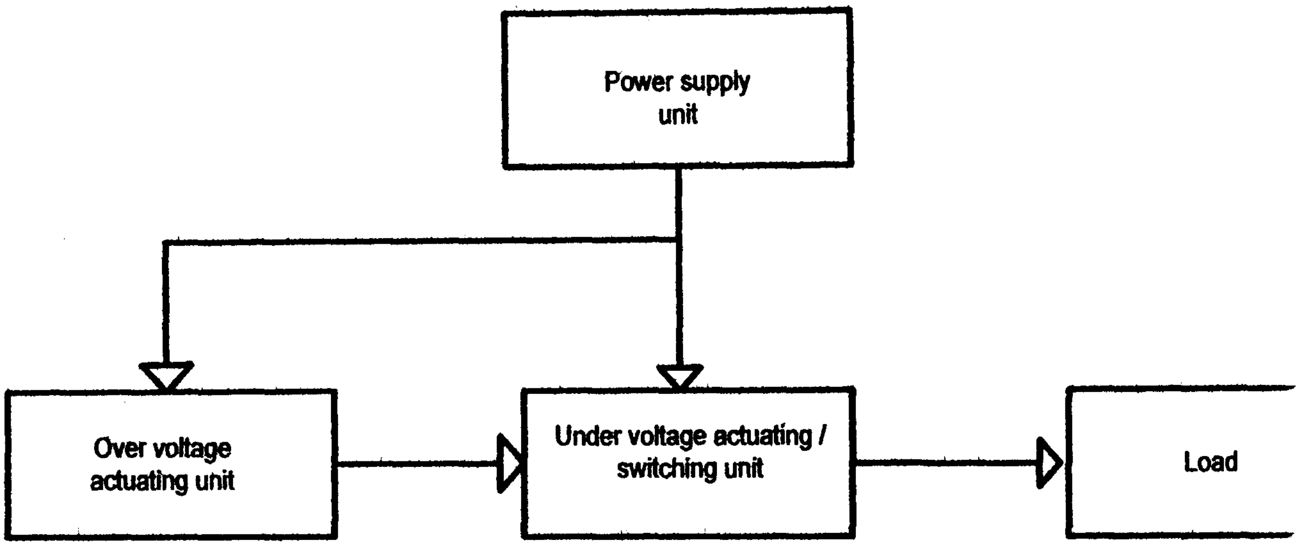

Fig 3.2 block diagram of Over voltage and under voltage protection

3.2.1 Power supply unit

Power supply from the mains voltage is stepped-down by transformer (T1). This voltage is rectified by the bridge rectifier network consisting of diodes D_1, D_2. D_3 and D_4, and is filtered by a smoothening capacitor C1 as shown in the figure below:

Since the upper limit of the monitoring voltage range is 220V, the secondary voltage of the step-down transformer, rated 240/24V, is shown in the relationship below:

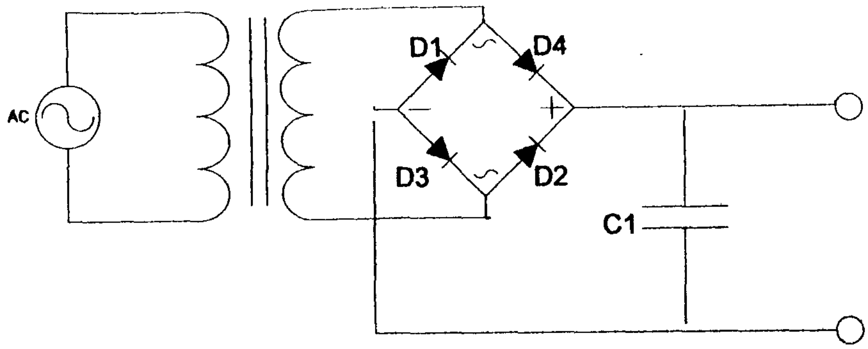

Fig.3.2.1 Power supply unit circuit diagram.

$$\frac{E_1}{E_2} = \frac{V_1}{V_2} \quad \text{--------------------------(1)}$$

Where E_1 is the rated primary voltage of the step-down transformer.

E_2 is the upper voltage limit of the voltage monitory unit.

V_1 is the step-down transformer voltage rating at the secondary.

V_2 is the corresponding secondary voltage when the input to the step-down transformer is 220V (peak value).

Therefore, E_1=240V, V_1 = 24V, E_2 = 220V & V_2 =?

$$V_2 = \frac{E_2 V_1}{E_1} = \frac{220 \times 24}{240} \quad \text{--------------------------(2)}$$

The corresponding voltage at the step-down transformer would be:

$$V_2 = \frac{220 \times 18}{240}$$

V_2 = 16.5V

The peak value of the transformer is taken as 18V when the input voltage is 240V. The choice of selection of a filter capacitor will be justified based on 18V secondary voltage. The peak voltage of the transformer secondary Vp,

is given by:

$$V_P = V_{rms} \times \sqrt{2}$$

Where Vrms is the root mean square value

$Vp = 18 * 1.43$

$V_p = 25.4V$

25. 4V is the input voltage to the rectifier diode, which implies that for safe operation for diodes D_1, D_2, D_3 and D_4, the Peak Inverse Voltage (PIV) rating of the diodes must be greater than 25.4V. For this reason, the part number for diodes D_1, D_2, D_3 and D_4 is IN4001 which has the peak inverse rating of 50V. The output of the bridge rectifier voltage, V_{dc}, is given by:

$D_{dc} = V_p - V_d$ -- (3)

where V_d is he voltage drop across rectifier diode.

For a full-wave rectifier, the voltage drop is about two-diode drop and for a silicon-type diode, the voltage drop is 0.6V and hence two-diode drops is:

$$V_d = 0.6 \times 2 = 1.2V$$

$$V_{dc} = 25.4 - 1.2$$

$$V_{dc} = 24.2V$$

An electrolytic capacitor was used to smoothen the voltage supply from the rectifier circuit. The turn ratio of the transformer is given by:

$\frac{V_1}{V_2} = \frac{N_1}{N_2}$ --(4)

Where

V_1 is the primary voltage input

V_2 is the secondary voltage

N_1 is the number of turns in the primary windings of the transformer

N_2 is the number of turns in the secondary windings of the transformer Since the transformer is rated 240/18V by the manufacturer, it therefore, means that the turn ration, n, is given by:

$$n = \frac{N_1}{N_2} = \frac{240}{18} \qquad \text{----------(5)}$$

$n = 13$

n = 20

3.2.2 Over voltage actuating circuit

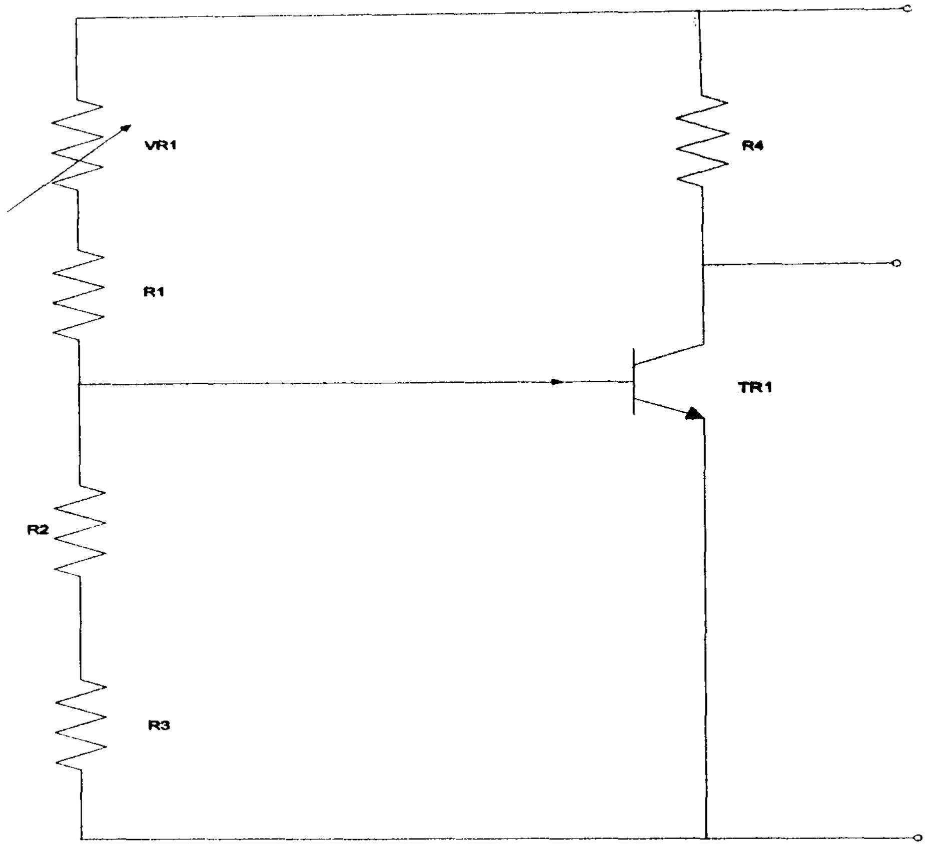

Fig 3.2.2 Over voltage actuating circuit

Under normal voltage range, the potential bias at the base of TR1 is insufficient to turn on TR1. The potential bias is only capable of turning on TRI when the input voltage exceeds the maximum limit of 240V. If R_2 and R_3 are fixed at 1kΩ and 2kΩ respectively so that RB = 3kΩ, then for a 240V mains supply limit, the base voltage, V_B, of TRI should be at 0.6V so that TRI is turned on. At this instant, V_s i.e rectified dc supply is:

$V_S = 24.2V$

By voltage divider action:

$$V_B = \frac{V_S * RB_1}{RB_1 + (R_1+VR_1)} \text{---(6)}$$

By making substitutions into the above equation, we have:

$$0.6 = \frac{24.2 \times 3000}{3000+ (R_1+VR_1)}$$

$$0.6\,(3000) + 0.6\,(R_1 + VR_1) = 24.2 \times 3000$$

$$1800 + 0.6\,(R_1 + VR_1) = 72600$$

$$0.6\,(R_1+VR_1) = 72600 - 1800$$

$$R_1+VR_1 = \frac{70800}{0.6}$$

$R_1 + VR_1 = 118000\Omega$

Assuming $R_1 = 100k = 100\ 000\Omega$

$$VR_1 = 118000 - R_1$$

$$VR_1 = 118000 - R_1$$

$$VR_1 = 18000\Omega = 18k\Omega$$

Since $18k\Omega$ is not a standard value, a value of $22k\Omega$ was chosen for VR_1.

When the voltage increases above the value of 24V, TR1 is turned on and driven into saturation. The output at the collector goes low. This cuts off supply to the base of TRI. When TRI is cut off, relay (RY) is also de-activated and so the power supply to the appliance will be disconnected.

2.3 Under Voltage Actuating/Switching Unit

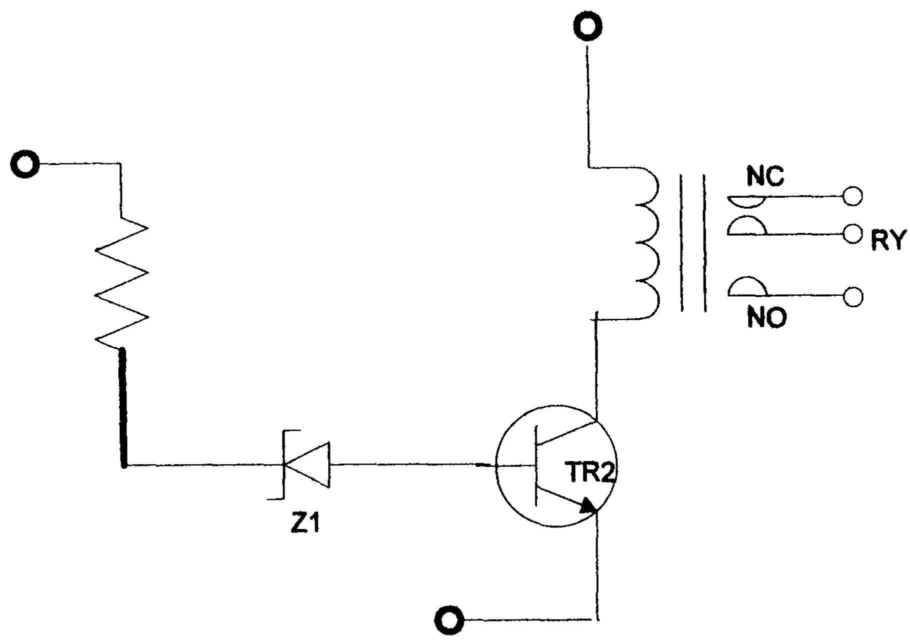

Fig.3.2.3 Under voltage actuating/switching circuit.

Under normal voltage condition, TR1 is cut off. The input voltage is sufficient enough to breakdown Z_1 and turn on TR2 which activities the RY and power is supplied to the load through the normally open contacts. As the voltage drops below normal range, the supply voltage is no longer sufficient to breakdown Z_1 and so TR2 is cut off. The relay (RY) in de-activated and power supply to the appliance is cut off. Since TR2 is functioning as a switch, it must be driven into saturation. The collector saturation current is given by:

$$I_{c\,(salt)} = \frac{V_{cc}}{R_c} \qquad (7)$$

where V_{cc} is the supply voltage

R_c is the collector resistance.

The collector resistance, in the case, is the resistance of the relay's coil and is equal to 1600Ω i.e $R_c = 1600\Omega$ and $V_{cc} = 24V$

$$I_{c\,(sat)} = \frac{24}{1600} = 0.015A$$

$$I_{c\,(sat)} = 0.015A = 15mA$$

The required base saturation current, $I_{B\,(Sat)}$, is given by:

$$I_{B(sat)} = \frac{I_{c\,(sat)}}{\beta} \text{ --(8)}$$

where β is the beta value (current gain) of the transistor which is got as 40 from manufacturer's data sheet.

Substituting this value into equation (7) above gives:

$$I_{B(saT)} = \frac{15}{40} = 0.375mA = 0.000375A$$

$I_{B\,(sat)} = 0.375mA$,

But, base current (I_B) at 24 volts is given:

$$I_B = \frac{V_S - V_Z - V_{BE}}{R_B} \text{ ____(9)}$$

where V_s is the dc supply; V_{BE} = base-emitter voltage

R_B is the base resistance; V_Z = zener breakdown voltage

Therefore,

$$V_S - I_BR_B + V_Z + V_{BE} \text{ ______________________________(10)}$$

$V_S = 0.000375\ (12) + 12 + 0.6 = 17.1$ volts

$V_s = 17.1V$

Now, the corresponding value of the a.c mains input when the d.c supply is 17.1 volts is the lower or under voltage cut off level. Working back from output to input, we would arrive at this value:

$$V_P = V_{dc} + V_{drop} \text{--} (11)$$

$$V_P = 17.1 + 1.2 = 18.3 \text{ volts}$$

$$V_P = 18.3 \text{ volts}$$

$$V_{rms} = \frac{V_p}{1.43} \text{--} (12)$$

$$V_{rms} = \frac{18.3}{1.43} = 12.9 \text{ volts}$$

$$V_{rms} = 12.9 \text{ volts}$$

From equation (5)

$$n = \frac{N_1}{N_2} = \frac{240}{18} = 13$$

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} = n = 13$$

Therefore,

$$\frac{V_1}{V_2} = 13$$

$$V_1 = V_2 \times 13$$

But $V_2 = 12.9$ volts

$$V_1 = 12.9 \times 13$$

This is the lower voltage range at which the supply to the load would be cut off.

3.3 Systems` specifications/functions

3.3.1 Power supply

Power supply is necessary for the conversion of a.c voltage of our electrical utility to the d.c voltage required in electronic circuits. The transformer used for this project is a 240/18V step-down transformer. The primary voltage is 240V while the secondary voltage is 18V. This lowers the voltage in the circuit but with a corresponding decrease in current. [5]

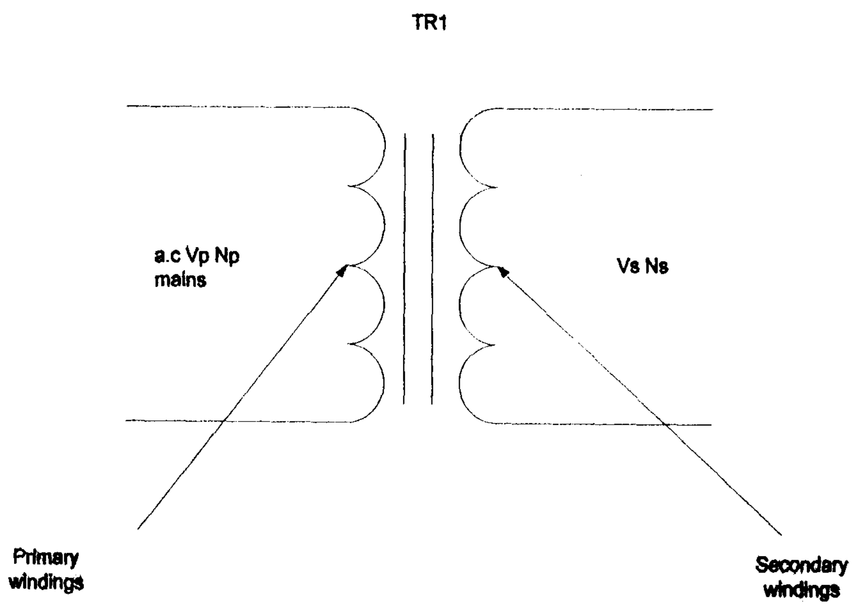

Fig 3.3.1 Power supply circuit

3.3.2 Rectification

Rectification is the conversion of an a.c voltage into a d.c voltage by eliminating the negative half cycle of the a.c voltage. The rectifier circuit, which has semiconductor devices such as diodes etc as its main components, is the circuit used to achieve the purpose of rectification. The full-wave bridge rectifier circuit was made use of for this project, whose function is to convert a.c signals (ripples) still obtainable in the circuit. [6]

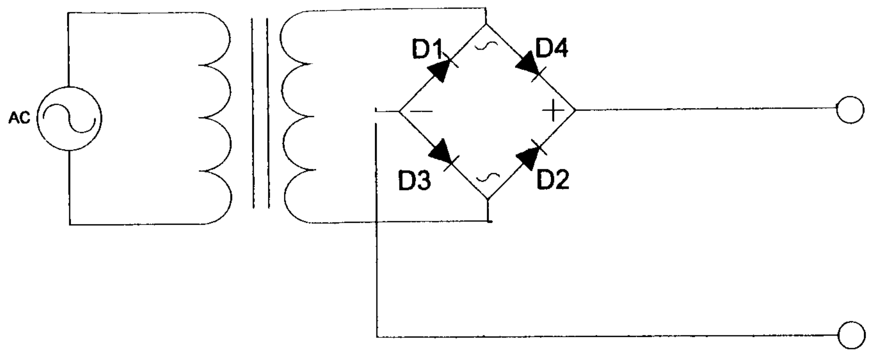

Fig 3.3.2 Rectifier circuit

3.3.3 Filter circuit

The filter circuit converts the full-wave rectified d.c signal to a smoothened d.c voltage. The main function of a filter circuit is to minimize the ripples` content in the rectifier output. [7]

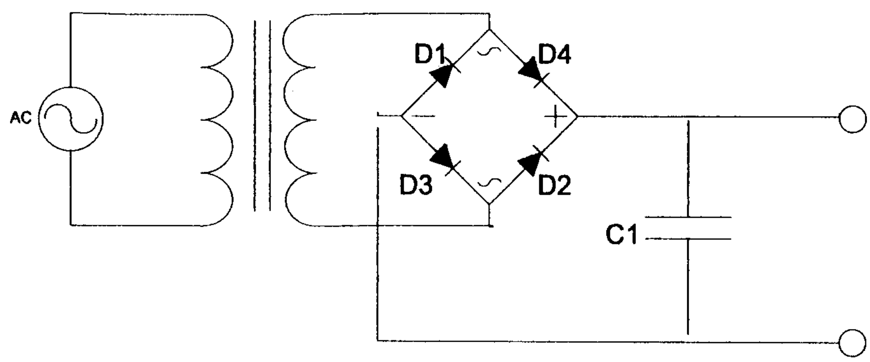

Fig 3.3.3 Filter circuit

3.3.4 Over voltage actuating unit

The over voltage actuating unit forms part of the circuit. Its function is to sense if the voltage has exceeded the upper range of the normal supply voltage.

3.3.5 Under voltage actuating/switching unit.

The under voltage actuating/switching unit is also one of the blocks that forms the entire circuit. Its function is to sense if the voltage has gone below the lower range of the normal supply voltage.

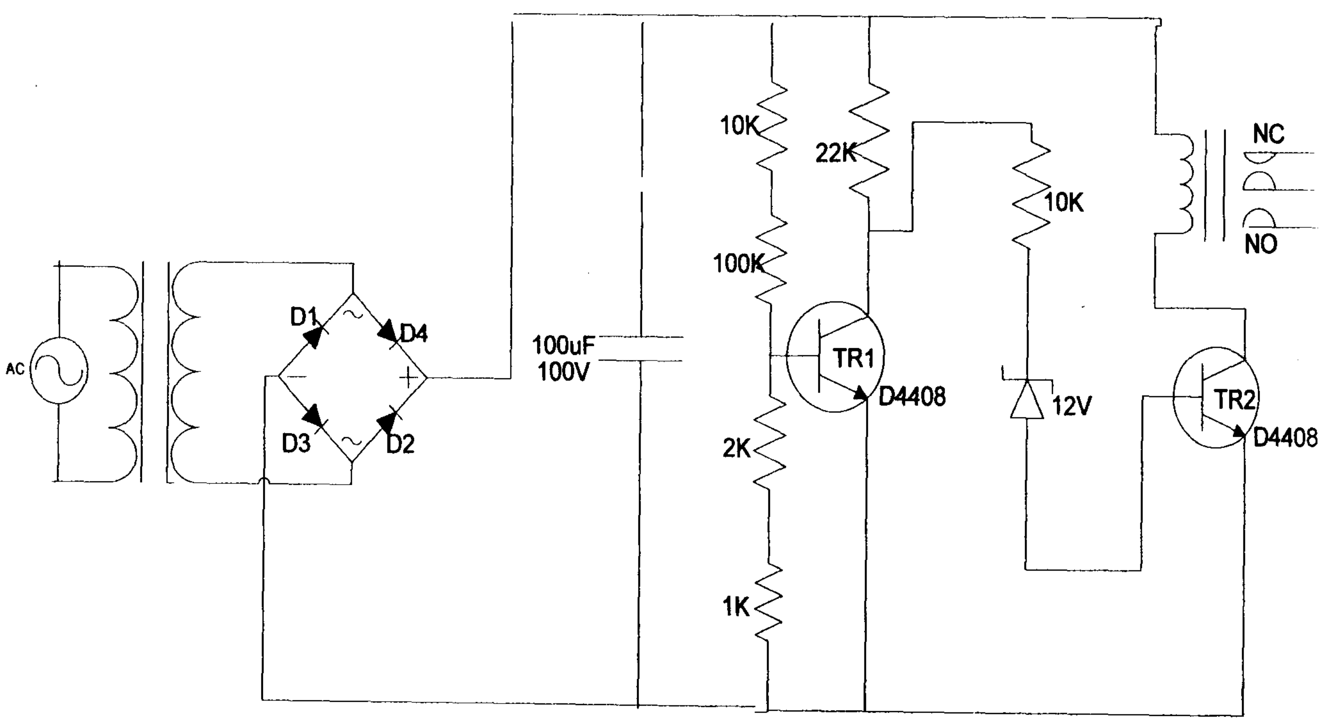

Fig 3.3.5 Circuit diagram of an Over voltage and under voltage protection

CHAPTER FOUR

Construction and Testing

4 .1 Steps taken to test the work.

Before the construction proper, the power supply unit, the over voltage actuating unit and the under voltage actuating/switching unit were simulated on computer using the Electronic Workbench and they were working as expected. In addition, the construction was carried out on bread board and it worked fine. The whole circuit was transferred to a vero board, soldered and tested okay to satisfaction.

The test aims at obtaining the voltage conditions (levels) at which the appliance will either connect to power supply or disconnect to power supply.

4.2 Results` tabulation

	Primary voltage (V)	Secondary voltage (V)
Low voltage	168	11.97
Normal voltage	240	17.1
High voltage	270	19.23

4.3 Discussion of Results

4.3.1 Under voltages condition (O-180V)

From the test, it was observed that at the voltage range of (110 – 180) volts, the relay switch was de-energized. The normally open contacts remained opened due to the low voltage.

4.3.2 Normal voltage condition (190-240V)

When the supply voltage from the mains was at this range (190-240) volts, it was observed that the relay was operating normally. The normally open contacts of the relay closed for the flow of current in the circuit.

4.3.3 Over voltage condition (250V and above)

When the supply voltage was at 250volts and above, the relay became de-energized as was observed. The normally open contacts of the relay remained open.

CHAPTER FIVE

Conclusion and Recommendation

5.1 Conclusion

The Design and Construction of Over voltage and Under voltage Protection was successfully carried out. The results from the testing of the project show that the device will compete well with other protective devices based on the following points:

i. During over voltage condition, it de-energizes (switches off) the load automatically, thereby giving it protection. against destruction.

ii. During normal voltage condition, it energizes (switches on) the load automatically, thereby giving it the enablement to operate successfully.

iii. During under voltage condition, it also de-energizes (switches off) the load automatically, thereby protecting it against destruction.

The project has shown the possibility of designing and constructing a low-cost device which can be used to protect electronic appliances against abnormal voltage conditions effectively.

5.2 Improvements

i. This project can be improved upon as higher voltages can also be regulated for industrial appliance.

ii. Alarm unit can be incorporated to sound a warning if the operating condition falls below or above the desired operation voltage range.

iii. Digital unit can also be incorporated to display readings of the operating conditions.

5.3 Suggestions

i. The principle of operation of this project could be implemented for a three-phase (3-Ø) load.

ii. The efficiency of the device can be improved upon by increasing the output of the device to be able to supply load, by replacing the current relay with higher rating.

5.4 Recommendations

i. The device is suitable for electrical/electronic appliances with input rating of not more than 240V; therefore, for efficient operation, the appliance to be protected by this project should fall below this range.

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