DESIGN CONSTRUCTION OF AN UNDER AND OVER VOLTAGE CUTOUT WITH VISUAL INDICATIONS

BY

ERIN PETER TAIYE

2001/11978EE

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Dedication

This project work is dedicated to almighty God who has always been my strength, the grace to move on in academics and to my mother Mrs. Joy Adurodija who is always encouraging and praying for me. My grand parents chief and chief (Mrs.) Adurodija and finally to my siblings Kenny, Lakan, and Jumoke for there advise, emotional support and prayers which is immeasurable.

Attestation/Declaration

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

3/12/2007

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Erin Peter Taiye
2001/11978EE

....

Signature and date

....

MR. Ozomata David Ahmed

O. D. Ahmed 03/12/07

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Signature and date

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ENGR. M.A. ABDULAIHI

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Signature and date

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Name of External Examiner

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Signature and date

Acknowledgement

Firstly, I give all honor, adoration, thanks and glory to God Almighty, who has been gracious to make it possible for me to write this project. Secondly, I owe a dept of sincere gratitude to grand parents who were always there in terms of needs

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My deepest gratitude goes to Mr. David Ozomata Ahmed, whose enormous contributions can not be over looked, and I am using this opportunity to acknowledge Mr. Nathaniel for sparing out of his tight schedule, to help me in one way or the other may almighty God continue to bless you mightily.

Finally, I want to use this medium to thank my siblings: Kenny, Lakan, and Jumoke for their encouragement and advice, may almighty God in his infinite mercy continue to bless them abundantly.

Abstract

This project is on the design and construction of an under voltage and over voltage cutout, which is used to cut off the supply to electrical appliances in our homes due to excessively high voltages not within the limit of 160V to 260V AC from the supply. The main aim of this project is to provide a simple, cost effective and user friendly electronic system that continuously monitors the ac line voltage.

The under voltage and over voltage cutout functions as above to connect or disconnect electrical appliances from supply in the event of under or over voltage supply.

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Chapter one

Introduction

The best operation of most electrical equipments and appliances requires that the supply voltage is kept constant or at least within fairly acceptable limits. In Nigeria, the normal main voltage is 240V Ac at a frequency of 50 Hz, but due to one reason or the other, it is very common to find our national supply voltage either falling below 160V or rising above 280V.A lot of factors cause voltage fluctuations, among which are transient occurrence, variation in loads applied to the AC power line, aging transformer, overloading, voltage drops in excessively long conductor cables [1], etc. the level of fluctuation is highly dangerous to many voltage- sensitive device especially those contain compressor like refrigerators, freezers, air conditioners, and are thereby prone to damages due to excessively high or excessively high or excessively low voltage

In other to avert the damage by this dangerous trend in our electrical supply we need the under/over voltage cutout that would monitor voltage levels supplied to an appliance to be in the range of 160V AC to 260V AC and would cut off supply to any appliance outside this range

The device is a small piece of electrical equipment to maintain supply to an appliance at the prescribed voltage range [2]. It is designed to be very portable with indications of over- voltage and under- voltage faults, indicated by LED's.

The over voltage and under voltage cutout is an electronic system that detects both under and over voltage conditions on the local AC mains and disconnecting the load from the local mains on detecting the presence of both.

The unit also incorporates hysterisis to prevent switching around a point, and thereby causing system instability.

The over voltage and under voltage levels are both presettable, giving the greatest degree of flexibility typical over voltage level might be fixed at 260V, and an under voltage level at 160V

The incorporated hysterisis makes sure the load is not connected until the AC mains voltage is about 180V, at which point the load is connected to the mains voltage. It stays connected until the input AC voltage drops to 160V, and it disconnected. Over voltage at about 260V disconnects the load from the input AC mains voltage likewise, and keeps the load disconnected until the input AC mains voltage drops to about 240V. At this power to the load is reconnected. The visual indicators were provided to communicate the system conditions to the status user.

The importance of a stable or steady power supply cannot be over emphasized in our homes and industries. The under voltage and over voltage cutout is a short cut to turning off electrical appliance when there is an abnormal voltage supply (i.e. high or low). The low voltage and over voltage protection are afforded by suitably rated relays [3] which are energized or de-energized by an appropriately biased transistor as the case arises.

The main components considered in the course of the design are transformer, comparator, relay, transistor, resistors zener diodes were tested for workability in Lagos, but proper and construction work would be done in school.

1.1 Aims and objective

The main aim of this project is to provide a simple, cost effective and user friendly electronic system that continuously monitors the AC line voltage and switches on its load when the supply voltage lies within the preset limit. When the supply voltage lies outside the limit the load is automatically disconnected.

This project is designed to operate in the following conditions.

1.2 High voltage: When the supply voltage to the voltage detector is higher then the upper trip-point voltage, pre-settable by a potentionemeter, the sensing circuit sends appropriate signal to disconnect the load through its relay. Excessively high voltage could result from phase-to-phase short circuit due to snapping and breaking of conductor lines, transients due to lightening induced in the main line [2], etc. This condition is indicated by a light emitting diode (LED).

1.3 Low voltage: when the sensing circuit of the voltage detector, made up of voltage comparators, senses that voltage is below the low is trip- point voltage, it sends the appropriate signal to its switching circuit to disconnect the load. The lower trip point voltage is also pre-settable by a potentiometer. Low voltage results from over loading of distribution transformers ie too few transformer supplying too many consumers of electricity, voltage drops in conductor cable, (the farther away a consumer is from the distribution transformer, the lower the terminal voltage at his premises) [1] etc.

The low voltage condition is also indicated by a light emitting diode (LED).

1.4 Normal voltage: When the supply voltage lies within the limits of the pre-set voltages, the voltage detector connects the load to the supply. If this condition exists, the light emitting diode light up indicating visually that the load is powered up.

The project comprises the followings units: step-down transformer, bridge rectifies, filter and regulator, sensing and witching circuit and the relay. The AC line voltage is stepped down transformer and to the contact of the relay. The input AC voltage is fed both to the step down transformer and to the contact of the relay. The input AC voltage is stepped down to 15V AC (rms), rectified and filtered to remove ripple voltage in the rectified AC voltage.

A portion of this resulting dc voltage are fed to the LM 7805 and LM 7809 regulator whose constant 5V and 9V dc output [4] powers the rest of the circuitry as well as providing the reference voltage for the sensing circuit made up of voltage comparators.

Another portion of the unregulated dc voltage is fed to a potential divider from which a sample representing the AC input voltage is derived to act as input of the other inputs of the voltage comparators.

1.5 Methodology

A Vero board that has copper strip on one side is used to amount the component [8], this is then housed in a case. An autotransformer was used to set the trip limits. Firstly, the auto transformer is set to 260V AC and connected to the primary of the transformer. The preset resistor (the variable resistor) is then adjusted such that relay energizes. This sets the high trip limit. Next, the output of the Autotransformer is set to 160V AC and the preset (variable resistor) adjusted such that the relay energizes.

A neon lamp with a suitable resistor could be connected between the AC supply lines as an ON indicator. Alternatively, LED with a current limiting resistor could be connected between the relay coils so that when the relay is energized the LED will indicate the situation.

Chapter two

Literature review

2.1 Historical developments

Since the discovery of electricity by Michael Faraday, humans have become more and more dependent on it for their everyday activity. From the simple electrical sources like dynamos and batteries, to huge generators like hydroelectric power and nuclear power generating stations. The control of electricity has become more complex and dangerous to both the appliance making use of the electricity and possessing them.

The use of fuses and circuit breakers as cutout switches, which was defined as:

2.1.1 Fuses: - fuses are rated according to the current they can pass safely. This may give the wrong idea that excessiv3e current will cause fuse to blow. Rather, the cause is power dissipation in the form of heat. Put in more familiar terms, it is the I^2R loss across the fuse element that causes the linkage to melt. The current rating of a given device, however, is not the brick wall protection value that may service people think it is. Fuse characteristics can be divided into three general categories: fast –acting, medium acting and slow-blow circuit protection for each type of design is a function of both current and time for example, a slow-blow fuse will allow approximately 6 times then rated current through a circuit for a fall second before opening. Such delay characteristic have the benefit of offering protection against nuisance blowing because high in rush currents during system start up. This features, however, comes with the price of possible exposure to system damage in the event of a component failure [4].

2.1.2 Circuit breakers: - circuit breakers are subject to similar circuit current_ let. Through constraint. They interrupt electrical circuit to prevent excess current, as that caused by a short circuit from damaging the electrical appliance in the circuit from causing a fire [4]. The minimum clearing time for the higher classification device is for a 400 percent overload. Similar to fuses, these delays are designed to prevent nuisance tripping caused by normally occurring current surges from (primarily) inductive of their rated continuously without tripping. They normally are specified to trip at between 101 and 135 percent of rated load after a period of time determined by the manufacturer. The most- trip point at 135 percent is 1 hour.

Circuit breakers are available in both thermal and magnetic designs. Magnetic protectors offer the benefit of relative immunity to changes in ambient temperature [4].

This has given a certain degree of control over electricity. But this can only protect against high voltage, they cannot prevent low voltages without user intervention. Besides, their action is not fast enough for most electric appliances.

But with modem development in technology, the design and use of under voltage and over voltage cutouts has been able to overcome these problems.

2.2 Comparative analyses

This project is similar to other voltage cutouts that were earlier designed by other people. But there are some differences, which sets them apart from this one. The earlier projects considered are:

The under/over voltage cutout which protect against under/over voltage conditions at about 160V for under voltage and 270V for over voltage conditions respectively. This device does not have an audible alarm. A 555 timer was used in the voltage detection network [6].

Another approach to be considered is the high and low voltage cutout with delay and melody. This circuit protects electrical equipment from high as will as low voltages and voltage surges (when power resume). It also gives a melodious tune when mains power resumes. The main components used in devices are 8 diodes, one 555 timer, 7 resistors, 2 transistors, 3 LED and an IC UM66 to generate the melody. This project is more complex and expensive than the one I designed [6]

The solid-state relay with under/over voltage protection. Electromechanical relays suffer from the disadvantages of making undesired audio noise and generating radio frequency interference during change over of contacts, accompanied by sparking. Besides the switching speed of electromechanically relays is comparatively very slow due to the mechanical inertia of their moving contacts. It incorporates such features as cutting off of the load on sensing under or over voltage conditions of the mains supply to the load, delayed switching, and provision of suitable isolation of between the high voltage and low voltage at control side. The circuit comprises four sections, viz, delay section, under/over voltage detector, zero crossing detectors, and switching section. The outputs of the former three sections are combined to serve as one of the two control inputs for the switching section while the other control voltage is provided externally to switch on the LED of opto- isolator [6].

Finally the under/over- voltage beep for manual stabilizer. Some manual stabilizers available in the market incorporate the high- voltage auto-cut-off facility to turn off the load when the output voltage of manual stabilizer to turn off the load when the output voltage of manual stabilizer exceeds certain preset high voltage limit. The output voltage may become high due to the rise in AC mains voltage or due to improper selection by the rotary switch on manual stabilizer. One of the major disadvantage of using a manual stabilizer in areas with a wide range of voltage fluctuations is that one has to keep a watch on the manual stabilizer's output voltage that is displayed on a voltmeter and keep changing it using its rotary switch or else, the output voltage may reach the preset auto cut-off limit to switch off the load without the users knowledge. To turn on the load again, one has to readjust the stabilizer voltage using its rotary switch. Such operation is very irritating and inconvenient for the user [6].

The under\over voltage cutout with visual and audio indicators presented here is a low cost and reliable circuit for protecting domestic appliances. The components used in the design are simple and easily available in the Nigerian market, so as to enable an effortless maintenance of the device. It is designed to function satisfactorily with the Nigerian power system and can be easily reset to adapt to any other power system. The choice of components used' makes it very sensitive to voltage variations, which makes it more reliable.

2.3 Protection alternatives

A facility or appliance can be protected from transient disturbance in two basic ways: the system approach or the discrete device approach. Table 1.0 outlines the major alternative available

(1) UPS stand-alone System.

(2) Shielded isolation transformers.

(3) Suppressor filters and lightning arrestors.

(4) Solid state line voltage regulator/ filters.

(1) The Uninterrupted power supply provides full protection to electrical and electronic appliances from power outage failures and transient disturbances; ideal for life safety loads [7].

Its weak point is that the hard ware is expensive and may require special construction; it is electrically and mechanically complex; it also required annual maintenance costs.

(2) Shielded isolation transformer: this device is electrically simple, and provides protection against most types of transients and noise, it cost of production is moderate and it does not required annual maintenance [7].

(3) Suppressors, Filters, and lightning arrestors this entire component are not expensive, units can be staged to provide transient protection exactly where needed in a plant; and it does not require periodic maintenance. But they did not provide protection from disturbances; transient protection is only as good as the installation job [7].

(4) Finally the solid-state line voltage regulator/filter: the device uses a combination of technologies to provide transient suppression and voltage regulation; and does not require periodic maintenance and its cost of production is moderate [7].

Chapter Three

System design and implementation

The over voltage and under voltage electronic circuit system was designed to meet the undeleted operations:

(i) Delay load voltage until; input voltage is greater than 180V.

(ii) Connect load until input voltage is less than 150V.

(iii) Detect voltage condition at 260V.

(iv) Disconnect load until input voltage falls to 240V.

(v) Provide visual indications of fault conditions.

The above-listed performance specifications were realized using various subsystems, Via:

(i) The power supply.

(ii) Schmitt trigger voltage comparators.

(iii) Visual indication

(iv) Electromechanical power switches (5A).

3.1 Block diagram

The block diagram of the over voltage and under voltage cutout is shown below

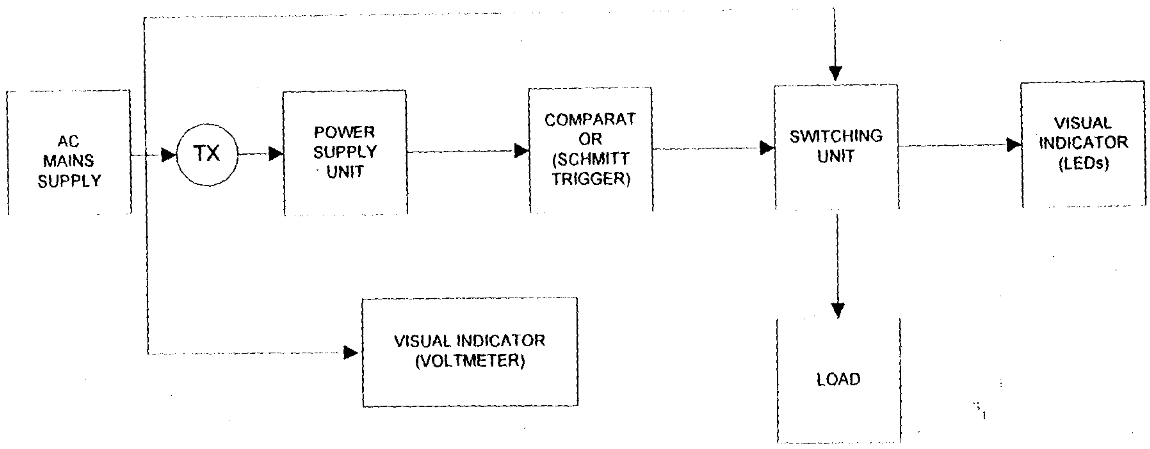

Fig.3.1 Block diagram.

The analysis and design of each of the functional blocks as explained in the next section.

3.2 Power supply unit

The power supply was contrived using an 18Volt transformer was wired to a full wave bridge rectifier as shown below. The discrete components used in electronic designs will be damaged if operated with the 240V supply from the mains supply. Hence, there is the need for circuit that is able to output a voltage level on which the discrete components can safely be operated. The power supply unit performs this function.

The power supply unit consists of 240/18V at its secondary terminals.

Discrete electronic components are generally not powered by an AC voltage [2], hence there is need for rectification of the stepped down voltage from the transformer secondary.

The rectification process is accomplished by a full wave bridge rectifier circuit.

The capacitor- resistor combination in the power supply unit is required in order to filter out voltage pulsation or ripple components.

In an unregulated power supply, output voltage changes whenever input supply or load resistance changes, it is never constant so to say. The aim of employing the use of regulators is to reduce these variations to zero or at least to the minimum possible value.

The circuit is designed to operate on 5V and 9V dc regulated supply respectively, thus the 7805 and 7809 voltage regulator ICs with constant 5V and 9V dc were used to achieve this.

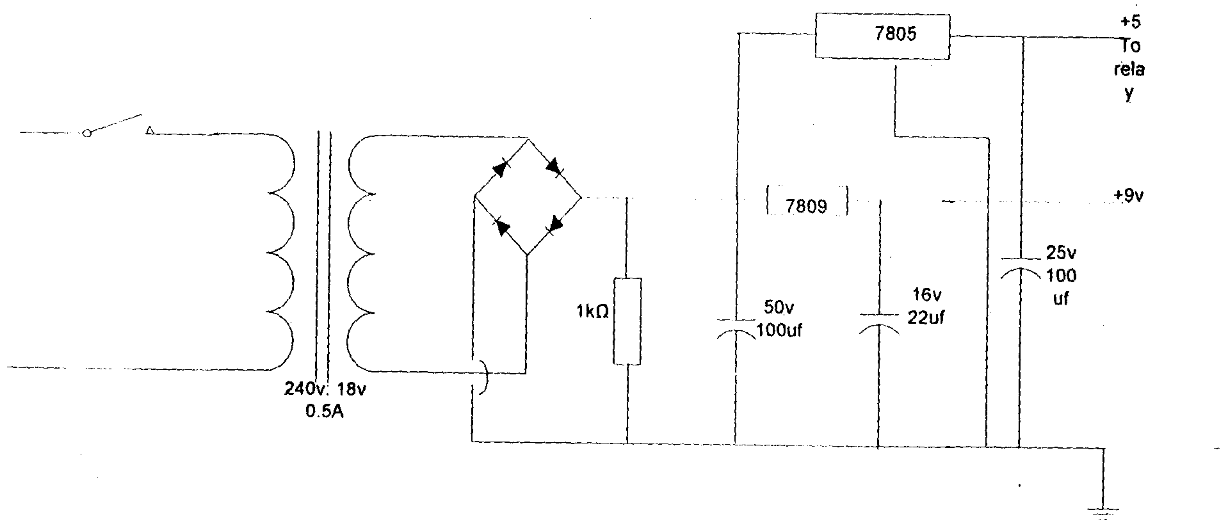

Fig 3.2 System power supply unit.

The 18V RMS secondary voltage was converted to a pulsating DC voltage by a full wave bridge rectifier. The rectifier produces a peak DC voltage of

$$V_{peak} = \left|\left(V_{rms}\sqrt{2}\right) - 1.4\right|$$

$$V_{peak} = \left(18\sqrt{2}\right) - 1.4$$

$$V_{peak} = 24.0V$$

This voltage was smoothed by a 1kΩ-1000μf capacitor combination.

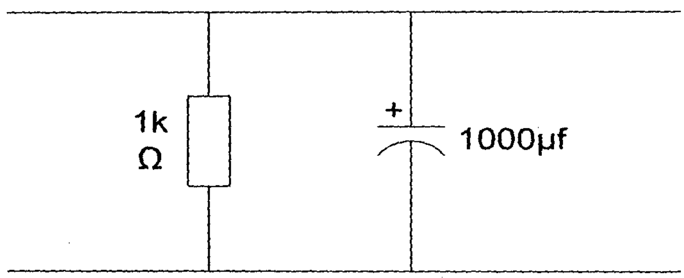

Fig 3.3 Tracking and smoothening circuit.

The resistor-capacitor combination functions as:

(i) A smoothening circuit.

(ii) Input voltage tracking circuit.

The DC voltage across the R-C combination is given by the expression:

$$V_{dc} = \frac{V_{peak}}{1 + \frac{1}{4FCRL}}$$

Where: $V_{peak} = \left(V_{rms}\sqrt{2}\right) - 1.4$

F = mains frequency (50Hz).

C = Value of capacitor across rectifier.

RL = Load resistance = 1kΩ

$$V_{dc} = \frac{\left(18\sqrt{2} - 1.4\right)}{\left(1 + \frac{1}{4 \times 50 \times 10^{-3} \times 10^{3}}\right)}$$

$$V_{dc} = \frac{24}{1 + \frac{1}{200}}$$

$V_{dc} = 23.9V$

This value of DC voltage was fed into two regulators to generate regulated +9V and +5V dc for system operation.

The tracking feature of the R-C network ensures that the capacitor voltage (Vc) follows the mains voltage since the capacitance is discharged at a rate

$T = RC = \left(1000 \times 10^{-3} \times 1000 \times 10^{3}\right)s = 1s$

Thus, if the instantaneous DC voltage across the RC network rises to V1 and subsequently falls to V2, the system responds to this variation in 0.1s.

The regulated outputs are stabilized by 2200µf and 1000µf capacitance respectively

3.3 The Schmitt trigger (modified comparator).

A comparator is an open-loop high-gain amplifier depicted below.

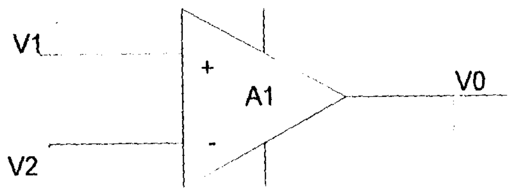

Fig 3.4 Op-amp comparator

Because of the very high open loop gain, a little differential voltage appearing between V1 and V2 is magnified by the gain factor (A) to force the output to reflect the greater of the two voltages

If $V_1 > V_2$; V_0 = positive (Vcc).

IF $V_1 < V_2$; V_0 = negative (Vcc).

Using a comparator, the differentl\an be deduced.

However, ordinary comparator are highly unstable around a single voltage, i.e. if $V_1 > V_2$, the output switches, if $V_1 < V_2$, the output switches. If V_1 and V_2 intersect each other rapidly, the output osculates between positive saturation and negative saturation, producing system instability.

To remedy this, a modified comparator with positive feedback is needed, i.e. a Schmitt trigger. A Schmitt trigger is voltage comparators, V_{ON} and V_{OFF}.

The representative op-amp Schmitt trigger is drawn out below.

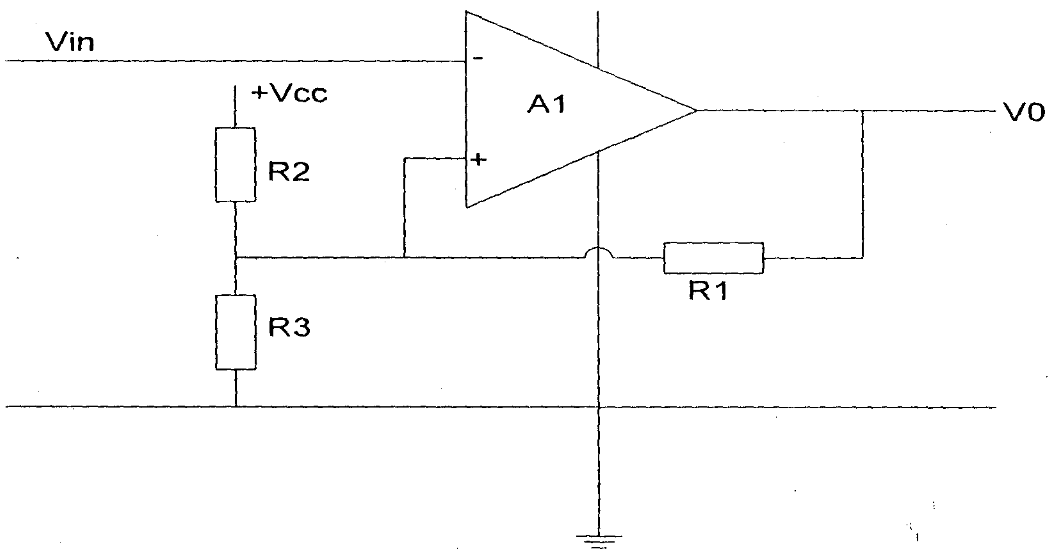

Fig 3.5 Modified comparator (Schmitt trigger).

R_2 and R_3 set the median switching reference voltage, R_3 provides the required hysterisis. Assuming the op-amp in positive saturation, i.e. V_0 = high (at $+V_{CC}$), the non-inverting input is held at a voltage,

$$V_1 = \frac{V_{CC} \times R_3}{(R_2 // R_1) + R_3} \quad \text{.....................(1)}$$

This gives the value of the input voltage needed to turn the output off (0V).

V_{IN} exceeds the value of voltage given by equation (1), the output switches low, and, the reference voltage becomes

$$\frac{V_{CC} \times (R_3 // R_1)}{R_2 + (R_3 // R_1)} \quad \text{..........................(2)}$$

The output remain low until the input voltage drops from $V_{(1)}$ to $V_{(2)}$ at which point the two voltage levels is the hysterisis i.e. VL.

Adding positive feedback greatly allows the switching point for the system to be well established.

A comparator supply voltage of 9V was chosen.

3.4 Under and over voltage detector or sensor.

The under/over voltage cutouts were configured as shown below.

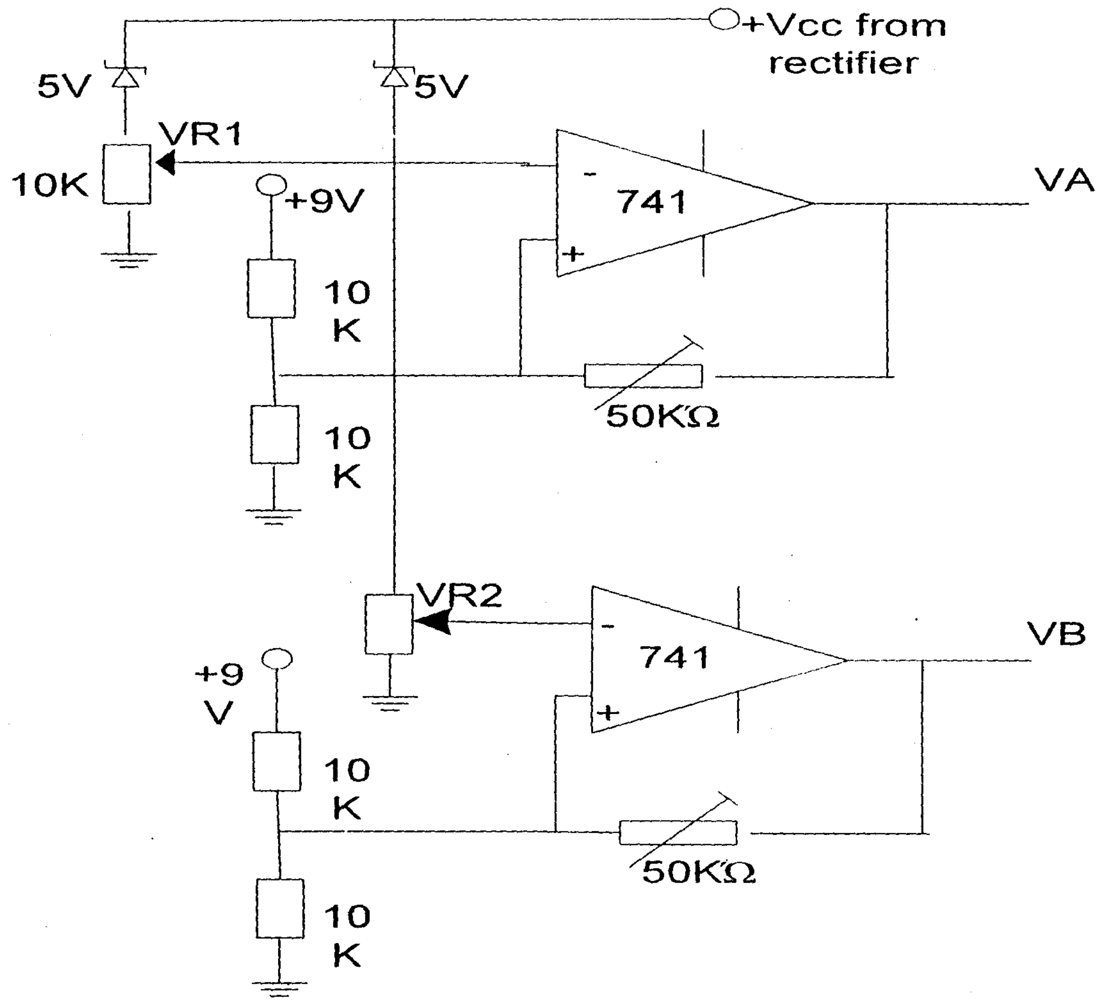

Fig 3.6 Under/over voltage cutout

The two comparators were biased by the 10KΩ potential divider to have switching points symmetrical around Vcc/2 i.e.

$(Vcc/2 \pm \Delta V)V$,

ΔV Vhysterisis

$\Delta V = V_{ON} - V_{OFF}$ from equation (1) and (2) respectively.

The input voltages were applied to the inverting inputs by two zener-resistor network connected to the rectified DC voltage source. A resistor-zener combination provides better responses than a resistor divider network. The upper trip point, i.e. over voltage is adjusted using VR_1, the under trip point by VR_2.

The hysterisis settings potentiomers were adjusted initially to have resistances equal to the values of the 10KΩ resistances, i.e. 10KΩ. This produced two switching thresholds of 1/3Vcc and 2/3Vcc, i.e. 3V and 6V at 260V must be lesser than or equal to 3V.

At 260V

$$V_{rms} = \frac{240:18}{260:x}$$

$$V_{rms} = 19.3V$$

$$V_{dc} = \left(19.5\sqrt{2}\right) - 1.4 = 26.2V$$

VR1 was adjusted to produce a voltage of 6V at this value of Dc voltage.

A 5- volt zener was used, thus:

The resistance needed to produce 6V at an anode voltage of 21.2V is calculated thus,

$$6 = \frac{21 \times R_X}{10000}$$

$$60000 = 22R_X$$

$$R_X = 2.86K\Omega$$

3.5 The switching circuit

The under voltage limit was set by VR_2, and fixed at 160V. V(-) was made greater than V- at normal operating voltages by setting V(+) at normal operating voltages by setting V(-) to a value greater than V(+) keeping A2's output low. V(+) was held at 3V. as the input voltage falls, V- also falls until V(-) < V(+) at which point the output swings high to switch on an NPN transistor connected to it as shown below

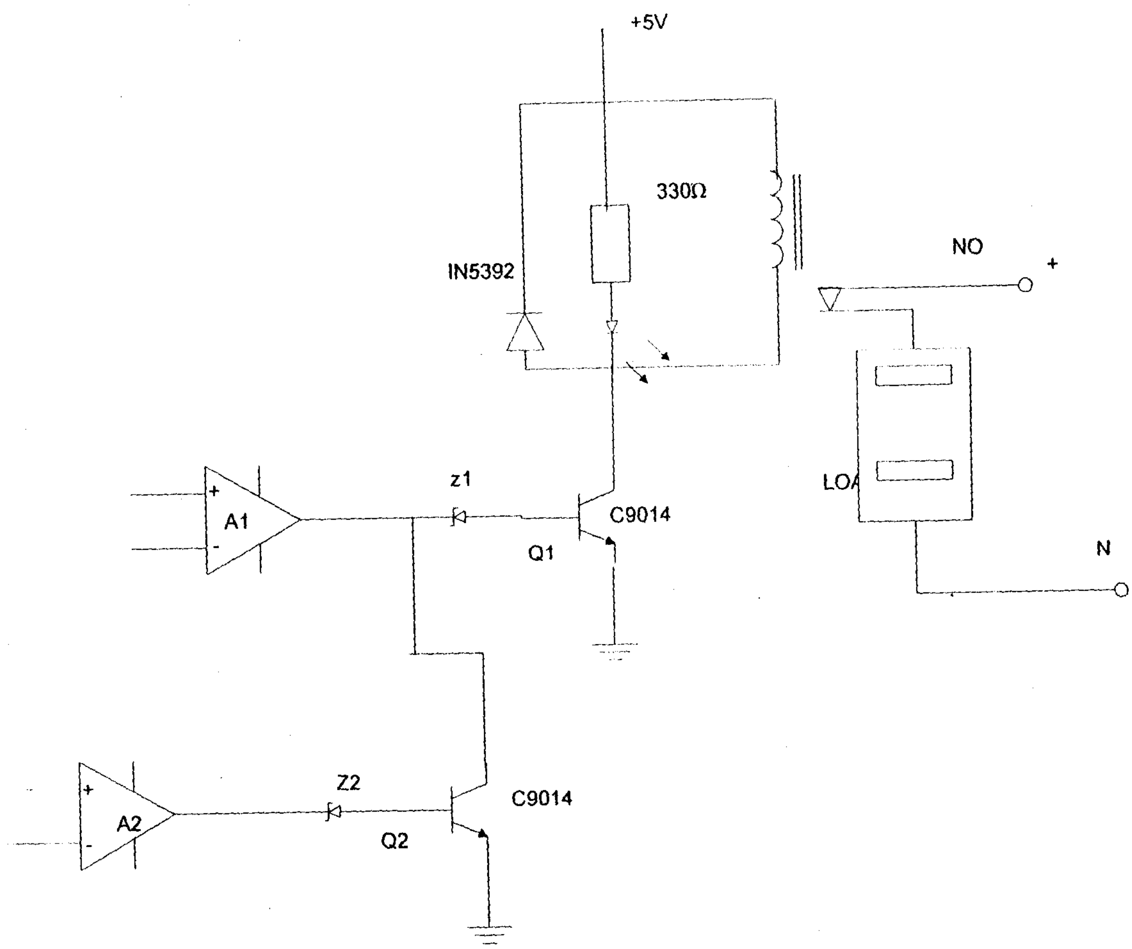

Fig 3.8 Switching circuit

The system states are controlled by Q1 and Q2. At normal line voltages, Q1 is on, and Q2 off, switching on the relay and connecting the load to AC.

At over voltage, Q1 would be turned on without Q2 in the system, but Q2 is on and since Q2's collector is connected to the base of Q1, the Q1 is forced off, and the relay de-energizes.

3.6 Visual indications

The system status is displayed by two LEDs to show:

(i) Normal line voltage condition

(ii) Fault conditions (under and over voltage conditions).

The normal line voltage indicator was wired in parallel with the relay. The voltage indicators were configured as shown in fig. 3.8

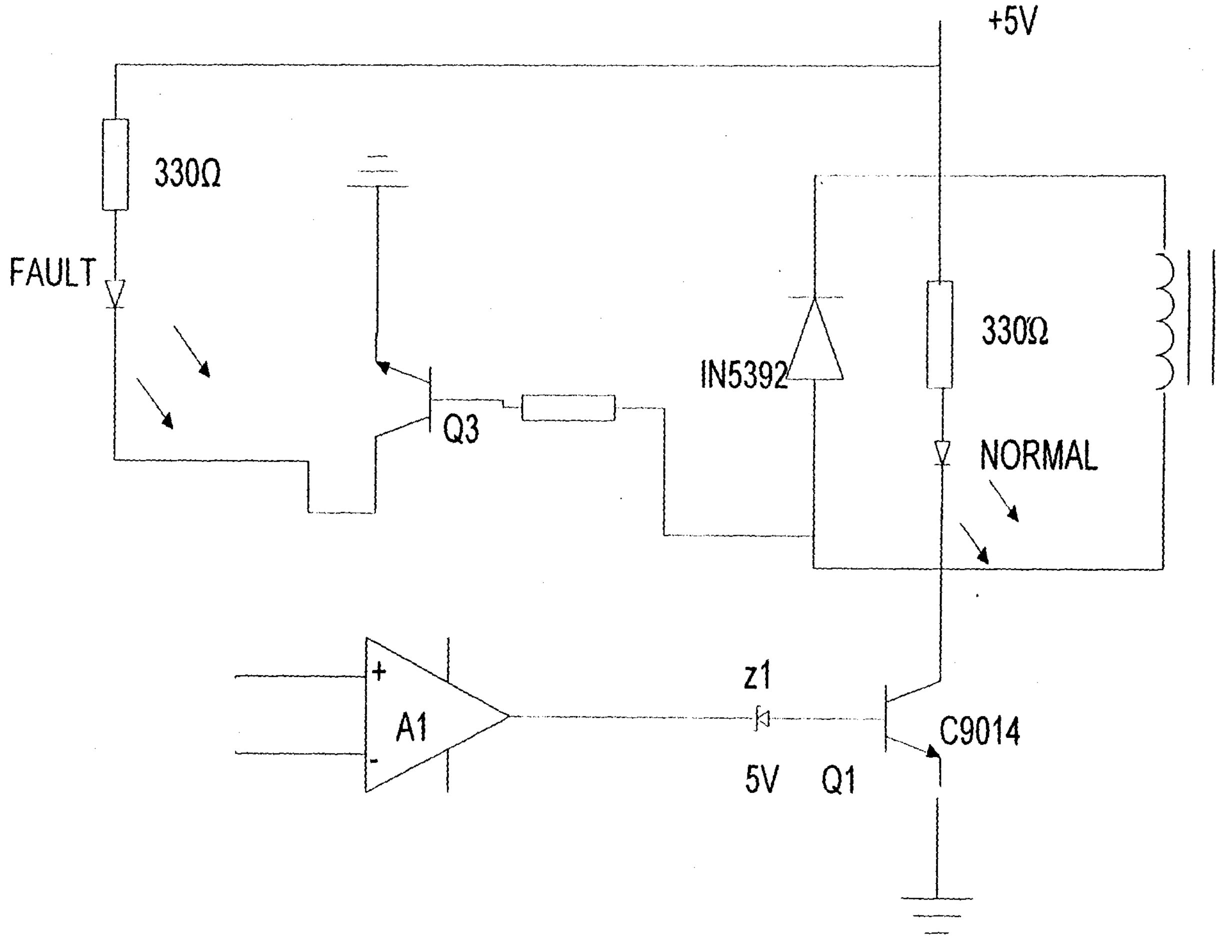

Fig. 3.9 The condition indicators.

The fault indicator is controlled by Q3 which in turn is controlled by Q1. Q1 is switched on or off depending on the state of A1's output. When A1 is high (normal; /line conditions), Q1 is ON the normal condition (red) LED is ON.

Q3 is OFF, turning off the fault condition (green) LED.

At fault condition, A1 is low, Q1 is OFF, and Q3 is ON, turning on the fault condition (green) LED. The current limiting resistance in series with the fault indicator, RS is calculated from:

$$R_S = \frac{V_S - V_{LED}}{I_{LED}} = \frac{5-2}{0.01}$$

$$R_S = 300\Omega$$

A 330Ω resistance was used.

At fault condition (under/over) voltage, the system reverts. A2 becomes high, A1 will also be high, Q2 is ON, Q1 is OFF, the relay is de-energised.Q3 is ON and the fault LED lights.

A moving coil AC meter and two LEDs were used for visual indications of the line voltage. It was connected across the input voltage supply unit.

Chapter four

Tests, Result, and discussion

4.1 Construction analyses

After calculating the required component values for this project, the components were bought and arranged on project board with the circuit diagram. The initial circuit was tested and areas not working properly were modified until a working circuit was produced.

The next step was converting the circuit diagram into a working project and ensuring that there is no cross-over voltage and that there is minimal use of jumper wires. It was also ensured that the various components to be used were carefully studied, understood their pinning procedures and their various biasing potentials. Care was taken not to violate any handling procedure of these components to avoid damage. It was also ensured that IC sockets were available or employed in the soldering, with these sockets; the IC can be easily removed when there is need for troubleshooting.

In soldering the components dry joints and overheating were avoided. The soldering iron bit was properly tinned before use to ensure good soldering and joints were ensured to be electrically and mechanically good.

During soldering, each block was tested upon completion process easier as places or parts where there could be problems or mistakes were easily corrected before moving further.

After soldering , the circuit board and the transformer were fixed into the casing appropriately. The choice of the casing material used was based on the reliability, strength and physical outlook of the equipment upon completion. The body of the casing was perforated to allow proper ventilation of components while in operation.

The body of the casing was drilled fixing the LED indicators which indicate the state and working condition of the project.

4.1.1 Instruments used in this project are:

1. Bread board.
2. Vero board.
3. Jumper wire.
4. Soldering iron.
5. Soldering lead.
6. Soldering sucker.
7. Multimeter.
8. Cutler.

4.2 Casing

The material used for the casing was carefully selected. Care was taken to make sure that

the dimensions were accurate. The circuit board and transformer were carefully fixed in the casing. The material of the casing is an insulator to avoid the circuit to be blown off if powered ON. The material was selected because it has good finishing and looks more presentable

Chapter five

Conclusion and Recommendation

5.1 Conclusions

All component used are cost effective reliable in line with the objective of the project.

This project is highly reliable and efficient as proved by testing. It can be used to protect electrical and electronic appliances from damage due to surges and excessively high or low voltage. The circuit can also be used in UPS to switch from main supply to back up during power fluctuation.

5.2 Recommendation

(i) This project can be considerable be improved upon by the addition of buzzer to help the hearing impaired person to know that an under or over voltage conditions has occurred.

(ii) The use of small component count is advantageous where a small factor is desired.

(iii) For an economic design, purpose designed chips (power supply supervisory ICs) like the MC 3423, 3424, 3425 etc will be used. As these offer under and over voltage detection functionality.

(iv) I also recommend that a voltage regulation circuit be incorporated into the design to help regulate the voltage so long as it is not outside the set range of the under and over voltage cutout.

(v) Autotransformers should be provided in the electrical laboratory to help student that would want to design project that have any thing to do with under and over voltage conditions to test there designed project.

(vi) Design and practical oriented courses could also be introduced into the academic calendar of the Electrical and Computer Engineering students. This will go a long way in making the project work a conversant routine exercises. The practical application of electronic components in project implementation seems to be miles away from the theoretical knowledge if proper care is not taken. It is a collective belief that with more emphasis on practical application of what we learn in the classrooms, the points made in the classrooms will be driven home better.

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Appendix

COMPLETE CIRCUIT DIAGRAM

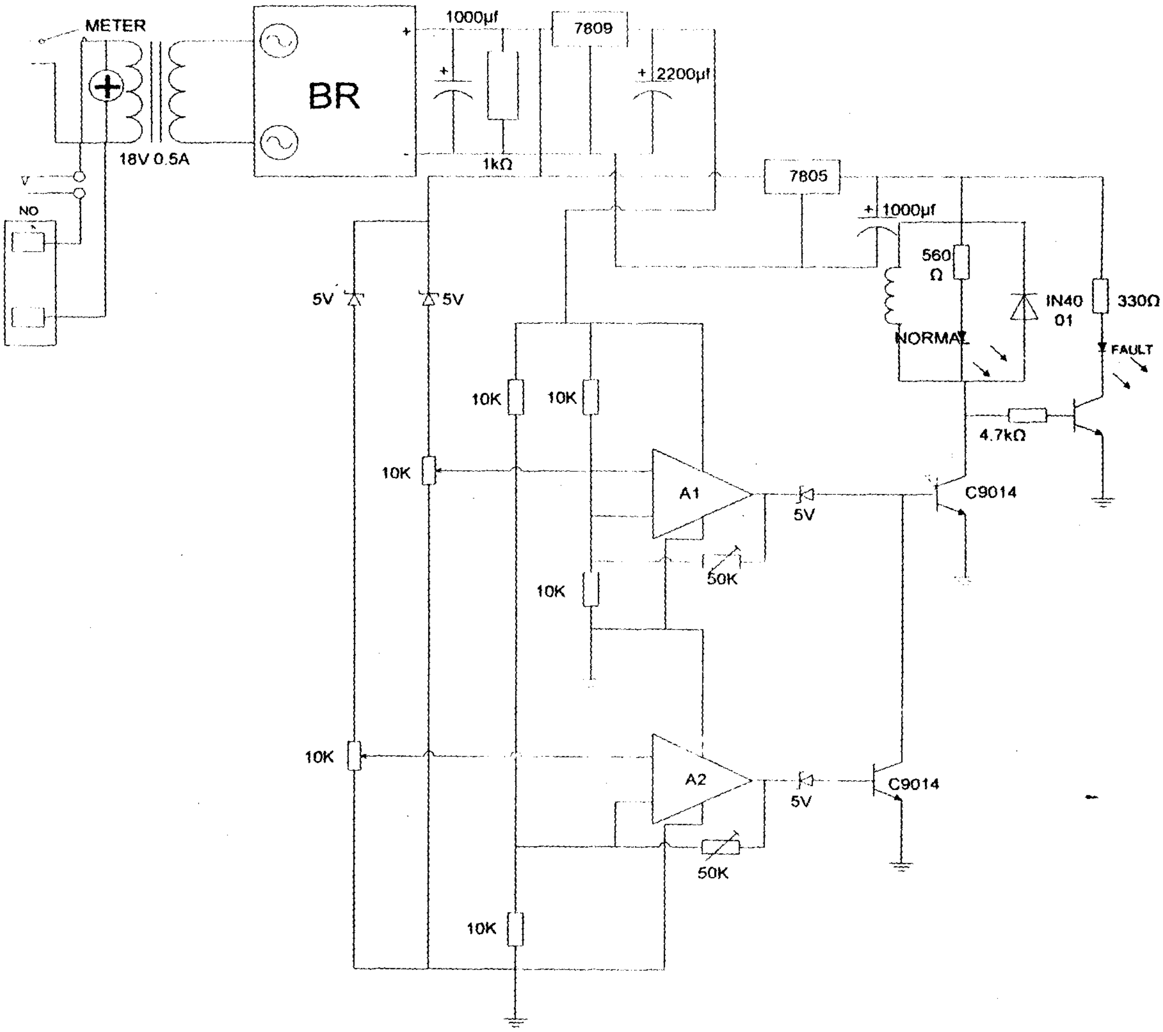

Fig.5.1 Complete circuit diagram.