DESIGN AND CONSTRUCTION OF ALTERNATING (AC) VOLTAGE REGULATOR WITH INPUT RANGE OF $70V_{RMS}$ TO $240V_{RMS}$ AND OUTPUT OF $220V_{RMS}$ +/- 10%.

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A project submitted in partial fulfillment of the requirements for the degree of bachelors of engineering in the department of electrical and computer engineering.

Federal university of technology Minna, Niger state.
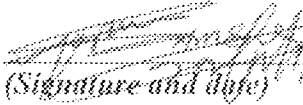
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Dedication

This project is dedicated to My Lord and Saviour Jesus Christ, and my dear parents Mr. &

Mrs. Yerima S Atiwurcha may the almighty God bless you abundantly amen.

Attestation/Declaration

I yerima musa Samson (2000/9939EE) declare that this work was done by me and has never been Presented else where for the award of a degree. I also hereby relinquish the copyright to the federal university of technology Minna.

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(Signature and date)

Acknowledgement

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My heart of gratitude also goes to my lecturer and head of department Engr M D Abdullahi; I say a big thank you for your fatherly advice, tireless assistance encouragement and counsel, care and understanding. I will never forget his word 'You can't be an Engineer if you are not an honest person'.

My appreciation also goes to every member of staff of my department and the school entirely for their effort and encouragement to me during the course of my training.

Abstract

Design and construction of an automatic voltage regulator is described in this report. the project is intended to produce a $220V_{rms}$ alternating voltage +/- 10 %(1KVA),with Input range of $70V-240V_{rms}$ the design employs the principle of achieving voltage regulation by sensing variation in the input voltage and responding by changing the taps on the power transformer such that a voltage close to the nominal value of 220Vrms(1KVA) is provided. This project is design to meet the extreme condition of PHCN low voltage supply, so as to protect domestic and industrial electronics.

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Chapter One

1.0 Introduction.

The automatic voltage regulator is an electronic device conceived based on the research work carried out on the voltage range supplied to homes by power holding company of Nigeria PHCN (formerly NEPA). Three month research was carried out at anguwar biri near FUT MINNA in bosso local government area of Niger state between January to April 2006.minimum and maximum voltages where recorded, the minimum average value obtained was $80V_{rms}$ while maximum average was $244V_{rms}$.

Supply from PHCN transformer to our homes is distributed in radial form. In radial system the consumer's substation are connected in series along the length of the transmission line away from the supply transformer. One of the problems of radial distribution is higher voltage drop due to the line resistance; the supply voltage close to the transformer will be greater than the voltage at the farthest point. [1]This low voltage at far point may not be enough to power electronic devices hence the need for an automatic voltage regulator.

Most electronic devices in Nigeria are rated at 220Vrms and can work with a voltage supply as low as 180Vrms. This AVR is design to give an output of 220Vrms+/-10% 200Vrms to 240Vrms) for an input range of 70Vrms to 250Vrms and power output of 1KVA.

In designing and constructing this project component availability was taken in to consideration, research was also carried out on the type of AVR available in the market and the input voltage range.

1.1 VOLTAGE AND FREQUENCY STANDARD SPECIFICATIONS[2]

The electrical power supply regulation requires that voltage level and frequency be kept within certain limits. The Federal Ministry of Power and Steel (revised 1979 Regulations yet to be released) has adopted the IEE Regulation that allows the variation in the consumer's voltage by ±6% and the frequency by ±1½%. Thus, in the case of a normal 415/240 V supply at 50Hz, the variations may be:

Table 1.1 voltage and frequency IEE rating

VOLTAGE (Vrms)	FREQUENCY(Hz)
390.1 – 415 – 439.9	49.25 – 50 – 50.75
225.6 – 240 – 254.4	

In some areas, the PHCN electrical supply voltage has been found to be as high as 250 V and as low as 70 V causing extensive damage to equipment and appliances. Worst affected are the transformers in the compressors of refrigerators and power supply circuits of radios and television sets and the coils of electric motors. Fluorescent tubes explode at high voltage or fail to start at low voltage. This has necessitated the use of Automatic Voltage Regulators and/or protection of equipment and appliances with Automatic Voltage Switchers (AVS). Computer users find the situation most annoying as the UPS may fail to function below 220 V.

Variation in Frequency affects the accuracy of electric clocks connected to the PHCN supply. It affects the running speed of induction motors and industrial process that depend on mains frequency. The output voltages of transformers are further reduced with a fall in frequency.

1.2 Voltage and frequency supplied by PHCN

Power holding company of Nigeria (PHCN) is the only company presently in Nigeria that is responsible for the generation, transmission and distribution of electrical energy. This has given them a monopolistic control over electrical energy utilization and the effect of monopolies are inefficiency, mismanagement of the system and lack of customer care. Power stability is the major problem faced by every Nigerian irrespective of his status in the community. There are basically three types of power problems, namely low voltage supply, total power outage and high voltage supply.

1.2.1 High voltage supply.

This is a situation where PHCN supply voltage above 255Vrms.In Nigeria today some places do experience voltage as high as 350Vrms which will cause damage to electronic devices that work at 220Vrms. Any voltage variation above the specified limit (above 255 V) is considered as over-voltage. Over-voltages of very short duration is referred to as surges. Surges have devastating effect on the electrical equipment and appliances. This calls for the use of surges protectors.

Surges may be due to lightning strike on a transmission line. Surges may also occur if there is a sudden under-loading, when a heavy load is suddenly switched off or a generator is switched on. Consumers in the urban areas and those near the supply transformers are most affected.

1.2.2 Power outage.

It means no power supply from PHCN.In this case most people rely on their generating set (generator) for electrical power supply. The cost of running a generator as a source of electrical energy is high hence not all can afford it. Outages are the results of

interruptions of supply of electricity. They cause suffering to life, underproduction and unemployment. The effect of power outages on an already depressed economy is devastating. It would do a world of good to the organizers of the National Poverty Eradiation Programme (NAPEP) to pay more attention to the provision of a stable electricity supply system in order to eradicate power outages. Outages may be the result of a failure or fault in the electrical generation, transmission and distribution system – more often it is due to lack of maintenance on the distribution system. A power outage may also be deliberately inflicted as in load shedding. Whatever the case may be, once an Authority undertakes to supply power, it must maintain it, at most economic costs. There are some services in which no power interruption should be allowed, such as computer installations, hospitals and water work. frequent power outages are the reason for the prevalence of standby generators in the country. These noisy and air-polluting machines are expensive to purchase, operate and maintain and as such have markedly added to the cost of industrial production.

1.2.3 Low voltage.

This is a situation where PHCN supply voltage below 225Vrms. A drop in the NEPA supply voltage is very common. Where this is due to over-loading of the power supply system, the supply cables draw excessive current. This is accompanied by heating up of the cables and switchgear, which may get burnt. Load shedding is resorted in order to keep the power supply within the specified voltage limits. Overloading in the transmission system results in the generators at the generating point running slower with consequent drop in frequency. If this persists, it may lead to distortion of the output waveform. This may further lead to the introduction of harmonics in the system, which is undesirable.

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In an integrated system, like the National Grid, a change in frequency of supply from a generating point is the first signal of over-loading or under-loading. Under-loading results in rise of generating frequency; the reverse is true in the case of overloading. In the case of over-loading the situation may be brought to normal by putting on additional generation in the system or taking off some loads. When a load is switched off from a generating point, it can be fed from another point under the direction of a Control Centre.

An integrated system, under one or two control points, is far more reliable and efficient than a proliferation of independent power plants, as it can take good advantage of diversity factor. The National Network Control Centre is at Oshogbo and there is a sub-centre at Shiroro.Another source of low voltage supply is when the system is working below capacity due to ageing or lack of maintenance.

1.24 Normal voltage.

The normal voltage as supplied by PHCN is 220Vrms.any variation by+/- 10% (200V to 240Vrms) is acceptable to operate electronic device that operate at 220Vrms.The design and construction of this AVR is based on this normal voltage.

1.3 AIMS AND OBJECTIVES

The aim of this project is to design and construct an automatic voltage regulator to meet the extreme condition of PHCN low voltage supply, so as to protect domestic and industrial electronics. It will work in an environment where low voltage is experienced daily.

1.4 METHODOLOGY

The project is composed of three stages. These are autotransformer, power transformer and display stage. Each of the stages was designed separately (i.e. modular approach method fig1).discreet component as well as IC were used to realize the project.
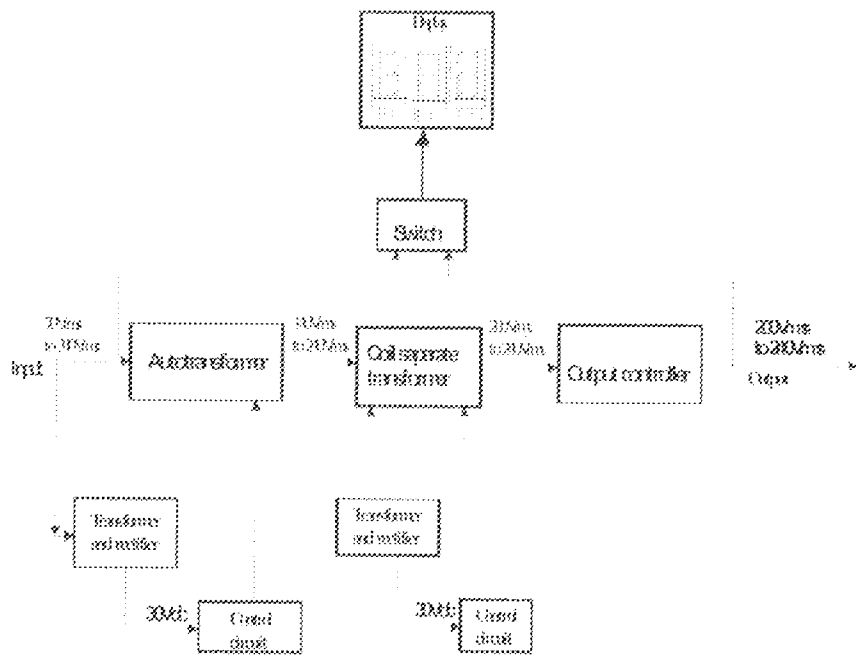
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Figure: Block diagram of the automatic voltage regulator

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Chapter Two

2.1 LITERATURE REVIEW

Due to the limiting factor encountered such as voltage drop due to resistance losses on the low voltage distribution, voltage regulation is necessary. The earliest attempt at obtaining an AVR employed a motorized system controlled by a control circuit to change the taps on the secondary of the auto transformer so as to step up the voltage when the input voltage is low. Or step down when the voltage is high, this came as a result of variation in the transmission voltage. The limitations of this system are thus; bulky, costly and the mechanical parts wear away resulting in improper contacts between the changer and the tape of the transformer.

Resonant circuit voltage regulator was another approach. This type involves raw component, inductance of a transformer coupled with a parallel inductance and capacitance resonant. Less current is drawn by the inductance and parallel circuit combination becomes capacitive when the line voltage falls below the rated value. The output voltage is raised by the capacity drawn through the transformer. If the line voltage rises above the rated value, the parallel circuit combination becomes less capacitive and the output voltage falls below the line voltage. Some of the shortcomings of this system are; it's frequency dependant and bulky.

Another approach was the principle of switch mode power supplies. The regulated DC output from the power supply is inverted using push-pull inversion and stepped up to the required constant AC output voltage using a transformer. Good regulation is produced through this method, as the output of the system is a square wave AC voltage that could be filtered to obtain a pure sinusoid. The complexity and high cost of this system led to the invention of another approach; the phase controlled ARV.

In this system, the load is connected in series with the voltage controlled devices which is usually a silicon controlled rectifier. This method is very fast in response to the voltage fluctuation of the input. The voltage control is achieved by triggering a phase angle determined by the control circuit in such away that the voltage across the load connected to the output terminals is regulated to the desired values. The limitation this method is that of the distorted output waveform.

Transistorized ARV is a present technology approach, which brings an improvement on motorized ARV method. It overcomes difficulties or limitation realized in the previous approaches. It is relatively cheaper; light in weight and it has a good regulation. .an electromechanical relay replaced the mechanical tap change. It has an autotransformer, which the turn ratio can be varied to give desired regulation; the control circuits determine the position of the relay contact on the taps of the transformer. The control circuit determines whether the low supply voltage is to be stepped down to the rated value at the output.

2.2 Transformer

A transformer is an electronic device that changes one AC voltage to a different AC voltage. There are two types of transformer namely separate two coil and single coil (autotransformer) transformer.

Separate coil

Basically it consists of a core made of many thin sheets of steel, with two coils of wire or windings. The windings are electrically insulated from each other and from the core .Electric energy is supplied to one winding called the primary winding, while the other winding is called the secondary winding, which deliver the energy at a different voltage. When the primary winding is energized by an AC source, an alternating magnetic field called flux is established in the transformer core .The alternating flux surround both winding and induces a voltage in both windings. Since the same flux cuts both windings, the same voltage is induced in each of turn of the windings. Hence the induced voltage is proportional to the total number of turns in each winding.

primary winding   transformer   secondary winding

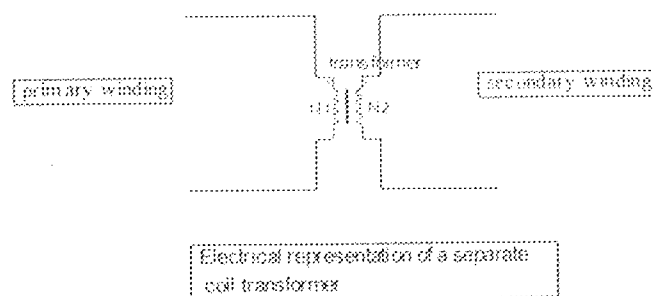Electrical representation of a separate coil transformer

figure 2.1

The voltage in the primary will be the same as that received from the source. But the voltage in the secondary will depend on the number of turns in the primary winding. If the secondary has the same number of turns as the primary, the voltage will be the same

in both windings. The secondary voltage is proportional to the primary voltage. The relationship between these voltages is given below.

$$\frac{E_p}{E_s} = \frac{N_p}{N_s} - - - - - - - - - - equation 2.0$$

Where; E_s =secondary voltage $\quad E_p$ =primary voltage

N_s =number of secondary turns $\quad N_p$ =number of primary turns

2.3 Transformer current and load.

When current flows through a coil a magnetic field is established. Any change in the magnetic flux of a coil creates an electric field that will induce a voltage in the selfsame coil or in any other coil on the core, in accordance with Faraday's law of electromagnetic induction. The transformer is perhaps the most widely used component in electrical engineering Where there is no connected load (secondary connection open) a transformer has only a very small no load current which is called the exciting or magnetizing current .the magnetizing current produces the magneto motive force that produces the transformer core flux. When load is connected then just as much current will flow in the primary as is required to deliver the required power to the secondary.

Experiment shows that if the primary and secondary have the same number of turns, the voltage of the primary and secondary will be the same, but current flowing in the primary from the power line adjust itself to the current demand of the secondary by the nature of the particular load connected to it .if the secondary has twice as many turns as the primary, the voltage of the secondary will be twice that of primary, but the current will be only half as great. If the secondary has ten times as many turns as the primary, the voltage in the secondary will be ten times that in the primary, but the current will be only one tenth as great. By reversing the proportion and having fewer turns in the secondary than in the primary it is equally simple to step the voltage down instead of up, but the

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current will then go up as the voltage goes down. The volt-ampere in the secondary, plus a small percentage, depending on the efficiency of the transformer .the minimum number of turns must be kept within the limit that good engineering has shown lead to the greatest efficiency, and wire sizes in both the primary and secondary must be adequate to carry the current involved. For an ideal transformer the volt-ampere of the primary is the same as the volt-ampere of the secondary. Hence:

Ideal transformer: primary volt-ampere =secondary volt ampere

$$E_S \times I_S = E_P \times I_P$$

$$\frac{E_S}{E_P} = \frac{I_P}{I_S} - - - - - - - - equation 2.1$$

$$\therefore \frac{E_S}{E_P} = \frac{N_S}{N_P} = \frac{I_P}{I_S} = n$$

Where; I_P=primary current (A)

$\quad\quad$ I_S=secondary current (A)

n=transformer ratio (secondary winding/primary winding)

From ohm`s law:

$$E = Z \times I$$
$\quad\quad\quad\quad\quad\quad$ Z=impedance of the circuit in ohm (Ω)

$\quad$ I= current flowing in the circuit (A)

From equation 2.1

$$\frac{E_s}{E_p} = \frac{Z_s \times I_s}{Z_p \times I_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s} = n \quad - - - - - - - - - - \quad equation\,2.2$$

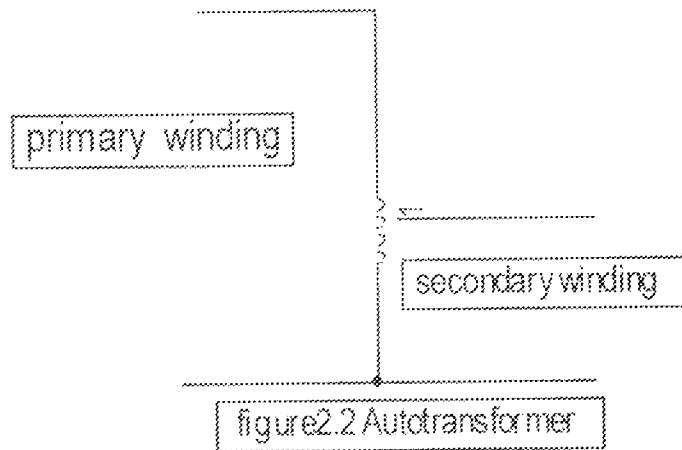$$\frac{Z_s \times I_s}{Z_p \times I_p} = \frac{I_p}{I_s}$$

$$Z_s \times I^2{}_s = Z_p \times I_p^2$$

$$Z_s = Z_p \times \left(\frac{I_p}{I_s}\right)^2 = Z_p \times n^2$$

This shows that a transformer of turn ratio n and primary impedance Z_p, has a secondary impedance Z_s proportional to square of the turn ratio.

2.4 Autotransformer:

It can be defined as a transformer in which a portion of the turn of a single winding is common to both primary and secondary. Let there be a tap at the mid point of the coil. This type of transformer being less expensive than two coil type is often used for transmission line, to boost the voltage level at homes and similar purposes.

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                          ┌─────────
                          │
        ┌─────────────┐   │
        │primary winding│  │
        └─────────────┘   ≈════════════
                          │  ┌──────────────┐
                          │  │secondary winding│
                          │  └──────────────┘
                          │
                ──────────┴────●──────────────
        ┌──────────────────────┐
        │figure2.2 Autotransformer│
        └──────────────────────┘
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Transformer serve two main purpose or functions in electronic instrument: they change the AC line voltage to a useful value that can be used by the circuit, and they "isolate" the electronic device from actual connection to the power line ,because the winding of a transformer are electrically insulated from each other power transformers (meant for use from the 220V power line)come in an enormous variety of secondary voltages and current :outputs as low as one volt or so up to several thousands volt .current rating from a few milliamps to hundred of ampere. Typical transformer for use in electronics instruments might have secondary voltage from 6 to 120V, with current rating of 0.1 to 10 amps or so.

Chapter Three

3.1 Design and implementation

As detailed in the previous chapter the automatic voltage regulator consist of four stages. Modular approach will be use to analysis the circuit.
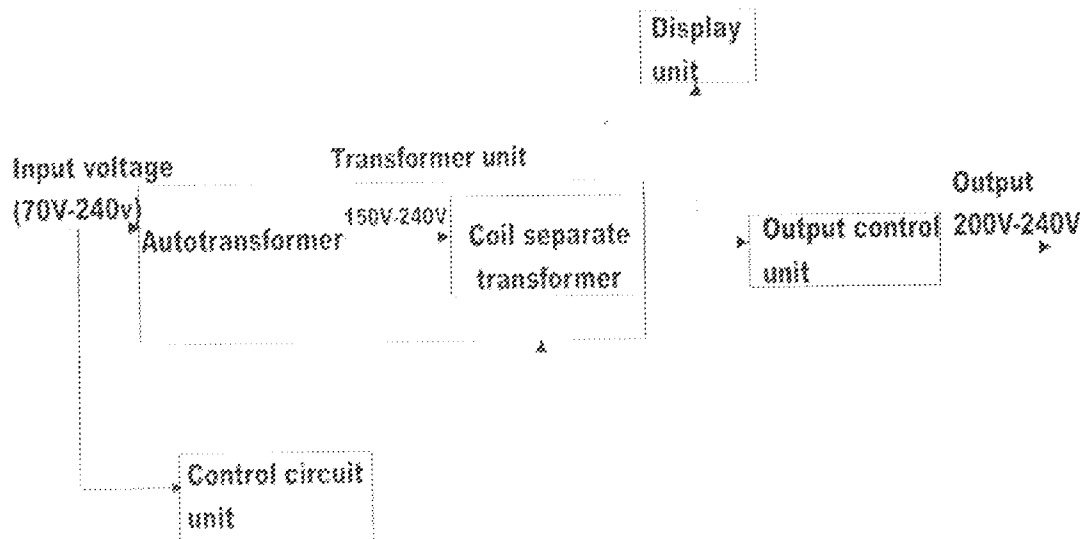

FIGURE 2.3 Block diagram of AVR

3.2 Transformer unit

The transformer unit consists of the autotransformer, separate coil transformer and four (4) relays. This unit forms the basis of the AVR, the input voltage is applied to this unit and the control unit determines which of the windings the input voltage will be applied to. The electrical circuit connection with and without the relay is shown below. Relay A to D is used to change input voltage while relay E is for output control.
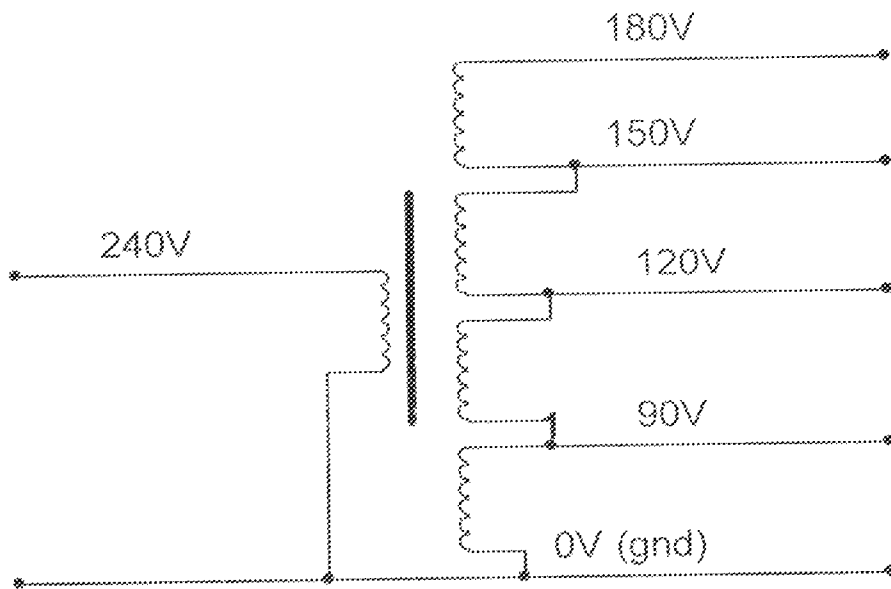
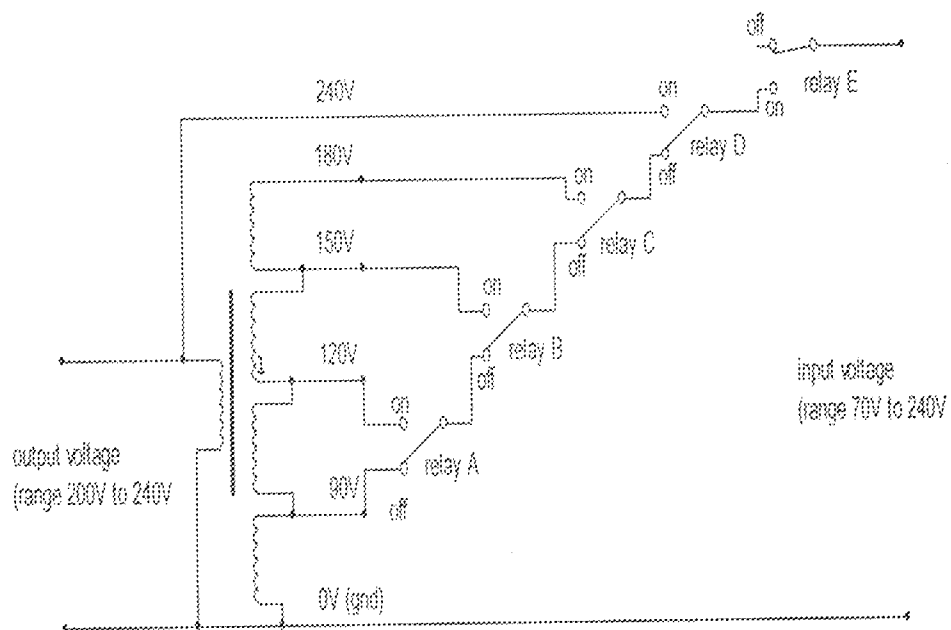Figure3.2 electrical circuit connection of the transformer unit

Figure3.3circuit connection of the transformer unit with control relays.

Table 3.1 inputs and relay combination to give the desired output voltage

Input range (voltage)	Relay A	Relay B	Relay C	Relay D	Output range(voltage)
70 -90	off	Off	off	off	200 - 240
90 - 120	on	Off	off	off	190 – 240
120 - 150	on	On	off	off	180 - 240
150 – 180	on	On	on	off	190 - 240
180 – 240	on	On	on	on	180 - 240

3.3 Control circuit unit.

This consists of relay circuit control and the comparator .the comparator compares the input voltage with the reference voltage. If the input voltage is above the reference voltage the appropriate relay is operated. The input voltage is stepped down by a factor of twenty (20) (hence if the input is 240V the input to the comparator is 12V).the four (4) comparators are connected in parallel-encoded form (flash encoding).in this method the input signal voltage is fed simultaneously to one input of each of the four comparators,. Lets say the input from PHCN is between 70V-90V,this means that the voltage to the input of the comparator is between 3.5V-4.5V.so long the voltage is below 90V(4.5) non of the relay will operate, this means the input will be applied to the transformer unit input. The output will now be between 200V-240V.above 90V but less than 120V relay A will operate and connect the input to the 120 side of the transformer. For input above 120V but less than 150V, relay A and B will operate and applied the supply to the input .for relay A, B and C to operate the voltage must be between 150V and 180V.above 180V the AVR allow the supply directly ,above 250V the AVR shut down.

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3.4 Input circuit:

The circuits below show the input circuit .this consist of DC power unit generated form the AC supply. It used for both DC power supply in the system and for regulation.
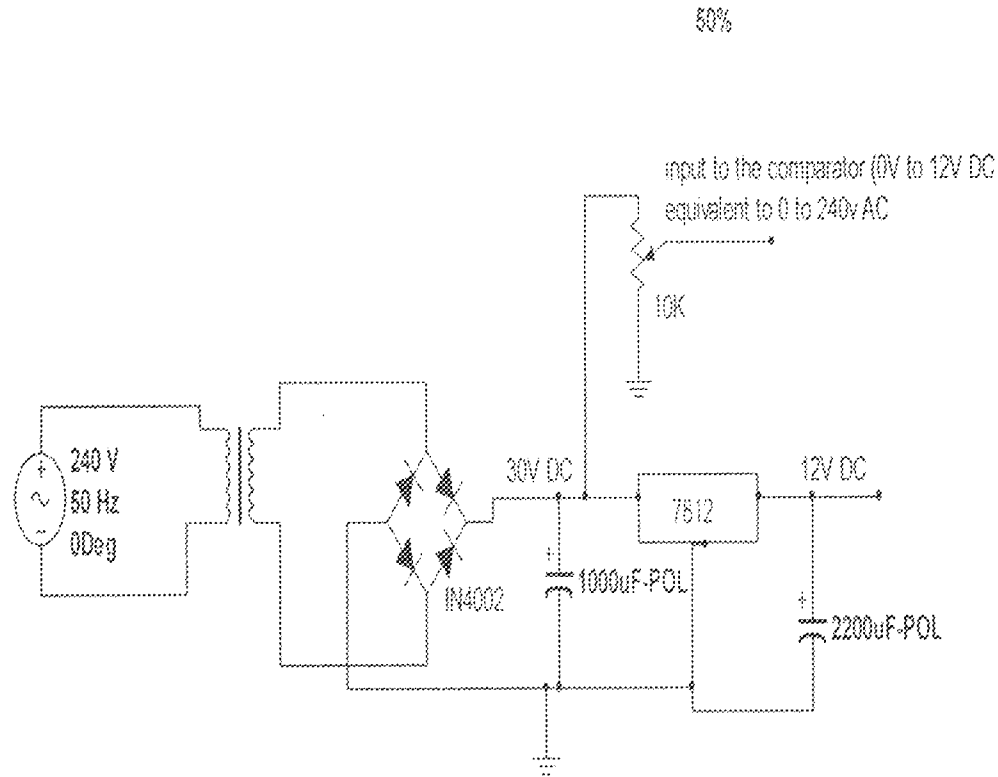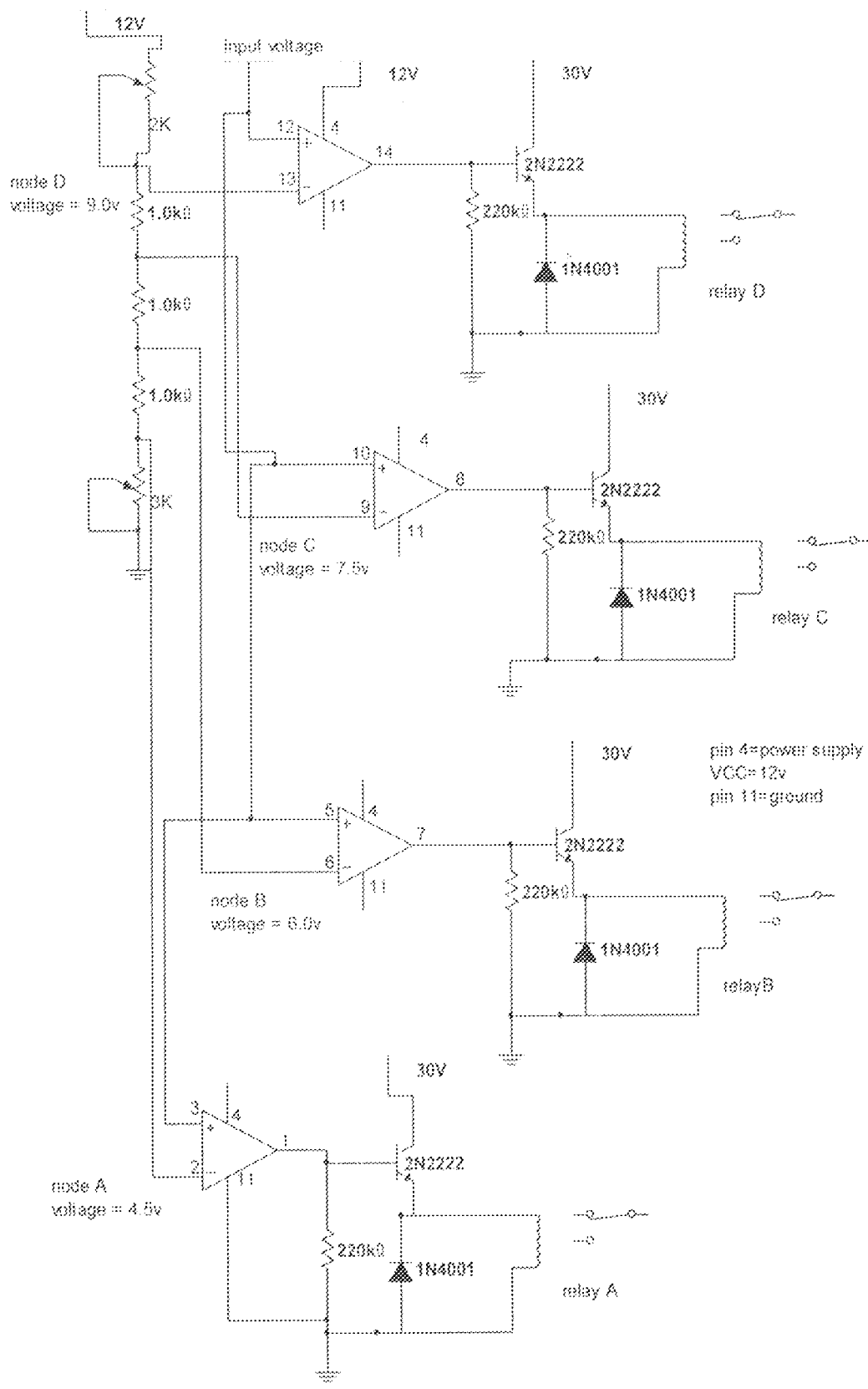

Figure 3.4 comparator input and DC power supply to the AVR.

3.5 Relay control circuit [3, 4].

The relay control circuit is shown below. Theoretical voltage at each node or pin of the LM324 is specified. if the input voltage at the noninverting input is greater than the reference voltage at the inverting input the appropriate relay will operate.

CONTROL CIRCUIT DIAGRAM OF THE AVR

From the circuit diagram, nodes voltages are determine as below:

Node A, this is required to operate relay A, voltage at pin 2 is given by

$$V_2 = \frac{3}{(3+1+1+1+2)} \times 12 = 4.5v$$

Once the voltage at pin 3 exceeds this voltage, relay A is operated .this can only occur if the AC voltage is above 90V.

Node B, this is required to operate relay B, voltage at pin 6 is given by

$$V_6 = \frac{4}{(3+1+1+1+2)} \times 12 = 6.0v$$

Once the voltage at pin 5 exceeds this voltage, relay B is operated .this can only occur if the AC voltage is above 120V.

Node C, this is required to operate relay C, voltage at pin 9 is given by

$$V_9 = \frac{5}{(3+1+1+1+2)} \times 12 = 7.5v$$

Once the voltage at pin 10 exceeds this voltage, relay A is operated .this can only occur if the AC voltage is above 150V.

Node D, this is required to operate relay D, voltage at pin 13 is given by

$$V_{?} = \frac{6}{(3+1+1+1+2)} \times 12 = 9.0v$$

Once the voltage at pin 12 exceeds this voltage, relay D is operated .this can only occur if the AC voltage is above 180V. None of the relay will operate for voltage below 90V, hence the input will be applied to the low voltage side of the transformer, this will cause the output to go to 220V .above 180Vthe input is applied directly to the output.

The 220kΩ and the transistor (2N2222 general purpose transistor) act as a follower or buffer .the 220kΩ resistor prevent noise and the finite slew rate of the op-amp from false triggering of the transistor. The transistor prevent the relay from loading the op-amp

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by acting as a buffer the relay is rated at 12v and 400Ω,therefore current into the relay is given by

$$I_{relay(max)} = \frac{12}{400} = 30mA$$

The transistor current equation is given by

$$I_E = I_C + I_B$$
$$I_C = \beta \times I_B$$
$$\therefore$$
$$I_E = \beta I_B + I_B = (\beta + 1) \times I_B$$

I_E=emitter current (A) I_B=base current (A) I_C=collector current (A)

β=current gain (typical value for 2N2222 is 100)

For the relay to operate the op-amp must supply a base current of;

$$I_B = \frac{I_E}{\beta + 1} = \frac{30mA}{(100 + 1)} = 297.03\mu A$$

When all the relays are operated the current given out by the op-amp is given by

$$297.03\mu A \times 4 = 1.19mA$$

Which is within the save operating region of the op-amp.

The diode 1N4001 is used as free wheeling diode. it provide a safe discharging path for the inductor of the relay so that the transistor will not be damaged.

3.6 Output control unit.

This consists of a circuit that controls the output of the AVR the circuit for the output control unit is shown below. The circuit consists of delay, two Op-amp buffer, transistor buffer and relay. The delay delays the output for some seconds within which the appropriate voltage level is determine. The buffers prevent the relay from loading the delay circuit. Once the capacitor (470µF) charges to 6V, it turns the relay E on

Delay time is given by $\tau = 0.7 \times R \times C = 0.7 \times 10K \times 470\mu F = 3.29s$
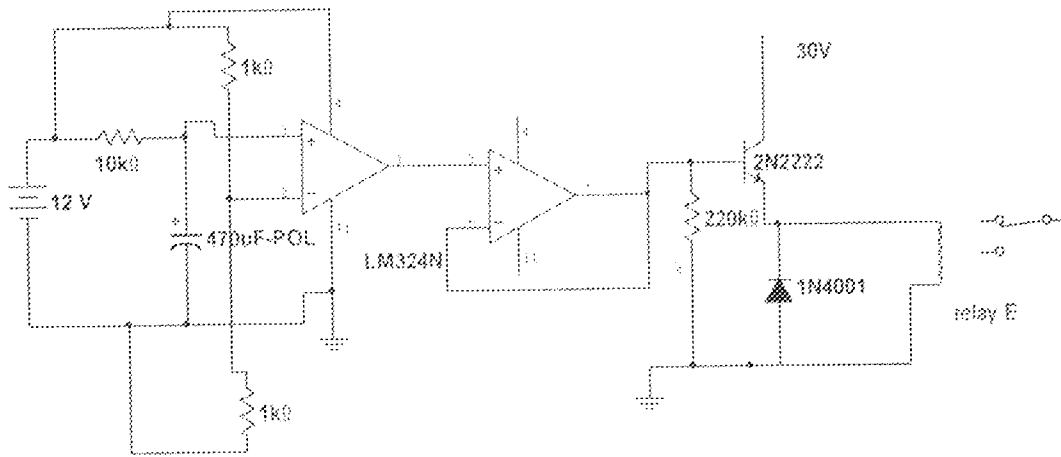

figure 3.6 output control unit

3.7 display unit.

This consist of two analogue displays, it shows the voltage level of Input /output continuously.

Chapter Four

TEST, RESULTS AND DISCUSSION

Testing is carried out primarily to see if the actual performance of the newly constructed device matches its expected performance. This makes it possible for the designer to estimate the accuracy of the fabricated device. Likewise also, the testing of the automatic voltage regulator was necessary for the simple reason stated above. The performance of the device in terms of its efficiency is reflected by the margin of variation between the theoretical value and the actual.

4.1 TEST

A test mode of operation was provided during the design of the device solely for test purposes. Computer system was connected to the AVR and the actual output value was recorded.

A digital multi meter was among the test tools required for the testing of the device. In order to test, the AVR device was simply powered on and the delay time was measured using stopwatch. The applied voltage was measured using the multi meter

.4.1.1 Results

Results gotten during the test exercise were tabulated as follows:

Table 4.1: Table of results

Input range (voltage)	Relay A	Relay B	Relay C	Relay D	Output range(voltage)
70 -90	off	off	off	off	180- 240
90 - 120	on	off	off	off	190 – 240
120 - 150	on	on	off	off	200 - 250
150 – 180	on	on	on	off	190 - 245
180 – 240	on	on	on	on	180 - 240

4.2 DISCUSSION OF RESULTS

From the results displayed in table 4.1 we see that a little discrepancy occurs between the actual output value and the expected value.

The delay time obtained is 3 second as against 3.3 second.

4.3 SHORTCOMINGS AND POSSIBLE REMEDIES

The discrepancy observed during the testing of the device presented little surprise as it was anticipated, though within a particular tolerance range. This is so because a few unavoidable limitations were encountered in the course of the project work.

Two prominent shortcomings experienced were the erratic operation of the relay and inability to procure precision resistor that has tolerance of 1% components. The only remedy available in an application where a higher accuracy is needed involves incorporating precision components since exact circuit parameters yield exact results.

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Chapter Five

CONCLUSION

5.1 SUMMARY

AVR are a very important electronic device especially in this country where supply fluctuate indiscriminately and damage electronic devices. , the PHCN electrical supply voltage has been found to be as high as 250 V and as low as 70 V causing extensive damage to equipment and appliances. Worst affected are the transformers in the compressors of refrigerators and power supply circuits of radios and television sets and the coils of electric, hence the need of AVR to guard against this fluctuation.Conclusively, since the objective of the design is met and the fabricated design works normally as expected with accuracy within the tolerance range, this project work/experience is considered successful, rewarding and fulfilling.

5.2 RECOMMENDATION

The operation of this device could be applied to electronic appliances that have a rating of 240V/1KVA like the Television. Where a higher accuracy is required, a digital display can be incorporated, which I deemed optional, in the light of my primary objective.

REFERENCES

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APPENDIX B

LIST OF COMPONENTS USED IN THE PROJECT WORK

COMPONENT TYPE	QUANTITY
Resistors	
5KΩ POTENTIOMETER	2
1kΩ	5
220kΩ	4
10kΩ	1
Capacitors	
2200µF (25V)	1
470µF	1
1000µF	1
Diodes	
IN4001	5
Rectifier diode	4
LED	2
Transistor 2N2222	5
Double pole double throw switches	1
Relay	4
Transformer (45V 3A)	1
Transformer (variable voltage 5A)	1
Analogue display	1
LM324N(Op-amp IC)	2