DESIGN AND CONSTRUCTION OF A 1500VA VOLTAGE REGULATOR

BY

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TO THE
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DEDICATION

This project is dedicated to Almighty Allah the Supreme Being, who sees me through my course and in honor of my Lovely parents and lecturers in the Department of Electrical and computer engineering of The Federal University of Technology Minna.

Declaration

I, NAFIU ABUBAKAR SIDIQ declare that this project work was done by me and has not 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.

The design and construction of a Voltage Regulator for sensitive industrial and domestic electronic equipment is described in this project.

The project design was carried out with the aim of providing a solution to the under voltage situation faced by residents of high density areas of urban cities by designing and constructing an effective and comparative cheap Voltage Regulator in order to boost up to the normal requirements for house hold and industrial appliances.

An Automatic voltage Regulator consists of three main sections namely the Power supply, rectification, regulation and stabilization sections

A low d.c 9V power supply is obtained through voltage transformation, which is achieved with the use of a transformer.

The second stage consists of the rectifying and filtering circuit, which changes A.C to D.C pulsating full wave.

The third stage consists of the current, voltage and amplifying circuit, which filters out pulsating full wave D.C to make more pure D.C. The stage also provides a constant output voltage.

TABLE OF CONTENTS

CHAPTER ONE

INTRODUCTION

This chapter gives a detailed introduction about the project. It also states the aims and objectives including the methodology of the project.

1.1 Need For Voltage Regulation.

Heat and light energy, being used as essential resources comes out of electrical energy. This energy is used in many areas such as in homes, factories and offices.

The correct operation of most equipments demands that the supply voltage is kept constant, or at least within fairly acceptable limits. The Institute of Electrical Engineers(I.E.E) regulations stipulates that for safe utilisation of electrical energy, the fluctuation in nominal supply voltage at any time must not exceed ±6% [1]

However in Nigeria today, due to many reasons, it is very common to find our national supply voltage either falling below 150V or rising above 280V hence representing a voltage fluctuation of 28%.

This level of fluctuation is highly dangerous to many voltage sensitive devices that tolerate a little degree of supply fluctuation for effective functioning.

In order to avert the damage of appliances, we need an Automatic Voltage Regulator (A.V.R).

The device is a small piece of electrical equipment designed to maintain a steady output at prescribed nominal voltage provided the fluctuation at the input falls within design specification of 220V ±20%.In this case(220V for Nigeria).

Voltage regulators come in various shapes and sizes ranging from small 300VA to 10KVA and above for both domestic and industrial use. To get the best out of a Voltage regulator, one has to choose the capacity that best suite the load intended to supply. It is advisable that the Voltage regulator rating be slightly higher than the equipment it is intended to supply.

The importance of a stable or steady power supply cannot be over emphasised in our homes and industries. The Voltage regulator is a shortcut to stable power supply. The over and under voltage protection are afforded by suitable relays which are energised or de-energised by suitable biased transistors as the case arises. The low voltage protection is achieved by a manually controlled rotary switch to increase the output voltage when the supply voltage is low.

How this project is achieved shall be discussed in subsequent chapters.

1.2 Aims And Objectives Of The Project.

The aim of this project is to design, construct and test a 1500 Watts Voltage regulator with input voltage range of between 80V to 280V with a steady output of 220V.This device should be capable of

(i) Providing a device or an appliance that could withstand and respond fast to tripping off of the system in case of over voltage condition and then step it down or up to normal voltage.

(ii) Providing solution to under voltage situations experienced by residents of high density areas of urban cities to boost it up to normal requirements.

1.3 Methodology.

The principle employed in the implementation of the design, construction and testing of a Voltage Regulator is the principle of electromagnetic induction. This principle explains the reaction of a transformer to voltage input through its input or primary winding; an induced voltage is derived at the secondary winding of the transformer.

For the purpose of this project, an Auto-transformer is used. An auto-transformer has multiple windings. The secondary windings are connected to some relays which selects the output voltage. The switching and selection action of the relays are determined by some transistors, comparators, resistors etc.

1.4 Scope of the Project.

This project is constructed to operate when the input voltage is in the range of 120V to 280V.When the input voltage drops and falls in the range of 80V to 120V, the device can be regulated with the aid of rotary switch and the output voltage can be increased to 220V.

The output that is produced by this device will suit all electronic appliances that are used with it.

The wattage of this device is exactly what is being mentioned which implies 1500Watts and hence total connected load to this device should not exceed 1200Watts for optimum performance.

1.5 Constraints to Achievable Performance.

The following were the problems encountered during the course of construction of this project.

(i) Scarcity of some component

(ii) Transformer not up to the wattage required.

(iii) Some components weren't working properly.

(iv) Not being able to find the proper I.C required.

(v) Some components got damaged during the assembling on board of the construction work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Historical Background.

Electricity was first discovered by Michael Faraday (1791-1867).Economics of scale and relative continuity all combined to promote the growth of Central Station Electric Power Service, which was the brain child of Thomas Edison. [2]

Voltage drop and the resistance losses on the low voltage d.c distribution circuits were the first limiting factors encountered. The problem of voltage regulation became more pronounced when the generating stations were so distanced to the final consumers.

However, as a solution to these problems, a remarkable landmark was made by George Westinghouse (in 1895) by introducing the A.C transformers. [2]

One of the major components of a power system like transformers, generators, transmission lines etc is the voltage regulators. It came into use soon after Thomas Edison's break through (late 19th century). Its usefulness was as a result of variation in transmission voltage. The earliest attempt at obtaining an A.V.R employed a motorised system controlled by a control circuit to change the taps on the secondary windings of an 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 short comings is that it is bulky, costly and the mechanical parts easily wear away resulting to improper contacts between the changer and the taps of the transformer.

Another approach was the resonant-circuit voltage regulator which involves few components, inductance of a transformer coupled with a parallel inductance and capacitance resonant. When the line voltage drops below the rated value, 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 rated value, the parallel circuit combination becomes less capacitive and the input voltage falls below the line value. The disadvantage of this approach is that it is bulky, heavy and frequency dependent.

The present technológical dispensation has changed voltage stabilisation techniques greatly. They came up with another approach known as regulated d.c inversion approach. This uses the principle of switch mode power supplies. The regulated d.c output from the power supply is inverted using push pull inversion and stepped up to the required constant a.c output voltage using a transformer. The output of the system is a square wave a.c voltage which could be filtered to obtain a pure sinusoidal wave. This method produces good regulation. The system is usually not heavy but very expensive and complex than other systems.

Phase controlled A.V.R is one of the attempt towards realising a good A.V.R. In this system, the load is connected in series with the voltage controlling device which is usually a silicon controlled rectifier (S.C.R) a thyristor. Voltage control is achieved by triggering the S.C.R at a phase angle determined by the control circuit in such a way that the voltage across the load connected to the output terminal is regulated to the desired value. This method is very fast in response to voltage fluctuations at the input. The system is not heavy and is not expensive however the output wave form is distorted. [3]

The last of the numerous methods to be considered is that of voltage regulation by transistors known as transistorised A.V.R. This approach is an improvement on motorised A.V.R method. The pure mechanical tap change was replaced by miniature electromechanical relays. The major component of this approach is the auto-transformer in which the turn ratio (referred to as taps) can be varied to give a desired regulation. The number of the taps on the transformer dictates the number of relays to be used. The position of the relay contact is dictated by the control circuit which determines whether the low supply voltage is to be stepped up the rated value or the high supply voltage is to be stepped down to the rated value at the output. The beauty of this approach is that it is relatively cheaper, light, reduced size, good response and regulations ability. The above reasons give rise to the use of operational amplifiers as comparators to increase sensitivity. Most A.V.R in the market today are transistorised A.V.R.[3]

CHAPTER THREE

DESIGN AND IMPLEMENTATION.

3.1 Circuit Design.

The main principle of operation of this work follows the combination of the block diagram shown in the figure below which consists of many stages such as power stage, rectifier stage, voltage regulation stage, comparator stage, switching stage and output stage.

The auto-transformer is the most important part of this design. It has different tapings from the windings, leading to different desired voltage output, since the transformer itself cannot do the changing over to the required voltage at a particular time, hence the need for a device that would do the switching.

In the event of advancement in the level of technology, the use of electronic circuit became useful. The electronic circuit aids the switching by the action of relays. In order to make a relay work, it has to be energised. For the purpose of this project, transistors are used to energise the relays. Before the transistor stage, there has to be a means of comparing a standard or reference voltage with the input voltage. The reference voltage is achieved by the use of a Zener Diode while an Operational Amplifier is used for comparing the reference voltage with the input voltage. We also need a d.c voltage supply to power the electronic circuit since the mains voltage supply is an alternating current (a.c).

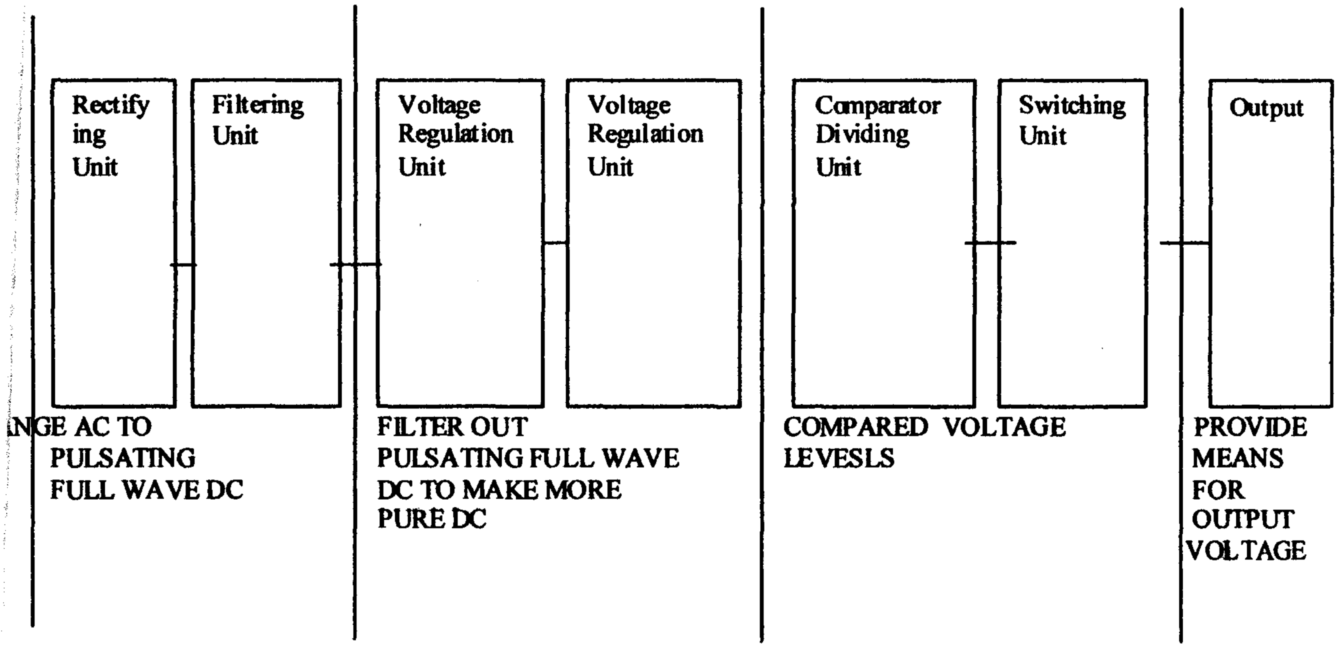


Fig 3.1 Block Diagram of a Voltage Regulator.

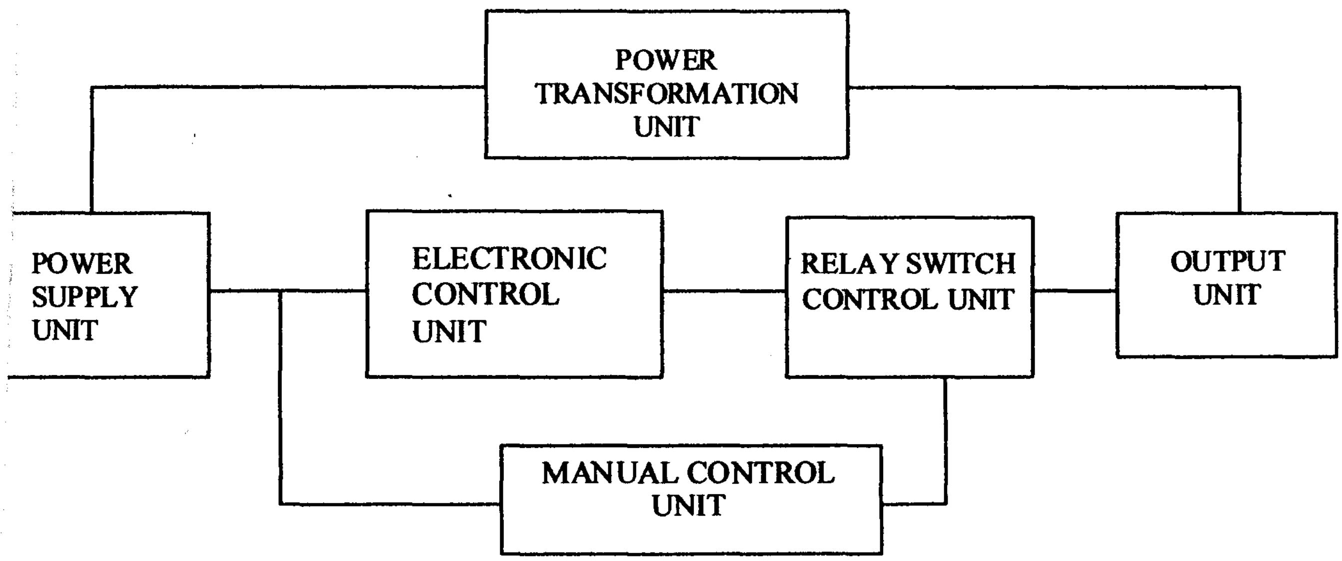


Fig 3.2 Block diagram of a voltage regulator showing the manually controlled rotary switch.

3.2 Selection of Components.

3.2.1 Transformer

This is an active component that is used for transfer of electric charge from one or more circuit to one or more other circuit without change in frequency usually with changed value of voltage and current. The purpose of a transformer is to change an alternating current from one value to another. To increase the voltage level of an a.c supply, we use a step up transformer also to reduce the value of an a.c supply, we use a step down transformer.

3.2.1.1 Principle of Operation of a Transformer.

The principle employed in the operation of a transformer is the principle of electromagnetic induction which depends on changing voltage across the primary winding causing a changing flux in the core which then induces a changing e.m.f in the secondary winding.[4].

3.2.2 Transistors

It is an active semiconductor device. It has three electrodes namely base, emitter and collector. It can amplify, oscillate and be used for switching and other purposes. Transistors are of two types i.e the NPN and PNP. For the purpose of this project, a D400 transistor is used.

3.2.3 Integrated Circuit

This is an operational amplifier; it is a general purpose electronics device i.e. a modular multi-stage amplifier. It has the following characteristics:

(i) Very high voltage gain.

(ii) Infinite input impedance.

(iii) Zero output impedance.

(iv) Zero output voltage.

(v) Wide bandwidth with high degree of stability against temperature and any other environmental changes.[4]

The integrated circuit can be used as an integrator, differentiator, perfect buffer, voltage regulator or comparators. In this project it is used as a comparator. The LM324 comparator is used in this project.

The LM 324 is a quad comparator designed to work independently. The output of each comparator turns high when the inverting(+) inputs goes higher than the non-inverting(-) input , which in turn switches a selected relay to select a voltage approximately 220V as output at any given input voltage ranging from 80V to 280V.

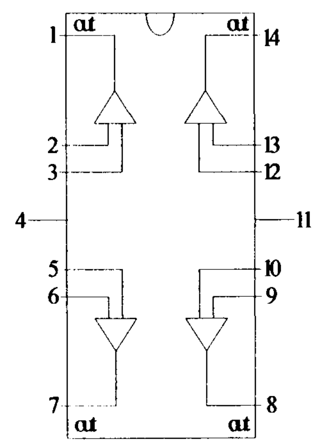


Fig 3.3 Internal Connection of LM324 I.C (Pin out).

Pin 1 = Output 1`

Pin 2 = Non inverting input 1

Pin 3 = Inverting input 1

Pin 4 = Positive power supply

Pin 5 = Inverting input 2

Pin 6 = Non inverting input 2

Pin 7 = Output 2

Pin 8 = Output 3

Pin 9 = Non inverting input 3

Pin 10 = Inverting input 3

Pin 11= Negative power supply

Pin 12 = Inverting input 4

Pin 13 = Non inverting input 4

Pin 14 = Output 4 [5].

3.2.4 Zener Diode

The Zener diode is a special kind of diode which is used to provide a standard or reference voltage. For this reason, it is used to stabilise the d.c voltage so that the circuit is provided with a stable value of d.c voltage. It can also be used as a discrete device in a circuit or it may be one of the components in a special integrated circuit called a voltage regulator. In this project it keeps the terminal voltage of the supply constant even when both load and input varies.

The zener diode is not allowed to operate in the forward bias direction where the current increases sharply as a rectifier diode; instead it is designed to operate in the reverse breakdown region where a rectifier would normally suffer a permanent damage.[4]

3.2.5 Diode.

The diode is a one way device offering low resistance when forward biased and behaves almost as an insulator when reversed biased. Hence it is used as rectifier.[6]

3.2.6 Electrolytic Capacitor

This is a passive component, the type of which consists of two plates or electrodes separated by an electrolyte. A dielectric film usually a thin layer or gas is formed on the surface of one electrode. It is used to store electric charge in the circuit. The capacitance of a capacitor is measured in Farad (F). Smaller units are Micro Farad (μF).[6]

3.2.7 Carbon Resistor

Resistor is a passive component; it is used to resist the flow of electric current. The type of resistor used in this project is the carbon resistor. The resistance of a resistor is measured in ohms (Ω).[6]

3.2.8 Variable Resistor.

This is a resistor with suitable mechanical feature that enables the variations in its resistance from zero to maximum rated value. For the purpose of this project, I used 100K variable resistor. The process of turning the variable resistor left or right is called presetting and can be used to preset the voltage range within which the stabiliser works.[6]

3.2.9 Relays

A relay is an electromechanical switch by design. A movable spring armature is mounted above the core of an electromagnet. When the core is energised, the armature is altered and the contact points open or close by responding to a change in some physical quantities such as current, voltage frequency, light sensitivity, temperature, pressure e.t.c. A relay in a normally closed position opens when activated and a normally open relay closes when energised. When the energising potential is removed, the point may be set several contacts for double pole and more complicated switching operations. Relays can be categorised as under current or over voltage relay.

An over current and over voltage relay operates when the actuating quantity (current or voltage) exceeds its operating or pick up values. An under current and under voltage relay operates when the actuating quantity (current or voltage) falls below the reset or drop out value.[7]

3.2.10 Fuse

Fuse is an essential component in every electronic equipment. A fuse is used to protect electronic equipment since they are made to blow when the current rating of the system is exceeded. [6]

3.2.11 Buzzer

This is used as an over voltage alarm in this project. It is a small horn incorporated in the design to sound when the supply voltage is higher than the selected input voltage range in the manual operation.

3.3.1 Low d.c Supply

The power supply is used to convert the 220V rms Mains supply into a low voltage 9V d.c supply that is needed to power the electronics control circuit. The mains transformer is used to reduce the mains a.c voltage (220V) to 9V.

3.3.2 Rectification.

The term rectification is defined as the process of producing a d.c voltage from a.c mains supply. This project employs the bridge rectification which uses four diodes each of which is the IN4007.

Before choosing any diode for a particular rectifying circuit, they must;

(i) It must pass the largest current that is likely to be needed when forward biased i.e greater d.c output current.

(ii) Largest voltage when forward biased.

(iii) Maximum reverse voltage should be far greater than a.c output voltage.[4]

3.3.3 Filter Network

We need a constant output voltage with no ripple at the rectifier output. Therefore the main function of a filter circuit is to minimise the ripple content in the rectifier output. This is necessary in order to prevent the break down of electronic component from fluctuation.[6]

Smoothing for conversion of raw d.c from output of rectifying circuit to fine d.c is then necessary. Smoothing is achieved by connecting a large value capacitor (25V 1000 µf) across with load as shown in fig 3.4 . The capacitor acts like a large electrical reservoir.

3.3.4 Regulation.

Since the operational amplifier LM324 in the switching control circuit are used as comparators, therefore one of the inputs must be constant. This constant voltage will serve as a reference voltage. This is achieved by the use of a 9V zener diode regulator. It is forward biased connected in series with a resistor. In this project, a standard 9V regulator I.C is used i.e the LM7809.

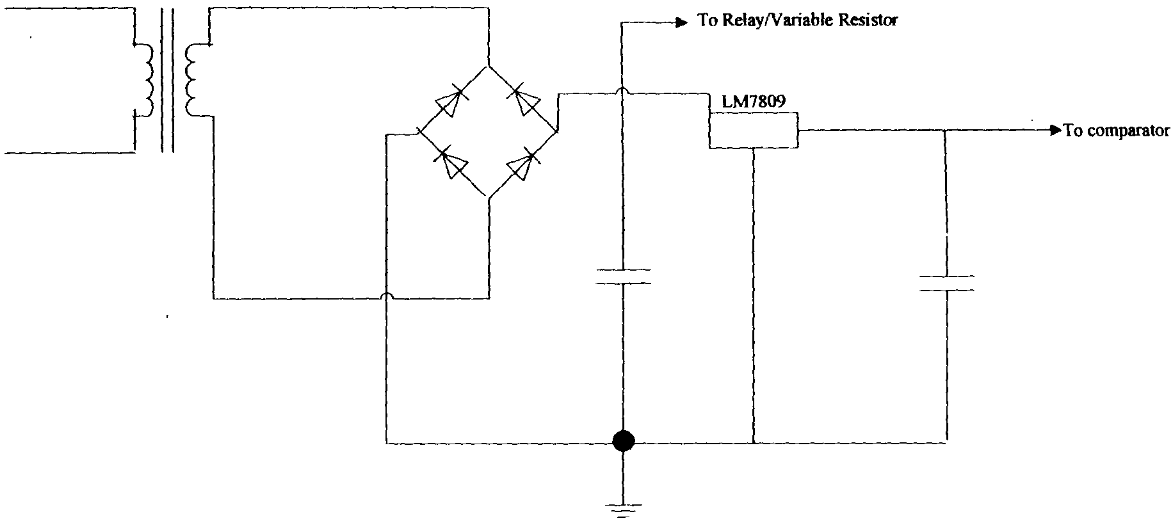


Fig 3.4 diagram showing low voltage d.c supply, rectifier network and voltage regulator.

3.3.5 Comparator Network

This is the OP-AMP, LM 324 IC configuration which is a quad comparator. This chip is designed for a very fast response. It usually has an open collector output with grounded emitter and it is suitably used in analogue to digital conversion.

The stew rate of a comparator is very important because it is used to determine the switching time or propagation delay versus input over drive.

A comparator, as the name implies, compares two voltage levels together at the same time.

It is used in this project because of the following advantages:

(i) It contains four OP-AMPS, which can be used for many purposes such as in comparison i.e as a comparator.

(ii) It has fast stew rate giving a relatively short switching time.

(iii) It has supply range of between 3V to 35V which is suitable for this project.[8]

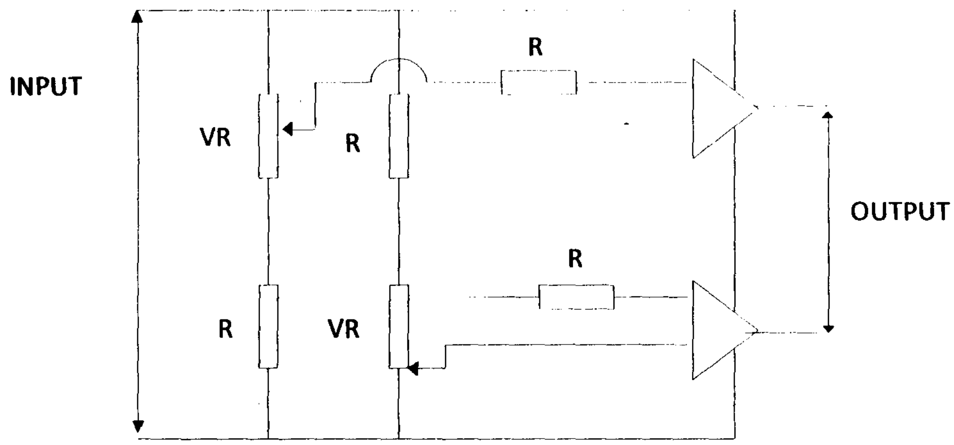


Fig 3.5 Comparator circuit.

3.3.6 The Switching Unit

(i) The automatic switching unit.

The purpose of the switching circuit is to effect appropriate switching on the compared voltage of the OP-AMP at the comparator stage.

This switching is achieved with the aid of the D400 transistor and the relays. The transistor is suitable for use as a switch because it can control the flow of large amount of power while loosing only small amount of this power to internal dissipation. The signal at the base resistor determines whether the switch is ON or OFF through effective response to the fluctuating main voltage and switching to desired voltages. The switching circuit helps us to achieve the aim of this project.

(ii) The manual switching unit.

Manual switching is achieved with the aid of a rotary switch. The rotary switch is connected directly to the tapping of the auto-transformer via the relays.

When the input supply is low (below 100V), the automatic switching unit goes off. In order to maximise the use of this project, we use the Main power switch to switch the

A.V.R to manual mode where the rotary switch is used to select a higher output value. When the input supply goes higher, an over voltage alarm sounds calling your attention to select a lower output so as not to damage the appliance connected to it.

Below is the circuit diagram of the automatic switching unit. The manual switching is shown in details in the complete circuit diagram.

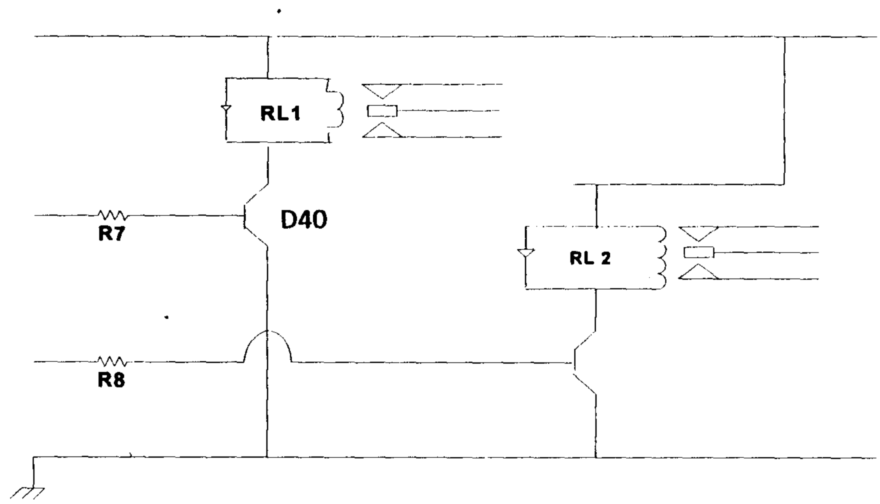
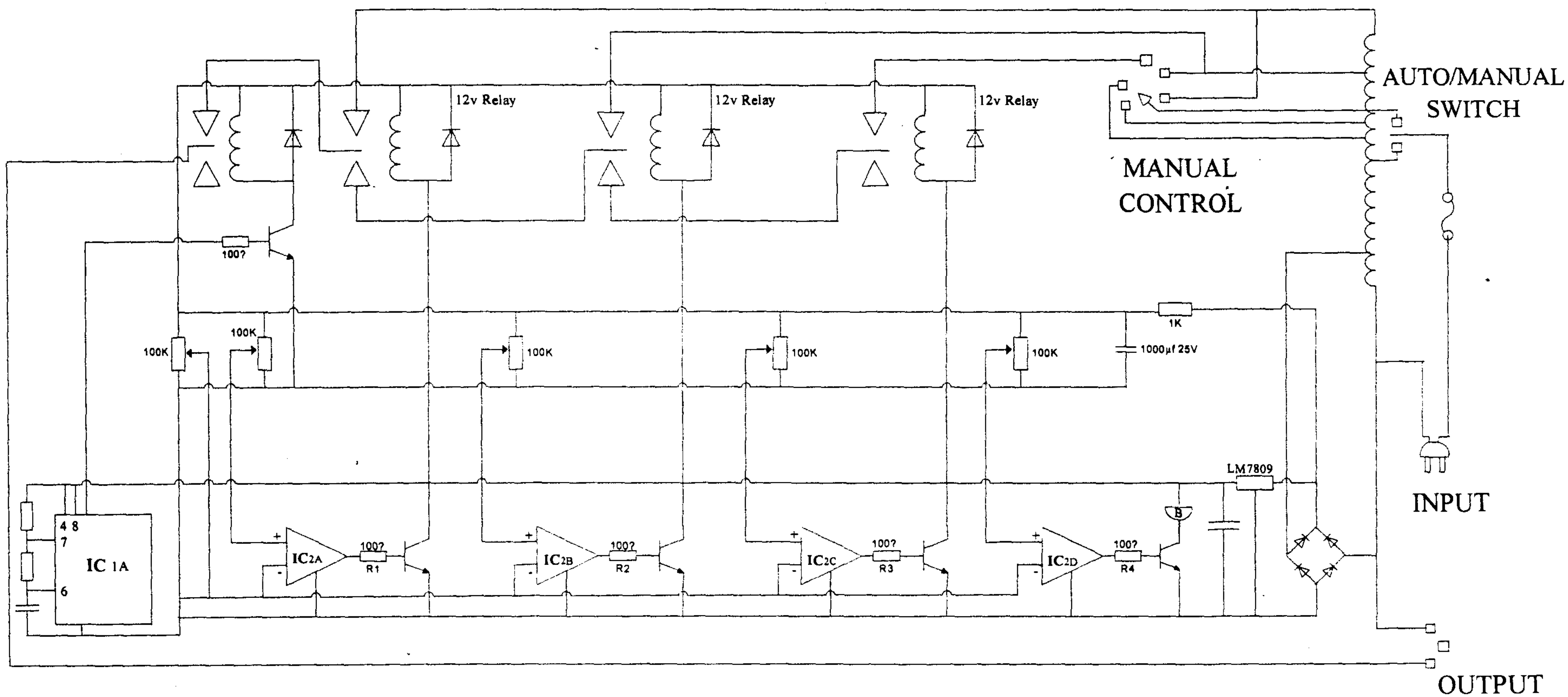


Fig 3.6 circuit diagram of the switching Circuit

COMPLETE CIRCUIT DIAGRAM



3.3.7 Fitting the Unit together.

The complete circuit diagram is achieved by joining the unit together. From the diagram it is seen that an auto-transformer was connected to the electronic control unit. The auto-transformer is a static electrical device consisting of two or more electrical circuits interlinked by a common magnetic circuit, for the purpose of electromagnetically transforming a.c energy from circuit or load to another usually with changed values either higher or lower voltage at the same frequency. A transformer, usually consist of two or more coils of insulated copper wire wound around a laminated iron core.

In operation, a.c supply is connected to the first set of turns which hereby becomes the primary winding automatically. The load is connected to the other set of turns referred to as the secondary windings.

3.40 Calculations

(i) Auto-transformer Calculation.

For the purpose of this design, the following are considered;

The volts per turn (v/t), tapings, windings, current in the windings and size of the winding conductor.

The requirements for this transformer design are;

(1) It should be able to handle power up to 1500VA

(2) The output of operation should be 220V ± 6V.

(3) The input voltage range may vary between 100V to 280V.

In addition to the relevant data, the following assumptions were also made;

(i) The line frequency of Nigeria is 50Hz

(ii) Subjective test had shown that a 100% efficiency is not realistic in practice, hence efficiency is assumed to be 90%.

(iii) For mild steel, the flux density varies from 1.0 – 1.5.

(iv) The current density for power transformer and space factor is 257Acm and 0.5 respectively.

(v) The secondary winding should have six tapings at 180V, 210V, 220V, 240V, 260V and 280V. The tapping at 210V, 220V and 240V are for automatic regulation while tapings at 180V, 220V, 240V, 260V and 280V is for the manual regulation.

Let

Vp = primary induced e.m.f

Vs = secondary induced e.m.f

Np = Number of turns in primary windings.

Ns = Number of turns in secondary windings.

V/T = Volts per turn ratio.

Ip = Current in primary winding.

Is = Current in secondary winding.

Efficiency = 90% = 0.9

Rating = 1500VA

Frequency = 50Hz

Vp = 220V

Vs = 180V, 210V, 220V, 240V, 260V, 280V.

The number of turns in each of the windings;

(i) $\frac{180V}{0.25}$=720 turns.

(ii) $\frac{210V}{0.25} = 840\ turns.$

(iii) $\frac{220V}{0.25} = 880\ turns$

(iv) $\frac{240V}{0.25} = 960\ turns.$

(v) $\frac{260V}{0.25} = 1040\ turns.$

(vi) $\frac{280V}{0.25}$ = 1120 turns.

CHAPTER FOUR

TESTING

4.10 Testing of Components.

Before the circuit containing an electronic component is to be constructed at all, it is necessary to test all the components making up the circuit to see how fit they are. Each of the constituting components of the circuit was tested with the aid of a multi meter set to the required specification as the case may be.

4.1.1 Transistors.

The NPN transistor was used for this project. The ohmmeter was used to test the transistor. The positive probe was placed on the base and the negative probe on the emitter or the collector and the meter reads a very high resistance. If the probes are interchanged, the meter then reads a very low resistance.

When the positive or the negative probes are placed on the collector and emitter respectively, even when the probes are interchanged, the meter reads high value in both cases.

4.1.2 Capacitors.

An ohmmeter was used to test the capacitor. The positive probe is placed on the positive terminal of the capacitor and the negative probe to the negative terminal of the capacitor. The meter reads high resistance value and gradually returns. This indicates charging and discharging of the capacitor which implies the capacitor is okay for use.

4.1.3 Diode.

The ohmmeter was used to test for the correct operation of the diode. The positive probe was connected to the Anode and the negative probe to the cathode. The pointer deflects. When the probes were reversed, there was no deflection indicating the diode is okay for use.

4.1.4 Resistors.

This can be tested with an ohmmeter. When either of the probes is placed on any of the resistors terminal, there was always deflection by the pointer. This indicates the resistor is working well.

4.1.5 Buzzer.

The buzzer was tested with the aid of a multi meter. The probes of the meter were connected to any of the two terminals of the buzzer. A sound was heard and a deflection was noticed on the meter.

4.20 Results.

After the whole unit has been assembled, it was tested using Television, Radio, Video and Oscilloscope. When each was connected to the output voltage of the A.V.R, all was functioning. When measured with a multi meter, the output voltage read 226V a.c The multi meter was left temporarily connected to the output of the A.V.R for several hours in order to monitor the response of the unit to fluctuation. It was noticed that at one instance of fluctuation, the relays contacts were opening and closing and during this period the output of 215V to 227V was maintained.

4.2.1 Discussion of Results.

The A.V.R was tested by connecting various home appliances to its output and all the appliances were found to be performing normal operation. The temperature of the auto-transformer was normal when touched.

The Institute of Electrical Engineers regulation for the electrical equipments of building stipulates that for safe utilization of Electrical energy, the fluctuation must not exceed ±6%. In Nigeria, the nominal domestic supply phase voltage is known to be 220V. Interpreting the above regulation for the above, means that the supply voltage must always be in the range of 202V – 233.2V. From this regulation, it can be deduced that the A.V.R is safe to be applied to voltage sensitive domestic devices and industrial electronics.

4.30 Trouble Shooting.

The Voltage Regulator is designed to withstand rugged handling and as such the chances of it developing a fault is minimum.

Below are some of the faults and corrections that the operator of this project may come across.

(i) If the V.R fails to power ON. The user should check the power cord for firm contact with the mains socket outlet or check the fuse.

(ii) If the V.R's output voltage is not sufficient to power the connected appliance. The user should switch the unit to Manual and adjust the knob until the desired response is achieved.

CHAPTER FIVE

5.0 CONCLUSION.

The design and construction of this project work (Voltage regulator) was not an easy task in anyway. It calls for precision and carefulness especially in the design and construction of the auto-transformer. The tapping of the transformer which was selected were wound properly and well identified with an identification tag on each tapping to avoid confusion. These tapings are connected to the terminals of the relays which functions as a switch maintaining a constant output voltage of approximately 220V.

5.10 Recommendation.

To improve the performance of the system, depending on desire and design. The control circuit could be wired in a cascade or stages employing more relays in order to obtain a more stable output.

The power rating of the system could be improved by replacing the transformer with a bigger one better still using a Toroid transformer.

Considering the economic situation of the country, I will recommend that more of this Voltage Regulator is to be constructed locally for usage not only because of its advantage to the society.

The school authority can set up a local production unit that will be manufacturing the device for local and foreign markets. This will not only provide jobs but also serve as a means of generating income for the institution.

5.20 Problems Encountered.

Because the transformer rating determines the rating of the Voltage regulator , care must be taken when winding the transformer to avoid under-rating or burning of the transformer coils when on load.

The building of the control circuit of the Voltage regulator is where I encountered most of the problems I went through while designing this project. Before any voltage regulator can function properly, there must be a good working control unit and this is achieved by selecting the right value of components while building the control. The issue of selecting appropriate value of components calls for calculation and extra cost.

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Page 151

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Page 67 -E. HUGES.

5 SEMICONDUCTOR DEVICES - HENRY ZANGA.

AND CIRCUITS

Page 184

6 BASIC ELECTRONICS - MALCON PLANT.

Page 325-334