DESIGN, CONSTRUCTION AND TESTING OF AUTOMATIC VOLTAGE REGULATOR

BY

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IN THE

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING SCHOOL OF ENGINEERING TECHNOLOGY, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA.

MARCH, 2000

DECLARATION

I hereby declare that this project was carried out by Inaolaji Idayat Olayinka of Electrical and Computer Engineering department of the Federal University of Technology, Minna under the supervision of Engineer Ahmed Shehu.

Signature of Student

Date

CERTIFICATION

This is to certify that this project titled " DESIGN, CONSTRUCTION AND TESTING OF AUTOMATIC VOLTAGE REGULATOR " was carried out by INAOLAJI IDAYAT OLAYINKA under the supervision of Eng. Ahmed Shehu and submitted to Electrical and Computer Engineering Department, Federal University of Technology, Minna in partial fulfillment of the requirements for the award of Bachelor of Engineering (B. ENG.) degree in Electrical and Computer Engineering.

Engr. Ahmed Shehu
Project supervisor

4/4/2000
Sign & Date

Dr. Y.A. Adediran
Head of Department

Sign & Date

Dr. J.O Oni
External Examiner

6/4
Sign & Date

DEDICATION

I dedicate this project to the Almighty Allah from whom all blessings and opportunities abound. To my parents Mr. and Mrs. T. Inaolaji.

ACKNOWLEDGEMENT

First of all, I wound like to thank Almighty Allah for giving me life and energy to carry out the project construction and other things successfully.

I sincerely acknowledge the solid support of all kinds rendered to me by my beloved and devoted mother Mrs. Muslimat Adepele Inaolaji, who stood firmly on her feet, denying herslef a lot of sleep and pleasure to see that I achieved this good and may Almighty Allah extend her life to reap what she has sown (Amin).

I will also seize this opportunity to express my profound gratitude to my father Alhaji T. Inaolaji and my step mother Mrs. Sidikat Inaolaji who contributed tremendously towards this achievement.

A very special acknowledgement goes to my brothers and sisters; Oladele, Akeem, Tawa, Kazim, Sakirat, Ganiat and Monsuru all of Inaolaji family May Almighty Allah bless this household.

This acknowledgement will not be complete without thanking my supervisor Engineer Ahmed Shehu and my H.O.D Dr. Y. Adediran, you been too good to us as students thank you for giving me a start on this project. This one goes to my brother in Minna Engineer S. Lawal May God continue to bless you and your household (business inclusive).

ABSTRACT

The design and construction of a 0.6KVA under- voltage and over-voltage regulator unit is what this write-up is all about.

The use of zener diode in obtaining a reference voltage which is being compared with the sensed voltage (variable in – coming voltage) by the operational amplifiers working as comparators is of importance.

The difference in voltage level is there after used to switch ON transistors as applicable which causes the magnetic relays to be energized to making contact on the level approximately delivering 220V on the auto-transformer as the normalized or regulated output voltage of the model (A.V.R)

When tested with voltage– sentive electronic equipment, the aim of the project was confirmed realised as a steady voltage was obtained during both normalised and abnormal (under and over) voltage conditions.

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CHAPTER ONE

1.1 GENERAL INTRODUCTION

INTRODUCTION

Voltage drops are experienced at points of utilization due to the conductors having resistance over a distance. This drop varies with time and load changes whenever there is a supply from the generating station.

Most electronics and electrical appliances usually whenever there is fluctuation in the supply voltage, voltage regulators are generally used to protect these appliances. One of the major factors that contribute to the damage of equipment's in this country is the instability or lack of good regulation of our electrical power supply. There are instances during which the voltage drops to as low as 160v and other times at which it rises to as high as 300v.

Neither the domestic nor the industrial equipment's have been spared by this problem of poor regulation but the most affected being the modern equipment's which are designed with very sensitive integrated circuits and as such are very sensitive to variation in power supply. These includes computers, CD players, Printers, Scanners and other office equipment's.

To arrest this situation, there is the necessary for voltage regulator which would automatically respond to variation in supply voltage.

The regulating circuit is capable of taking in any voltage value between 160v and 300v and produce at the output constant voltage of 220v.

The automatic voltage regulator is intended to give a regulated output voltage of 220v within a variation of $\pm$ 10% of the input supply voltage. It will do this by sensing the variation in the mains supply and responding to the variation by changing the number of turns to which the mains is applied such that the output of the auto transformer will be 220v. The automatic voltage regulator takes care of these voltage variations and supply a steady voltage of electrical appliances and equipment, irrespective of the supply or load variations.

These voltage regulators are used only for single phase domestic and office loads and appliances like televisions, radio freezers, fridges, computers, electrical typewriters, fax moderns etc.

The objective of this project is to achieve the construction of an automatic voltage regulator with a high power output so that high voltage appliances can use as that which supplies constant required voltage for their use.

There are two types of voltage regulators

(a) Continuous – control or dynamic type

(b) Discontinuous – control or static type

The discontinous – control does not affect stabilization of voltage as long as the voltage is within certain limits. It is when the voltage goes outside these limits that correction of voltage is carried out. This type is commonly used for large loads. For the Minna area, it has been observed that the main supply ranges between 170v and 209v around 7pm, in the evening it ranges between 170 and 180v but improves to about 190v to 210v in the night

This has prompted many consumers of electricity not to use their electrical equipment for fear of breakdown from the incessant voltage variations. Investigation have also revealed that no place recorded abnormally high voltages, abnormality in voltage supplied from NEPA can be experienced only during switching in the NEPA sub-stations and last for a few seconds or during faults.

Furthermore, booster voltage regulators with high voltage protection are commonly used and economically suited for the operation of electrical equipment in most towns and cities in Nigeria.

1.2 LITERATURE SURVEY

It is no doubt that Automatic Voltage Regulator have been in existence before now but nevertheless, improvements on existing ones bring about enhancement by eliminating problems faced by the design.

Early Automatic Voltage Regulator are the rheostat voltage regulators which can be classified into direct and indirect type (acting). In the direct acting types, the voltage sensitive element of the regulator (magnet / torque motor) controls the rheostat through a direct mechanical connection. Special type of rheostat must be used to obtain a small amount of energy to vary the resistance from one extreme to the other. In the indirect type, the voltage sensitive element operates contacts which in turn controls a motor to drive the rheostat. This action initiates a correct small or gradual change of voltage but the motion of the rheostat is too slow for rapid correction of sudden large changes in voltage.

The variable auto-transformer is one of the electromechanical variable regulator. An input is applied to the transformer and a control arm termed the wipe picks up the output voltage of the auto-transformer and feeds it to the linear boost transformer in series with the A.C line.

The boost transformer either increases or decreases the line voltage depending on the position of the wipe arm. The control arm is moved by a motor wound with two field coils for bi-directional movement. A voltage sensitive bridge is used to control this motor hence, the direction of motion of the wiper arm.

The disadvantages are slow response to line voltage changes, limited regulation, accuracy and maintenance difficulty caused by the moving parts.

The single-phase step type (Tap changing) is another electromechanical voltage regulator. Its commercial tap changing transformer is a highly move complete equipment equipped with spark quenching device, the exciting winding is connected across the mains (phase) and the series winding in the line conductor of the same phase control is incorporated to effect the automatic movement of the control arm. The control arm is arranged to move in the up position in the event of reduction in the input voltage to raise the output voltage to the required level. The control arm moves towards the down position in the event of increase in the input voltage to reduce the output voltage at the centre position. The regulation is normal. Its disadvantages are poor regulation and maintenance problem due to moving parts.

The constant voltage regulator is the last electromechanical voltage regulator that will be mentioned. The regulating circuit is due to the variation in the amount of voltage drop across the inductor which either boosts or bucks the main line change. The circuit consists of a saturable core reactor (inductor) and a capacitor in addition with a linear transformer. Since the inductor is saturable, the equivalent inductance of this component is variable depending upon the voltage drop across it. This result in bucking or boosting of the line voltage due to voltage drop across it. Its own disadvantages are poor regulation and changes in the supply frequency. But the emergence of the integrated circuit from discovery of transistors in 1948 has reduced a great deal of sizes of most voltage regulators for portability and improved technology in their mode of operation. This project, construction, designing and testing of an automatic voltage regulator has recognized the evolution in this noble invention and has stuck to the current trend.

1.3 PROJECT OBJECTIVE / MOTIVATION

As Engineer in training with all the rediments needed for solving some physical problem confronting the entire populace in the field electronics and computer, I am motivated in doing this Automatic voltage regulator because of the rampant fluctuation in the voltage supply of this country from say 160v to 300v which adversely affects domestic and the industrial equipment's.

The most affected of them all are the modern equipment with very sensitive integrated circuit whose responsiveness to voltage variation is freat.

The Automatic voltage regulator presented in this project if well built and constructed on large scale will go a long way in curbing and eradicating voltage drop what it does is to regulate the voltage between ± 5 to the needed voltage.

I strongly believe it will go a long way eradicating untimely destruction and damage caused by voltage fluctuation most especially in the country of ours Nigeria.

1.4 PROJECT LAYOUT

The Automatic voltage regulator is a very important instrument that is useful in protecting both electrical and electronic appliances. This thesis outlines the design procedures and techniques involved in the automatic voltage regulator.

Chapter one explains the general introduction, it gives first hand information about the project. The chapter introduces the automatic voltage regulator, gives the literature survey and the objectives which the project is designed to achieve.

Chapter two discusses about the steps involved in the system design. It gives information about the operating principle of the Automatic voltage regulator.

Chapter three covers the details involved in the construction and testing of the project, it explains how the various components were soldered on the veroboard and how the device was tested.

Finally, chapter four talks about the discussion of results, conclusions reached and recommendations.

CHAPTER TWO

2.1 PRINCIPLE OF OPERATION

The operating principle of Automatic voltage regulator is based on the maximum power transfer theorem, i.e. a particular value of the input voltage is allowed at the output. The AVR is intended to give a regulated output voltage of 220v $\pm 3\%$ within a variation of $\pm 10\%$ of the mains supply. It does this by sensing the variations in the mains supply and responding to the variations by adjusting the number of turns to which the mains is applied across an auto-transformer such that the output will be required 220v.

The Automatic voltage Regulator consists of five stages, which are the power supply, sensing stage, comparator stage, switching stage and the transformation stage. The block diagram of the AVR showing the stages is shown in Fig 2.1

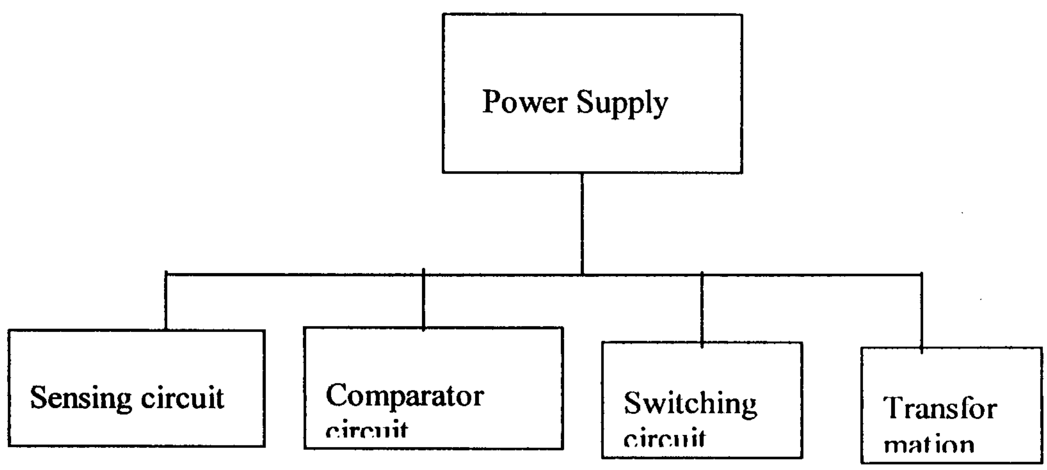


Fig 2.1 Block diagram of Automatic voltage regulator

The power supply circuit is used in converting the alternating 220v mains supply voltage to a undirectional voltage that will be required by the other circuits of the regulator. The sensing circuit is also designed to sense the changes in the mains voltage, its output is sent to the comparator circuit where it is compared against a reference voltage. The output of the comparator circuit is used to control the switching circuit. The circuit is essentially a transistor circuit used in driving a relay.

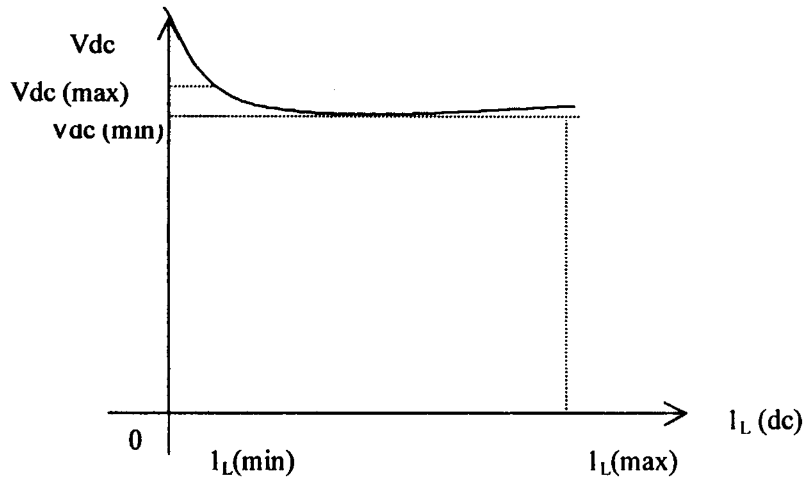
Finally, the transformation stage transforms output of the switching circuit to the desired regulated voltage of 220v.

2.2 REGULATION

The change in the load voltage with changes with in load current is called the regulation. It is usually defined as a percentage i.e.

$$\% \text{ regulation } = \frac{V_{dc(\max)} - V_{dc(\min)}}{V_{dc(\max)}} x100\%$$

The regulation curve shows that $V_{dc\ (max)}$ occurs at $I_L = 0$ and $V_{dc(min)}$ occurs at the maximum value Of I_L. ideally V_{dc} should not vary with changing load current. This suggests a horizontal straight line of value $V_{dc\ (max)}$ on the graph below.



In practical circuit applications the finite output resistance of the power supply could cause problem since signal voltages could appear across the power supply and find their way to other signal circuits causing possible oscillations due to feed back. At high signal frequencies this is not a problem since the shunt capacitance of the rectifier circuit appears as a short-circuit at those frequencies.

2.2.1 VOLTAGE REGULATOR

It is desirable for a power output voltage to remain constant regardless of load current variations. Factors such as variations in the input voltage to the power supply should also not affect the circuit output. A block diagram of a voltage regulator is shown.

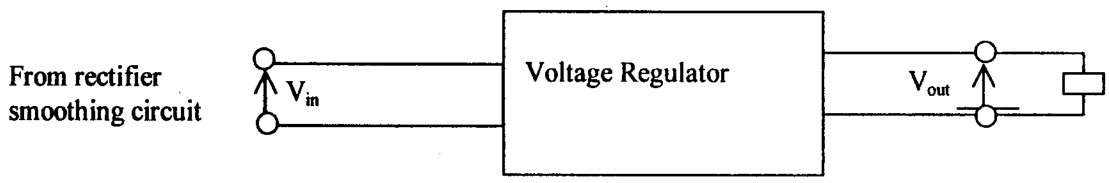


Fig 2.2

2.3 THE DESIGN PROCESS

The design of the project is divided into 5 parts as shown in Fig 2.3.

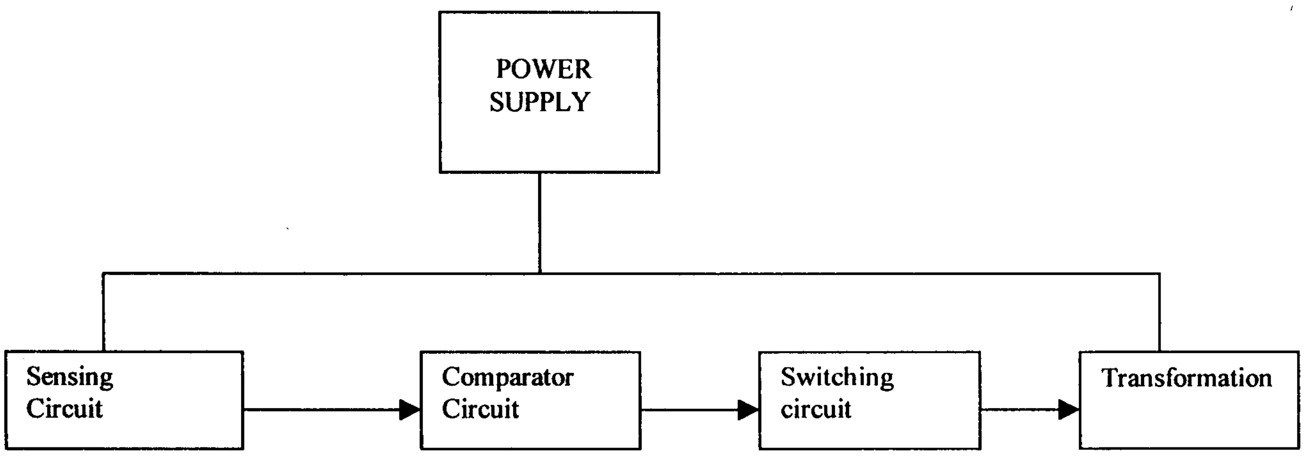


Fig 2.3

2.3.1 POWER SUPPLY

The conversion of the alternating 220v mains supply voltage at a frequency of 50H3 to 12v and 6v undirectional voltage that is required for both sensing and control circuit of the regulator is done by the power supply.

2.3.2 RECTIFICATION

After the step-down of voltage to 12v and 6v the process of rectification is used to convert A.C voltage to D.C voltage. A bridge rectifier is used to produce a full-wave rectification for the project.

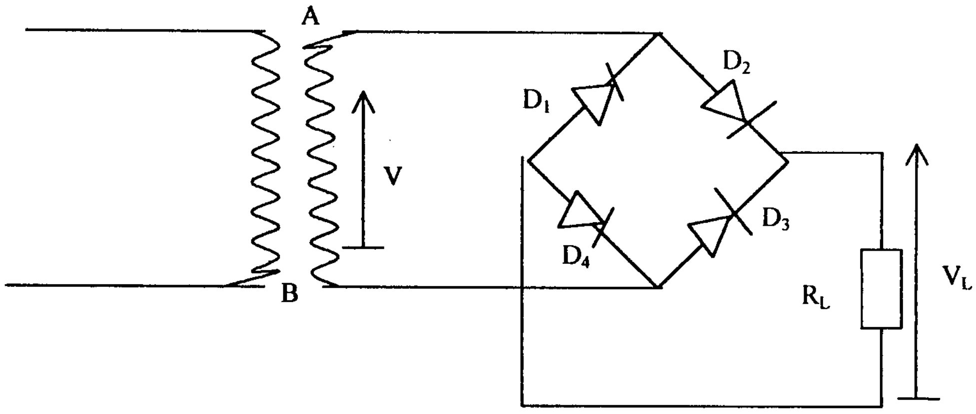


Fig 2.4

During the ½ - cycle when point A is positive with respect to point B, diodes D_2 and D_4 are conducting while D_1 and D_3 are reverse based. During the second ½ -cycle where point B is positive with respect to point A, diode D_1 and D_3 conduct while D_2 and D are reverse biased.

The full-wave bridge rectifier gives an improved average D.C voltage levels with reduced ripple.

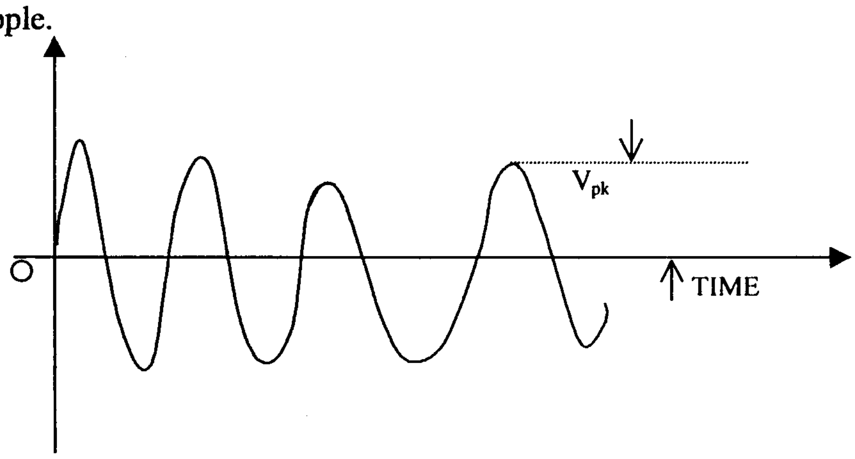


Fig 2.5a

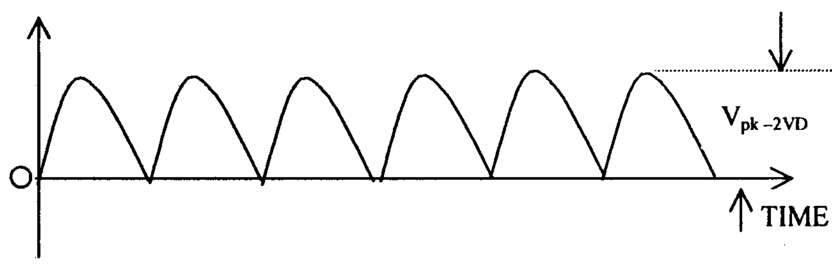


Fig 2.5b

2.3.3 FILTERING CIRCUIT

Owing to the higher frequency that is attributed to full-wave rectifier circuit, ripples are more easily filtered. For the design, the capacitor filter 16v reservoir capacitor is used.

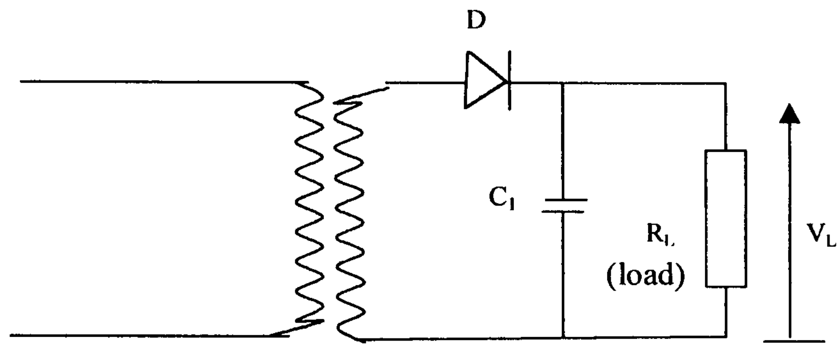


Fig 2.6

It is placed in parallel with the resistive load. The function is to remove the unwanted A.C component and to reduce ripple in the rectifier, the capacitance is adequate to make the filter more effective.

In attempting to keep the output voltage constant, the capacitor will discharge into the load connected across it.

The figure 2.7 below shows the waveform of a full-wave rectifier with filter capacitor.

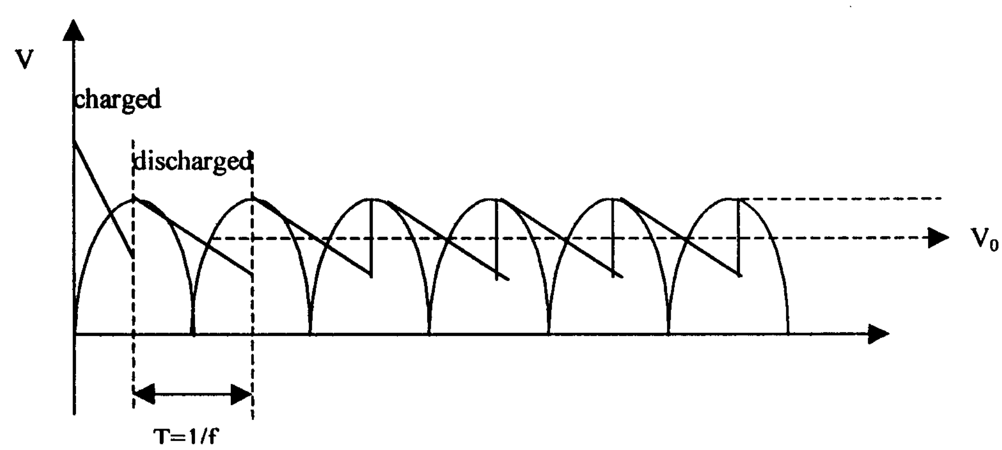


Fig 2.7

2.4 SENSING CIRCUIT

What sensing circuit does in the automatic voltage regulator is to sense the changes in the main supply and its input is to be sent to input of the comparator circuit where it is compared with a standard reference voltage, it is an important part of the control circuit, it responds to changes in the mains supply whether it is an increase or a decrease in the mains voltage.

For the purpose of this project we shall use a reference of 6volts while the sensing circuit is designed to give an output of 12volts.

The sensing circuit has its voltage from a separate winding in the transformer such that whenever there is any variation in the input voltage there is going to be a corresponding change in the sensing voltage. The reference voltage obtained its own supply directly from the main voltage, it is rectified, divider (using voltage divider method) and regulated using an 11volts zener diode.

2.5 THE COMPARATOR CIRCUIT

The comparator circuit is achieved by means of the general purpose transistor S9014. The comparator is designed to compare a voltage from the sensing circuit, which is fed to the collector via a collector resistor, against a reference voltage, which is fed to the base of the transistor through a voltage divider network.

The theory of this analogous to the integrated circuit comparator LM393. The LM393 consists of two independent precision voltage comparators designed to operate from a single power supply over a wide range of voltages operation from a split power supply is also possible, the comparator operates as an open collector.

When the inverting input attains a higher potential then the non-inverting input, the comparator goes low an the output is such that GROUND or OV appears at its output.

On the other hand when the non-inverting inputs is at higher potential, the comparator output goes high and no current flows through its output. The comparator circuit is as shown below in Fig 2.8

Comparator three, having a lower voltage at it's inverting input than comparator two and comparator one will respond first before the latter respond when the voltage from the sensing circuit increases.

The voltage divider network is an arrangement of resistors for the purpose of obtaining a desired voltage across any of the comparators. The reference supply voltage is normally applied at one end and the other end.

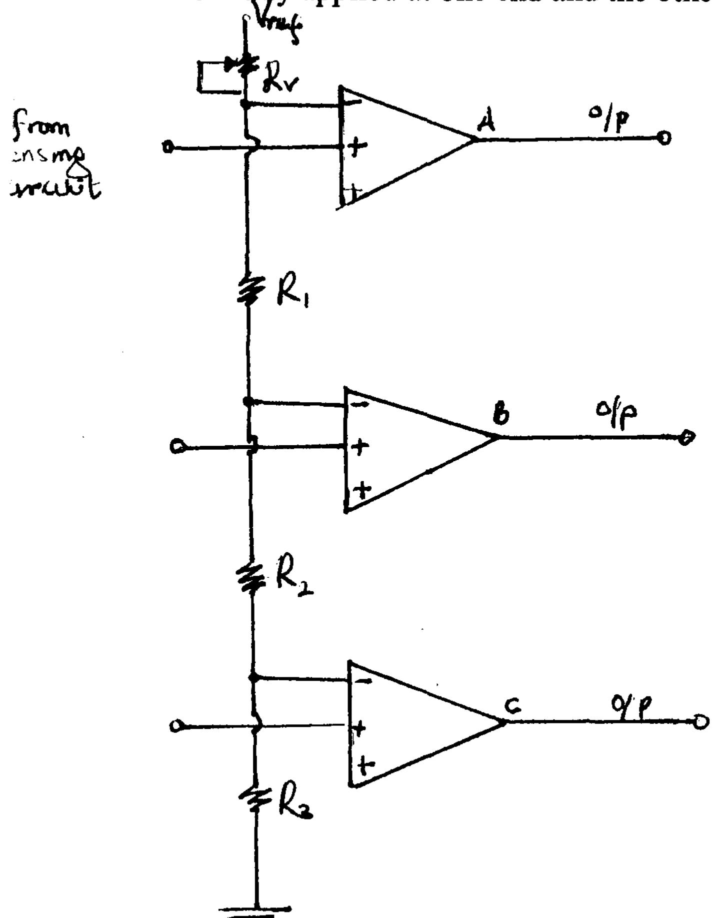


Fig 2.9a Fig

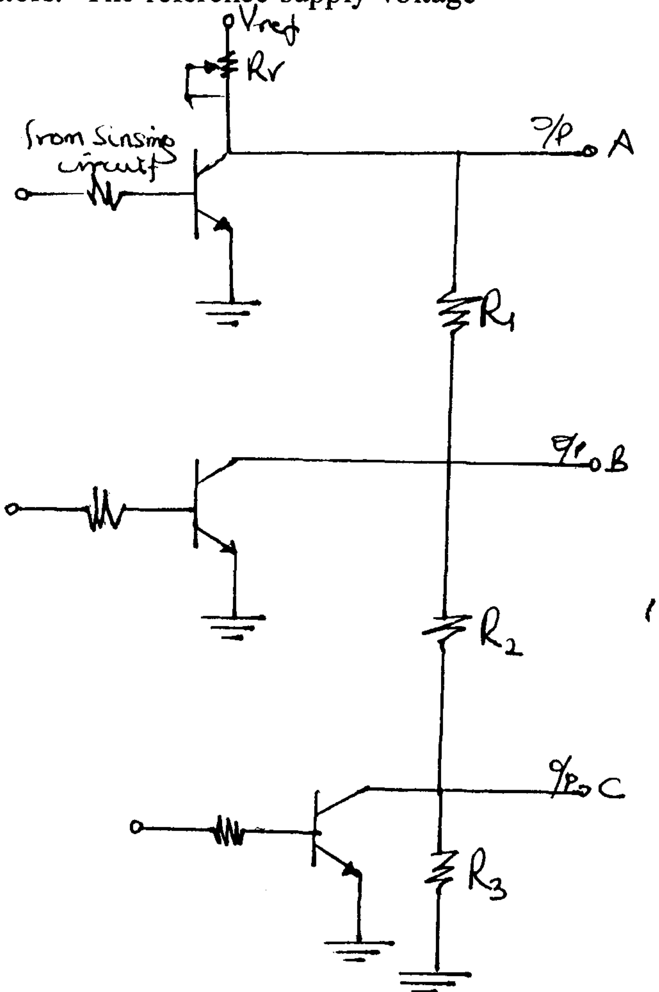


Fig 2.9b

2.6 THE SWITCHING CIRCUIT

The output of the comparator circuit is used to control the switching circuit. The circuit is essentially a transistor switching circuit used in driving a relay, with the transistor operating between cut-off and saturation. This can be accomplished by proper biasing of the transistor such that base saturation current flows in the base circuit when the transistor is to switch ON and base current equals zero when it is to switch OFF.

In using the transistor as a switch, the base emitter junction should be forward biased and the load current should not exceed the maximum collector current. The current is shown in Fig 2.10

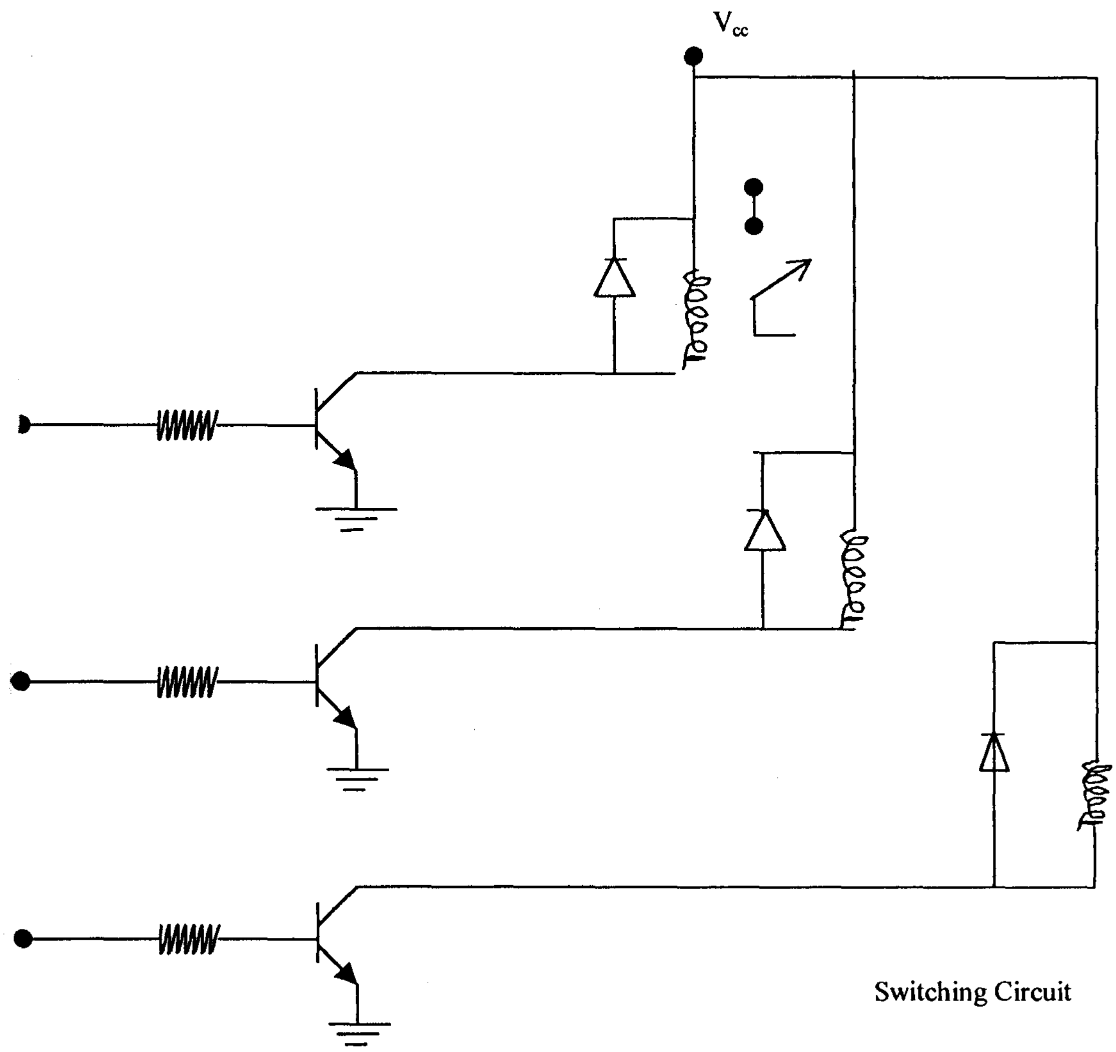


Fig 2.10

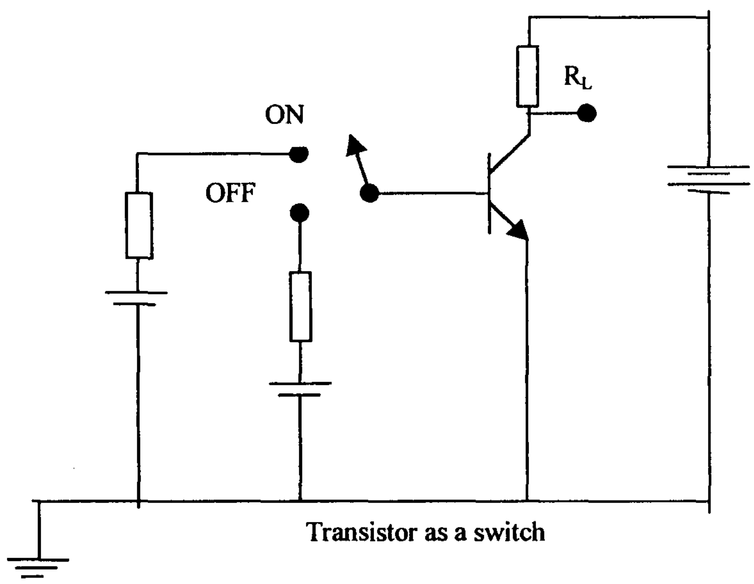
Transistors work in an analogous way to a mechanical switch with the advantage that they may be controlled electrically and they switch at very faster rates.

A transistor may be switched off to on and ON to OFF in millionths of seconds or less. From the figure above, when a voltage is applied across the base-emitter terminal of an NPN transistor so that the P- type is positive with respect to the N – type emitter, the P–N base emitter junction will be forward biased and current will flow in the base. This base current I_B will cause the transistor to conduct between the collector and emitter terminal. If this current is of sufficient magnitude it will cause the transistor to conduct strongly.

In the out state, the collector emitter voltage is very small,. Typically 0.35v or less for silicon transistors. Hence nearly all the supply voltage is applied across the load giving the main circuit current (the collector current).

$$IC = \frac{Vcc - Vce}{RL} \approx \frac{V_{cc}}{R_L}$$
$$as V_{cc} >> V_{CE}$$

when a negative voltage is applied across the base-emitter junction, the base –emitter junction is reversed biased and no current is fed into the base. Since base current is necessary to produce significant current flow through the transistor, the application of reversed bias results in practically zero collector current. In actual fact there is a very small collector current known as the reverse collector saturation current. I_{cbo}) due to the flow of minority carriers across the collector-base junction which acts as a reverse biased diode. Under these conditions, we say that the transistor is in its off or cut-off state. In the off state, Ic and the main circuit current is virtually zero. The off state of the transistor is equivalent to a switch S- when open.



Transistor as a switch

Fig 2.11

2.6.1 RELAY DIVIDER CIRCUIT AND THE PURPOSE FOR A DIODE

When the energising current is switched off sharply by the transistor the energy of the relay coils magnetic field produces a back e.m.f which in turn could cause a damaging current surge respect to the driver battery polarity. The diode is this connected so that the induced current dissipates its energy in the diode relay circuit as shown in Fig 2.12 below.

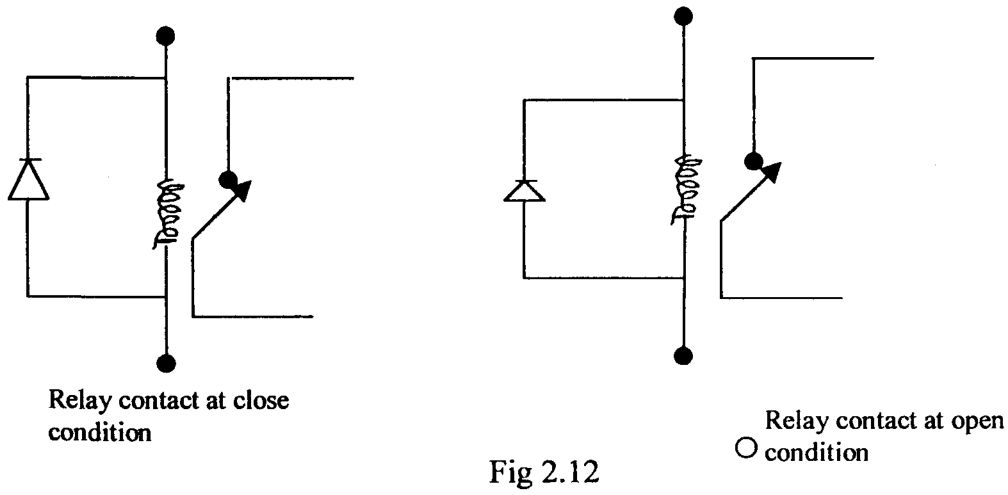


Fig 2.12

2.7 DESIGN ANALYSIS FOR THE SENSING, COMPARATOR AND SWITCHING CIRCUIT

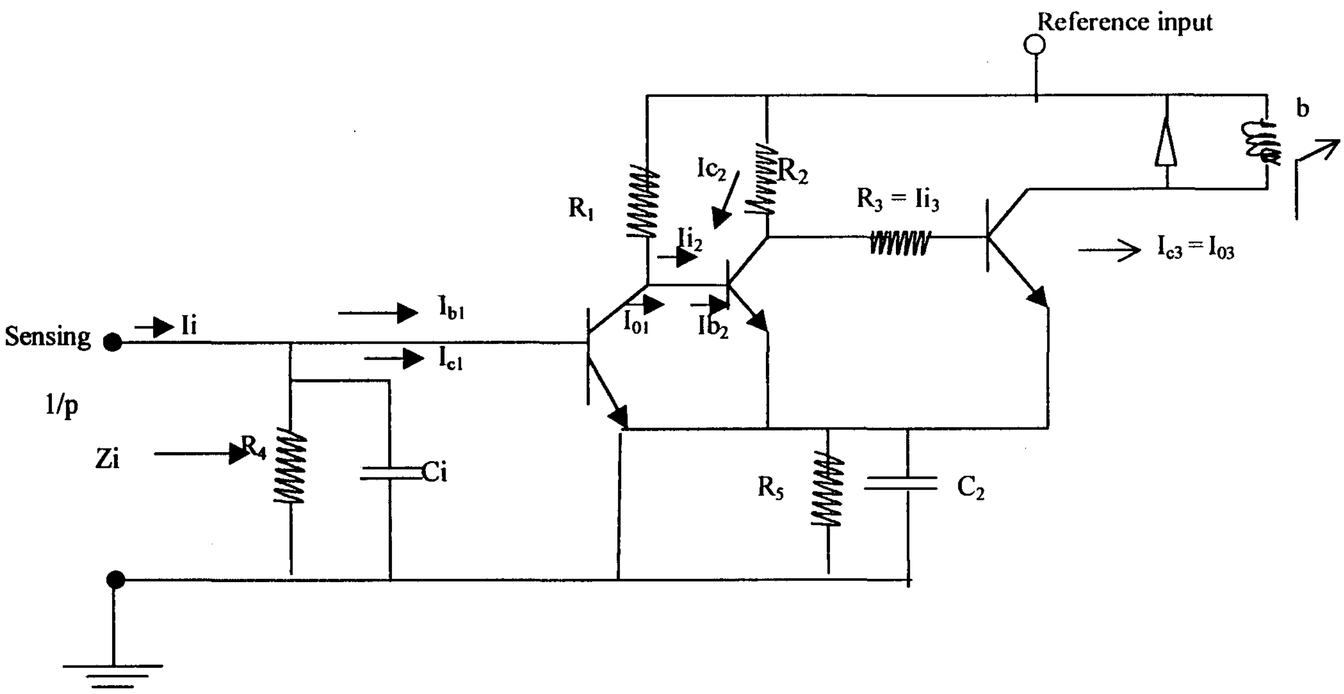


Fig 2.12

Specification for the transistor chosen

Ic(max) - 100mA

hfe – 110

hie – 0.5kΩ

V_{CE} - 3v

Reference voltage = 6v

Relay impedence R_L =400 Ω

Small signal analysis of the circuit in figure above reduce to

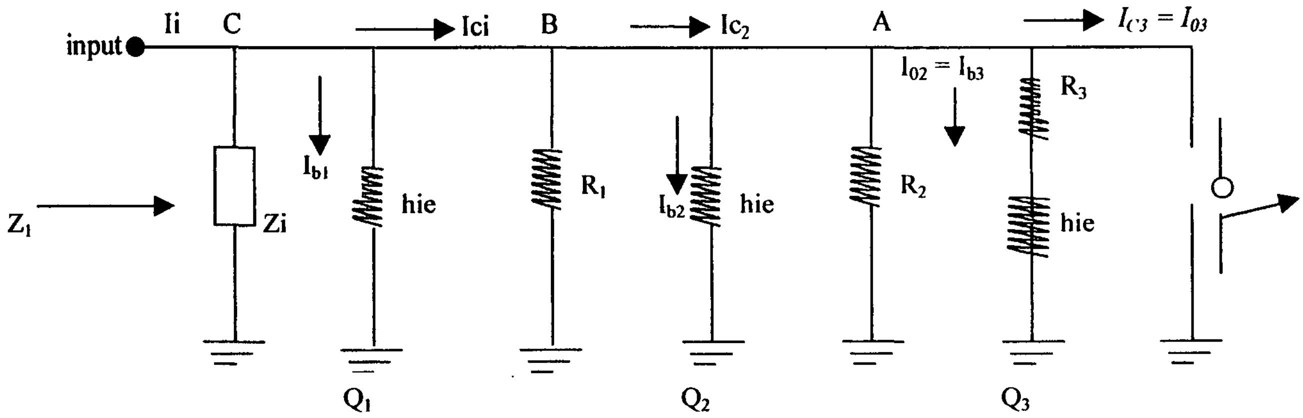


Fig 2.13

From Figure 2.13 the input circuit

$$Zi = Z_1 || hie = \frac{Z_1 hie}{Z_1 + hie}$$

Rillhie

Ie R_{L1} = Rillhie ---(8)

$$Av_1 = \frac{-hfe}{hie} \text{ (Rillhie)} \text{ --(9)}$$

2nd stage Analysis

By applying current rule to Node A, we have that

$$I_{b3} = I_{02} = \frac{R_2}{R_2 + (R_3 + hie)} I_{c2} \text{ ---------------------------------(10)}$$

At node A, $I_{C2} = I_{b3} + I_{03}$ ---(10.1)

$I_{C3} = I_{O3} = hfe\, I_{b3}$ ----------------------------------(10.2)

Curent gain of the 2nd stage

$$Ai_2 = \frac{I_{02}}{Ii_2} = \frac{I_{02}}{I_{b2}} \text{ ---------------------------------------(11)}$$

Output impedance o f the second stage is given by

$R_{L2} = R_2 11 (R_3 + hie)$---------------------------------(12)

And $AV_2 = \frac{-hfe}{hie} [R_2 // (R_3 + hie)]$-------------------------(13)

3rd stage Analysis

$Ic_3 = Io_3 = hfe\, I_{b3}$--(14)

Current gain of the 3rd stage

$$Ai_3 = -\frac{-I_{03}}{Ii_3} = \frac{-I_{03}}{I_{b3}} \text{ ---------------------------------------(15)}$$

$$\text{Voltage gain, } Av_3 = \frac{-hfe}{hie}R_L \text{ ------------------------------(16)}$$

Where R_L is the relay resistance.

Deductions of circuit parameters

Stage 3

$I_{03} = Ic_3 = Ic(max) = 100mA$

And $Ic_3 = hfeI_{b3}$ from equation (14)

$$\text{i.e } Ib_3 = \frac{Ic_3}{hfe} = \frac{100}{110}mA$$

$Ib_3 = 0.909mA$

$Ic_3 = 1000mA$

$Ib_3 = 0.909mA$

From equation (15), the circuit gain is given by

$$Ai_3 = \frac{-I_{03}}{Ii_3} = \frac{-I_{C3}}{I_{b3}}$$

$$\text{ie } Ai_3 = \frac{-I_{01}}{Ii_3} = \frac{-I_{C3}}{I_{b3}}$$

$$\text{ie } Ai_3 = \frac{-100mA}{0.909mA} = -110$$

$Ai_3 = -110$

Similarly from equation (16), the voltage gain of the 3rd stage is given by

$$AV_3 = \frac{-hfe}{hie}R_L \text{ where } R_L \text{ is the relay impedance} = 400\,\Omega$$

$$\Rightarrow AV_3 = \frac{-110}{500}(400)$$

$AV_3 = -88$

$Ai_3 = -110$

$AV_3 = -88$

$$\frac{R_1}{h_1 + hie} = \frac{I_{b2}}{Ic_1}$$

$$\frac{R_1}{R_1 + hie} = \frac{0.01585mA}{1.75985mA}$$

$$\frac{R_1}{R_1 + hie} = 0.0090$$

$$R_1(1 - 0.009) = 500(0.009)$$
$$0.99R_1 = 4.5032$$
$$R_1 = \frac{4.5032}{0.99}$$
$$R_1 = 4.55\Omega$$

The current gain Ai_1 from equation (7) is given by

$$Ai_1 = \frac{-Io_1}{Ii_1}$$

$$Ai_1 = \frac{I_{b2}}{I_{b1}}$$

$$I_{b1} = \frac{Ic_1}{B}$$
$$= \frac{1.75985mA}{110}$$
$$I_{b1} = 0.015999mA$$

Putting this value for I_{b1} in the current gain above

$$\Rightarrow Ai_1 = \frac{0.01585mA}{0.01599mA}$$
$$Ai_1 = -0.991$$

the voltage gain of stage 1 is given by equation 9 as

$$AV_1 = \frac{-hfe}{hie}(R_1 // hie)$$

$$R_{L2} = R_2(R_2 + hie)$$
$$= \frac{(3.3k\Omega)(2.53 + 3.3)k\Omega}{(3.3 + 2.53 + 3.3)k\Omega}$$
$$= \frac{19.239}{9.13}k\Omega$$

$RL_2 = 2.107k\Omega$

From equation (13), the voltage gain of the second stage is given by

$$Av_2 = \frac{-hfe}{hie}[R_{L2}]$$
$$= \frac{-110}{500}x2107$$
$$Av_2 = -463.54$$

at the mode A from figure above, the second stage output and 3[rd] stage current input relationship is given by equation (4) as

$$Io_2 = [\frac{R_2}{R_2+(R_3+hie)}]Ic_2$$

$$where Io_2 = I_{b3}$$

and Ic_2 can be deduced as

$$\left[Ic_2 = \frac{R_2+(R_3+hie)}{R_2}Io_2\right]$$
$$= \left[\frac{3.3k+(2.53+0.5)k\Omega}{3.3k\Omega}\right]0.909mA$$
$$= \frac{6.33}{3.3}(0.909mA)$$

$$\text{Where } R_1 // \text{ hie} = \frac{4.55(500)}{4.55+500}$$
$$= \frac{2275}{504.55}\Omega$$
$$R_1 // hie = 4.509\Omega$$

Putting this value in the above voltage gain expression, we have that

$$Ai_1 = \frac{-110}{500}(4.509)$$

$$Av_1 = -0.99198$$

$$Ai_1 = -0.991$$
$$Av_1 = -0.992$$

At node c by equation (4) we have that

$$Ii = I_{b1} + Ic_1$$

$$Ii = 0.015999\ mA + 1.75985\ mA$$
$$= 1.77584\ mA$$

From equation (3), base input impedance, Z_1 of the transistor Q_1 is obtained as

$$I_{b1} = \left(\frac{Z_1}{Z_1 + hie} \right) Zi$$

$$\frac{Z_1}{Z_{1+hie}} = \frac{I_{b1}}{Ii}$$

$$\frac{Z_1}{Z_1 + hie} = \frac{0.01599\ mA}{1.77554\ mA}$$

$$\frac{Z_1}{Z_1 + hie} = 0.009$$

$$Zi = \frac{Zihie}{(Zi + hie)} \quad \text{...(1)}$$

Where $Z_i = \dfrac{R_4}{1 + R_4(2\nabla fci)}$ ....(2)

From the equivalent circuit, by applying circuit rule to Node C, we have that

$$I_{b1} = \left(\frac{Z_1}{Z_1 + hie} \right) Ii \quad \text{...(3)}$$

At node c

$Ii = I_{b1} + Ic_1$...(4)

And $I_{b1} = \dfrac{Ic_1}{hfe}$ ....(4.1)

By applying current rule to Node B, we have that

$$Ib_2 = I_{01} = \left(\frac{R_1}{R_1 + hie} \right) Ic_1 \quad \text{...(5)}$$

note that $I_{b2} = Io_1 = Ii_2$...(6)

also at node B $Ic_1 = Ib_2 + Ic_2$ ....(6.1)

$Ic_2 = hfe\ I_{b2}$ ....(6.2)

Current gain of 1st stage

$$Ai_1 = \frac{-Io_1}{Ii_1}$$

Voltage gain is defined as

$$Av = \frac{-hfe}{hie} R_L$$

Stage 2

From the figure above, the collector and base circuit equation for Q_2 and Q_3 respectively with reference to point Y is given by

$Vref = Io_2 R_2 + V_{CE2}$ ....(17)

Where $Io_2 = I_{b3}$

$V_{CE2} = Io_2 R_3 + V_{BE3}$ ....(18)

From the equation (18), we have that

$$R_3 = \frac{V_{CE2} - V_{BE3}}{Io_2}$$

$$= \frac{V_{CE2} - V_{BE3}}{I_{b3}}$$

$$R_3 = \frac{3 - 0.7}{0.909mA}$$

$$R_3 = 2.53k\Omega$$

Similarly from equation (17)

$$R_2 = \frac{V_{REf} - V_{CE2}}{Io_2}$$

$$= \frac{V_{REf} - V_{CE2}}{Ib_3}$$

$$= \frac{6 - 3}{0.909mA}$$

$$R_2 = 3.3k\Omega$$

The output impedance of the 2nd stage can be deduced from equation (12)

$Ic_2 = 1.744mA$

From equation (10.2), I_{b2} is obtained as

$$Ib_2 = \frac{Ic_2}{\beta} = \frac{1.744mA}{110}$$

$$Ib_2 = 0.01585mA$$

The current gain of the 2nd stage according to equation (11) is given by

$$Ai_2 = \frac{Io_2}{Ii_2} = \frac{Io_2}{I_{b2}} = \frac{I_{b3}}{I_{b2}}$$

$$= \frac{0.909mA}{0.01585mA}$$

$$Ai_2 = 57.35$$

Stage 1

At node B from figure above given by equation 5, we have that

$$Io_1 = \left(\frac{R_1}{R_1 + hie}\right) Ic_i \text{..} (5)$$

$$Io_1 = I_{b2}$$

similarly at node B by equation (6.1) we have that

$$Ic_1 = I_{b2} + Ic_2 \text{..} (6.1)$$

From equation 6.1

$$Ic_1 = 0.01585mA + 1.744mA$$

$$Ic_1 = 1.75985mA$$

Then by substituting for Ic_1 and $Io_1 = I_{b2}$ in equation 5 above

$$\frac{Io_1}{Ic_1} = \frac{R_1}{h_1 + hie}$$

$$ie \frac{I_{b2}}{Ic_1} = \frac{R_1}{R_1 + hie}$$

$$Z\,(1 - 009) = 0.009hie$$
$$0.99Z_1 = 0.009(500)$$
$$Z_1 = 4.55\Omega$$

From equation, the circuit input impedance, Zi is obtained as

$$Zi = Z_1 // hie$$
$$= \frac{4.55(500)}{4.55+500}$$

$$Zi = 4.51\Omega$$

by choosing $C_1 = 10\,\mu F$ in the input circuit, then from equation (2), where

$$Z_1 = \frac{R_4}{1+2\Pi fR_4C_1}$$

$$1+2\wedge fR_4C_1 = \frac{R_4}{Z_1}$$
$$1 = \frac{R_4}{Z_1} - 2\Pi fR_4C_1$$
$$1 = R_4\left(\frac{1}{Z_1} - 2\Pi fC_1\right)$$

$$ieR_4 = \frac{1}{(\frac{1}{Z_1} - 2\Pi fC_1)}$$

$$= \frac{1}{[\frac{1}{4.5} - 100\Pi x10x10^{-6}]}$$
$$= \frac{1}{0.2198-0.00314}$$

$$R_4 = \frac{1}{0.216658}$$
$$R_4 = 4.62\Omega$$

Total current gain of the circuit

$$Ai_T = \frac{-Io_3}{Ii} = \frac{100mA}{1.77584mA}$$

$$Ai_T = -56.31$$

total voltage gain AV_T

$$AV_T = (AV_1)(AV_2)(AV_3$$
$$= (-0.992)(-463.54)(-88)$$
$$AV_T = -40.465x10^3$$

2.7.1 TRANSFORMER RATIO CALCULATION

By neglecting the smallest impedance drop

$E = V$

$\phi m = Bm\ Ac\ ]$ ....(16)

For A SINGLE PHASE TRANSFORMER

Copper area for each conductor = ½ $A_W k_W$ ....(17)

For either primary or secondary copper area =

¼ Awkw ....(18)

for single phase from (7)

VA/Phase = 4.44 + ϕm NI

$= 4.44 fBm\ NA_c\ ida$

$= 4.44 fB_m\ NA_c id\ (1/2\ \frac{A_w k_w}{N})$

$= 4.44 fBm\ NA_c id\ (1/2\ A_w k_w)$

$= 2.22 fBm\ A_c ci_d\ Awkw$..................................(19)

for three phase

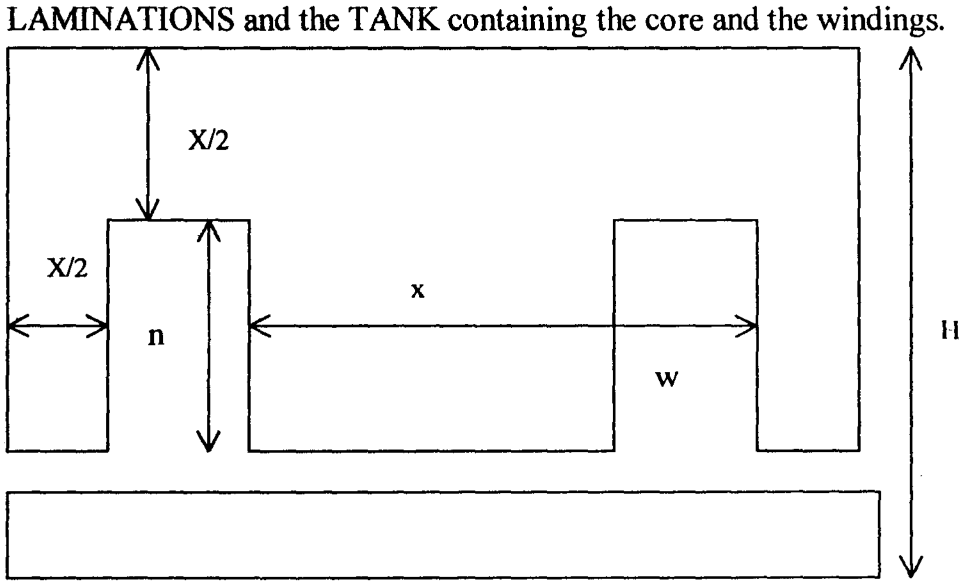
$3VA/\ phase = 3.33\ fBm\ A_c i_d\ Aw_{kw}$ ....(20)

KVA Rating

$KVA = 2.22 fBm\ AcAwkwid \times 10^3$ ....(single phase

$= 3.33\ f\ Bm\ Ac\ k_{wid} \times 10^3$ (3-phase) ....(21)

The main parts of the transformer are the core, the windings, the STACKINGS OR LAMINATIONS and the TANK containing the core and the windings.



$$\frac{volt/turn}{\sqrt{KVAperphase}} = 4.44 fBmA_c \text{...}(1)$$

$$KVA = 2.22f\,Bm\,Ai\,A_w k_w J \text{ ....}(2)$$

$$\frac{E_3}{N_S} = \frac{E_P}{N_p} = \frac{volt/turn}{\sqrt{KVA/phase}} \text{...}(3)$$

Area of core Ac is directly proportional to the square of length of the stacking

i.e. AC α L^2

$Ac = CL^2$ where c is the constant of core

Similarly area of core is also equal to

$$Ac = \frac{K_o k_s \Pi D_0^{\ 2}}{4} \text{...}(4)$$

Where k_0, k_S are iron space factor and stacking factor respectively.

D_0 is the core circle diameter

$= 7.269 \times 10^{-4} m^2$

i.e. $Ac = 7.269cm^2$

From equation (4) length of stacking

$$L = \sqrt{\frac{AC}{C}} = \sqrt{\frac{7.269}{0.66}}$$

$$= \sqrt{11.0136}$$
$$L = 3.32cm$$

From equation five (5)

$$D_0 = \sqrt{\frac{4Ac}{K_0 K_S \Pi}}$$

$$= \sqrt{\frac{4x7.269}{0.64x0.94x\Pi}} = \sqrt{\frac{29.076}{1.8899}}$$

$$D_0 = 3.92cm$$

From equation (6) window width is obtained as

$w = 0.7D_0$ for the two windows

0.7 x 3.92

w = 2.74cm

For 1 window $\frac{w}{2}$ = 1.37cm

From equation (3) Area of window can be divided as

$$Aw = \frac{KVA}{2.22xfxBmxAcxKwxJ}$$

$$= \frac{0.6}{2.22xfxBmxAxcaKwxJ}$$

$$= \frac{0.6}{2.22x50x0.4x7.269x10^{-4}x0.01x1x10^{6}A/m^{2}}$$

$$= \frac{0.6}{322.7436}m^{2}$$

$$= 18.59x10^{-4}m^{2}$$

w is the window width = 0.7 D_0

Similarly Ac = xL ....(7)

Where L is the length of stacking and $N_L = \frac{L}{t}$.................(8)

N_L = no of lamination

T = thickness of lamination

Height of window h = $\frac{Aw}{w}$..(9)

Area of copper wire used is obtained as follows

$$Ip = \frac{KVA}{E_p}$$

$$Is = \frac{KVA}{Es} \quad \text{...(10)}$$

And

$$Ap = \frac{Ip}{J}$$

$$As = \frac{I_s}{J} \quad \text{..(11)}$$

Design Assumptions for 600VA transformer

Volt/turn = 0.05

Iron space factor $K_0 = 0.64$

Stacking factor $K_s = 0.94$

Window space constant $K_w = 0.01$

Flux density Bm = 0.4 tesla

Current density $1 A/mm^2$

Thickness of laminations used t = 0.5mm

Constant of core c = 0.66

These assumptions are true for a 500-1000VA transformer.

From equation (1)

$$Ac = \frac{volt/turn}{\sqrt{KVA/phase(4.44fBm)}}$$

$$= \frac{0.05}{\sqrt{0.6(4.44x50x0.4)}}$$

$$Aw = 18.59cm^2$$

from the equation (8), the height of the window is given as

$$h = \frac{Aw}{w}$$
$$= \frac{18.59}{2.74}$$

$$h = 6.78cm$$

from equation (7), the core width x is obtained as

$$x = \frac{Ac}{L} = \frac{7.269}{3.32}$$

$$x = 2.189cm$$

from equation (10)

$$Ip = \frac{KVA}{Ep} = \frac{0.6}{220}$$

$$= 2.72x10^{-3} A$$

$$= 2.72mA$$

$$Is = \frac{KVA}{Es} = \frac{0.6}{12}$$

$$= 0.05A$$

$$Ap = \frac{Ip}{J} = \frac{2.72x10^{-3}}{1}$$

$$= 2.72x10^{-3} mm^2$$

From the table

The size wire gauge SWG for primary = 46

The size wire gauge SWG for secondary = 33.

CHAPTER THREE

CONSTRUCTION AND TESTING

3.0 CONSTRUCTION

In constructing this project, a lot of things were put into consideration, the method of soldering, either with the vero board as it is or scrapping the copper-coated surfaces and using the fused wire.

A 14mm by 7mm vero board was used in the construction and assembly of the components of the control circuit of the automatic voltage regulator.

The surface of the board was scrapped. The fused wire method was used for soldering, because of its effectiveness and rehability resulting in easy identification of faulty tracks .

60W power output of soldering iron was used, a lead sucker fused wire and high quality lead wire used to carry out the construction. First, on the vero board, the positive side(live) of the circuit voltage flow was laid and properly soldered.

Four diodes were soldered in the full-wave bridge rectifier mode (it is the method used for the D.C supply) after which the 470 μF, 25V capacitor was soldered across the live and earth as shown in the circuit diagram.

The sensing circuit has the variable resistors connected across and the third pin which serves as the varying indicator was connected to the transistor which was used as a comparator. The reference circuit was also properly linked to ensure a proper connection to transistor op-amp, the soldering was also properly done to avoid any form of wrong connection. The transistor was also well connected to the relays. Short-circuiting was guarded against.

The components were neatly arranged on the vero board. The tracks were properly on line. With the completion of the assembly, we have an Automatic Voltage Regulator. Data books were consulted and used to ensure correct connections of the components.

The components used for the construction of the Automatic Voltage Regulator are:

1. Variable Resistor –50k
2. IN4001 diode
3. ¼ watt resistors
4. zener diode
5. BC 547/S9014 – transistors
6. 47O μ F 25V smoothing capacitor
7. 10F μ F16V filter capacitor
8. Relays (3) – 12v
9. Voltmeter
10. Fuse 2A
11. Pilot lamp
12. Power switch
13. Output socket
14. Metal casing
15. 13A plug with wire
16. Transformer 600VA.

3.1 TESTING

The test on this project was carried out by getting a 13amp 250V plug connected to the input wires and plugged into the NEPA A.C mains. The mains voltage when measured with the multimeter was 170V, the output obtained from the Automatic voltage regulator was regulated to 220V. The NEPA input was then boosted up or step-up by a step-up transformer to 200V and the Automatic voltage Regulation output was still regulated to 220V.

When a 20inches television and a radio was connected to the AVR, it supplied a voltage of 220V.

This actually proves there is a regulation of voltage by the AVR to normal voltage of 220V.

3.2 TROUBLESHOOTING

When the circuit was tested initially, it was noticed that there was no output, the various components in the circuit was then tested to which one was bad, it was discovered that they relays are bad in that they are not switching properly because they are making partial contact internally.

The relays was removed and replaced with a new one that is switching properly when testing the circuit again it was noticed that one of the transistor used as comparator circuit was bad, and it was replaced. It was then given the correct value.

CHAPTER FOUR

CONCLUSION AND RECOMMENDATION

4.1 CONCLUSION

The design constructions of project, Automatic Voltage Regulator has not being an easy task in any way we look at it. It calls for precision carefulness especially in the design and construction results obtained the Automatic Voltage Regulation is actually regulating the voltage.

Therefore it can be said conclusively that the aims and objectives has been achieved.

4.2 RECOMMENDATION

Most Automatic voltage regulator cannot regulate low voltage between 80V-140V, I thereby recommend that the next generation of Automatic voltage regulator to be constructed should be able to cater for these low voltage ranges.

The power output of the Automatic voltage Regulator can still be improved upon such that it will have that capability of supplying more loads.

It is recommended for any devices be it computer, fridge, radio or television used in any location be it home, office, laboratories, factories and library should be used with Automatic voltage regulator because of the NEPA fluctuation.

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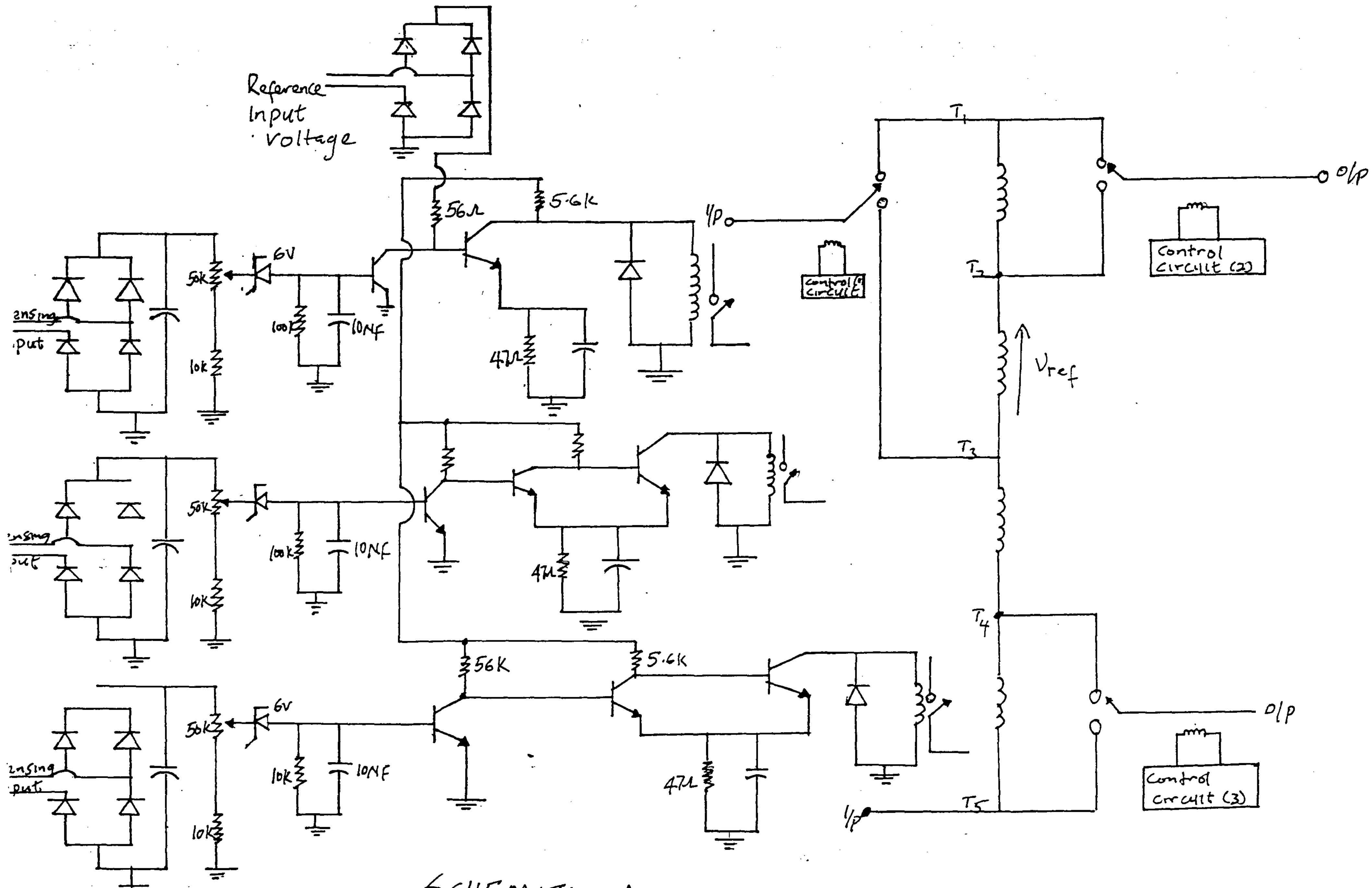

SCHEMATIC DIAGRAM OF AUTOMATIC VOLTAGE REGULATOR OF 600VA RATING.