Digitally Controlled Automatic Voltage Regulator

Project Report

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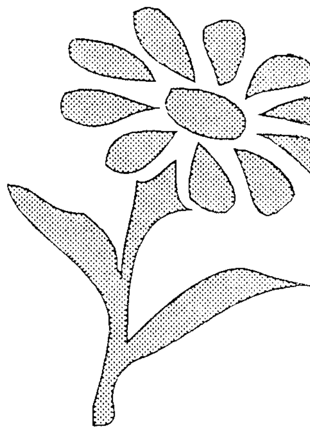
In partial fulfilment of the requirements for the Award of the degree of BACHELOR OF ENGINEERING in ELECTRICAL AND ELECTRONICS ENGINEERING of the Bharathiar University, Coimbatore

Department of Electrical and Electronics Engineering

Kumaraguru College of Technology

COIMBATORE - 641 006



Certificate

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

KUMARAGURU COLLEGE OF TECHNOLOGY

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CERTIFICATE

This is to certify that the Project Report entitled

DIGITALLY CONTROLLED AUTOMATIC VOLTAGE REGULATOR

has been submitted by

P. VIJAY [illegible] , [illegible]

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in partial fulfilment for the award of the degree of
Bachelor of Engineering in Electrical and Electronics Engineering Branch of
the Bharathiar University
During the academic year 1996-97

9/4/97

Guide

Professor and Head

Certified that the Candidate with University Register No.________________ was examined by us in Project Work Viva-Voce Examination held on ____________

Internal Examiner

External Examiner

Cansoft Systems (P) Ltd.,

Coimbatore - 30
27.3.97

This is to certify that the follwing **ELECTRICAL AND ELECTRONICS ENGINEERING** branch students of **KUMARAGURU COLLEGE OF TECHNOLOGY, COIMBATORE** have successfully completed and tested the project titled "**DIGITALLY CONTROLLED AUTOMATIC VOLTAGE REGULATOR**" in our concern.

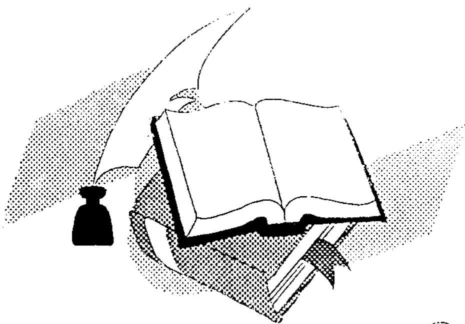
1. **Mr. P. VIJAY**
2. **Mr. M. VIJAYAKUMAR**
3. **Mr. L. SURESH**
4. **Mr. N.P. SUBRAMANIAM**

in the period of December '96 to March '97.

For **CANSOFT SYSTEMS (P) LTD.,**

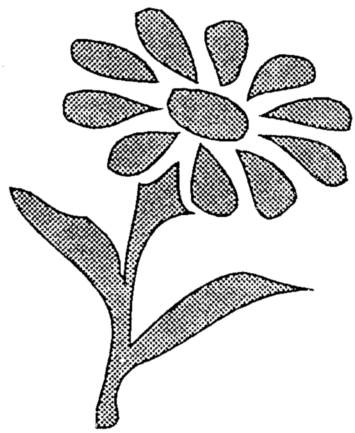
R. Anantha Krishnan

Mr. R. ANANTHAKRISHNAN
(Director)



Dedicated to our beloved

Parents



Acknowledgement

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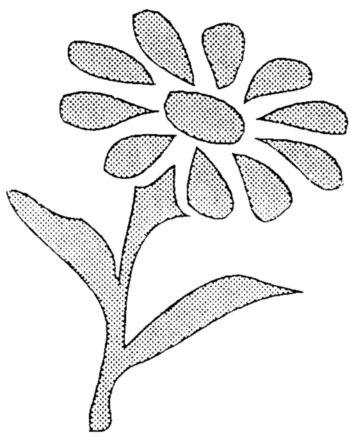
Our sincere thanks are due to all the Members of the Staff, Department of Electrical and Electronics Engineering and all the student friends for their co-operation to carry out this project.



Synopsis

SYNOPSIS

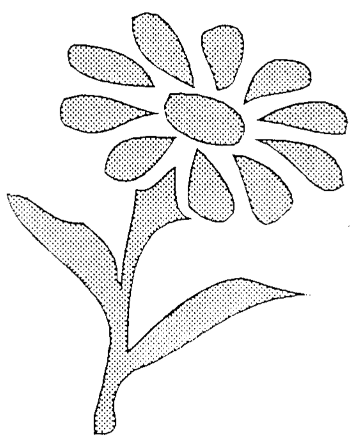
The machine of the modern era required power supplies within a specified range of voltage and the immediate requirement is controlled output voltage for all the electrical appliances.

Our project, titled "Digitally Controlled Automatic Voltage Regulator", is a step towards satisfying the market requirement.

This project basically deals with the design, fabrication and testing of automatic voltage regulator which includes PCB fabrication and computer aided transformer design. The program is developed in C Language.

Consequently the shape and size of the unit has been designed so that it is portable. Necessary indications have also been provided to indicate the state of the unit.

The design particulars, fabrication details, the mode of triggering and the testing procedure have been extensively dealt with in this report.



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Introduction

CHAPTER 1

INTRODUCTION

1.1 NEED FOR VOLTAGE STABILIZER

According to Indian Electricity Act, the power supply voltages should not drop or rise by more than four percent, but we find voltage fluctuations taking the 230 V mains supply voltages to as low as 150 V or as high as 300 V occasionally.

With enormous increase in loads connected to a distribution transformer, the electricity suppliers now find it exceedingly difficult to maintain the voltage within stipulated values. And that has necessitated use of automatic voltage stabiliser for almost every instrument. From expensive equipment like Computers, Fax, Electronic typewriters, Electronic Weighing Machines etc. to domestic appliances like Refrigerators, TV sets etc.

1.2 PRINCIPLES OF VOLTAGE STABILIZERS

Fig 1.1 shows the block diagram of a voltage stabilizer connected to an appliance or load. When there is a change in input voltage from 160 V to 275 V, the output voltage is constant at 200 V to 240 V.

The stabilisers size increases generally with its rating, which is given in KVA (volts x amps x 10^{-3}).

1.3 TYPES OF VOLTAGE STABILISER

The various types of voltage stabilisers are

a. Ferro resonant type stabilisers

b. Relay type stabilisers

c. Servo type stabilisers

1.3.1 FERRO RESONANT TYPE STABILISERS

This type of stabiliser uses two transformers and one of them is of saturating core. The principle at ferro resonance in a saturating core was used to keep the output voltage constant even though input voltage had variations over and below the rated nominal voltage.

But the output voltage waveform in such a stabiliser is distorted due to saturation effects. Hence this type has now assumed less importance and servo stabilisers have replaced them, though it is very reliable with no moving parts.

1.3.2 RELAY TYPE AUTOMATIC STABILISERS

This type of stabilisers are used for small variations in input voltage. They employ one or two relays to switch a voltage into the line so as to add to the input voltage, when the output drops below nominal 220 V value. If the input rises above the nominal value, it bucks or subtracts the voltage. The winding of a transformer is thus connected to either boost or buck the input voltage. Usually, if a 10 percent variation is permitted below and above the nominal value 220 V, a winding of the transformer with 22 V (10 percent) is connected in either way to provide for inputs fluctuating from 200 to 240 V. The two positions of the relays (up and down in Fig. 1.2) are able to give a plus or minus 22 V variation. But if the input goes to 260 V, it will give 242 V and not 220 V output. Likewise, if the input goes below to 180 V, it will give only about 198 V.

The relay contact changeover is done by a sensing circuit. This compares a fraction of the (Rectified) input voltage with a fixed reference (zener diode) voltage and depending on the valve being over or below the reference, it causes the relays to operate up or down position.

Essentially these relay type voltage stabilisers have these main **disadvantages** :

1. Power is off momentarily during relay change over; sensitive equipment like computers cannot afford this.

2. The voltage range is very limited.

3. Relay contact gives problems.

4. Accuracy is limited - not better than 10 percent.

1.3.3 SERVO STABILISERS

These stabilisers employ a toroidal autotransformer and a servo motor driven by a circuit which senses the voltage as shown in Fig. 2.3. The toroidal autotransformer has a toroidal core. It has a contact arm housing a carbon brush, which makes a sliding contact with the coil wound over the toroid, just as in a potentiometer. The toroidal core is circular in shape with a diameter of about 35 cm.

Enamelled copper wire, which is wound around the toroid uniformly, is exposed (uncovered by enamel) at the top side where the contact is made by the carbon brush of the moving assembly. The output voltage is varied automatically on varying the position of this contact. For this purpose, a servo motor fitted with gears is coupled to the contact arm.

The sensing circuit senses the voltage difference between the output and the nominal voltage. It drives the servo motor, after suitable power amplification, in clockwise or anticlockwise direction. As the motor moves the contact on the winding of the autotransformer, it reduces the voltage difference which becomes zero when output voltage reaches the nominal value. As there is no error signal now, the servo motor stops. Further variations in mains cause the motor to move forward or backward again, thus correcting the voltage.

The servo stabiliser is quite accurate as its resolution is the voltage across each turn of the toroidal winding. This resolution depends on core size of the toroid. If an autotransformer is wound for 280 V range, it may have 1 V per turn and thus 280 turns wound over the toroid.

A servo stabiliser, however has the **disadvantage** that

i. it tends to 'hunt' if the input voltage fluctuated too often.

ii. Also, it acts slowly and cannot adjust to sudden shoots or dips of main voltage.

iii. Actually, the servo motor takes atleast a second to make a movement for, say, a 20 V input change, But if the voltage fluctuates suddenly from, say, 180 V to 260 V, as is common when a heavy power load is switched off on the distribution line, it will take more than one second and, during this time, the equipment will be subjected to this sudden over voltage of 260 V. In fact, it is the sudden fluctuations that really spoil equipment and for this reason, the servo stabiliser is not worth the heavy price paid for it.

1.4 SPECIAL FEATURES OF SOLID STATE SERVO STABILISER

The servo stabiliser of the motor-toroidal auto transformer type is very difficult to construct as the motor assembly has to be fitted on the transformers moving contact. A machine shop is invariably needed for fabricating it.

On the other hand, this circuit uses no motor or mechanical moving part. It can be assembled by an electronics enthusiast without any workshop facility.

The cost of making a motorised servo, even for a 1 KVA rated unit, it is not less than Rs. 3000, the contrary, this simple circuit accomplishes the same for around Rs. 1500, when carefully built. Instead of a toroidal autotransformer and moving contact brush, it just needs an ordinary transformer with several winding sections or taps.

The motorised servo stabiliser takes time to move the contact while correcting for the voltage fluctuations. This circuit acts very much faster, thus taking care of sudden overshoots or under shoots of the mains voltage.

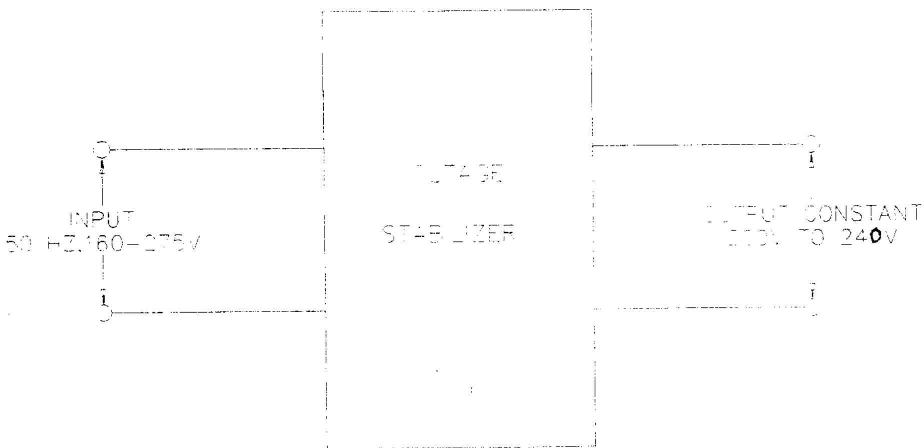
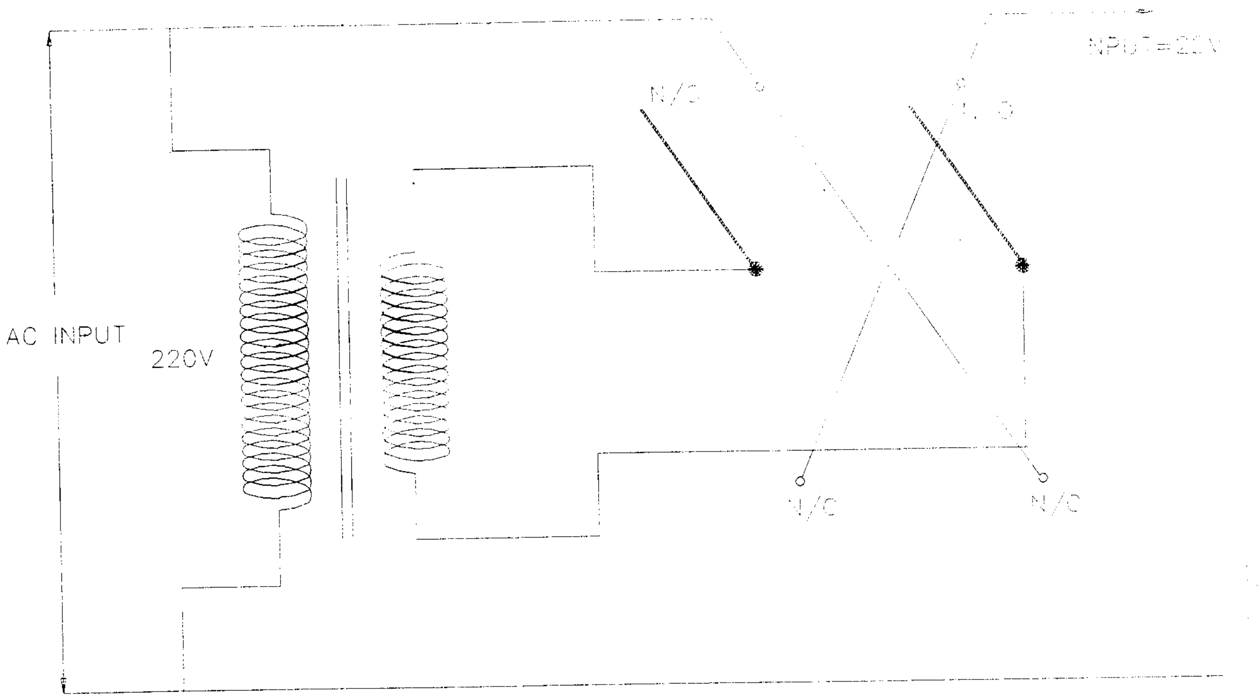
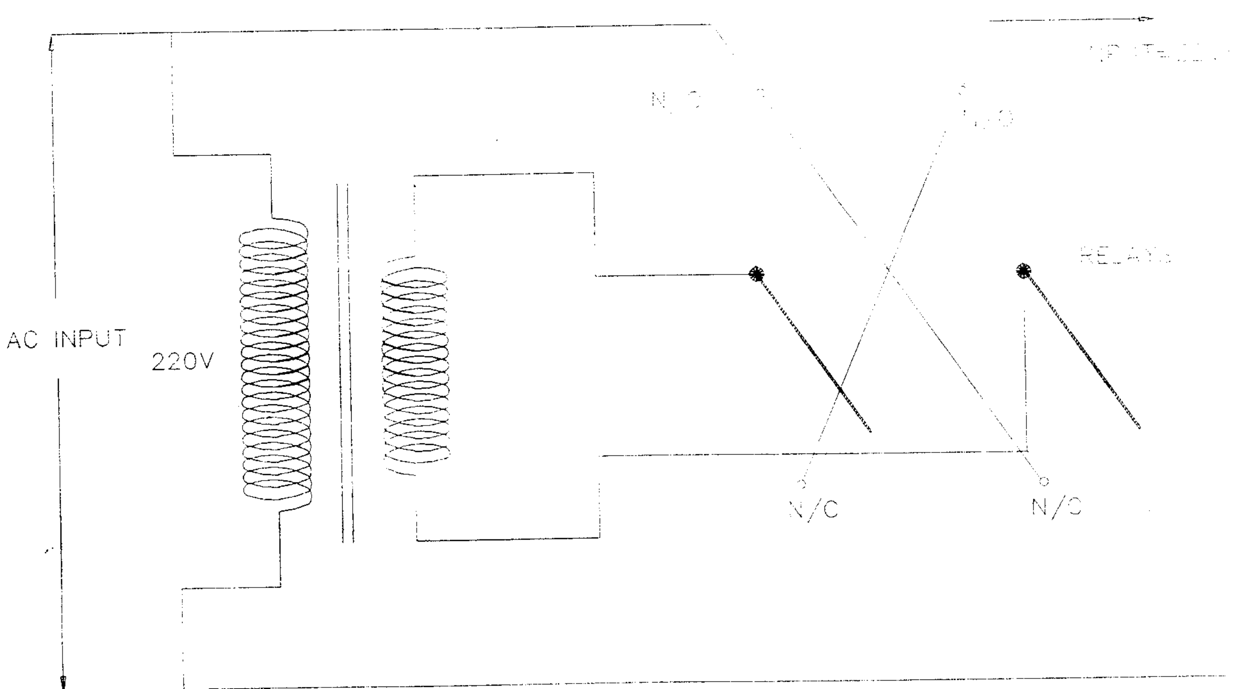


FIG 1.1 BLOCK DIAGRAM

RELAY TYPE STABILIZER





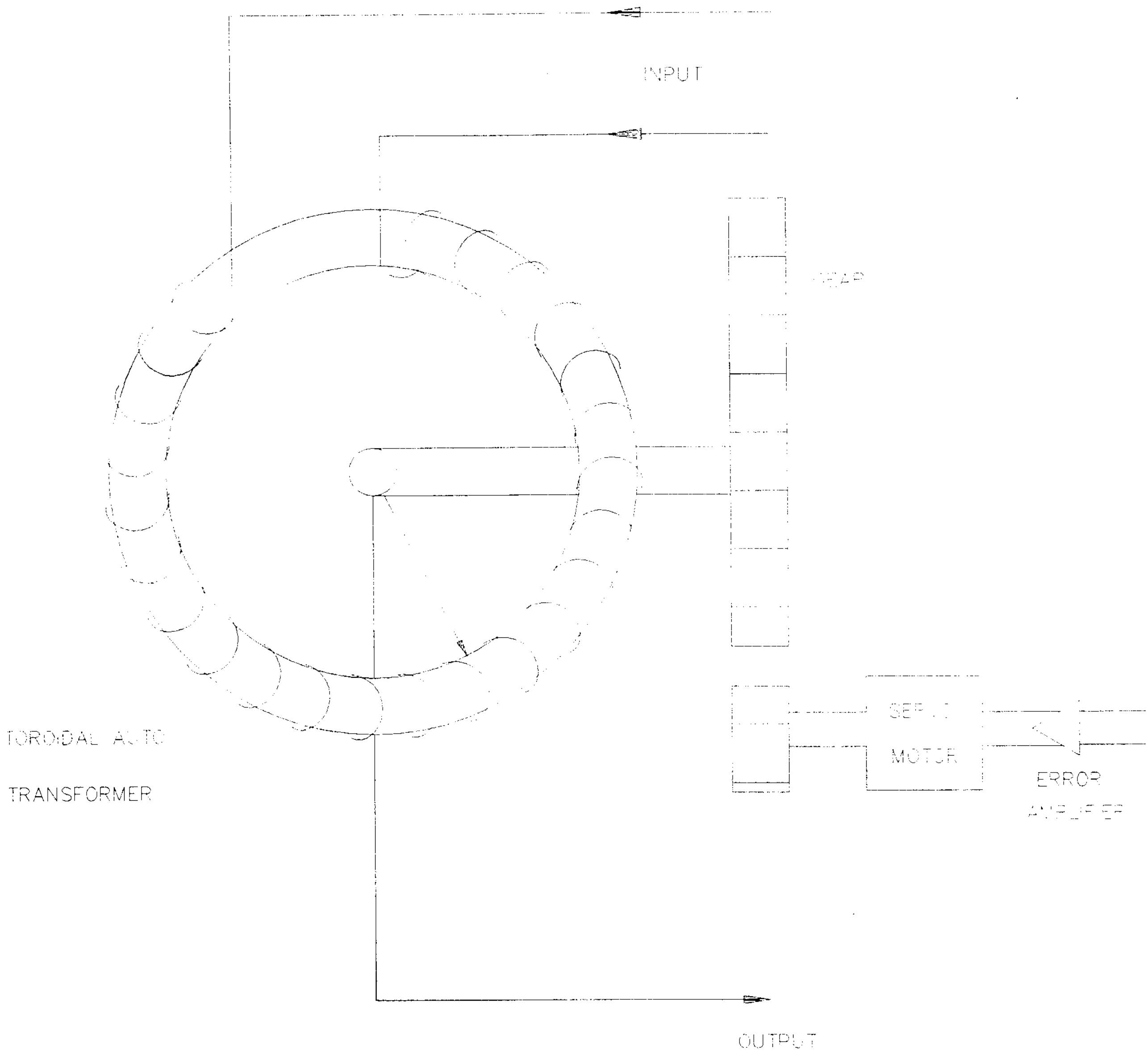
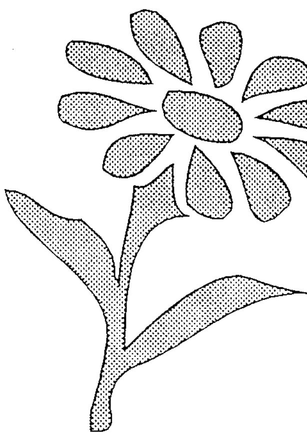


FIG 1.3 SERVO STABILIZER

CHAPTER 2



Block Diagram & Operation of the Unit

CHAPTER 2

BLOCK DIAGRAM AND OPERATION OF THE UNIT

The Block Diagram of the automatic voltage regulator is shown in Fig. 2.1.

In general, our project is put under two categories they are transformer and PCB fabrication.

The input is first given to a step down transformer which has outputs (2), which are given to the control card. The control card consist of rectifier, comparator, latch and switching devices (triac). The input to the control card is first rectified and given to the voltage regulator and comparator. The output of the comparator is provided to the switching circuits which selects the proper tapping of the transformer. Accordingly the voltage is boosted or bucked, so as to give the constant output voltage.

To explain the operation of the unit, a brief discussion on each block is made.

The supply voltage is directly given to **step down transformer**. One of the tapping from the step down transformer is given to the rectifier and other to the reference voltage generator.

The voltage provided at the **Bridge Rectifier** 'input is' rectified and dc output voltage is obtained.

This dc voltage is given to **comparator** and the constant dc voltage from reference voltage generator through the ladder network is also given to the comparator.

A comparator is a circuit which compares a signal voltage applied at one input of an op-amp with a known reference voltage at other input. The ideal characteristics of op-amp in open loop configuration is shown in Fig. 2.

There are basically two types of comparators.

i. Non-inverting comparator and

ii. Inverting comparator.

According to the application of the input signal to the non-inverting terminal or the inverting terminal respectively. The non-inverting type is been used for the purpose.

When the input signal V_i is greater than V_{ref}, the output voltage is at $+V_{sat}$. and V_0 goes to $-V_{sat}$ when input signal goes less than the reference voltage.

The output of the comparator is given to the **latching device**. A group of flip-flops sensitive to pulse duration is usually called a latch.

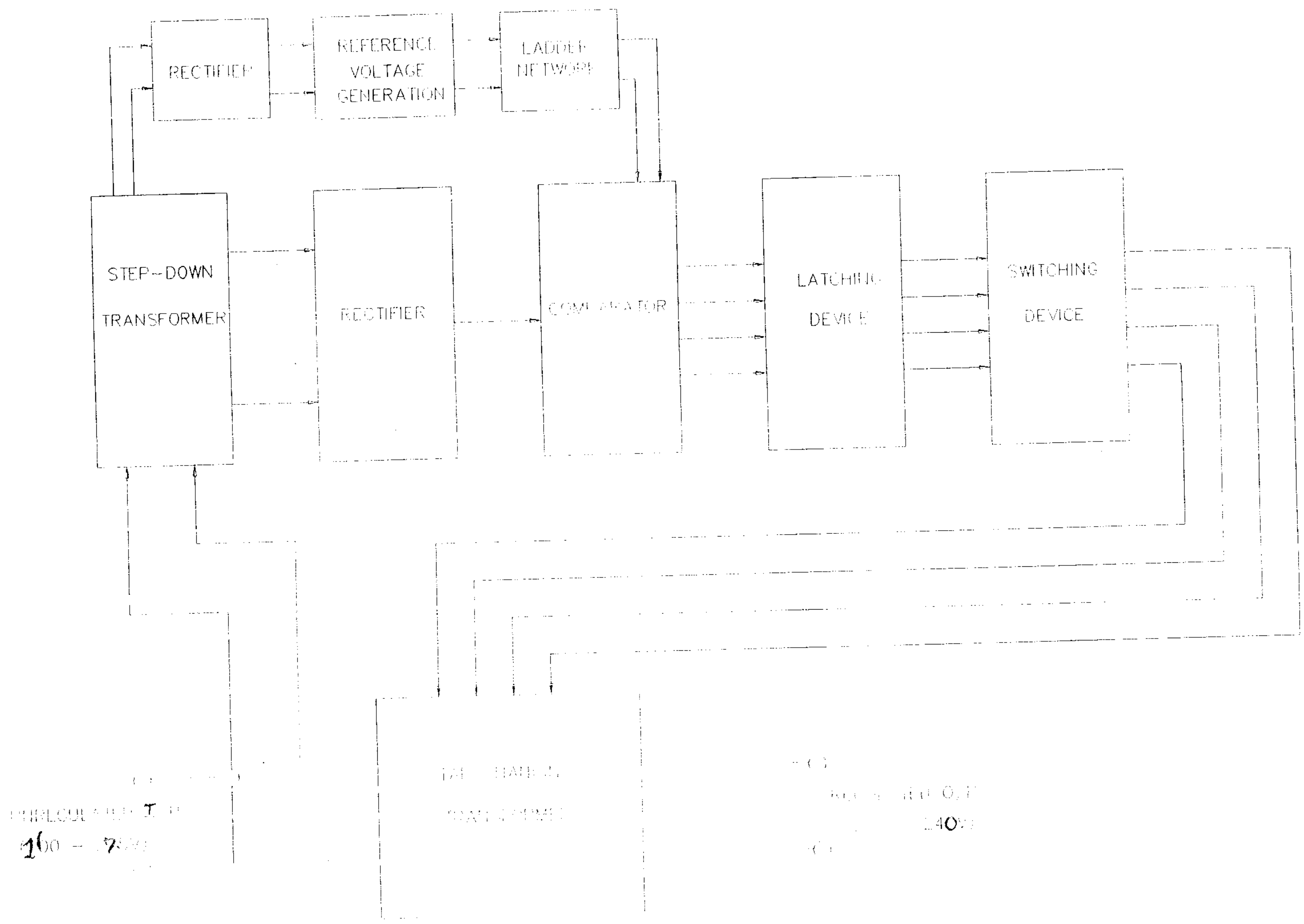
Latches are suitable for use as temporary storage of binary information that is to be transferred to an external destination. They should not be used in the design of sequential circuits that have feedback connections (combinational gates).

The output of latch is given to the **switching circuits** which is the transistor - triac combination used on the switch.

Without any trigger pulse, the triac blocks conduction and is like an open switch. If the applied voltage exceeds beyond a 'blocking voltage', it would conduct however. As this phenomenon occurs in both directions, the triac is self-protected against destruction by high-voltage transients, provided the load current and its rate of rise are within limits.

The triac which is been triggered, selects the proper tappings in the **main transformer**. The transformer is of shell type designed for the capacity of 1 KVA, either boosts or bucks the voltage depending upon the input voltage.

BLOCK DIAGRAM :



CHAPTER 3

Control Circuit

CHAPTER 3

CONTROL CIRCUITS

The important role of the control circuit is the selection of the particular stage corresponding to the input voltage level.

We refer so, because this circuit have the control over the lines triggering the triac of switching circuit. This part of the circuit includes ladder network, op-amp comparator, EX OR gates and latch. The brief description about these devices and some specific characteristics corresponding them are highlighted in this chapter. It also includes details about IC regulators for constant voltage generation.

3.1 OPERATION OF THE VOLTAGE CONTROL CIRCUITRY

The circuit diagram of the control circuit is as shown in the Fig. 3.1. The function of the control circuit is to select the voltage range depending upon the input voltage to trigger the particular triac which selects the tapping of the voltage transformer for boosting the voltage or buck in of the voltage.

The control circuit consists of the ladder network for dividing the voltage, the opamp, the EX OR gate and the latch. The constant voltage (+5V) is given to the negative terminal of the op-amp through the resistor ladder as shown. Now the input voltage is stepped down using the 230/8V transformer and is given to the bridge rectifier. The output of the bridge rectifier is given to the +ve terminal of the op-amplifier. Now depending upon the input voltage, any one or more of the op-amp output goes high and the rest goes low. The output of two consecutive op-amp is given as input to the two input terminals of the EX OR gate. Depending upon the input value the EX OR gate output goes high or low. At a time, only one of the gate output is high and the output is given to the triac through the latch which conducts when a clock pulse is given. The clock pulse is given to the latch such that the latch conducts only when the input voltage wave crosses zero. This is done inorder to avoid arc which will be produced when the latch conducts during the other period of the voltage waveform. Thus the operation of the whole control circuit is explained.

3.2 LADDER NETWORK

The constant voltage from voltage regulator circuit is given to the negative terminal of the op-amp as reference voltage through set of parallel resistors connected parallely as shown in Fig. 3.1.

The resistor value are designed such that the comparator stage has highest reference voltage and other stages have in decreasing order. The design is also based on the particular voltage at which the particular comparator stage should go high. Now depending upon the value input rectified voltage, the comparator stages are either high or low. Using the ladder, by changing the value of resistors, the range of voltage between one comparator stage and the other comparator stage output high can also be altered and hence input range can be divided as required.

3.3 COMPARATOR SECTION

3.3.1 FUNCTION OF COMPARATOR

A comparator is a circuit which compares a signal voltage applied at one input of an op-amp with a known reference at the other input. The non-inverting comparator is used for the purpose with the rectified input given to the non inverting terminal and reference to the inverting terminal.

The general circuit representation of a non-inverting op-amp comparator and its input and output waveforms are as shown in Fig. 3.2 (a) and (b). The truth table of the comparator are given below.

Voltage Input	**Logic Output X**
$V_a > V_b$	x = 1
$V_a < V_b$	x = 0
$V_a = V_b$	Previous value

V_a, V_b - Voltage applied to non inverting and inverting terminal respectively

3.3.2 DESIGN OF COMPARATOR

The circuit shown in Fig. 3.2 (a) suffers from one basic drawback in that if the input signal is a slowly varying low level signal, the comparator may be forced to stay within its linear region between the output high and low states for an undesirable length of time. This happens, it runs the risk of oscillating since it is basically an uncompensated, high gain op-amp. To prevent this, a small amount of positive feedback or hysterisis is added around the comparator. Fig. 3.3 shows a comparator with a small amount of positive feed back. In order to insure proper comparator action, the comparator should be chosen as follows :

$$R_{PULL\text{-}UP} < R_{LOAD}$$

$$R_1 < R_{PULL\ UP}$$

This will insure that the comparator will always switch fully upto V_{cc} and not to be pulled down by the load or feed back. The amount of feed back is chosen as follows.

Let V_1 be the hysterisis width.

R_1, R_2 be the resistors.

The known reference voltage V_{ref} is given to the inverting terminal.

The voltage at the input of non-inverting terminal ($V_{IN\text{-}1}$) $= \dfrac{V_{ref}(R_1 + R_2)}{R_2}$

$$\text{Since } V_{ref} = \frac{V_{IN-1}\ R_2}{R_1 + R_2}$$

After the instant of turn on,

The voltage at non-inverting terminal (V_A) $= \dfrac{(V_{IN} + V_{cc} - V_{IN-1})}{R_2}$

To make the comparator switch back to its low state (V_0 = GND)

Now the input voltage at the non-inverting terminal (V_{IN2}) $= \dfrac{V_{ref}(R_1 + R_2)-V_{cc}R_1}{R_2}$

Since

$$V_{ref} = V_{IN2} \frac{R_2}{R_1 + R_2} + V_{cc} \frac{R_1}{R_1 + R_2}$$

Therefore $V_{ref}\, R_1 + R_2 = V_{IN2}\, R_2 + V_{cc}\, R_1$

$$\text{Hysterisis} \quad V = V_{IN1} - V_{IN2} = \frac{V_{cc}\, R_1}{R_2}$$

3.4 EXCLUSIVE OR SECTION

It is a combinational circuit, since its output is independent of the previous state and only depends on the present state inputs.

The logical symbol and truth table for the Exclusive OR gate are as shown below.

TRUTH TABLE

A	B	C
0	0	0
0	1	1
1	0	1
1	1	0

When the input voltage goes higher than the reference voltage, the comparator output goes high. Both the inputs of the comparator are given the dc value and hence as soon as the input voltage increases or reduces than the reference voltage, the comparator output goes high or low immediately.

The general truth table of the four stage comparator with the EX OR gate output for this particular application with the voltage ranges are given below.

	Comparator O/P				EX OR Gate O/P			
INPUT VOLTAGE	C_1	C_2	C_3	C_4	Y_1	Y_2	Y_3	Y_4
< 160			TRIP		-	-	-	-
160-190 V	1	0	0	0	1	0	0	0
191-210 V	1	1	0	0	0	1	0	0
211-245 V	1	1	1	0	0	0	1	0
246-275 V	1	1	1	1	0	0	0	1
> 275 v			TRIP					

Depending on the input voltage, the output of one or more of the comparator goes high as shown in the truth table. If the input voltage is less than 160 V, none of the comparator output goes high and hence the output is zero.

If the input voltage is in the first range ie. 160 V - 190 V the first comparator output goes high. Now only one of the EX-OP gate is high and the other is low of the first EX-OR gate and hence the output Y_1 alone is high and other outputs are low. The output is carried to the latch.

When the input voltage is in the second stage, the two comparators C_1 and C_2 goes high as its input voltage is higher than the reference voltage. Now the input for the first EX-OR gate are high and hence the Y_1 is low, but now Y_2 goes high as only one of its input C_2 alone is high and C_3 is low.

When the input voltage is in the third stage, three of the comparator goes high simultaneously due to the comparator operation. The input for EX-OR gate 1 are both high and hence Y_1 is low. Similarly Y_2 is also low but now the C_3 is high and C_4 is low which is the input for EX-OR gate 3 and hence its output goes high and is carried to the latch.

When the input voltage is in fourth stage, all the comparator stage output goes high and hence Y_1, Y_2 and Y_3 are low. Now the input for the fourth gate are C_4 and other is low and hence now the output Y_4 is high and this is carried to the latch. If the voltage goes above 275V, the circuit switches off or trips off and hence the output voltage is zero. Thus depending on the input, the output is carried to latch through the comparator.

The circuit diagram for upper cut off is as shown in Fig. 3.4. The comparator input is given such that comparator output is always high for voltages less than 275 V. As the comparator output is high, the transistor is on and this closes the switching circuitry.

When the voltage goes above 275 V, the comparator input becomes such that the output goes low. So the transistor is switched off and now the switching circuitry becomes open circuited. Thus the upper cut off is designed so that the output is zero for voltages higher than 275 V.

The input voltage does not remain constant but oscillates. But as per the circuit, if the input voltage goes slightly say 1 V above the reference voltage, the output goes high and if dips below, the output reduces to low stage. Now if the voltage is oscillating around, the comparator stages goes on and off and hence the triacs are triggered on and off often. This difficulty is overcome by the hysteresis property of the op-amp. When the comparator output is high and due to oscillations, if the input reduces but not much, the output does not go low.

Thus the different stages are selected and the output is carried to the latch.

3.5 LATCH

A group of flip-flops which are sensitive to pulse signal is called a latch. A flip-flop is the one which can maintain a binary state as long as power is delivered to the circuit or until it is directed by an input signal.

The latch used for this particular application is 74LS374. It is a 20 pin IC with 8 inputs and 8 outputs. The input of one of the flip-flop does not affect the other output. This particular application requires only 4 stages and even if the number of stages is increased, this can be used. This has a latch enable pin. If a clock pulse is given to this pin, the output is low. The clock pulse is generated such that pulse is given when the input voltage crosses zero. This is done in order to avoid the arc produced. The output from the particular comparator stage is stored in flip & flop and when the pulse is given this is carried to the triac.

3.6 REFERENCE VOLTAGE GENERATION

The function of a voltage regulator is to provide a stable dc voltage for powering other electronic circuits. A voltage regulator should be capable of providing substantial output current. Voltage regulators are classified as :

i. Series regulator and

ii. Switching regulator.

Series regulators use a power transistor connected in series between the unregulated dc input and the load. The output voltage is controlled by the continuous voltage drop taking place across the series pass transistor. Since transistor conducts in active or linear region, these regulators are also called linear regulators. With advent of micro-electronics, it is possible to incorporate the complete circuit on a monolithic silicon chip. This gives low cost, high reliability, reduction in size and excellent performance.

Examples for monolithic regulators,

78XX/79XX series and 723 general purpose regulators.

78XX series are three terminal, positive fixed voltage regulators. There are seven output options available such as 5, 6, 8, 12, 15, 18 and 24 V. In 78XX, the last two numbers (XX) indicate the output voltage. This fixed voltage generated is used for powering electronic circuits such as ladder and for other IC's.

This particular application requires +5V for powering other electronic circuits such as ladder. We choose 7805, since it is a positive voltage regulator and give output of +5V. Its standard representation is shown in Fig. 3.5.

This IC has three terminals, the input, output and the ground. The unregulated 13V supply is given to the input terminal through capacitance filter.

The regulated constant +5V output is obtained at output terminal.

The characteristics of this IC regulator are listed below :

1. $V_{in} \geq V_o + 2$ Volts : The unregulated input voltage must be atleast 2V more than the regulated output voltage. For eg. $V_0 = 5V$, then $V_{in} \geq 7V$.

2. $I_{(0)max}$: The load current may vary from 0 to rated maximum output current. The IC is usually provided with a heat sink, otherwise it may not provide the rated output max. current.

3. Thermal shut down : The IC has a temperature sensor (built in) which turns off the IC when it becomes too hot (usually 125° to 150° C). The output current will drop and remain there until the IC has cooled significantly.

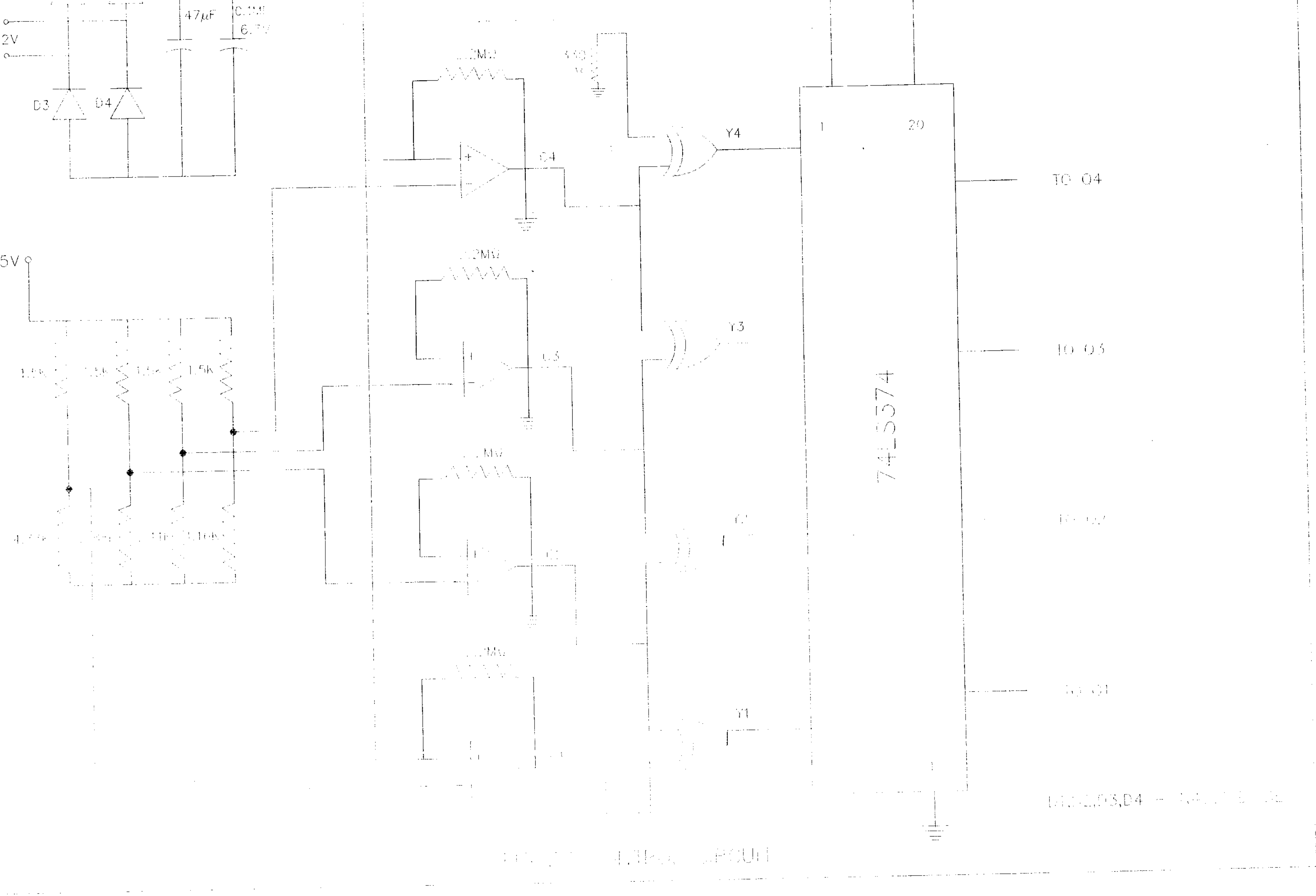
4. Ripple Rejection : The IC regulator not only keeps the output voltage constant but also reduces the amount of ripple voltage. It is usually expressed in dB. Typical value for 7805 is 78dB.

5. Load and line regulation : Typical value of load regulation for 7805 is 15mV for 5mA < I_0 < 1.5A. The typical value for line regulation from the data sheet of 7805 is 3mV.

3.7 ZERO CROSSING DETECTING CIRCUIT

When the stage changes from one to the other at highest voltages arc is produced. To avoid this the latch should be enabled at the zero crossing instant of the input voltage. This zero crossing detector circuit is shown in Fig. 3.6.

The input voltage to the transistor is given from the bridge rectifier output. Whenever the input base emitter voltage (V_{BE}) is greater than 0.7V, the transistor is switched on. Hence there will be no enable signal to the latch and the latch is disabled. When the input voltage is at zero, the transistor input (V_{BE}) is zero and it is switched off. Now the regulated supply +5V is given to the latch and hence the latch is enabled.



2V
47μF
D3
D4
5V
1.5K
Y4
Y3
Y1
1
20
74LS574
TO O4

NON-INVERTING COMPARATOR

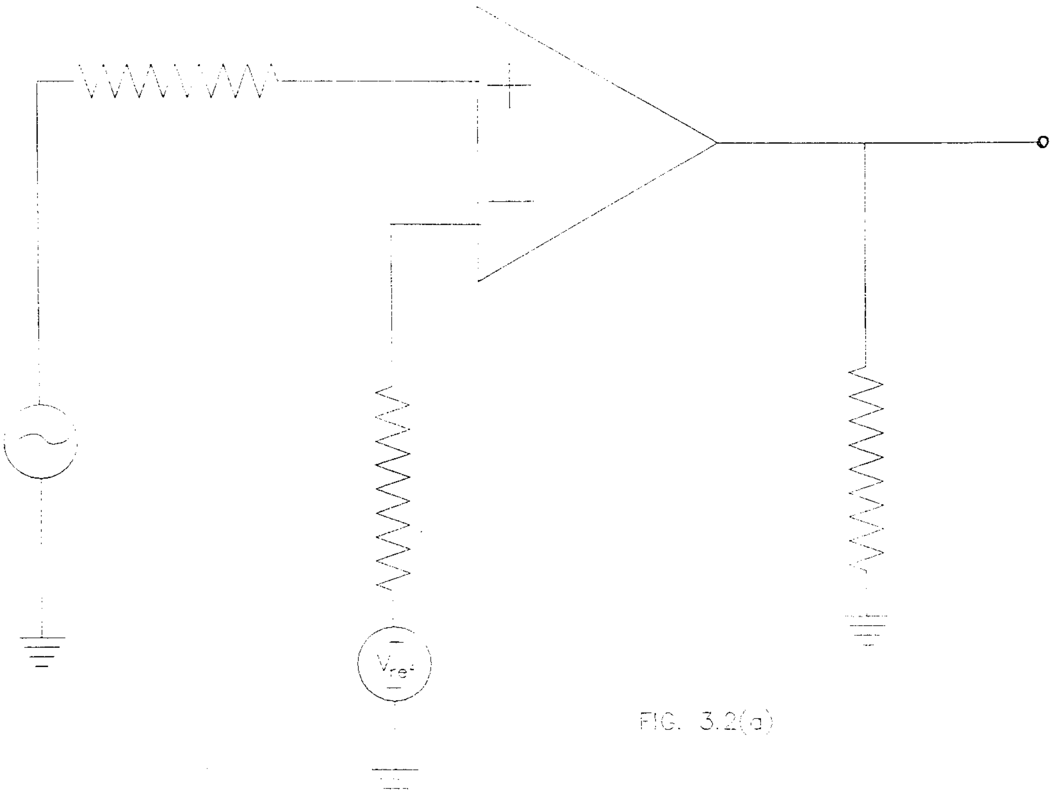


FIG. 3.2(a)

INPUT AND OUTPUT WAVEFORMS

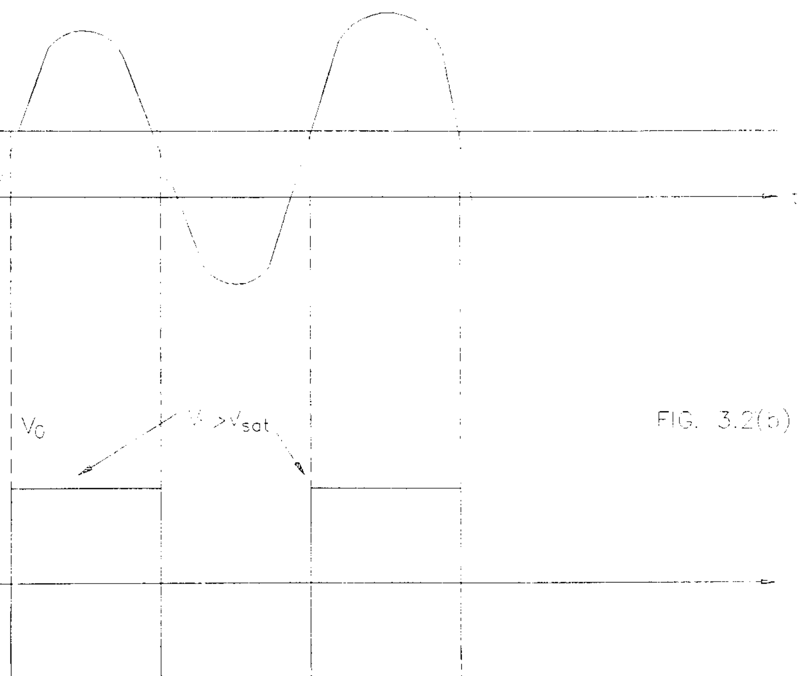


FIG. 3.2(b)

NON-INVERTING COMPARATOR WITH HYSTERESIS

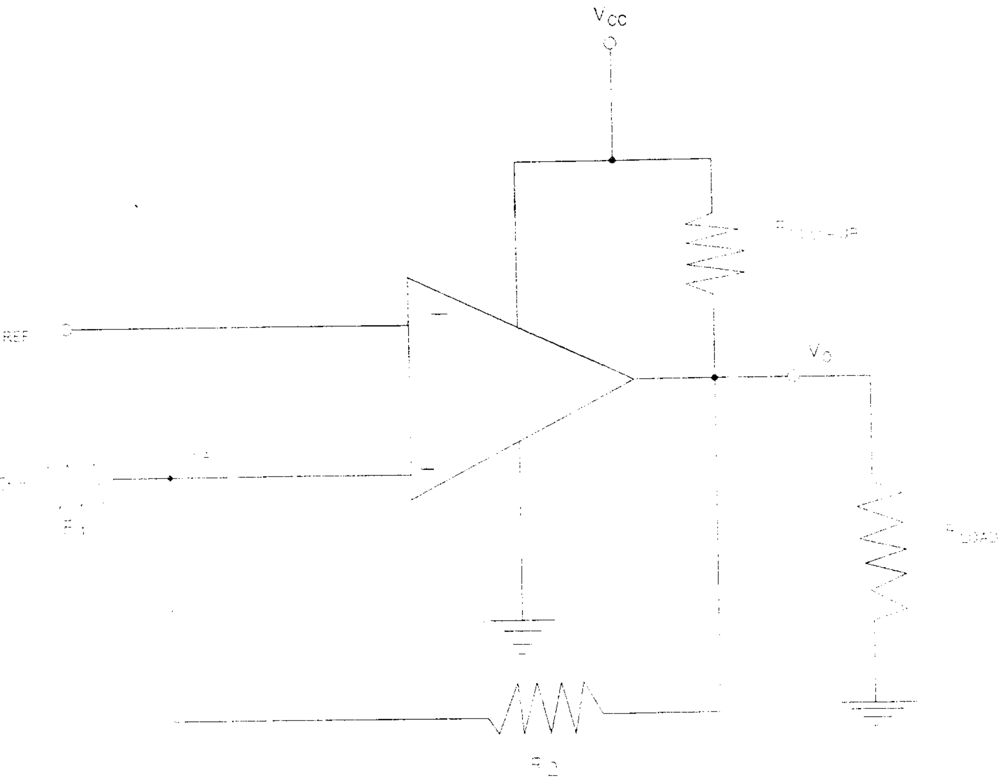


FIG 3.3(a)

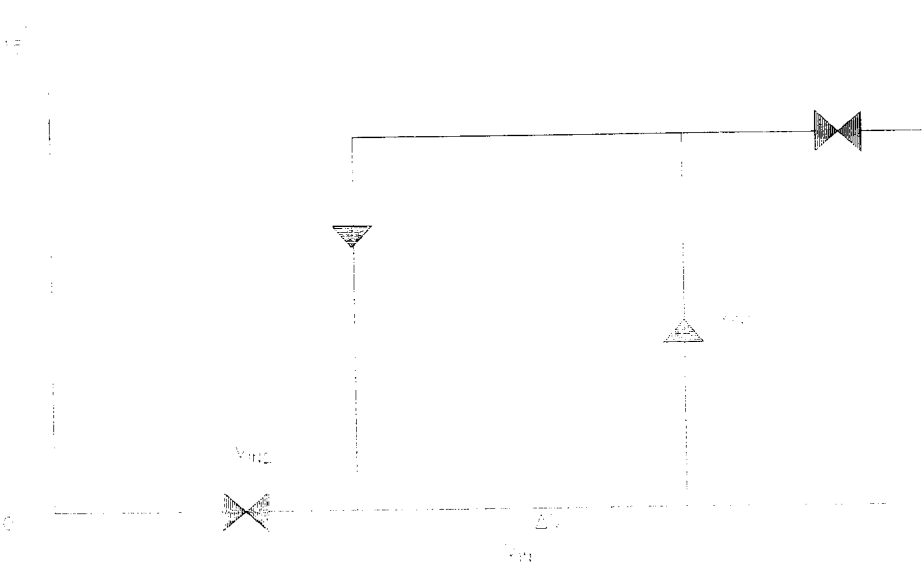


FIG 3.3(b)

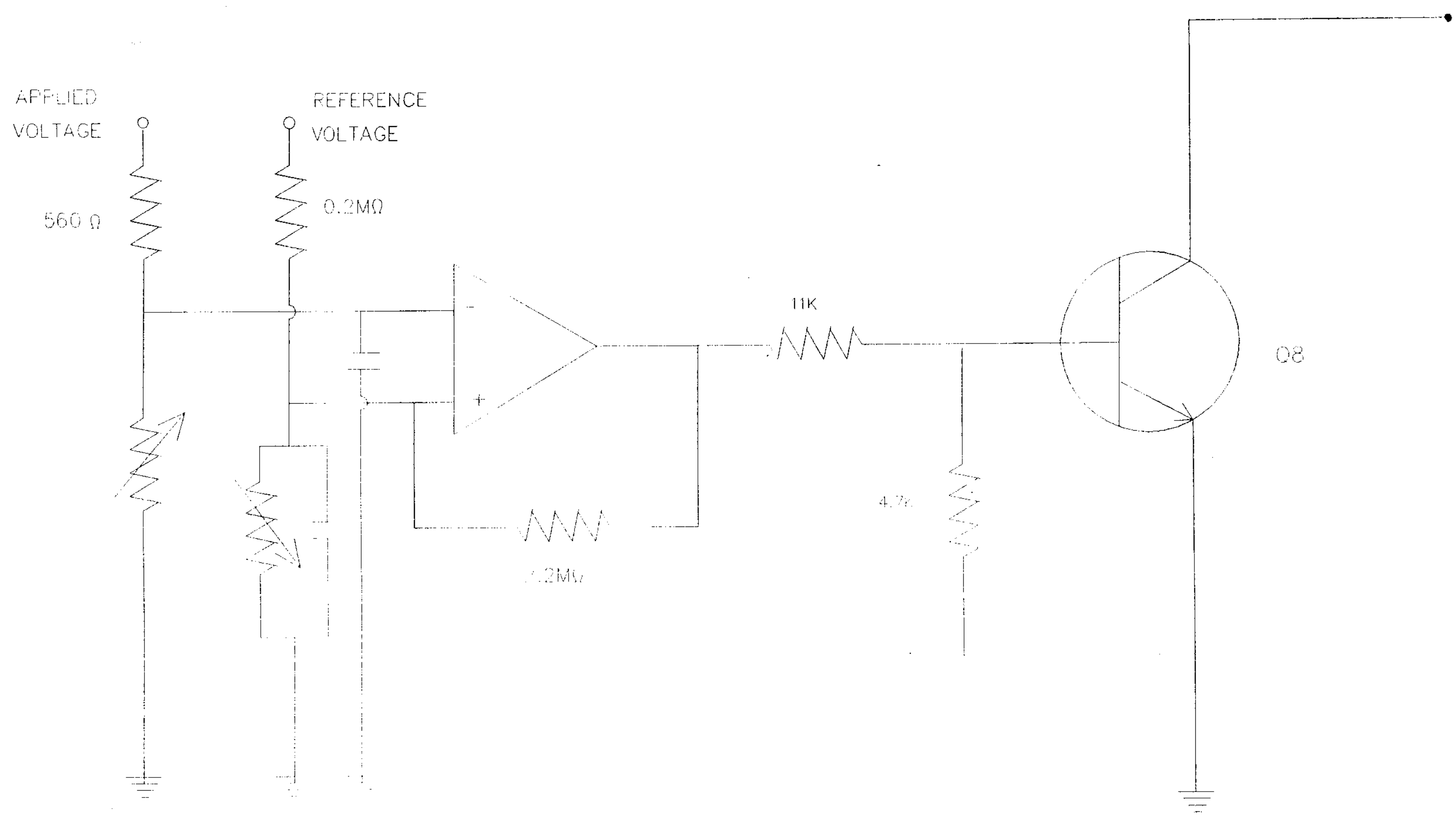
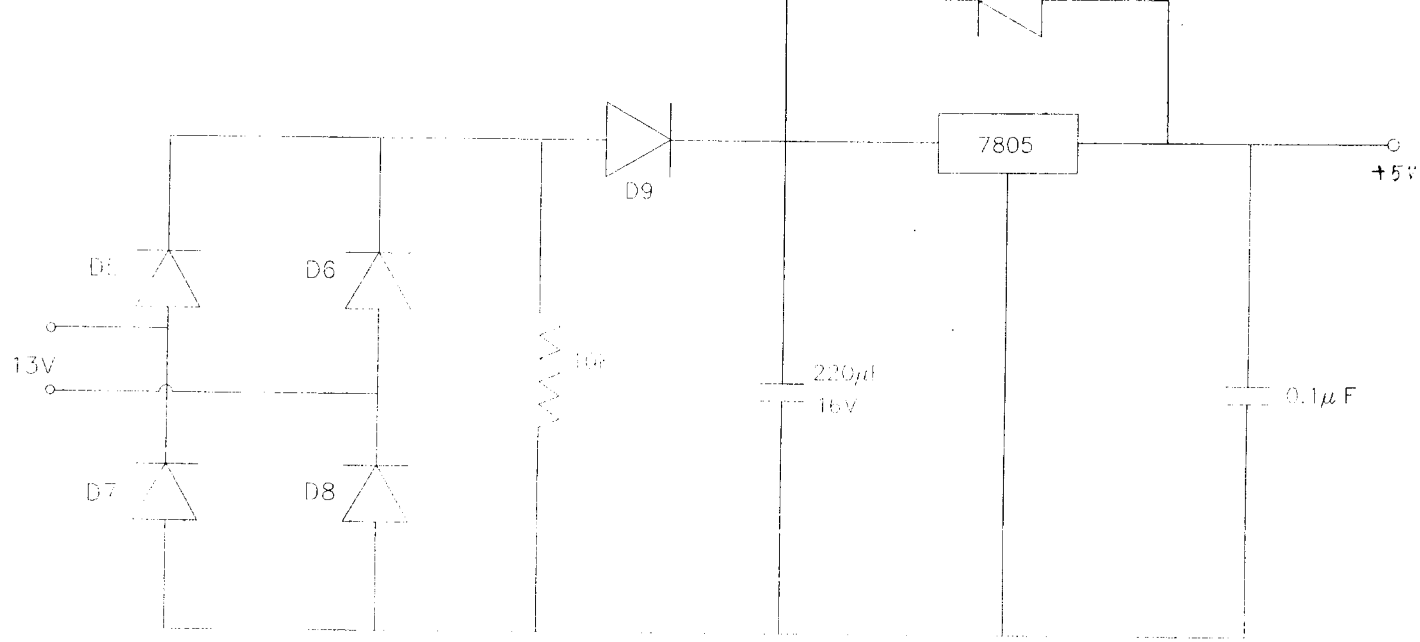
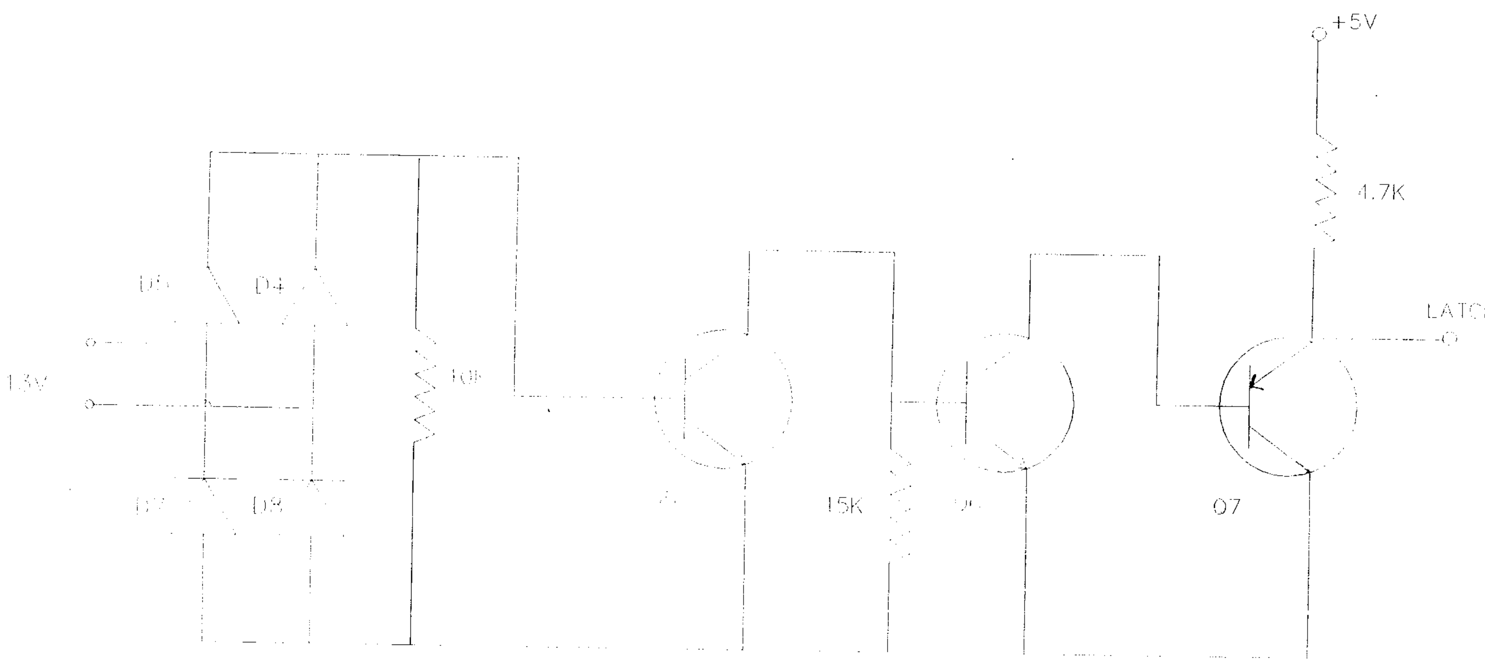


FIG [illegible] CIRCUIT FOR UPPER CUTOFF



7805 - REGULATOR IC

FIG. 2.5 REFERENCE VOLTAGE GENERATION



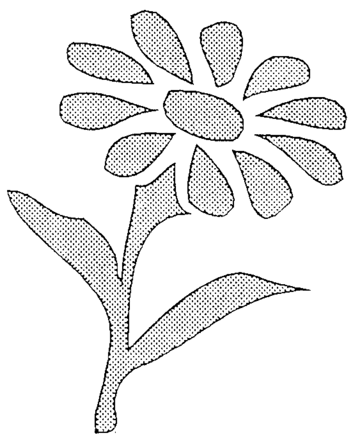
[illegible] – [illegible]N TRANSISTOR

[illegible]7 – [illegible]P TRANSISTOR

[illegible] D8 – [illegible]4001 DIODE

[illegible] 3.6 [illegible]

CHAPTER 4



Switching Circuit

CHAPTER 4

SWITCHING CIRCUIT

The purpose of this part of this circuit in the control card is to act as switch, hence we refer to this as switching circuit. This chapter explains at which part, this circuit is included and how it is operated. It also includes a brief description about the devices used. Such as triggering of the devices, protection circuits and its design.

4.1 GENERAL OPERATION OF THE CIRCUIT

This part consists of transistor and triac as shown in Fig. 4.2.

The output of the control circuit is given to the switching circuit through four leads. Each lead triggering a separate transistor - triac combination. The output of the switching circuit is given to the tapping transformer which selects a proper tapping according to the input voltage level so as to maintain a constant output voltage.

The output of the control circuit is given to the base of transistor (NPN configuration). When signal to the base of the transistor goes high, the transistor gets into 'ON' state which makes the flow of current through the GATE of the TRIAC and the TRIAC is triggered.

4.2 TRIAC - GENERAL DESCRIPTION

The triac is a thyristor controllable in both directions. Its voltage-current characteristic and circuit symbol are shown in Fig. 4.1.

A triac is a power semiconductor device with a special p-n-p-n structure. It has three pins, Main Terminal 1 [MT_1], Main Terminal 2 [MT_2] and Gate (G). It can conduct alternating current in both half cycles and it is like two thyristors connected in parallel, one pointing towards right and another towards left. A trigger pulse is required to initiate conduction in any half cycle of the AC wave.

4.3.1 TRIGGERING OF TRIAC

Without any trigger pulse, the triac blocks conduction and is like an open switch. If the applied voltage exceeds beyond a 'blocking voltage', it would conduct however. As this phenomenon occurs in block directions, the triac is self protected against destruction by high voltage transients provided the load current and its rate of rise are within limits.

Normally, the triac fire by application of positive or negative trigger pulses to its gate and MT_2 pins. But in this case steady dc voltage is applied for triggering.

The current through a triac should drop to zero inorder to cut off condition. With unity power factor loads, this occurs at zero crossing and slightly later in the cycle for lower power factor loads. It must be triggered in each and every half cycle to continue conduction.

In AC power applications, there are two uses of a triac.

a. To control the AC voltage by varying the trigger pulse angle.

b. To use it as a switch, by triggering it at zero crossings of the AC wave. The switch is open if no trigger pulse are given to gate. It is closed either if pulses are given continuously twice every AC wave, at each zero crossing or applying the steady dc voltage.

It is the second application that is employed in this circuit. There are four triacs, one of which is switched on as per the input voltage level, and all the rest then remain in the off state.

4.2.2 PROTECTION CIRCUIT

With forward voltage across the MT_2 and MT_1 and a Triac among the three junctions, two junctions are forward biased but the remaining one junction is reverse biased. This reverse biased junction has the characteristics of a capacitor due to charges existing across the junction. If the entire voltage (V_a) appears across the reverse biased junction and the charge is denoted by Q, then a charging current i given by following equation.

$$i = \frac{dQ}{dt}$$

$$= \frac{d}{dt}(C_j V_a)$$

$$= C_j \frac{dV_a}{dt} + V_a \frac{dC_j}{dt}$$

As C_j, the capacitance of junction is almost constant, the current is given by

$$i = C_j \frac{dV_a}{dt}$$

If the rate of rise of forward voltage dV_a/dt is high, the charging current i will be more. This charging current plays the role of gate current and turns on the Triac even when gate signal is zero. Such phenomena of turning-on a Triac, called dv/dt turn-on, must be avoided as it leads to false operation of the

Triac circuit. For controllable operation of the Triac, the rate of rise of forward voltage dV_a/dt must be kept below the specified rated limit.

False turn on of a Triac by large dV_a/dt can be prevented by using a snubber circuit in parallel with the device.

4.2.3 SNUBBER DESIGN

$$\frac{dv}{dt} = \frac{0.632\ V_s}{\tau}$$

$$= \frac{0.632\ V_s}{R_s C_s}$$

Where, V_s - applied voltage = 270 V

$$\text{Selected} \quad \frac{dv}{t} = 50\ \text{V/msec}$$

$$R_s C_s = \frac{0.632 \times 270}{50 \times 10^6}$$

$$= 3.4128 \times 10^{-6}$$

Choose $C_s = 0.1\ \mu F$.

$$R_s = \frac{3.4128 \times 10^{-6}}{0.1 \times 10^{-6}}$$

$$= 34\ \Omega$$

$$R_s = 33\ \Omega$$

$$C_s = 0.1\mu F$$

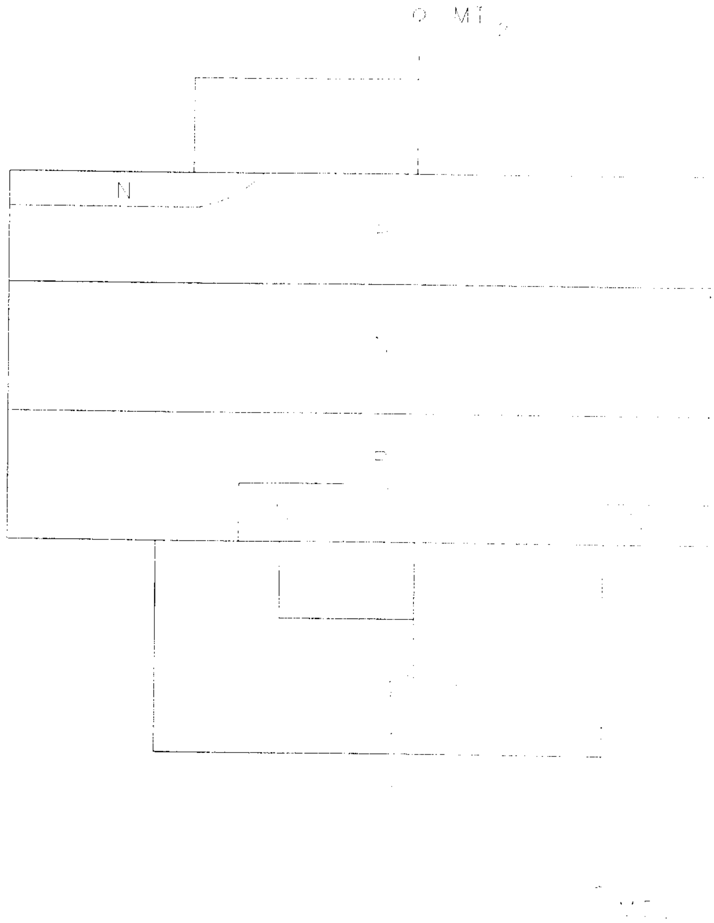
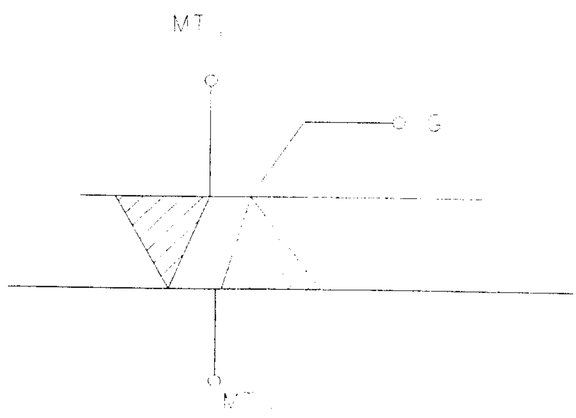
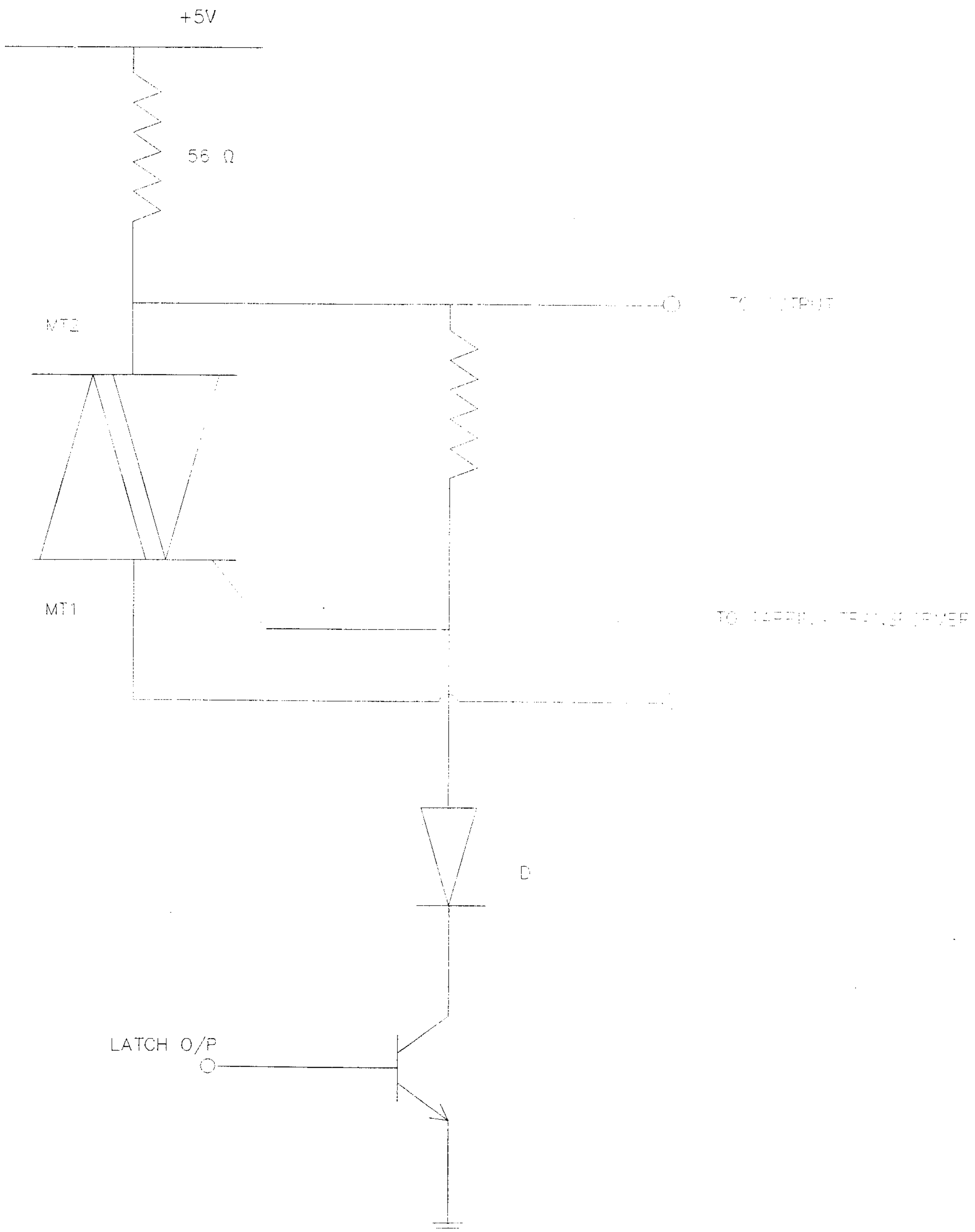


FIG.4.12 TRIAC STRUCTURE

SYMBOL



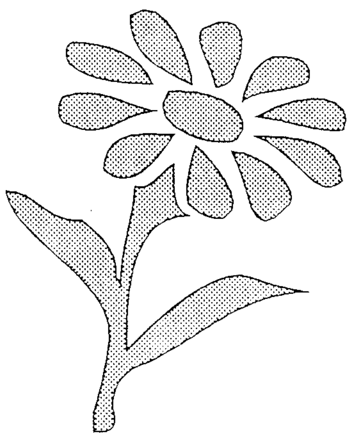


D – DIODE IN4001

Q – NPN TRANSISTOR

FIG 4.2 SWITCHING CIRCUIT

CHAPTER 5



Transformer

CHAPTER 5

TRANSFORMER

The unit consist of two transformers, one of which is a control transformer and other one is the main transformer.

The control transformer is a step down transformer which lowers the voltage. There are two outputs tapped from the control transformer. The input to the control transformer is the supply voltage and its outputs are 8V and 13V.

The main transformer of capacity 1KVA is a tapping transformer, which has four tappings. The output range across the tappings is given by 0 - 25V - 55V - 85V. Once the proper tapping is been selected. That amount of secondary voltage is combined with primary voltage through phasor addition or subtraction. So as to maintain constant output voltage.

This chapter discusses about the general description about the construction of the transformer and the steps involved in the design of the transformer. The design calculations are also made with use of the program in the C language to make the calculation ease. And tables required for the design is also attached at the end.

5.1 GENERAL DESCRIPTION

The transformer is basically a very simple device. It consists of windings wound on a laminated magnetic core and insulated from iron and from each other. The core is actually a magnetic circuit which serves as a path for the mutual flux. Therefore, the windings encircle the core and the core encircles the windings. There are two general types of construction employed to achieve this in transformers. Consequently, depending upon the type of construction used, the transformers are classified into two categories as :

i. core type and ii. Shell type.

We are in use of shell type transformer in which the windings are put around the central limb and the flux path is completed through two side limbs as shown in Fig. 5.1. The central limb carries the total mutual flux while the side limbs forming a part of a parallel magnetic circuit carry half the total flux. Consequently, the cross sectional area (and hence width) of the central limb is twice that of each of the side limbs.

Both high voltage (h.v.) and low voltage (l.v.) windings are divided into a number of coils. The h.v. and l.v. coils are shaped like pancakes and are arranged longitudinally along the core alternately. This gives rise to a sandwich winding with h.v coils sandwiched between l.v. coils.

In the core type the impression is created that the windings surround the core, whereas with the shell type that the cores surround the windings.

The shell type gains more importance when compared to core type transformer as far as reliability and leakage reactance is concerned. In modern power networks, the reliability of transformer operation is very important and therefore the design of the transformers should be such that the windings suffer no damage when short circuited. It is amply clear from Fig. 5.2 that windings in a shell type transformer have greater capability of withstanding forces produced under short circuit conditions as these windings are surrounded and thus braced (or supported) by the core over a large portion of length. On the other hand the windings in core type construction have a poorer mechanical strength, because they (the windings) are not braced or supported. Therefore, the windings in core type transformers are more susceptible to damage under short circuit conditions, then the windings of a shell type transformer. And also due to large space required between the high and low voltage windings, it is not easily possible to subdivide the windings to a great extent in the case of core type transformers. While in the shell type, the windings can be easily subdivided by using sandwich coils. Thus it is possible to reduce the leakage reactance of shell type transformer to any desired value.

5.1.1 TRANSFORMER CORE

The transformer core is a closed magnetic circuit through the mutual flux. i.e, the flux which links with both the winding passes. The core material and construction should be such that both magnetizing current and the core losses are minimum. The cores of transformers are laminated in order to reduce the eddy current losses. The eddy current loss is proportional to the square of thickness of the laminations. This apparently implies, that the thickness of the laminations should be extremely small in order to reduce the eddy current losses to a minimum. However, there is a practical limit beyond which the thickness of the laminations cannot be decreased further on account of mechanical considerations. The practical limit of thickness is 0.3 mm. The thickness should not be reduced below 0.3mm because in that case, the laminations become mechanically weak and tend to buckle. These laminations are made of the so called transformer grade steel containing 3-5% silicon. The higher content of silicon increases the resistivity of the core, thereby reducing the eddy current core loss. High content silicon steel is a soft iron material having a narrow hysteresis loop and thus the hysteresis losses are also small. This material has a high permeability and hence the magnetising current is also small. The steel used for transformer cores may be hot rolled or cold rolled. The hot rolled steel which permitted a maximum flux density of 1.45 wb/m^2 was in use for a considerable length of time. In recent years, this type of steel has completely been superceded by 0.33 mm (or 0.35 mm) thick cold rolled steel allowing much higher flux densities upto 1.8 wb/m^2 to be used. Although, cold rolled steel is 25-35% more expensive than the hot rolled steel, the increase in value of maximum flux density makes it possible to reduce the amount of core material.

However, the use of cold rolled steel involves a more complicated core construction and requires new methods for machining the laminations.

The hot rolled steel is sheared to size by power guillotines and then punched in multiple process with cold rolled steel, rolls of mass upto 2 tons are slit into widths by gang operated slitters. This working of cold rolled steel impairs its property and therefore it is annealed to relieve stresses. The annealing process involves heating sheets or complete small cores at 800°C in an inert atmosphere (to avoid oxidation and carbon contamination). The insulation on the surface of laminations is kaolin or varnish in the case of hot rolled steel but for cold rolled oriented steel, phosphate-base coating is used. This coating is done by the makers of the steel and can withstand annealing process. Cores of small transformers need no further insulation if made of C.R.O.S. However, the transformers of capacity 10 mVA and above kaolin or varnish must be applied to the lamination (in addition to phosphate base coating which already exists).

5.1.2 TRANSFORMER WINDINGS

The windings used in transformers are of different types and employ different arrangements for coils.

Shell type transformers use sandwich type of windings with coil shaped as pancakes. In this type of windings both low and high voltage windings are split up into a number of coils. Each high voltage coil lies (or is sandwiched) between two low voltage coils as shown in Fig. 5.2. The two low voltage coils at the ends have half the turns of a normal low voltage coil and therefore these coils are called half coils. The subdivision of low and high voltage windings into a number of coils gives a better coupling between the two windings and therefore results in lower leakage flux thereby reducing the leakage reactance. The leakage flux and leakage reactance of the windings depends upon the number of sections in which the windings are divided; the larger the number of coils (and hence sections), the lower is the leakage reactance. Therefore, the advantage of sandwich coil is that with their use the leakage reactance of the transformer can be controlled to any desired value with a suitable divisions of windings.

5.2 MAIN TRANSFORMER DESIGN

5.2.1 PRELIMINARY DESIGN

As the first step to the design of a transformer, the primary and secondary voltage ratings must be clearly stated. Thus decide on the core material to be used ordinary steel stampings or cold rolled grain oriented (CRGO) stampings. CRGO has a higher allowable flux density and lower losses.

Primary voltage	=	230 v
Secondary voltage	=	0 - 25v - 55v - 85v
Secondary current	=	4 Amps

Core area, is assumed to have a value greater than the square root of the output voltamperes.

Output voltamperes	=	85 x 4 = 340 VA
CA	=	1.052 (output volt Amperes)$^{1/2}$
	=	19.36 cm^2

This can be approximately found using the Table I, which gives the core area has 3 inch^2 corresponding to the output voltamperes.

CA	=	3 inch^2
	=	3(6.37) cm^2
	=	19.11 cm^2

Turns/volt, the flux density is assumed to be 1 Wb/cm^2

Turns/volt	=	1/(4.44 x 10^{-4} x 50 19.36 x 1)
	=	2.3267

5.2.2 PRIMARY WINDING DESIGN

Primary current, the current drawn by the primary is calculated assuming the efficiency of the transformer to be 90%

$$\text{Primary current} = \frac{(\text{sum of (o/p volts x o/p Amps))}}{\text{Primary volts x Efficiency}}$$

$$= \frac{85 \times 4}{230 \times 0.9} = 1.64$$

From table II, the value of the primary current corresponds to gauge of 20 SWG. So the wire selected is 20 SWG.

Primary turns = Turns/volt x primary volts

= 2.3267 x 230

= 535 turns

5.2.3 SECONDARY WINDING DESIGN

Secondary current = 4 Amps

From table II, the wire selected is 17 SWG

Secondary turns = Turns/volt x secondary volts

For 25v tapping = 2.3267 x 25

= 58 turns

For 55v tapping = 2.3267 x 55

= 128 turns

For 85v tapping = 2.3267 x 85

= 197 turns

5.2.4 CORE SIZE

The main criterion in selecting the core is a total window area of winding space available.

Total window area = Primary window area + secondary window area + space for former and insulation

Primary window area,

$$\text{Primary winding area} = \frac{\text{Primary turns}}{\text{Turns/inch}^2} \quad \text{from Table II}$$

$$= \frac{535}{680}$$

$$= 0.787 \text{ inch}^2$$

Secondary window area,

$$\text{Secondary winding area} = \frac{\text{Secondary turns}}{\text{Turns/inch}^2} \quad \text{from Table II}$$

$$= \frac{197}{272}$$

$$= 0.724 \text{ inch}^2$$

Some extra area is required to accomodate the former and insulation between windings. The actual amount of extra area varies, although 20% may be taken to start with but may have to be modified later. The suitable core size i.e., Type No. can be selected from Table III

$$\text{Total window area} = 1.2\,(0.787 + 0.724)$$

$$= 1.8132 \text{ inch}^2$$

This area is considered to be the available winding area and approximate winding area can be found from Table I.

i.e., for particular o/p voltamperes and core area the approx. winding area is 2 3/8 inch^2.

From table III, the Type No. is selected as Type 43.

And standard type of E and I laminations are used

From table III, width of tongue chin's corresponding to 3.0 square inch cross sectional area of core is 1 7/8 inch

$$\text{Therefore, stack height} = \frac{\text{Gross core area}}{\text{Width of tongue chin's}}$$

$$= 3 \times 8/15$$

$$= 1.6 \text{ inch}$$

$$= 1.5 \text{ inch (approx.)}$$

5.2.5 DESIGN RESULTS

Pri-wdg	:	535 turns of 20 SWG
Sec-wdg	:	0-58-128-197 turns of 17 SWG
Core	:	Type No. 43; stack 1 1/2 inch

5.3 DESIGN SPECIFICATIONS OF CONTROL TRANSFORMER

Primary voltage	-	0 - 230v
Secondary voltage	-	0-13, and 0-8v
Secondary current	-	500 mA and 100 mA respectively.

The core dimensions are 34 mm x 20 mm core Type 30 and Laminations are of standard E and 1 types

For the primary,

the wire used is 35 SWG

Primary turns are

1518 turns for 0-230v

For the secondary,

the wire used is 23 SWG for 0.5 Amps

and the wire used is 28 SWG for 0.1 Amps

Secondary turns,

86 turns for 0-13v

53 turns for 0-8v

ASSEMBLY

The windings are wound on an insulating former which fits over the central limb of the core. The primary is usually wound first, then the secondary with insulation between the windings. A final insulating layer is provided over the windings to protect them from mechanical damage.

When thin wires are used, their ends must be soldered and thicker wires for bringing the terminals outside the former. The laminations are assembled over the former with alternate laminations reversed in assembly. The laminations must be held together tightly by a suitable clamping frame or by screws (if holes are provided in the laminations).

SHIELD

It is good practice to use an electrostatic field between the primary and the secondary windings to prevent disturbances from passing through to the secondary from the primary. The shield is made out of a copper foil which is wound between the two windings for a slightly over a turn. Insulation must be provided along the length of the coil and care taken so that the two ends of the coil do not touch each other. A wire solder to the coil is brought out and connected to the ground.

5.4 COMPUTER AIDED DESIGN 'USING LANGUAGE C'

5.4.1 ALGORITHM

1. Get the input voltage in primary and secondary KVA.

2. Preliminary Design (Calculation of core area and turns/volt).

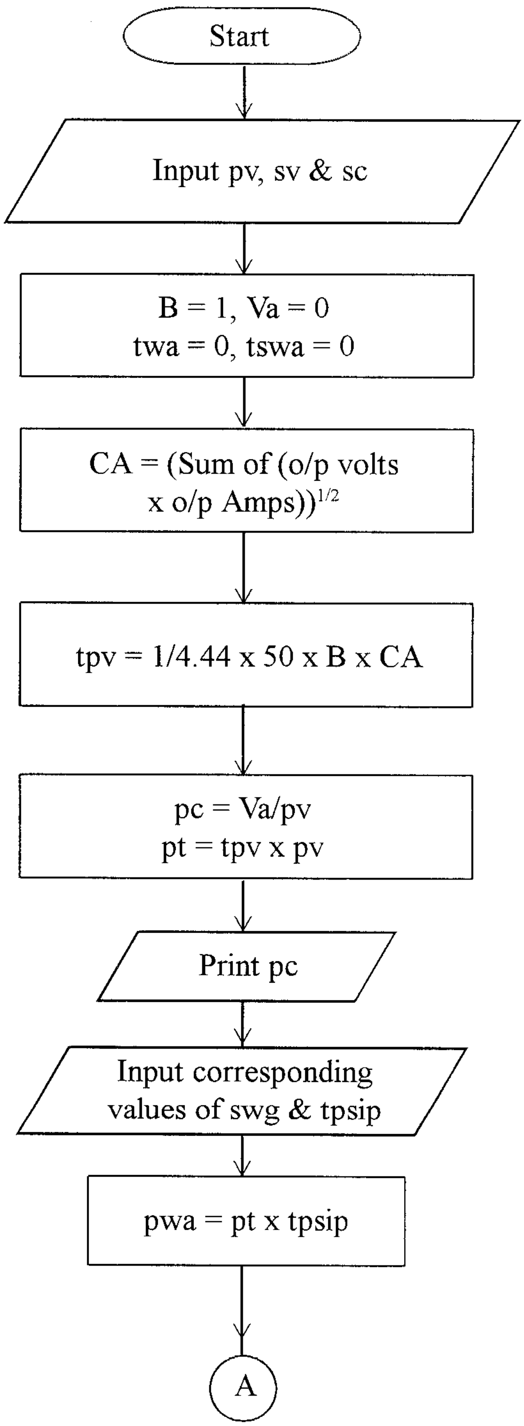
3. Design of primary winding (primary ct, turns, winding area)

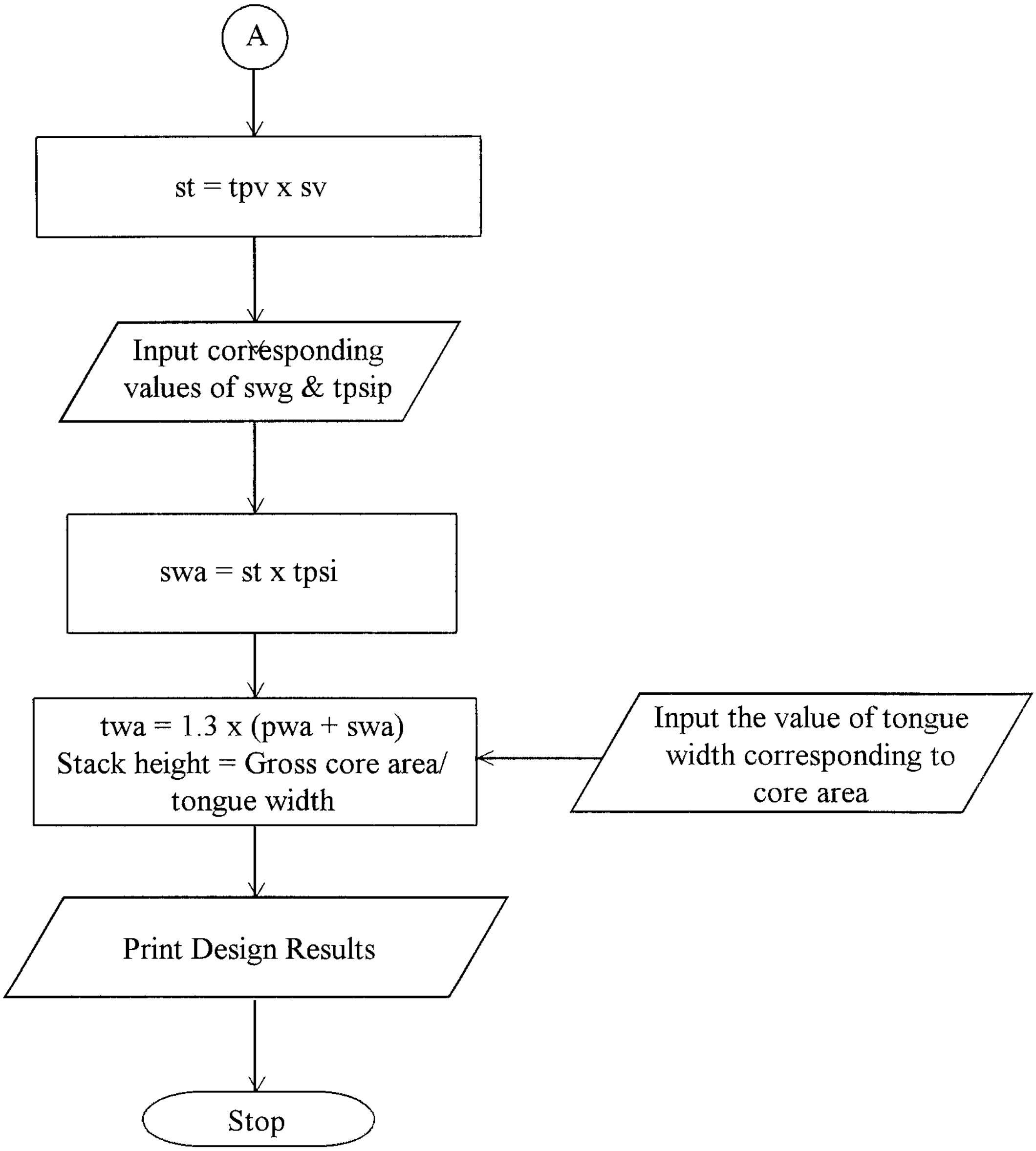
4. Design of secondary winding (secondary turns, winding area).

5. Gauge selection (SWG wire)

6. Design of coresize (Type No) and stack height.

5.4.2 FLOW CHART




A
st = tpv x sv
Input corresponding values of swg & tpsip
swa = st x tpsi
twa = 1.3 x (pwa + swa)
Stack height = Gross core area/ tongue width
Input the value of tongue width corresponding to core area
Print Design Results
Stop

PROGRAM IN LANGAUGE 'C'

```
le <stdio.h>
le <math.h>

v,sv[4],sc[4],va=0,i,ty,pswg,sswg,st[4],pt,
 ca,pc,tpv,b=1,twa=0,pwa,swa[4],tswa=0,tw,sn,
f("------------------------------------------------------------
f("give the value of primary voltage\n");
("%d", &pv);
f("give sec.voltages&currents of 4tappings\n");
=0;i<4;++i)
nf("%d", &sv[i]);
nf("%d", &sc[i]);}
ntf("preliminary design\n");
ntf("----------------------\n");
=0;i<4;++i)
va+(sv[i]*sc[i]);}
1.052*sqrt(va);
f("corearea = %f square cm \n", ca);
 1/((4.44/10000)*50*b*ca);
f("turns/volt = %f \n", tpv);
f("primary design\n");
f("-----------------\n");
va/(pv*n);
f("primary current = %f amps\n", pc);
f("give the value of gauge selected for primary\n");
("%d", &pswg);
tpv*pv;
f("primary turns = %d\n", pt);
f("give the value of turns per inch square\n");
("%f", &tpsip);
pt/tpsip;
f("primary winding area = %f square inch\n", pwa);
f("secondary design\n");
f("--------------------\n");
nf("sec.turns between the tappings on the secondary are\n");
i=0;i<4;++i)
i] = tpv*sv[i];
ntf("%d\n", st[i]);  }
ntf("give the value of turns per square inch\n");
nf("%f", &tpsi);
(i=0;i<4;++i)
[i]= st[i]/tpsi;
for(i=0;i<4;++i)
tswa= tswa+swa[i];
intf("secondary winding area %f square inch\n", tswa);
intf("give the value of gauge selected for secondary\n");
anf("%d", &sswg);
intf("core design\n");
intf("------------------\n");
wa = 1.1*(pwa+tswa);
rintf("total widing area = %f square inch\n", twa);
printf("give the type of core for corresponding winding area\n");
scanf("%d", &ty);
printf("give the tongue width\n");
scanf("%f", &tw);
```

```
printf("primary turns %d of %o swg \n[illegible]
printf("secondary turns are ");
for(i=0;i<4;++i)
tst= tst+st[i];
printf("%d-",tst);
printf("wire selected for secondary is %d swg \n[illegible]
printf("type of core %d & stack height %[illegible]
printf("-------------------------------------------------------------[illegible]
 getch();
```

```
esign
------------------------------------------------------------------------
 value of primary voltage

.voltages&currents of 4tappings




ary design
------------------
 = 19.397921 square cm
0t = 2.322158
design
------------
current = 1.642512 amps
 value of gauge selected for primary

turns = 534
 value of turns per inch square

winding area = 0.953571 square inch
y design
-----------------
s between the tappings on the secondaary or




 value of turns per square inch

y winding area 0.720588 square inch
 value of gauge selected for secondary



ign
------------
ding area = 1.641576 square inch
 type of core for corresponding winding area

 tongue width

esults
-------------
turns 534 of 19 swg
y turns are 196-wire selected for secondary is 17 swg
core 43 & stack height 1.624106 i
```

SHELL TYPE SINGLE PHASE TRANSFORMER

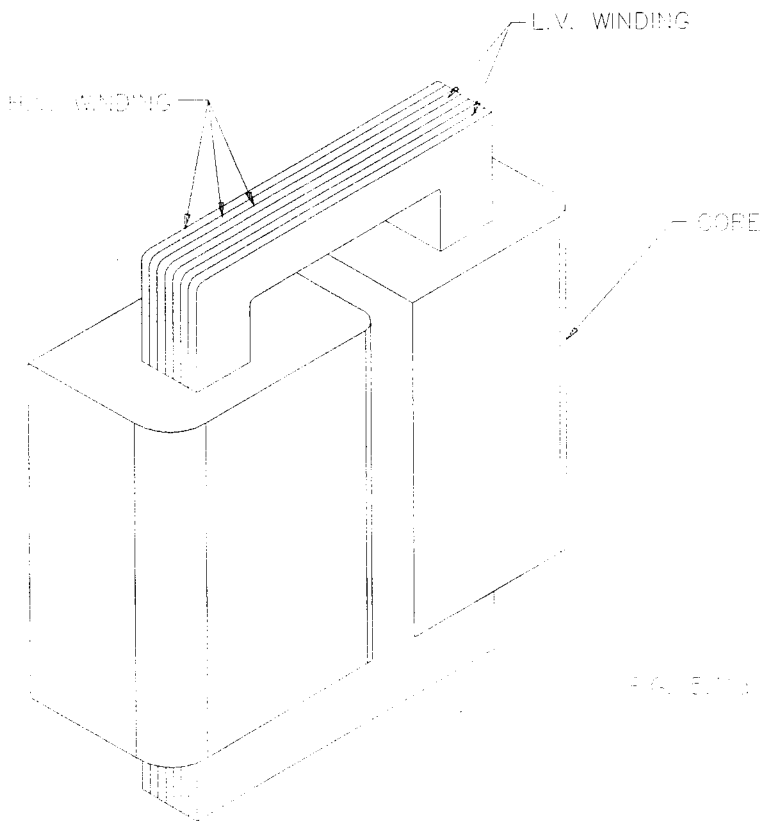


FIG. 5.1(a)

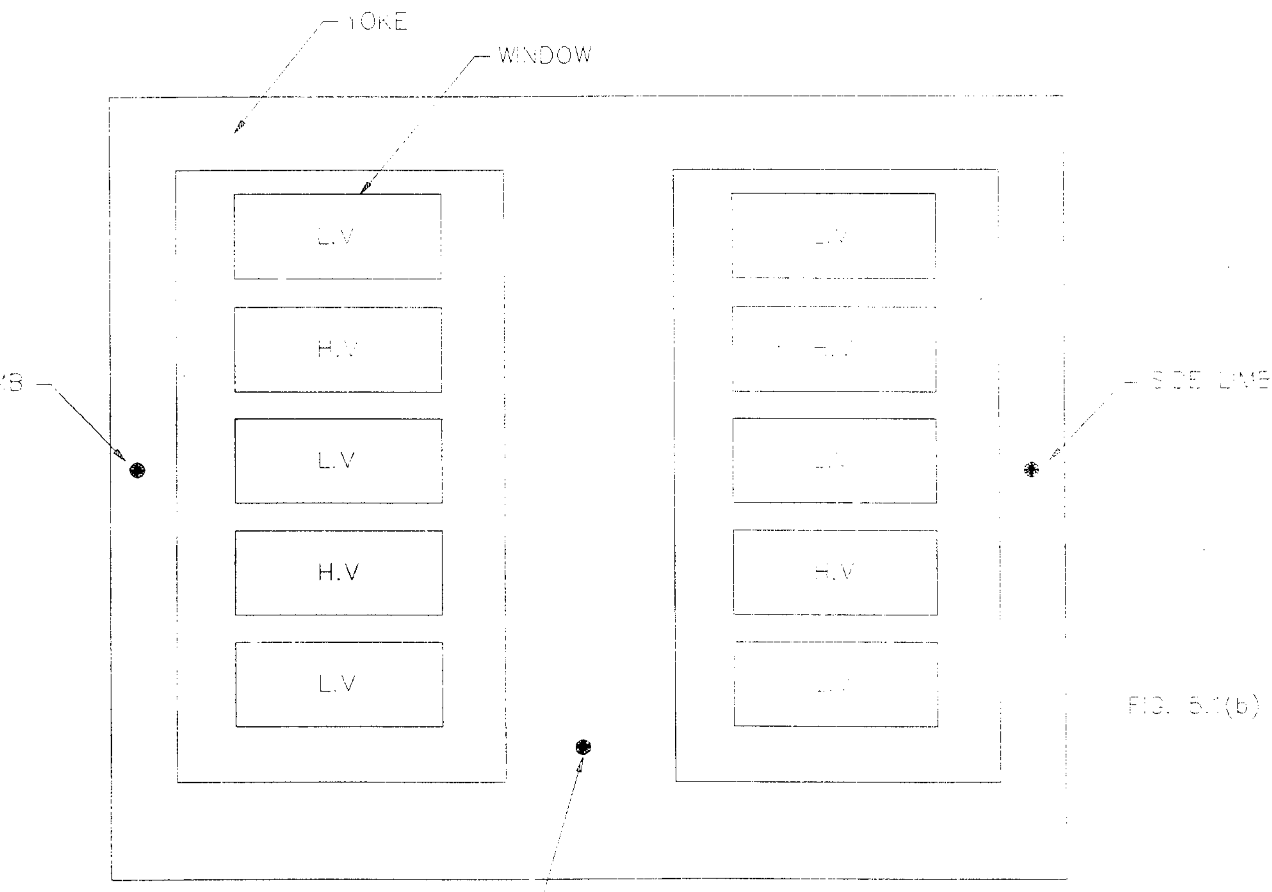
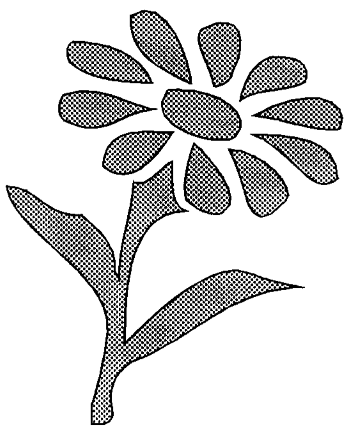


FIG. 5.1(b)



Circuit Diagram

CHAPTER 6

Features

6. FEATURES

6.1 TEST RESULTS

The volatge response of the automatic voltage controlled A.C. supply for each 10V of interval at no load are tabulated as follows

NO LOAD		LOAD (500 W)	
INPUT (V)	OUT PUT (V)	INPUT (V)	OUT PUT (V)
< 160	TRIP	160	TRIP
170	210	170	205
180	220	180	218
190	230	190	230
200	220	200	220
210	230	210	228
220	212	220	235
230	225	230	218
240	210	240	228
250	218	250	212
260	222	260	220
270	230	270	228
> 275	TRIP	> 275	TRIP

6.2 COST ESTIMATION

	Component	Quantity	Amount (Rs.)
1.	Tapping transformer core	1	400
2.	Copper wire for tapping transformer		400
3.	Control transformer	1	150
4.	Triac	4	140
5.	CD 4030	1	12
6.	LM 339	2	44
7.	IC 7805	1	15
8.	Transistor	8	16
9.	74 LS 374	1	18
10.	LED	4	5
11.	PCB cost		500
12.	IC base	4	50
13.	Other components		250
	Total		**2000**

6.3 ADVANTAGES

a. Fast acting, unlike servo stabiliser.

b. Less weight, since no bulky transformer as in case of capacitive voltage transformer.

c. Highly economical.

d. High efficiency.

e. Simple circuit! so that a single PCB can be made use of.

f. Wide range of input voltage : 160-275v.

g. Same circuit for any capacity, only total to be altered.

h. Cuts OFF automatically if supply voltage is too high or too low.

CHAPTER 7

Conclusion

7. CONCLUSION

A Digitally Controlled Automatic Voltage Regulator of 1 KVA, Input Voltage of 160 to 275 V and Output Voltage of 200 to 240 V has been designed, fabricated and tested successfully.

The main feature of this project, is the use of solid state devices in stabilisers due to which speed and efficiency of the stabiliser is improved. And this project is new to the market. It is to replace capacitive voltage transformers (abbreviated as CVT), costs more and also weighs more. Since, in recent days computer price goes on falling, it is not possible to go for CVT's which costs one third the price of computer.

Further the output voltage can be maintained within a very narrow range by increasing the number of stages.

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Appendices

A. PIN DETAILS OF ICS

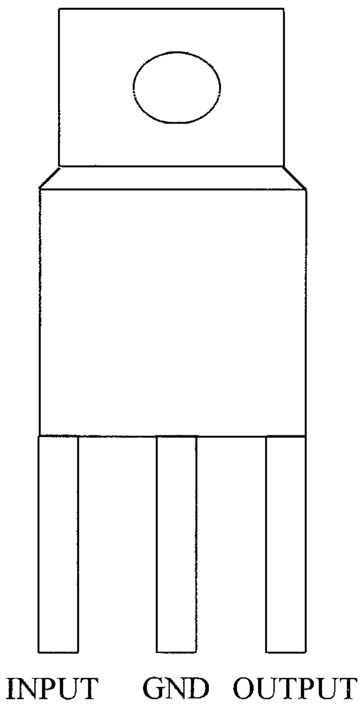

FIG. A.1. IC 7805

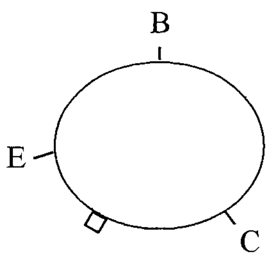

FIG. A.2.a. NPN

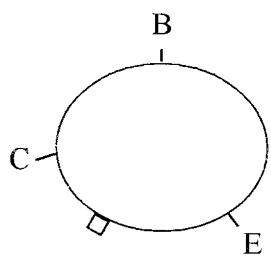

FIG. A.2.b. PNP

FIG. A.2. TRANSISTOR CONFIGURATIONS

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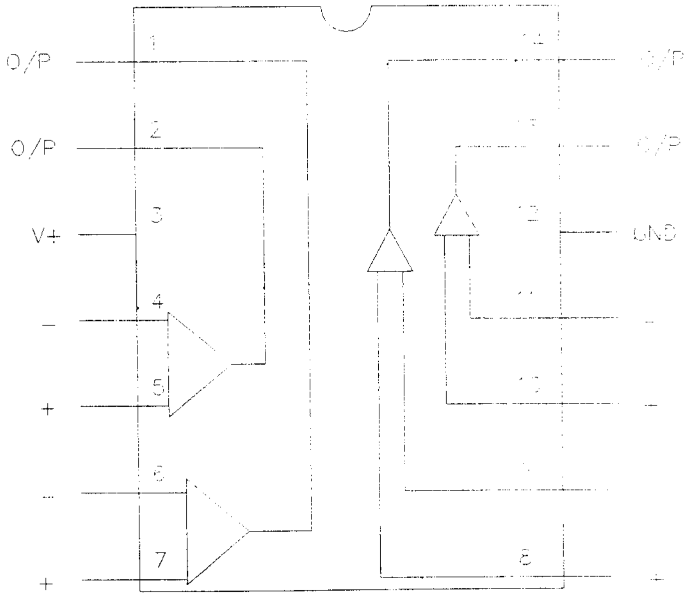

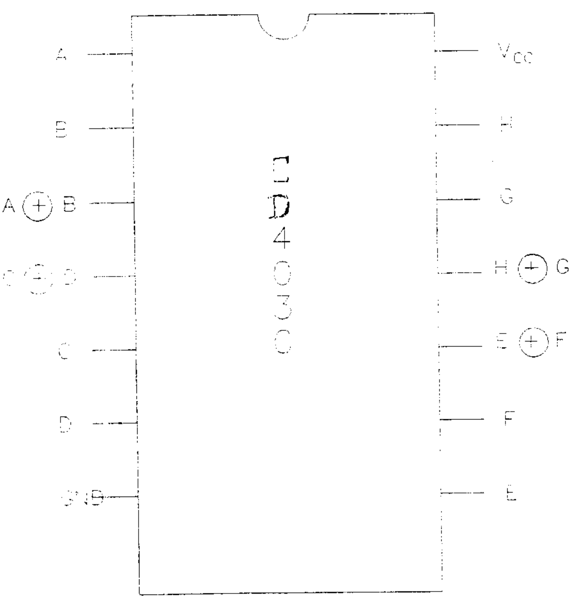

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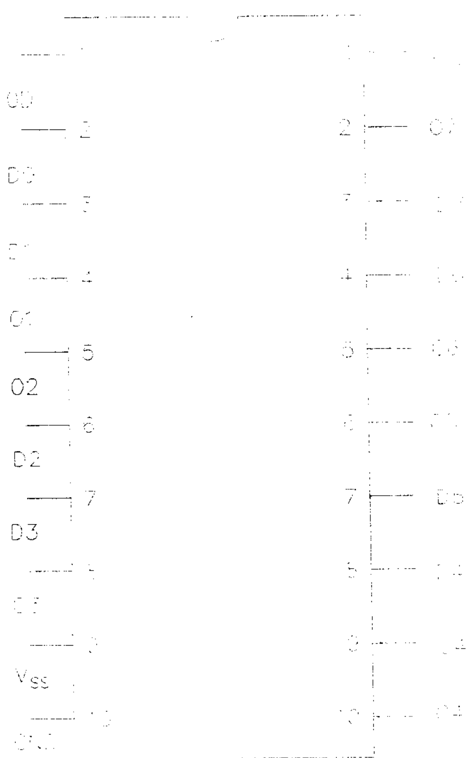

B. TRANSFORMER DATA DETAILS

TABLE I

SHOWING BEST AVERAGE VALUES OF CORE AREA FOR OUTPUTS OF 10-1000 VOLTAMPERES

Output	Core section (square) inch stalloy 50 cycle	Approxi. winding area sq. inch
10	0.3	5/8
15	0.4	3/4
20	0.5	7/8
25	0.6	7/8
50	1.0	1
75	1.25	1 1/4
100	1.5	1 3/8
125	1.5	1 1/2
150	1.75	1 5/8
175	2.0	1 3/4
200	2.0	1 7/8
250	2.5	2
300	2.5	2 1/4
350	3.0	2 3/8
400	3.0	3
450	3.25	3 1/8
500	3.5	4
750	4.0	5
1000	4.5	5 3/4

TABLE II

Current ampere	Wire size S.W.G.	Turns per square inch
30.0	8	30
23.5	9	45
19.3	10	57
15.8	11	69
12.7	12	85
9.9	13	108
7.5	14	139
6.1	15	172
4.8	16	213
3.7	17	272
2.7	18	376
1.9	19	560
1.5	20	680
1.2	21	865
0.92	22	1110
0.68	23	1510
0.57	24	1775
0.4	25	2120
0.38	26	2560
0.32	27	3120
0.26	28	3760
0.22	29	4390
0.18	30	5380
0.158	31	6060
0.137	32	6890
0.118	33	9900
0.100	34	6610
0.083	35	11250
0.068	36	13450
0.054	37	16400
0.042	38	20400
0.032	39	28250
0.027	40	32450
0.026	41	39204
0.022	42	50176
0.018	43	61504
0.014	44	79524

TABLE III

S.No.	Type No.	Actual winding	Available winding
1.	17	0.1875	0.1125
2.	12 A	0.2929	0.1759
3.	21	0.5156	0.3093
4.	10	0.6875	0.4125
5.	10 A	0.6875	0.4125
6.	1	1.0156	0.6093
7.	74	0.3544	0.2126
8.	23	0.4218	0.2531
9.	11	1.125	0.675
10.	11 A	1.4062	0.8437
11.	2	1.6875	1.0125
12.	30	0.4678	0.2807
13.	31	0.5742	0.3445
14.	45	0.5742	0.3445
15.	15	0.75	0.45
16.	44	0.75	0.45
17.	14	1.0156	0.6093
18.	4	2.4609	1.4765
19.	33	0.9113	0.5463
20.	3	1.1718	0.703
21.	13	2.1875	1.3125
22.	4 A	1.5937	0.9562
23.	16	1.6875	1.0125
24.	5	1.9687	1.1812
25.	6	3	1.8
26.	7	2.9375	1.7625
27.	43	3	1.8
28.	8 & 8 B	7.7187	4.6312
29.	100	18	10.8

TABLE IV

Sectional area of core square inch	Width of tongue chin
0.25	1/2
0.3	5/8
0.4	5/8
0.5	3/4
0.6	3/4
0.7	7/8
0.8	1 5/6
0.9	1
1.0	1
1.25	1 1/4
1.5	1 1/4
1.75	1 1/4
2.0	1 1/2
2.25	1 5/8
2.5	1 5/8
2.75	1 3/4
3.0	1 7/8
3.25	2
3.5	2
3.75	2
4.0	2
4.5	2 1/4
5.0	2 1/4
5.5	2 1/2
6.0	2 1/2
6.5	2 3/4
7.0	2 3/4
7.5	2 7/8
8.0	3
9.0	3 1/8