AUTOMATION OF STAR-DELTA STARTER USING TRIACS

PROJECT REPORT

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR
THE AWARD OF DEGREE OF **BACHELOR OF ENGINEERING**
IN ELECTRICAL AND ELECTRONICS ENGINEERING BRANCH
OF THE BHARATHIAR UNIVERSITY, COIMBATORE.

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ACKNOWLEDGEMENT

We express our sincere gratitude to our guide **Mrs. RANI THOTTUNGAL**, M.A., M.E., MISTE, who inspired us right from the time of conception of idea till the completion of the project.

Words are not enough to express our profound gratitude to **Dr. K. A. PALANISWAMY**, B.E., M.Sc (Engg.), Ph.D., C.Eng(I)., MISTE, FIE, Professor and the Head of Department of Electrical and Electronics Engineering, for his valuable help and encouragement in the successful completion of this project.

We express our gratitude to the Principal, **Dr. S. SUBRAMANIAN**, B.E., M.Sc(Engg).,Ph.D., SMIEEE for his kind patronage and valuable encouragement.

We will be failing in our duty if we forget to mention the name of **Mr. R. NAGARATHINAM**, B.E., EXECUTIVE (QUALITY CONTROL & DEVELOPMENT), GEM MANUFACTURERS LIMITED, GANAPATHY, COIMBATORE - 641 006, for his constant encouragement, valuable guidance and sustained motivation during the various phases of our project work.

Last but not the least, we would like to thank all the members of staff of the Department of EEE for their help to finish this project.

SYNOPSIS

Miniaturization Technology is the latest trend in modern manufacturing methods. Automation of any process is catching up nowadays. Our project titled "Automation of Star-Delta Starter" is aimed at providing a totally electrical means of starting a three phase Induction Motor without the use of any mechanical components (relays and contactors). Automation of the starter is achieved by the use of power semi-conductor devices (TRIAC's) as switching devices.

The project consists of a power circuit, control circuit and a timing circuit. The control circuit provides triggering signals for operating the TRIAC's and the timing circuit handles the change-over of star connection of windings of the stator of the Induction Motor to delta by providing the necessary time delay.

The power circuit with the TRIAC's and the motor terminal knobs are fabricated into one section. The second section consists of the control circuit together with the timer.

Added features like speed control of Induction Motor and variation of time delay between Star-delta conversion can be implemented in the circuit for operation of the motor under loaded conditions.

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CHAPTER I

INTRODUCTION

1.1 Starting of Induction Motor

1.1.1 Operating Principle

The polyphase Induction Motors is, by a very considerable margin, the most widely used a.c motor for various kinds of industrial drives. The reasons are its low cost, simple and extremely rugged construction, high efficiency, reasonably good power factor, low maintenance cost and simple starting arrangement.

It differs from other types of motors in that there is no electrical connection from the rotor winding to any source of supply. The necessary voltage and current in the rotor circuit are produced by induction from the stator winding, that is why, it is called an Induction Motor. This chapter deals with the operating principle of Induction Motor that is exactly same way as that of the secondary of a transformer that receives its power from the primary.

The reason for the rotation of rotor of Induction Motor is explained as follows. When three phase windings are fed by a three phase supply, a magnetic flux of constant magnitude but rotating at synchronous speed is setup. The flux passes through the air-gap and sweeps past the rotor surface so that it cuts the rotor conductor that are stationary. Due to the relative speed between the rotating flux and stationary conductors, an electromotive force (emf) is induced in the rotor.

Since the rotor bars and conductors form a closed surface, rotating current is produced such as to oppose the very cause producing it. Here the cause that produces the rotor current is the relative velocity between the rotating flux of the stator and the stationary rotor conductors. Hence to reduce the relative speed, the rotor starts running in the same direction as that of flux and tries to catch up with the rotating flux.

1.2 Slip

The speed of the polyphase Induction Motor must always be less than the synchronous speed and that as the load is increased, the speed of the motor will decrease. The difference between the speed of the stator field, known as Synchronous speed (N_s) and the actual speed of the rotor (N) is known as the slip and is denoted by S. Though the slip can be expressed in r.p.m or in radians per second, it is usually expressed as a fraction or percentage of synchronous speed.

$$\text{Fraction Slip , s} = \frac{\text{Synchronous speed - Rotor speed}}{\text{Synchronous speed}}$$

or

$$s = \frac{N_S - N}{N_s} \qquad \text{..(1.1)}$$

or Percentage slip $= \frac{N_s - N}{N_s} \times 100$ ....(1.2)

1.3 Derivation of Starting Torque

The torque developed by the motor at the instant of starting is called Starting torque. In some cases, it is greater than the normal running torque whereas in some other cases it is somewhat less.

Let I_2 = Rotor current per phase

E_2 = Rotor e.m.f per phase at standstill.

R_2 = Rotor resistance per phase

X_2 = Rotor reactance per phase at standstill.

$\cos \phi_2$ = Power factor of rotor current.

Z_2 = Rotor impedance per phase at standstill.

$Z_2 = \sqrt{[R_2^2 + X_2^2]}$ ....(1.3)

Hence $I_2 = E_2 / Z_2 = E_2 / \sqrt{(R_2^2 + X_2^2)}$..................(1.4)

$\cos \phi_2 = R_2 / Z_2 = R_2 / \sqrt{(R_2^2 + X_2^2)}$ ....(1.5)

Standstill or starting torque,

$T_{st} = K_1 E_2 I_2 \cos \phi_2$ ....(1.6)

$$= K_1 E_2 (E_2/\surd(R_2^2+X_2^2)).(R_2/\surd(R_2^2+X_2^2))$$

$$= K_1 E_2^2 R_2/(R_2^2+X_2^2) \quad \text{.......................................(1.7)}$$

If supply voltage V is constant, then the flux ϕ and hence E_2 both are constant.

$$T_{st} = K_2 R_2/(R_2^2+X_2^2)$$

$$= K_2 R_2 /Z_2^2 \quad \text{..(1.8)}$$

where K_2 is some other constant.

If the motor is started without using starter, the current drawn by the motor is high but starting torque is less. To get high starting torque with minimum current, starters are used.

1.4 Methods of Starting of Induction Motors

In the case of an induction motor, at start when rotor is at standstill, the rotor is just like a short-circuited secondary. Therefore the currents in the rotor circuit will be very high and consequently the stator will also draw a high current from the supply lines if full line voltage were applied at start. Of course, the generated voltage in the rotor circuit decreases with increase in speed of the rotor, so that both the rotor and the stator currents drop to values determined by the mechanical load.

It is true that the starting of Induction Motor does not impose electrical stresses that are as severe as those experienced by commutator type motors; nevertheless it is important that the starting current be minimized to such an extent that the line-voltage drop does not affect the operation of other equipment connected to the same distribution network. Modern well - designed induction motors will usually draw about 5 to 7 times the rated full load current at the starting instant if rated voltage is applied to it. This heavy current although may not be dangerous for a motor because of the short duration of time during which such a large current flows through the motor windings. This will cause a large drop in the line voltage supplying the motor. It is therefore recommended that large three phase squirrel cage induction motors be started with reduced voltage applied across the stator terminals at starting.

Various methods of starting induction motors are

(a) Direct on line starting method
(b) Reduced voltage or Line resistance starter method
(c) Autotransformer starting method
(d) Wound rotor method
(e) Star-Delta switching method

1.4.1 Direct On Line Starting Method

Although there is no limitation on the size of the motor that may be started by this method, it should be understood that objectionable line voltage drops will usually occur, especially if large motors are started frequently. If normal voltage is employed will therefore depend upon the following factors.

- (i) the size and design of the motor
- (ii) the kind of application
- (iii) the location of the motor in the distribution system and
- (iv) the capacity of the power system and the rules governing such installations as established by power supply companies.

Torque developed on starting the motor by direct switching :

Input power to the rotor = $T\omega$ ....(1.9)

Rotor copper loss = S x Input power to the rotor

(or) $3I_2^2R_2$ = $ST\omega$ ....(1.10)

where I_2 is the rotor current per phase

R_2 is the rotor resistance per phase

T is the torque developed

S is the slip

ω is the supply angular velocity

Torque developed = $3\ I_2^2\ R_2/S\omega$ ....(1.11) i.e., $T \quad \alpha \quad I_2^2 \ / \ S$ ....(1.12)

if rotor resistance is constant.

Since rotor current is proportional to stator current I_1 ,

$T \quad \alpha \quad I_1^2/S$

(or)

$T \quad = \quad KI_1^2/S$ ....(1.13)

where K is any constant.

At starting S is unity, therefore starting torque,

$T_{st} \quad = \quad K\,(I_{st})^2$ ....(1.14)

where I_{st} is the starting current.

Full load torque $\quad T_f \quad = \quad K\,I_f^2 \ / \ S_f$ ....(1.15)

where I_f is the full load motor current and

S_f is the full load slip

$T_{st}/T_f = \quad K\,I_{st}^2 \ / \ (K\,I_f^2/S_f) \ = \ (I_{st} \ / \ I_f)^2 \ S_f$

$T_{st} \quad = \quad T_f \ x(I_{st} \ / \ I_f)^2 S_f$ ....(1.16)

When the motor is connected directly across the supply mains, then

Starting Current $\quad I_{st} \quad = \quad$ Short circuit current I_{sc}

Starting Torque $\quad T_{st} \quad = \quad I_f(I_{sc}/I_f)^2 S_f$ ....(1.17)

1.4.2. Reduced Voltage (or) Line Resistance Starter Method

In this method of starting a three phase induction motor, reduced voltage is obtained by means of resistances that are connected in series with each stator lead during the starting period. The voltage drop in the resistors causes a reduced voltage across the motor terminals. At a definite time after the motor is connected through the resistors, accelerating contacts close which short circuit the starting resistors and apply full voltage to the motor terminals.

Here the reduced voltage that is applied to the stator winding of the motor reduces the current taken from the supply during starting. The resistors cause unnecessary power loss that is not adjustable.

If normal line voltage = V volts and by using line resistance starter the voltage is reduced to KV volts, then starting current is also reduced in the same ratio.

I.e., Starting current I_{st} = KI_{sc} where I_{sc} is the short circuit current.

Starting torque, $T_{st} = T_f (I_{st} / I_f)^2\ S_f$

$= T_f \times K^2\ (I_{sc} / I_f)^2\ S_f$ ....(1.18)

$= K^2 \times$ Torque obtained by switching the motor directly

1.4.3. Auto-transformer Starting Method

In auto-transformer starting method, the reduced voltage is obtained by taking tappings at suitable points from a three phase auto-transformer. The auto-transformers are generally tapped at the 50, 60 and 80 per cent points, so that adjustment at these voltages may be made for proper starting torque requirements. Auto-transformer starters may be either manually or magnetically operated. This method is not an economical one because of the high cost of the auto-transformer that has limited use (i.e) for starting only.

But this type of starter is suitable for the star-connected as well as delta-connected motors.

Let the motor be started by an auto-transformer having transformation ratio K. If I_{sc} is the starting current when normal voltage is applied.

Applied voltage to stator winding at starting = KV

Motor input current I_{st} = KI_{sc}

Supply current = Primary current of auto-transformer

= K x Secondary current of auto-transformer

= $K^2 I_{sc}$ ....(1.19)

Starting torque $T_{st} = T_f (I_{st}/I_f)^2 S_f$

$= T_f \, x K^2 (I_{sc}/I_f)^2 \, S_f$ ....(1.20)

$= K^2$ x Torque obtained directly by switching the motor

Hence line current and starting torque has been reduced in the square ratio.

1.4.4. Wound Rotor Method

Starting torque equation of an Induction Motor = $K_2 (R_2 / Z_2^2) V^2$ ....(1.21)

By increasing the rotor resistance R_2, the starting torque is increased. This method cannot be applied for squirrel cage induction motor but only for wound rotor method.

Compared to the starters described above, the Star-Delta starter is found to be more advantageous and hence more emphasis has been made on this starter in the section that follows.

1.4.5. Star - Delta Switching Method

In this project STAR-DELTA is being used with additional circuits for protection of motor towards various abnormal operations. So it is necessary to have a good knowledge of STAR-DELTA starters.

This method is based upon the principle that with three windings connected in Star, the voltage across each winding is $1/\sqrt{3}$ i.e., 57.7 % of the line to line voltage whereas the same windings when connected in Delta will have full line to line voltage across each of them.

The Star-Delta starter connects the three stator windings of an induction motor in Star at the starting instant. After the motor attains the required speed, the same windings through a change-over switch are connected in delta across the supply voltage.

Since at starting instant, the stator windings are connected in Star, the voltage across each phase of the winding is reduced to $1/\sqrt{3}$ of the line voltage and therefore, starting current per phase becomes equal to $I_{sc} / \sqrt{3} = 0.577\ I_{sc}$.

Starting line current by connecting the stator windings in star at the starting instant = Starting motor current per phase = $I_{sc} /\sqrt{3}$

Starting line current by direct switching = $\sqrt{3}\ I_{sc}$

$$\frac{\text{Line Current with star-delta starting}}{\text{Line Current with Direct switching}} = (I_{sc}/\sqrt{3}) / \sqrt{3}\, I_{sc} = 1/3$$

Hence by star-delta starting the line current is reduced to one-third of line current with direct switching.

$$\text{Starting torque} \quad T_{st} = T_f (I_{st} / I_f)^2 S_f$$
$$= T_f ((I_{sc}/\sqrt{3}) / I_f)^2 \; S_f$$
$$= 1/3 \; T_f (I_{sc}/I_f)^2 S_f \quad \text{.......................} (1.22)$$

Hence with Star-delta starting, the starting torque is also reduced to one-third of starting torque obtained with direct switching. By this method, no power is lost in starting the motor.

It consists of a two way switch that connects the motor in star for starting and then in delta for normal running. The need for conversion of connections can be explained as follows. The torque of an Induction Motor can be improved by increasing the resistance of the rotor circuit. However, it is feasible only for slip ring induction motor. But in this case the initial current inrush is controlled by applying a reduced voltage to the stator during the starting period, full normal voltage being applied when the motor has run upto normal speed. For this action to take place, we use star-delta starter that initially applies reduced voltage to the stator by connecting the windings in star and later connects the windings in delta after the motor has picked up speed so that full voltage is applied.

This is the main advantage of star-delta starters over other types used for Induction motor starting.

Effect of Change in Supply Voltage

The starting torque is proportional to square of the voltage. Hence the torque is very sensitive to any change in the supply voltage. A change of 5 % in supply voltage, for example, will produce a change of approximately 10 % in the rotor torque. This fact is of greater importance in Star-Delta starters.

The usual connection for star-delta technique is shown in Fig.1.1 and the windings arrangement for Star and Delta are shown in Fig. 1.2

When connected in star, the applied voltage over each motor phase is reduced by a factor of $1/\sqrt{3}$ and hence the torque developed becomes 1/3 of that which would have been developed if motor were directly connected in delta.

This method is the cheapest and effective provided the starting torque required is not to be more than 1.5 times the full load torque. Hence it is used for machine tools, pumps and motors, etc.

1.5. Types Of Star-Delta Starters

Three types of Star-Delta starters exist for the starting of the Induction Motors in industries. They are as follows :

1. Manual Star-Delta Starters
2. Semi-automatic Star-Delta Starters.
3. Automatic Star-Delta Starters.

1.5.1. Manual Type of Star-Delta Starters

In manual type of Star-Delta Starters, two lever positions are provided, one for connecting the stator windings of the Induction Motor in Star and the second lever position for connecting the windings in Delta.

To start the motor, the lever is put on to position 1 (Star) so that the motor draws sufficient current for starting. The lever is held in this position till the speed picks up and then it is switched over to position 2 (Delta) so that full voltage is applied across the stator windings.

1.5.2. Semi-automatic type of Star-Delta Starters

In Semi-automatic type of starters, a push button is provided. This button is pressed so that the stator windings are connected in Star drawing the required current for starting. After few seconds the button is released so that the windings are automatically connected in Delta.

1.5.3 Automatic Type of Star-Delta Starters

In Automatic Star-Delta starter, a separate timer takes care of the time delay between Star-Delta conversion. A button is pressed to start the motor (with windings connected in Star). After some few seconds, once the speed picks up to the rated value, the mechanical timing circuit switches over the windings of the stator to delta.

In all the 3 types of starters discussed above, relays and contactors form the operating components and hence conversion of windings from Star to Delta is purely by mechanical means.

In our project, switching devices (TRIAC's) have been used to automatically switch Star connection of windings of the Stator of the Induction Motor to Delta. This is done purely by a control circuit and change-over is by electrical means.

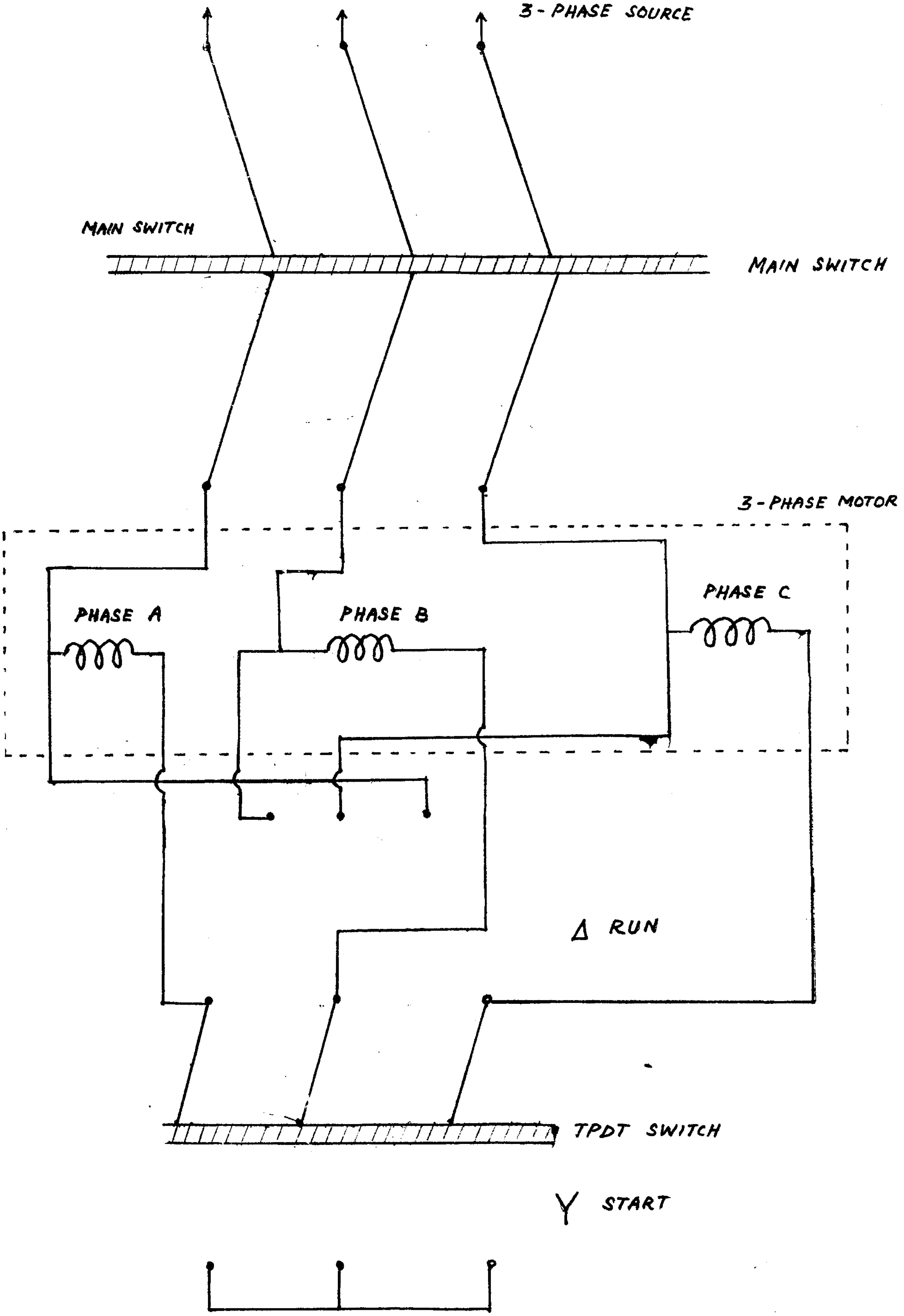

Fig 1·1 Wiring Diagram for Y-Δ method

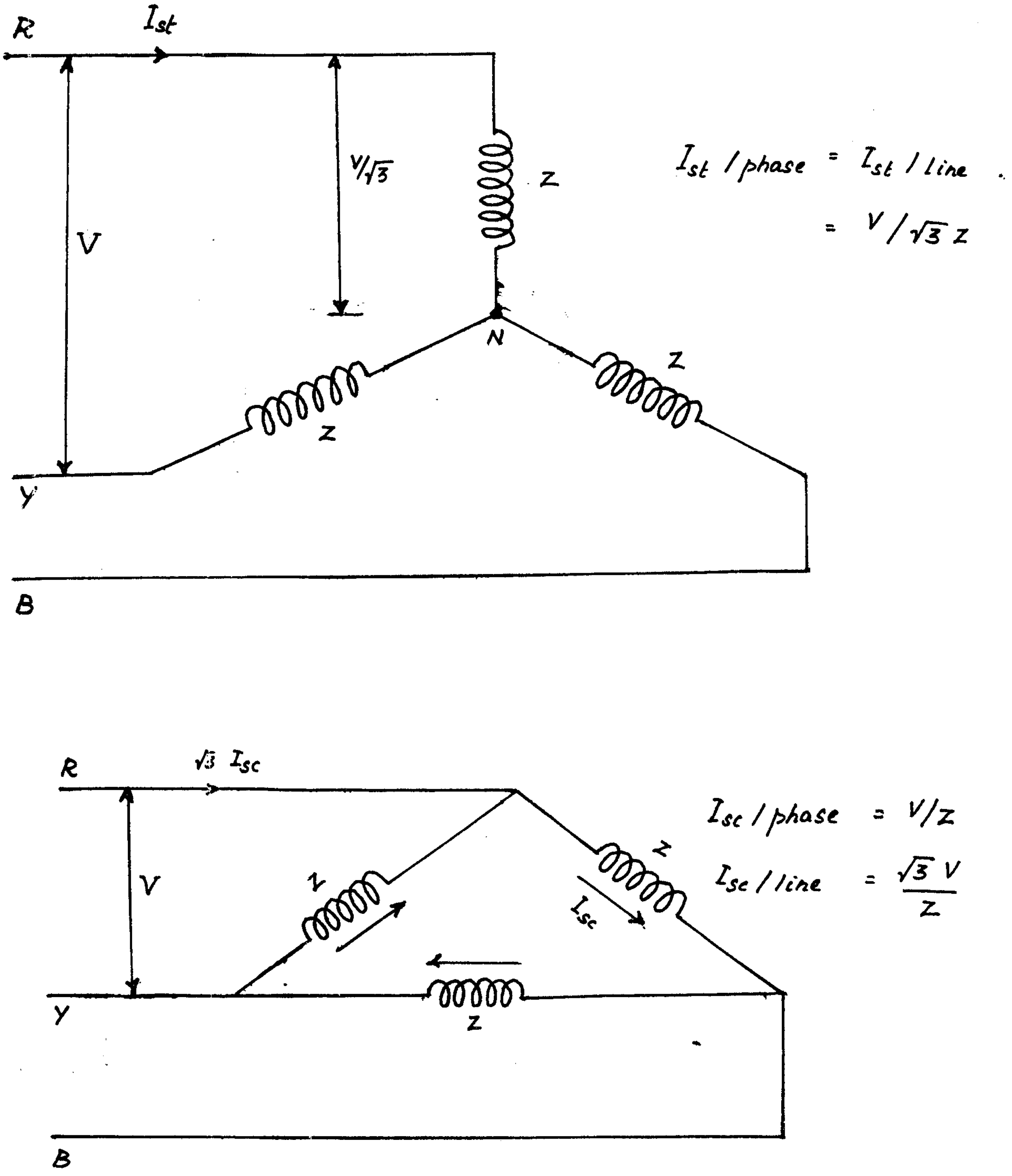

Fig 1·2 Winding Arrangement for Star-Delta

CHAPTER II

TRIACS

2.1. Introduction

The name 'TRIAC' is an acronym that has been coined to identify the TRIODE AC semi-conductor switch which is triggered into conduction by a gate signal in a manner similar to the action of an SCR. But it differs from the SCR in that it can conduct in both directions of current flow in response to a positive or negative gate signal. TRIAC is used in ac phase control. It can be considered as two SCR's connected in anti-parallel with a common gate connection. Since the terms 'anode' and 'cathode' are not applicable to the TRIAC, the terminals are simply designated by MT_1 and MT_2. The terminal MT_1 is the reference point for measurement of voltages and currents at the gate terminal and MT_2. The TRIAC symbol is shown in the Fig. 2.1.

2.2. V-I Characteristics of TRIAC

With single gate signal, the TRIAC is triggered to conduct symmetrically in both directions. Due to this characteristic, the TRIAC is very useful in controlling a.c power as in a.c motor control, heat control of a furnace, lamp dimmers, etc.

The terminal characteristics of the TRIAC are based on the terminal MT_1 as the reference point. The first quadrant is the region wherein MT_2 is positive with respect to MT_1 and vice versa for the third quadrant. The peak voltage applied across the device in either direction must be less than the break-over voltage in order to retain control by the gate. A gate current of specified amplitude of either polarity will trigger the TRIAC into conduction in either quadrant, assuming that the device is in a blocking condition initially before the gate signal is applied. The characteristics of a TRIAC, as shown in Fig. 2.2, is similar to that of an SCR, both in blocking and conducting states, except for the fact that the SCR conducts only in the forward direction whereas the TRIAC conducts in both the directions. A typical TRIAC structure is shown in Fig. 2.3. Depending upon the polarity of a gate pulse and biasing conditions, the main four layer structure that turns on by a regenerative process could be one of $P_1N_1P_2N_2$, $P_1N_1P_2N_3$ OR $P_2N_1P_1N_4$.

2.3. Triggering Mechanism Of a TRIAC

A TRIAC can be turned on with positive or negative gate current keeping the MT_2 terminal at positive or negative potential. There are four possible electrode potential combinations. They are as follows :

1. Main Terminal MT_2 positive, positive gate current
2. Main Terminal MT_2 positive, negative gate current
3. Main Terminal MT_2 negative, positive gate current
4. Main Terminal MT_2 negative, negative gate current

Let us examine how the TRIAC switches into conduction in each case.

2.3.1. Main Terminal MT_2 positive, positive gate current

The device operates in the first quadrant of V-I characteristics. Fig.2.4(a) shows the Cross Sectional view of the structure. The device turns on in the conventional manner as in case of an SCR. However, in the case of a TRIAC, the gate current requirement is higher for turn on at a particular voltage. The gate current flows from the gate lead to the terminal MT_1 through the semi-conductor P_2 - N_2 junction. Because of ohmic contacts of gate and MT_1 terminals on the P_2 layer, some more gate current flows from the gate lead G to the main terminal MT_1 through the semi-conductor P_2 layer without passing through the P_2 - N_2 junction. In this case, the structure of a TRIAC is similar to that of a shorted-emitter SCR. This is represented by a resistance between gate and MT_1 terminals in the two-transistor circuit model of the device as shown in Fig.2.4(b). The main structure which ultimately turns on through regenerative action is $P_1N_1P_2N_2$. When the gate current flows across the P_2 - N_2 junction P_2 layer is flooded with electrons. These electrons diffuse to the edge of the junction J_2, and are collected by the N_1 layer. As a result, the electrons build a space charge in the N_1 region and more holes from P_1 diffuse into N_1 to neutralize the negative space charge. These holes arrive at the junction J_2. They produce a positive space charge in the P_2 region which results in more electrons being injected from N_2 into P_2. This results in positive regeneration and ultimately the structure $P_1N_1P_2N_2$ conducts the external current. The device is more sensitive in this mode compared to the other modes of operation. This is the recommended method of triggering if the conduction is desired in the First Quadrant.

2.3.2 Main Terminal MT_2 positive, negative gate current

A cross sectional view of the structure is shown in Fig.2.5 . This structure is similar to a typical junction gate thyristor structure. The main structure that conducts ultimately is $P_1N_1P_2N_2$. However, the initiation of conduction process is provided by the auxiliary structure $P_1N_1P_2N_3$. Initially, the gate current I_G forward biases the gate junction P_2 - N_3 of the auxiliary $P_1N_1P_2N_3$ structure, and this structure turns on by normal regenerative action. As $P_1N_1P_2N_3$ turns on, the voltage drop across it falls, and the right hand section of the region P_2 moves towards anode potential. Since the left hand section of the region P_2 is clamped to the cathode potential, a transverse voltage gradient now exists across P_2 and current flows laterally through P_2. As the right hand edge of P_2N_2 becomes forward biased, electrons are injected at this point and the main structure turns on. The device auxiliary structure, $P_1N_1P_2N_3$ may be considered as a pilot SCR while the structure $P_1N_1P_2N_2$ may be regarded as the main SCR both being built in one common structure. The anode current of the pilot SCR serves as a gate drive to the main SCR. Comparing the turn on action with the positive gate current, the device is somewhat less sensitive and therefore requires more gate current in this mode.

2.3.3 Main Terminal MT_2 negative, positive gate current

In this mode, the device operates in third quadrant when it is triggered into conduction. The turn on is initiated by remote gate control. The main structure that leads to turn on is $P_2N_1P_1N_4$ with N_2 acting as a remote gate as shown in Fig. 2.6(a). The junction P_2N_2 is forward biased by the external gate current I_G. It injects electrons as shown by the dotted line. These electrons diffuse through the region P_2 and are collected by the junction P_2N_1. The electrons from N_2 collected by P_2N_1 junction cause an increase of current through the junction P_2N_1. The holes injected from P_2, diffuse through N_1 and arrive in P_1. As a result, a positive space charge builds up in the P_1 region. More electrons from N_4 diffuse into P_1 to neutralize the positive space charge. These electrons arrive at the junction J_2. They produce a negative space charge in the N_1 region which results in more holes being injected from P_2 into N_1. This regenerative process continues until the structure $P_2N_1P_1N_4$ completely turns on and conducts the current which is limited by the external load.

The turn on process can also be explained by the transistor analogy. Fig.2.6(b) shows the transistor equivalent circuit. The two transistors $P_2N_1P_1$ and $N_1P_1N_4$ form the main structure while the remote layer N_2 in conjunction with the P_2N_1 form an additional transistor. Since the gate (base of $N_2P_2N_1$) is held at a positive potential with reference to the main terminal MT_1, electrons are injected from the emitter N_2. These are collected by transistor $P_2N_1P_1$. This initiates the regenerative action of the main structure $P_2N_1P_1N_4$ and ultimately the device switches into conduction. In the third quadrant, the device is less sensitive with the positive gate current.

2.3.4 Main Terminal MT_2 negative, negative gate current

Fig. 2.7 (a) shows the cross section of main structure $P_2N_1P_1N_4$ and its transistor equivalent circuit Fig.2.7 (b). N_3 acts as a remote gate. The external gate current I_G causes P_2N_3 junction to become forward biased, and electrons are injected as shown by the dotted lines. These electrons from N_3 collected by P_2N_1 cause an increase of current across P_1N_1. The structure turns on by the regenerative action. Looking at the structure by transistor circuit analogy, the remote transistor $N_3P_2N_1$ is properly biased to inject electrons to the collector N_1. This increases the base drive of $P_2N_2P_1$ initiating the regenerative action of the main structure $P_2N_1P_1N_4$. This leads to switching of the device into conduction. The device is more sensitive in this mode compared with the turn on by the positive gate current.

In all the modes of operation, the sensitivity of the TRIAC is the greatest in the first quadrant with the positive gate current and in the third quadrant with the negative gate current. The sensitivity is slightly lower in the first quadrant with the negative gate current. Further the device is much less sensitive in the third quadrant with the positive gate current. This particular mode of operation is not commonly used. The magnitude of the gate current required to turn on indicates the degree of sensitivity.

2.4. Commutation of TRIACS

A TRIAC is equivalent to a pair of thyristors connected in anti-parallel. The output voltage waveform in an a.c circuit with a TRIAC is the same as that obtainable with a pair of thyristors connected in anti-parallel. However, one important difference between them is that with SCR's each SCR has an entire half-cycle for its turn off, but the TRIAC must turn off during the brief interval while the load current is passing through zero. For resistive loads, this is fairly simple to accomplish since the time available for the TRIAC to turn-off extends from the time the device current drops below the holding current until the reapplied voltage exceeds the value of the line voltage required to allow latching current. With inductive loads the task of commutating the TRIAC becomes more difficult.

The Fig 2.8 shows the circuit of a TRIAC with inductive load. The waveforms of TRIAC voltage and current are also shown. For the sake of clarity, the waveform at the commutation point A is amplified and shown in Fig 2.9. It can be seen from the current waveform that the recovery current may act as a virtual gate current and turn the device on again. In addition there is a component to the reverse current which is due to the junction capacitance and the reapplied dv/dt. This component directly adds to the recovery current but does not appear until the triac begins to block a voltage of opposite polarity. As the rate of removal of current (- di/dt) decreases, the recovery current also decreases. This then implies that at lower values of di/dt, higher values of reapplied dv/dt are permissible for a given commutation capability. If by chance, the reapplied dv/dt is higher than the permissible value for a given di/dt rating, then additional protection circuits must be incorporated. The standard method is to use RC snubber circuits such as R_s, C_s as shown in Fig 2.8 (as shown dotted). The values of R_s and

C_s depend upon the load current, line voltage and reverse recovery charge of the TRIAC.

It is also to be noted that a TRIAC cannot be turned off by the application of negative triggering voltage from a.c mains or by negative triggering voltage obtained from the commutation circuit. This happens because the TRIAC can conduct in either direction with positive or negative triggering voltage. Only possible method of turn-off of a TRIAC is the natural turn-off (or line commutation) during which the TRIAC current is lowered below the latching value.

2.5 Triggering Methods of TRIAC's

Triggering circuit is the line between control and power circuit. If the gate signal is a slow variation of d.c voltage or a sine wave the firing point of the TRIAC will vary because of the change in junction temperature.

There are three types of triggering systems that can be employed based on the type of application.

1. DC Triggering
2. Single Pulse Triggering
3. Pulse Train Triggering

2.5.1 Pulse Train Triggering

Pulse Train triggering system uses large number of pulses in the form of a train to trigger the TRIAC and pulse duration is chosen to give sufficient duration for the TRIAC to latch.

2.5.2 Single Pulse Triggering

This method employs a single pulse for triggering, the width of the pulse being sufficiently large to suit resistive and moderately inductive loads. This type of triggering will fail to work in case of highly inductive loads and back emf loads.

2.5.3 DC Triggering

In this method, d.c voltage is applied to the gate in the entire interval of conduction. It is used to latch very highly inductive loads. Since the positive gate voltage is being applied, the TRIAC is said to be operated in the first quadrant.

In the first quadrant operating mode, the gate is most sensitive in triggering TRIAC on. In the other modes, more current is needed.

2.6 Advantages of TRIAC's

Having explained the various modes of operation of the TRIAC's, TRIAC commutation and its triggering, it is important to discuss the advantages of using this power semi-conductor device in a.c applications.. Comparison of the TRIAC has been made with SCR's to bring out the advantages :

1. TRIAC's need a single heat sink of slightly larger size but anti-parallel thyristor pairs needs two heat sinks of slightly smaller size. This requires more space for mounting the thyristors.

2. TRIAC's need a single fuse for their protection. This helps in simplified construction.

3. TRIAC's can be turned on by the application of both positive and negative triggering voltages.

4. In some d.c applications, SCR is protected against reverse voltages by connecting a diode across its terminals. But in the case of TRIAC's, this is not necessary since soft breakdown is possible in either directions.

2.7 Disadvantages of TRIAC's

1. SCR's are available in larger ratings compared to TRIAC's

2. Triggering circuit for TRIAC's needs careful considerations as TRIAC's can be triggered in either directions.

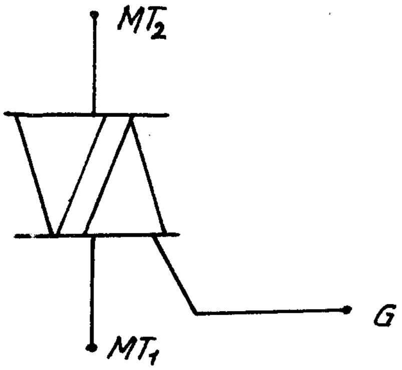

Fig 2·1 Triac Symbol

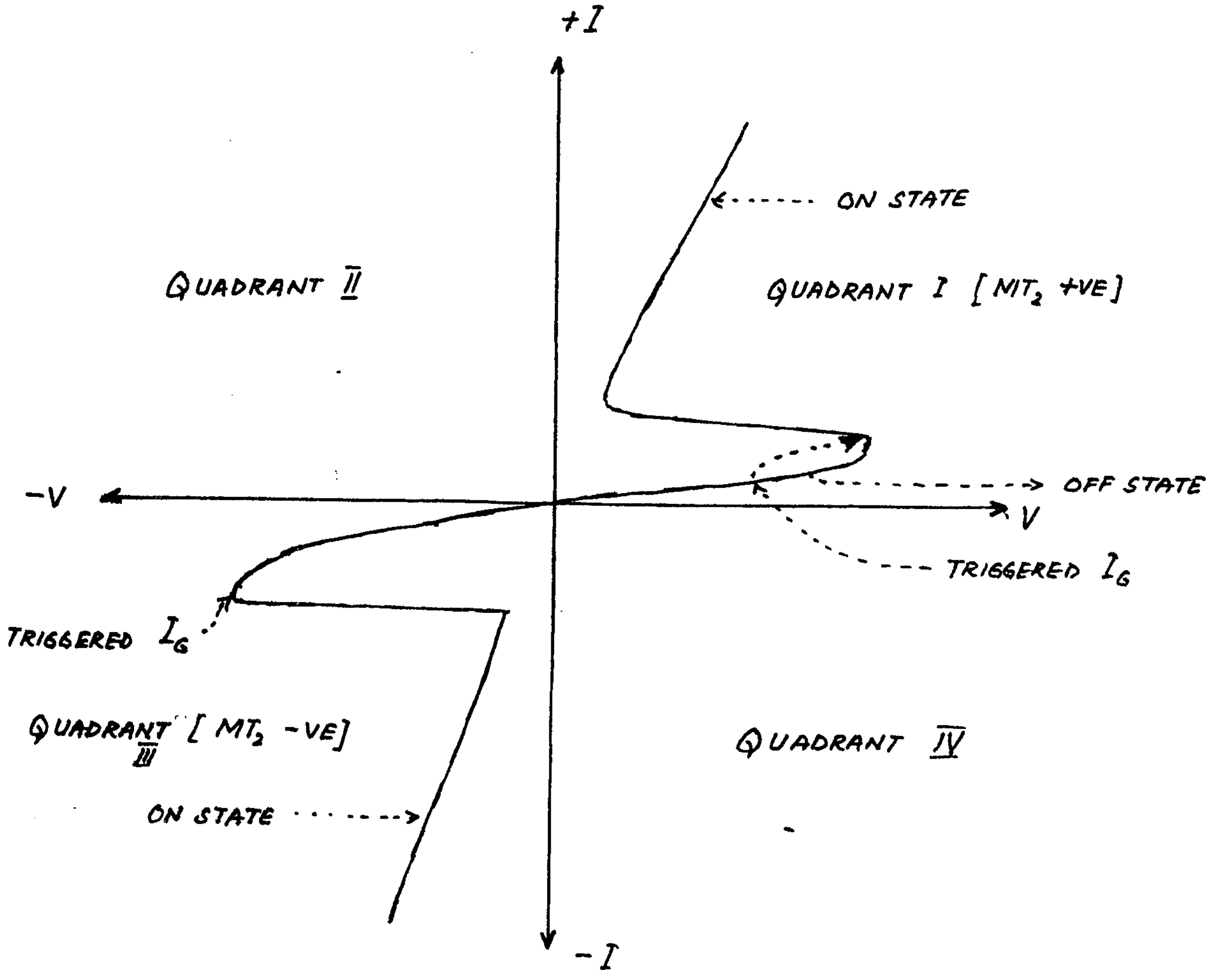

Fig 2·2 V-I Characteristics of TRIAC

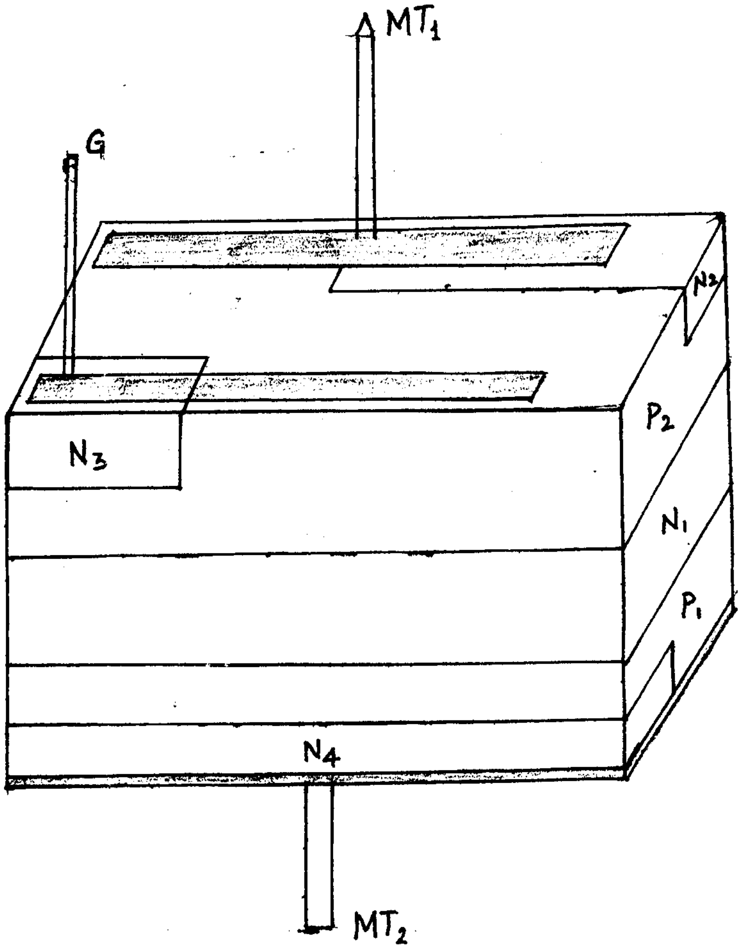

Fig 2.3 Typical TRIAC Structure

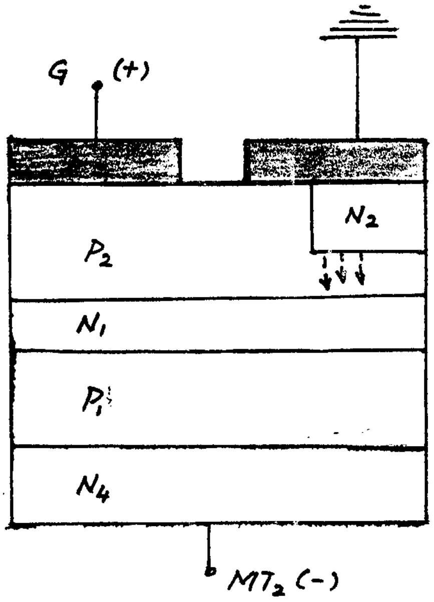

Fig 2·4(a) MT_2 (-), I_G(+)

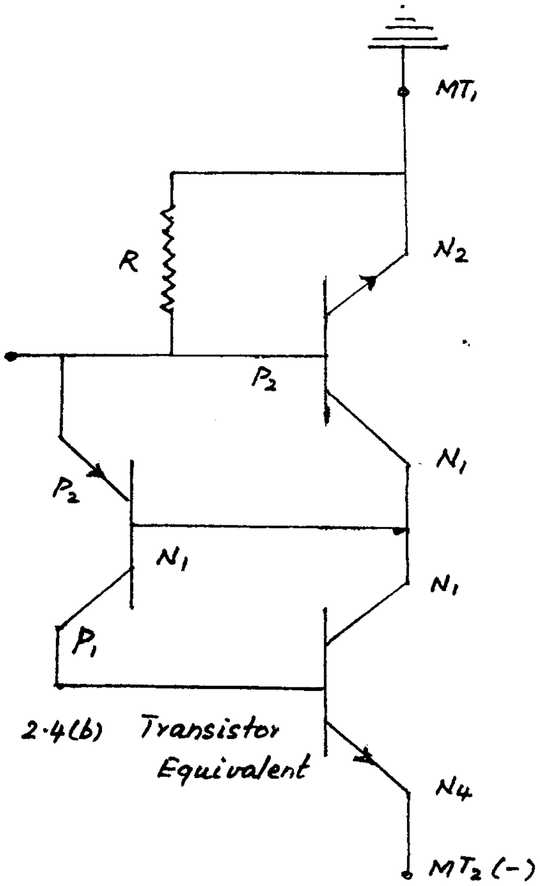

Fig 2·4(b) Transistor Equivalent

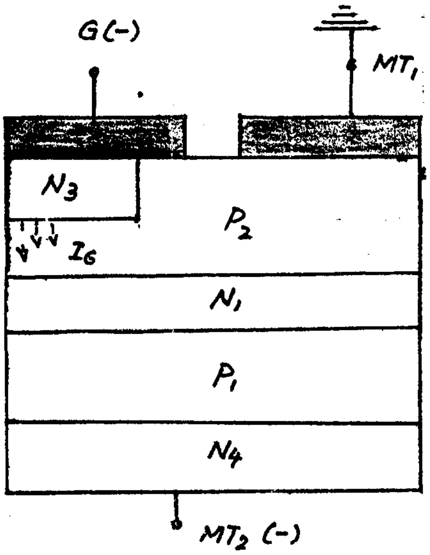

Fig 2·5(a) MT_2 (-) I_G (-)

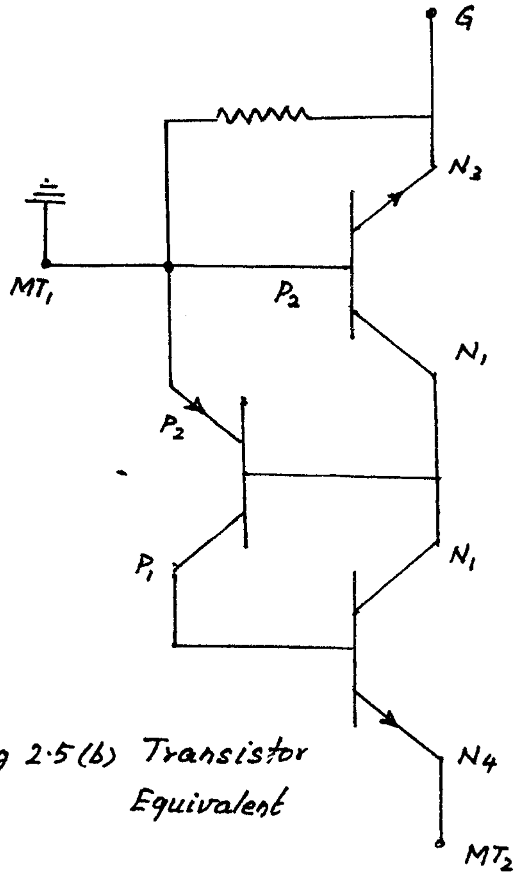

Fig 2·5(b) Transistor Equivalent

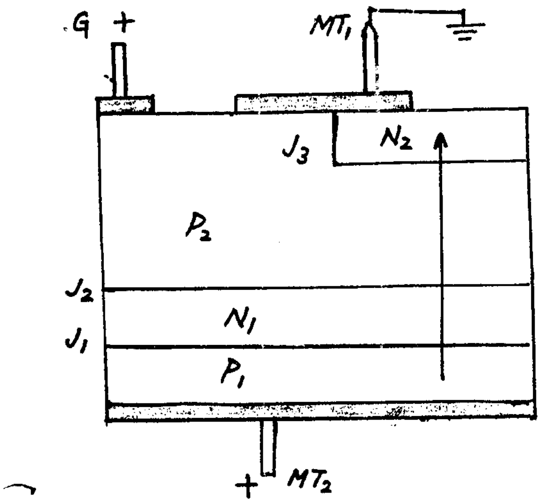

Fig 2·6(a) MT_2 (+) I_G (+)

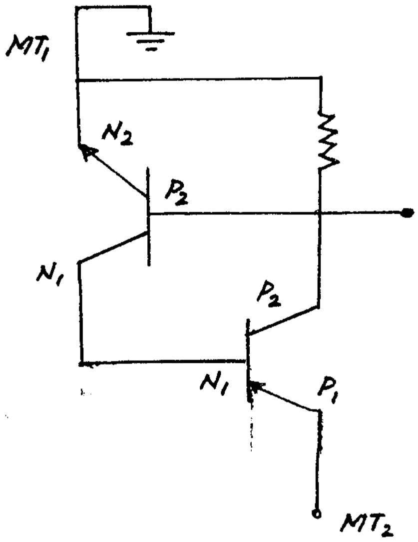

Fig 2·6(b) Transistor Equivalent

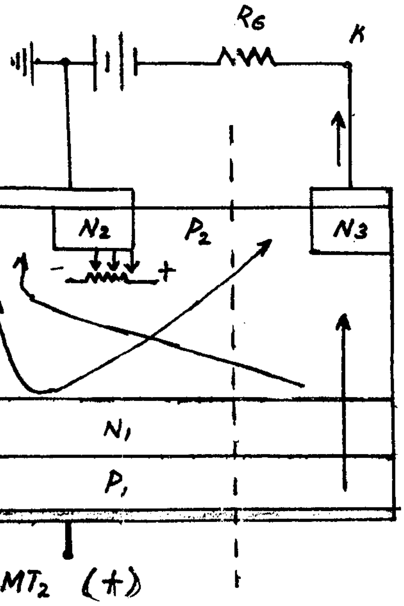

Fig 2·7(a) MT_2 (+) I_G (-)

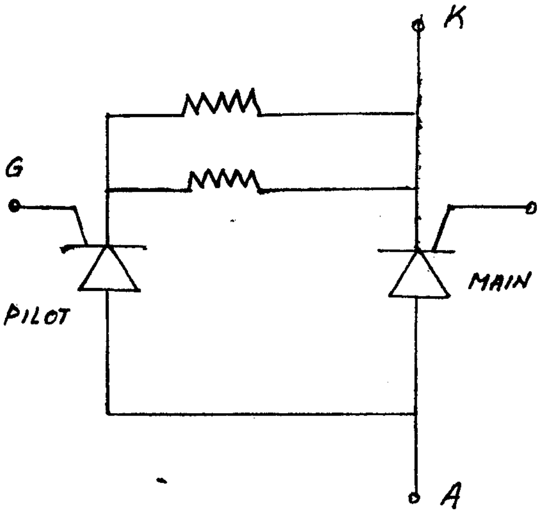

Fig 2·7(b) SCR Equivalent.

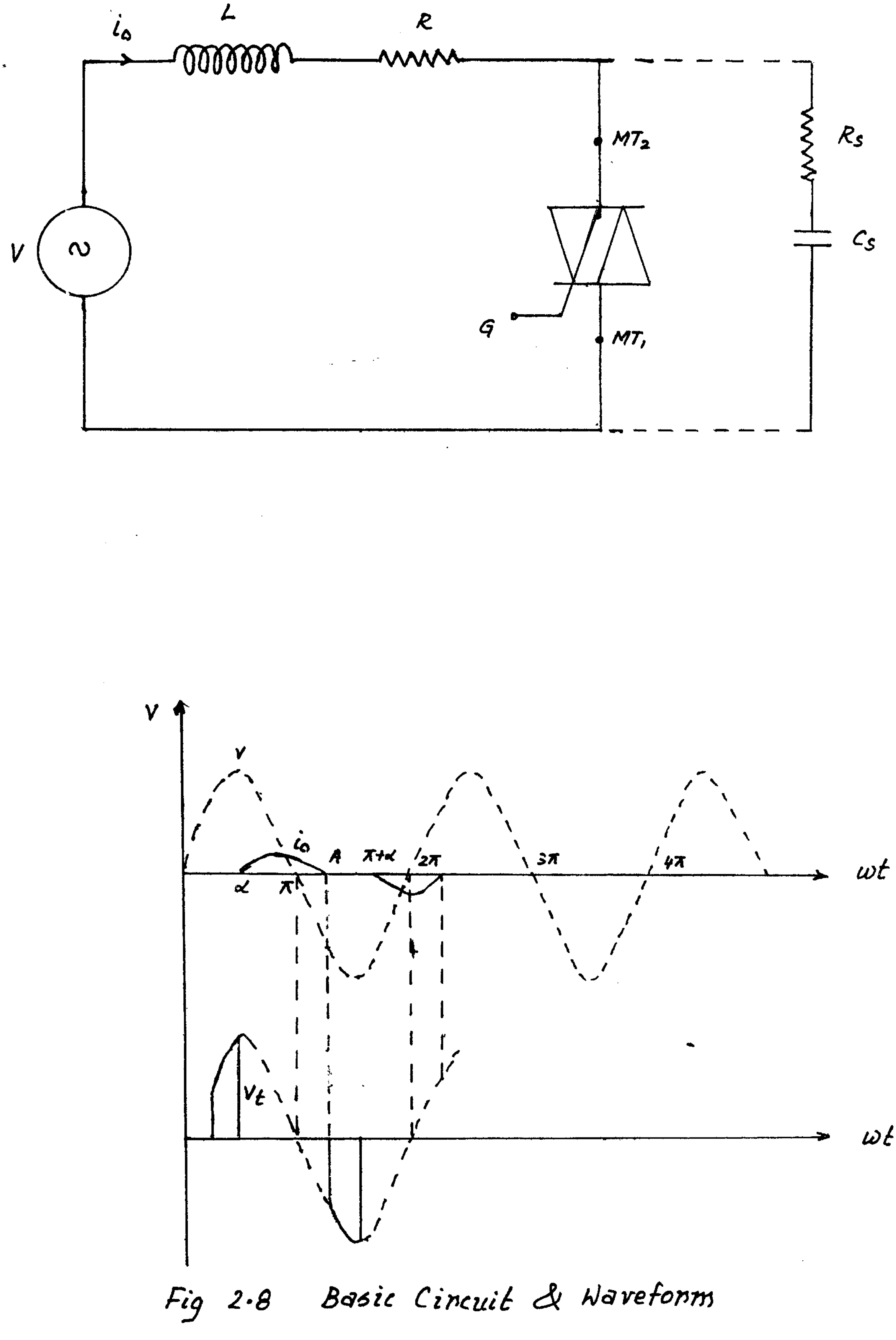

Fig 2.8 Basic Circuit & Waveform

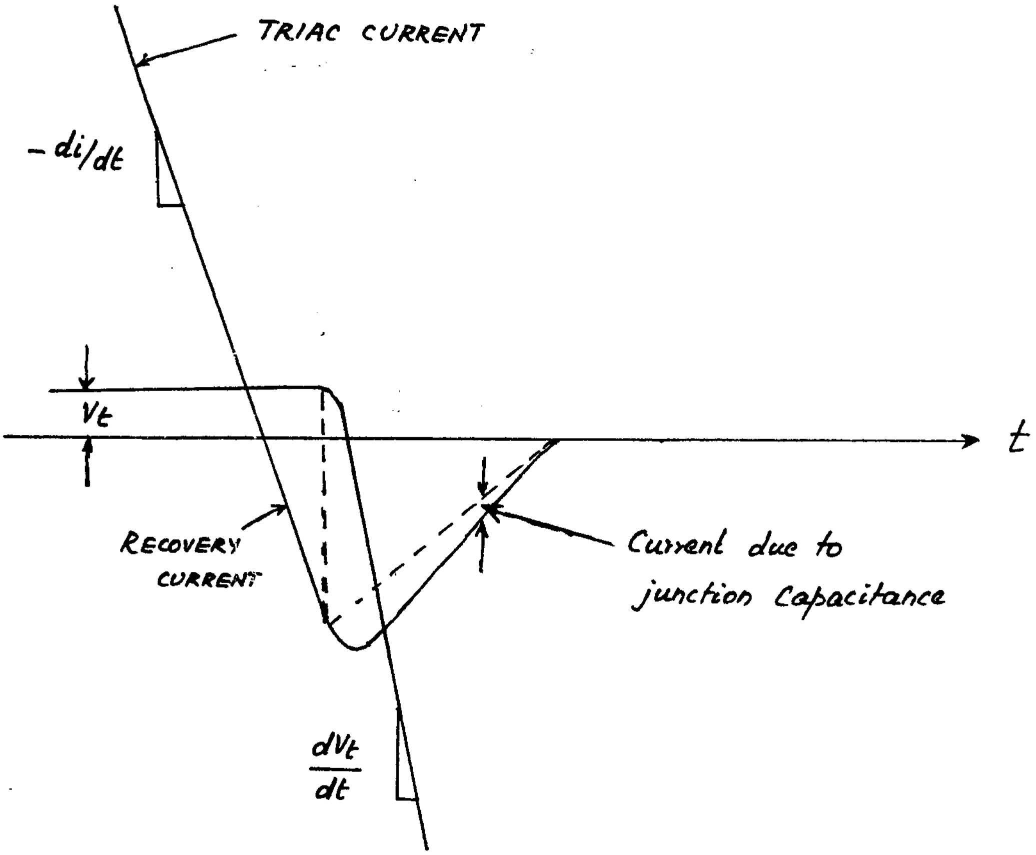

Fig 2.9 Expanded Commutation interval of a TRIAC.

CHAPTER III

POWER CIRCUIT

3.1 Theory of Operation

The power circuit consists of 6 TRIAC's mounted as shown in the power circuit diagram (Fig. 3.1). These TRIAC's act as switching devices and their function in the circuit to convert the star connection of the windings of the stator of the Induction Motor to Delta connection.

When the power is switched on, the three TRIAC's (T_4. T_5. T_6) connected in the star part of the circuit are triggered by the d.c voltage provided by the control circuit i.e.,

(a) Winding terminals A_1, B_1 and C_1 are connected to the supply R, Y and B respectively

(b) Winding terminals A_2, B_2 and C_2 are shorted to obtain the Star Point.

Under this condition, the motor operates under reduced voltage and higher current. The motor draws the necessary current for starting . After few seconds, once the speed picks up, the control circuit triggers the set of TRIAC's (T_1, T_2, T_3) and simultaneously commutates the set of TRIAC's that were connected in Star i.e.,

(a) Winding terminal A_1 connected to terminal C_2 is given to the R-phase

(b) Winding terminal B_1 connected to terminal A_2 is given to the Y-phase

(c) Winding terminal C_1 connected to terminal B_2 is given to the B-phase

This connects the windings of the motor in Delta and the motor runs under rated voltage applied across its terminals. The connection of the stator windings of the motor under star and delta are represented in Fig 1.2.

When the windings of the stator are connected in Star, reduced voltage is applied across the winding. This is achieved by adjusting the variable voltage regulator LM-317 provided in the control circuit. This could be explained in detail as follows :

When the d.c triggering voltage is varied using the variable voltage regulator LM-317, the triggering point of the TRIAC is varied. This leads to phase control of the TRIAC i.e., if the firing or delay angle of the TRIAC is increased, less voltage is applied across the windings of the motor.

Heat sinks are provided for each TRIAC used in the power circuit to dissipate the heat that is developed during the operation of the TRIAC. The heat sinks are made of aluminium in order to dissipate the heat more effectively. The TRIAC is mounted on these heat sinks.

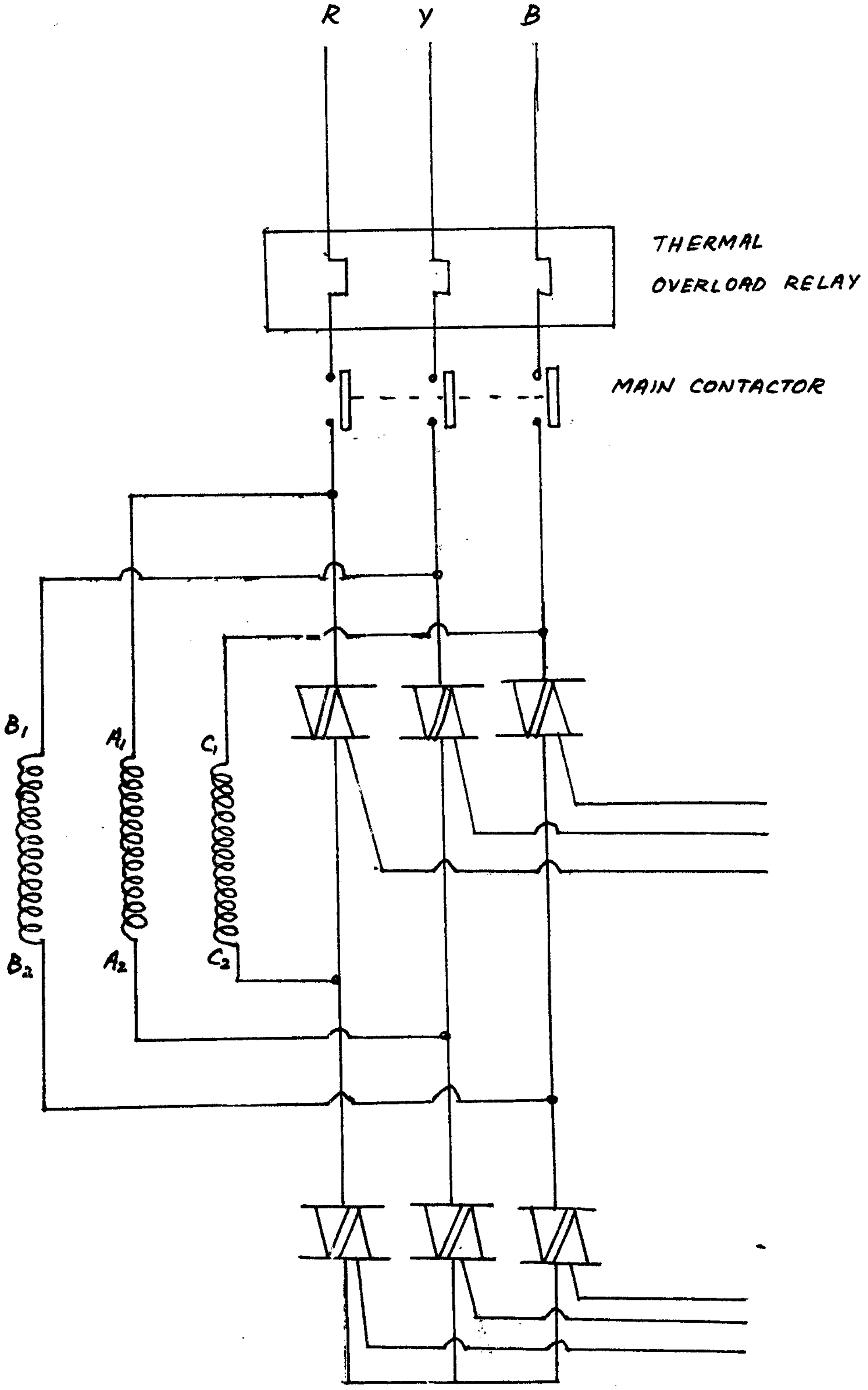

Fig 3.1 Power Circuit

CHAPTER IV

CONTROL CIRCUIT

4.1 Components used and its purpose

1. Bridge Rectifiers Type ICB2

An IC bridge rectifier is used to produce unidirectional pulsating d.c voltage from a 12V a.c signal obtained by means of a 230/12 V step-down transformer.

2. Fixed IC Voltage Regulator Type IC 7812

The function of the voltage regulator is to provide a stable d.c voltage for powering the electronic components or circuits. Usually regulators are classified into two categories, namely :

(a) Series Regulators
(b) Switching Regulators

The regulator used in the control circuit of our project is Series voltage regulator which is also called as Linear Regulators. They consist of a power transistor connected in series between the unregulated d.c input and the load. The output voltage is controlled by the continuous voltage drop taking place across the series pass transistor. Since the transistor conducts in the linear region, the regulator is called as linear regulator. The schematic diagram of the series voltage regulator is shown in Fig 4.1.

As seen from the figure, the series voltage regulator consists of a reference voltage circuit, error amplifier, series pass transistor and feedback network. Q_1 is in series with the unregulated d.c voltage V_{in} and the regulated output voltage V_o . Q_1 is conected as emitter follower and therefore provides sufficient current gain to drive the load. The output voltage is sampled by R_1-R_2 divider and fedback to the negative input terminal of the error amplifier. The sampled voltage is compared with reference voltage and output V_o' of the error amplifier which drives the transistor Q_1 .

If the output voltage increases, the sampled voltage βV_o also increases. This in turn, decreases the output voltage of the error amplifier due to 180° phase difference provided by the error amplifier. Since Q_1 acts as the emitter follower V_0 follows V_0', that is V_0 also decreases. Hence the increase in output is nullified. Similarly, the reduction in V_0 also gets regulated.

With the 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. Such type of monolithic IC is 78XX / 79XX series.

78XX IC voltage regulators are 3-terminal fixed output voltage regulators. The 'XX' represents the amount of output voltage. For e.g., the 7812 IC is a 12V fixed output voltage regulator. The standard representation of monolithic IC voltage regulator is shown in Fig 4.2.

The capacitor at the input side C_1 is usually connected between the input terminals and ground to cancel the inductive effects due to long distribution loads. The output capacitance C_2 improves the transient response.

3. Adjustable IC Voltage Regulators Type LM - 317

LM - 317 is a 3-terminal monolithic adjustable IC voltage regulator. The output voltage of this regulator can be varied from 1.2 to 40 Volts. The standard representation of LM - 317 is shown in Fig 4.3.

By varying the potentiometer, the output voltage can be varied.

4. Optocouplers Type MCT - 2E

Usually the power circuit should be isolated from the control circuit by means of some devices like pulse transformers and optocouplers. The main disadvantage of using pulse transformers is that the inter-winding capacitance of conventional pulse transformer may pose a serious problem for series operation of power semi-conductor devices particularly when the rate of rise of voltage is high. A high value of dv/dt can induce currents to flow in the inter-winding capacitance and may lead to false triggering. This problem can be avoided by the use of optical isolation between the firing circuits of power semi-conductor devices used in the circuit. For this purpose of optical isolation, we make use of optocouplers. An ideal optocoupler consists of a light emitter and light detector. Usually a LED is used for emitting light and this light output from the LED proportional to the input current makes it an ideal device for coupling one device to other by means of a photo sensor. When the emitter and sensor are placed in the same light-tight package, they are known as coupled pair or opto isolators. The sensor may be a phot transistor or a photo SCR. This package provides an output current proportional to input current with a high degree of isolation. The optocoupler here used is MCT - 2E and the schematic diagram is shown in Fig 4.4.

5. Relays

An electro-mechanical relay is a magnetic switch. It turns the load circuit on or off by energising the electromagnet. The relay used here is the NO-NC relay. When the relay coil is energised the armature is attracted towards the coil and hence forms the NC connection. When the coil is de-energised, the armature moves in the opposite direction to open (NO) the circuit by means of spring action.

4.2 Theory of Operation

The circuit diagram of the control circuit is as shown in Fig 4.5 Using a 230 / 12 V step-down transformer, the voltage is converted to a pulsating dc output using the 4-terminal Bridge rectifier. The output of this bridge rectifier is fed to the Fixed IC voltage regulator, IC 7812. This converts the voltage to pure d.c (12 V) and the capacitors C_1 and C_2 acts as filter to eliminate any a.c components.

The pure d.c output voltage from here is fed to the Variable IC voltage regulator LM - 317. The purpose of using the variable voltage regulator is to obtain the speed control of the Induction motor i.e., when the output voltage of the LM - 317 is varied, the d.c triggering voltage varies and this leads to phase control of the TRIAC's. Once phase control is achieved, it is possible to control the speed of the Induction motor. The outputs of the variable voltage regulators are fed as inputs to the optocouplers and are also used to bias the photo-transistor in the optocoupler.

The control circuit consists of two sets of three optocouplers. One set of optocouplers are used to isolate the set of TRIAC's in the star part of the power circuit from the control circuit. The other set of optocouplers are used to isolate the TRIAC's used in the delta part of the power circuit. The output of the optocouplers are pure d.c voltages which are used for the purpose of triggering the set of TRIAC's in their respective portions.

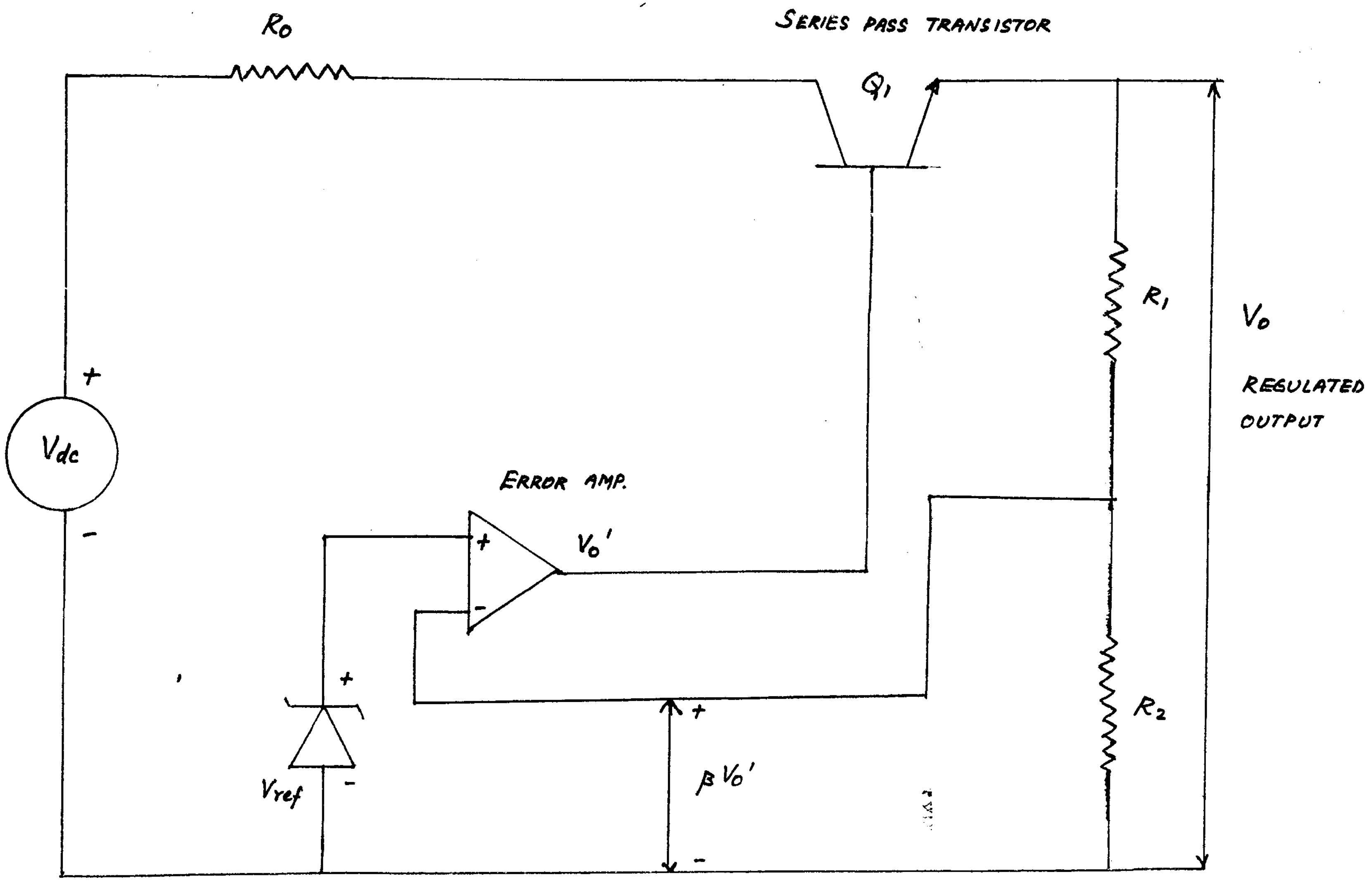

Fig 4·1 Schematic Diagram of Series Voltage Regulator

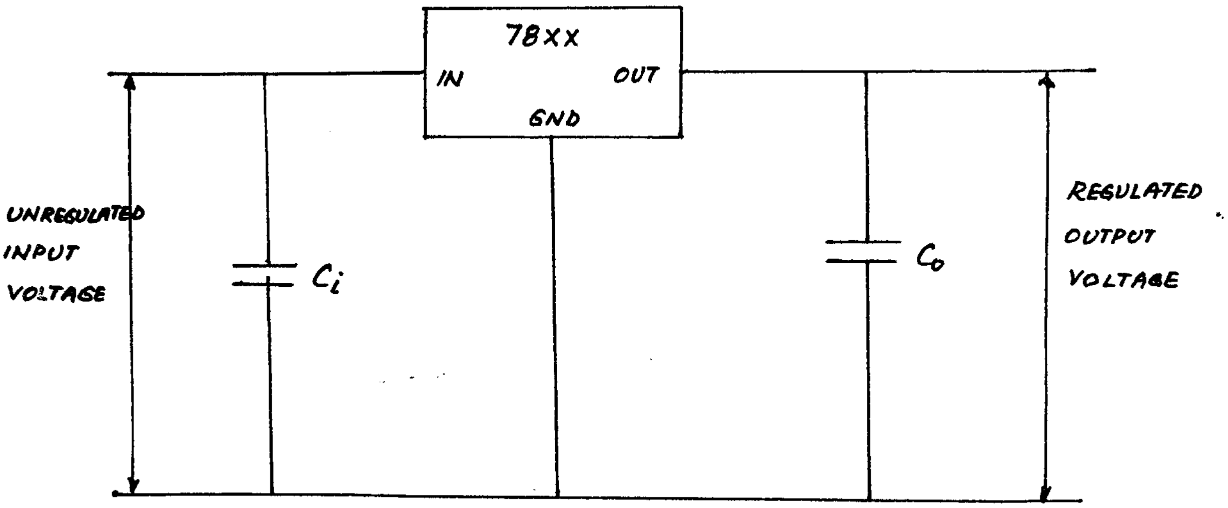

Fig 4·2 Standard Representation of Fixed IC Voltage Regulator

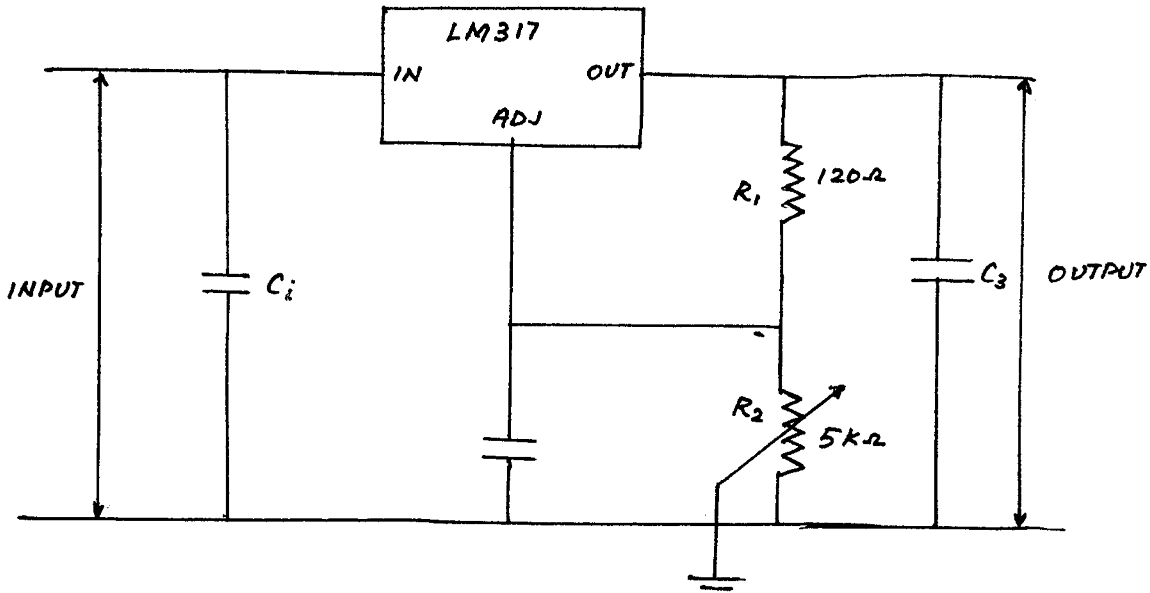

Fig 4·3 Standard Representation of Adjustable Voltage Regulator

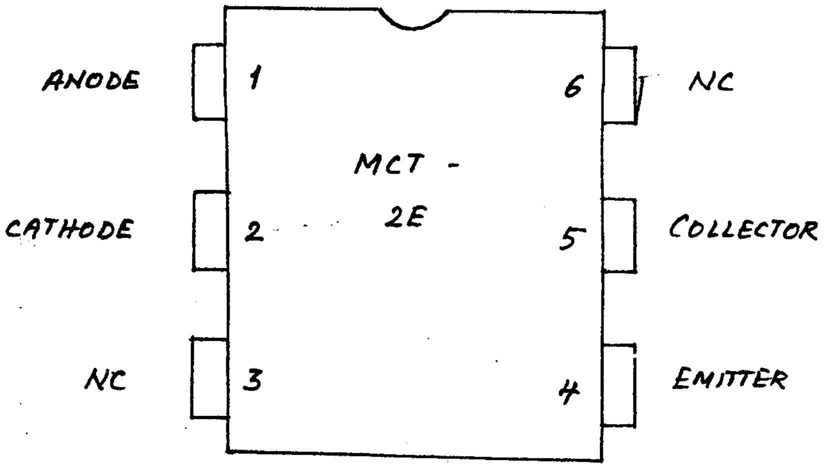

Fig 4.4 Pin Diagram of optocoupler

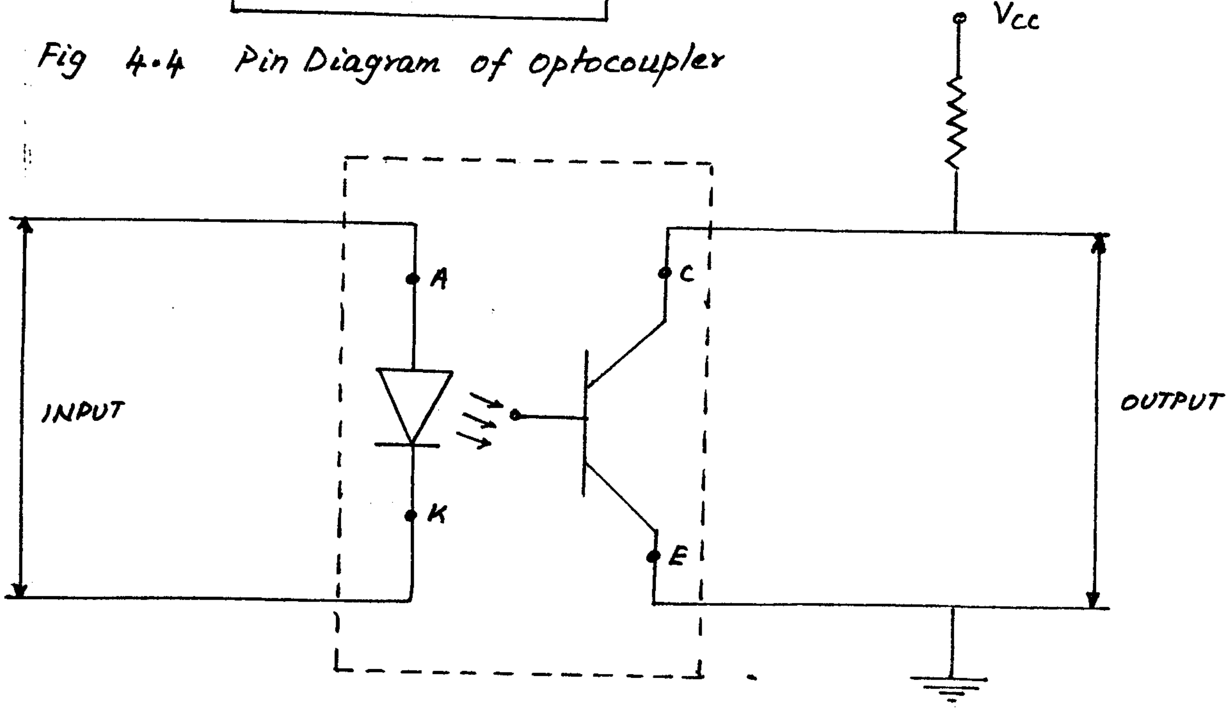

Fig 4.4 Schematic Diagram of MCT - 2E

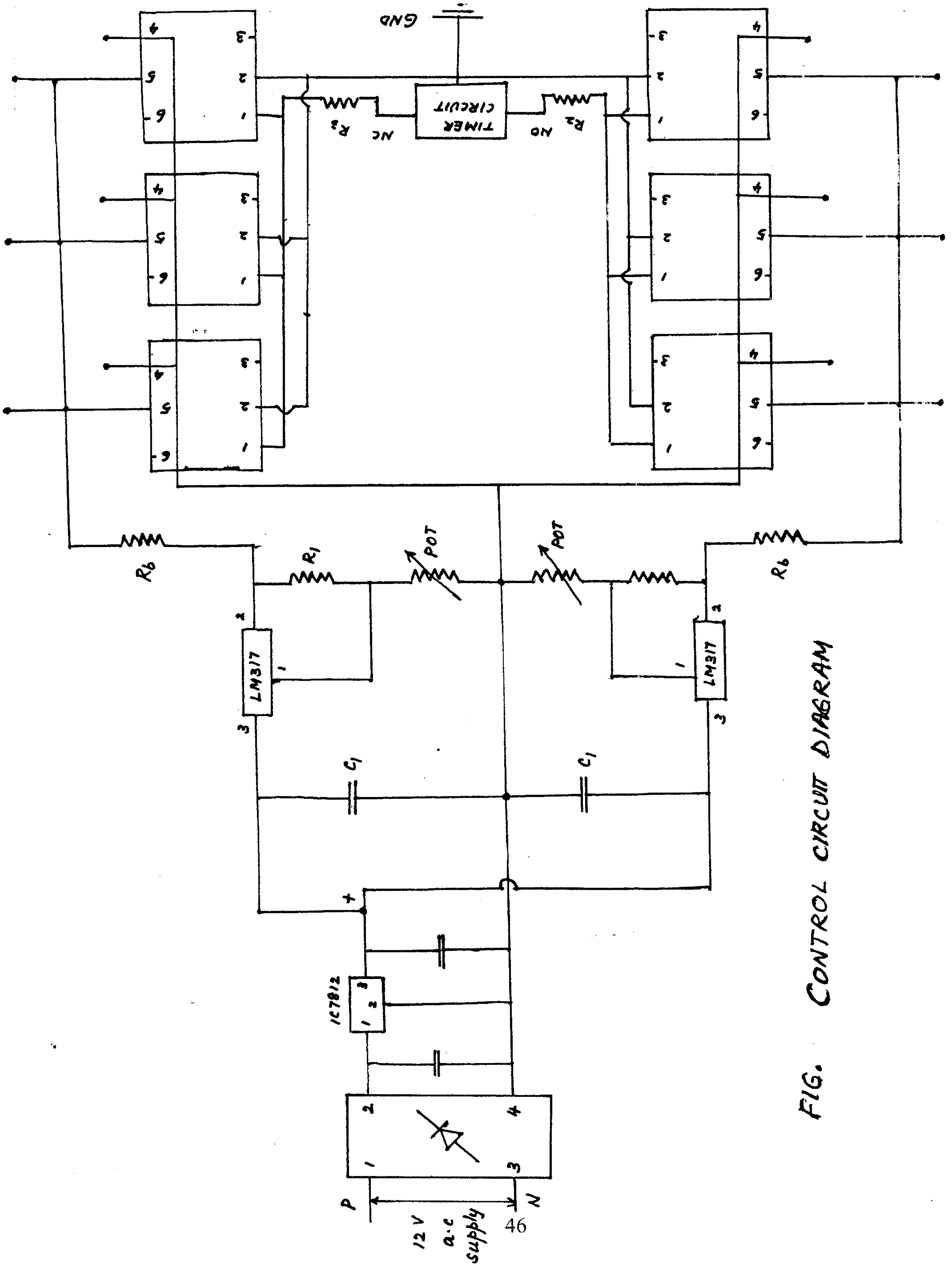

FIG. CONTROL CIRCUIT DIAGRAM

CHAPTER V

TIMING CIRCUITS

5.1 Components used and its purpose

1. 555 Timer Type NE - 555

The 555 timer is a highly stable device for generating accurate time delay or oscillation. A single 555 timer can provide time delay ranging from microseconds to hours. The 555 timer can be used with supply voltage in the range of + 5 V to + 18 V and can drive a load upto 200 mA.

The pin configuration and functional diagram of the 555 timer are shown in Fig 5.1 and Fig 5.2 respectively.

Referring to the functional diagram, three 5K internal resistors acts as voltage divider providing bias voltage 2/3 V_{cc} to the upper comparator and 1/3 V_{cc} to LC where V_{cc} is the supply voltage. Since these two voltages fix the necessary comparator threshold voltage, they also aid in determining the timing interval. It is possible to vary the time electronically too, by applying a modulation voltage to the control voltage input terminal (pin 5). In applications where no such modulation is intended, it is recommended that a capacitor (0.01 μF) be connected between the control voltage terminal (Pin 5) and ground to bypass noise or ripple from the supply. In the stable or stand-by state, the output of the flip-flop is high. This makes the output low because of the power amplifier, which is basically an inverter.

A negative pulse is applied to pin 2 and should have its d.c level greater than the threshold level of the lower comparator (i.e., $V_{cc} / 3$), the negative going edge of the trigger. As the trigger passes through $V_{cc} / 3$ the output of the lower comparator goes high and sets the flip-flop. During the positive excursion, when the threshold voltage at pin 6 passes through 2/3 V_{cc}, the output of the upper comparator goes high and resets the flip-flop. The reset input pin 4 provides a mechanism to reset the flip-floop in a manner which overrides the effect of any instruction coming to the flip-flop from the lower comparator. The transistor Q_2 serves as a buffer to isolate the reset input from the flip-flop and transistor Q_1.

2. Reset Button

A reset button is provided to reset the timer whenever the induction motor stops running due to overloaded condition. This reset button serves to run the starter back in Star, since the electromagnetic relay is de-energised.

3. Potentiometer

A potentiometer is provided using which the time delay can be varied ranging from 0 seconds to 100 seconds. For typical operation of Star-Delta starter, the time delay for conversion from star to delta is 3 seconds to 12 seconds. This time can be set using the potentiometer. The time, if required, can also be increased for operating the induction motor under loaded conditions.

5.2 Theory of Operation

The timing circuit diagram is shown in Fig 5.3. As mentioned earlier, the timer used is IC NE - 555. The timer is operated in the monostable mode to provide the necessary time delay and this monostable operation is explained below.

5.2.1 Monostable Mode of Operation

In the stand-by state, the flip-flop holds the transistor Q_1 ON thus clamping the external timing capacitor C t ground. The output remains at ground potential i.e., low. As the trigger passes through V_{cc} / 3, the flip-flop is set i.e., Q' = 0. This makes the transistor Q_1 off and the short-circuit across the timing capacitor C is released. When Q' is low, the output goes high. The timing cycle now begins. Since C is unclamped across, it raises exponentially through R towards V_{cc} with a time constant RC. After a time period T, the capacitor voltage is just greater than 2/3 V_{cc} and the upper comparator resets the flip-flop i.e., R = 1, S = 0. This makes Q' = 1, transistor Q_1 goes ON, thereby discharging the capacitor C rapidly to ground potential. The output returns to stand-by state or ground potential.

Voltage across the capacitor $V_c = V_{cc}(1-e^{-t/RC})$ ....(5.1)

At $t = T$, $V_c = 2/3\ V_{cc}$

$2/3\ V_{cc} = V_{cc}(1-e^{-t/RC})$ ....(5.2)

$T = RC \ln (1/3)$

$= 1.1\ RC$ seconds ....(5.3)

It is evident from the above equation that the timing interval is independant of the supply voltage. It may also be noted that once triggered, the output remains in the HIGH state until time T elapses, which depends only upon R & C. Any additional trigger pulse coming during this time will not change the output state.

However, if a negative going reset pulse is applied to the reset terminal (pin 4) during the timing cycle, transistor Q_2 goes off, Q_1 becomes ON and the external timing capacitor C is immediately discharged.

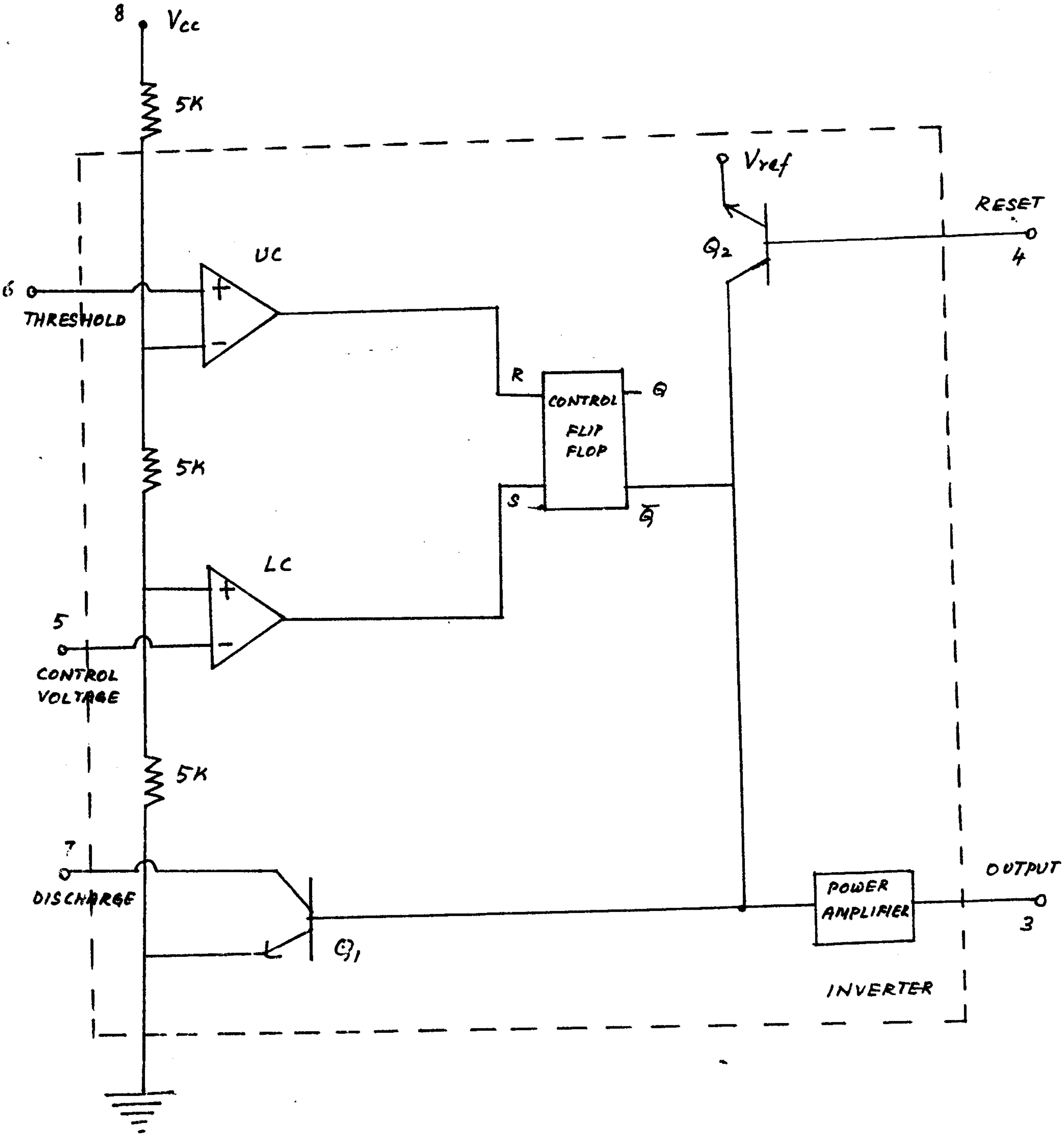

Fig 5.2 Functional Diagram of IC 555

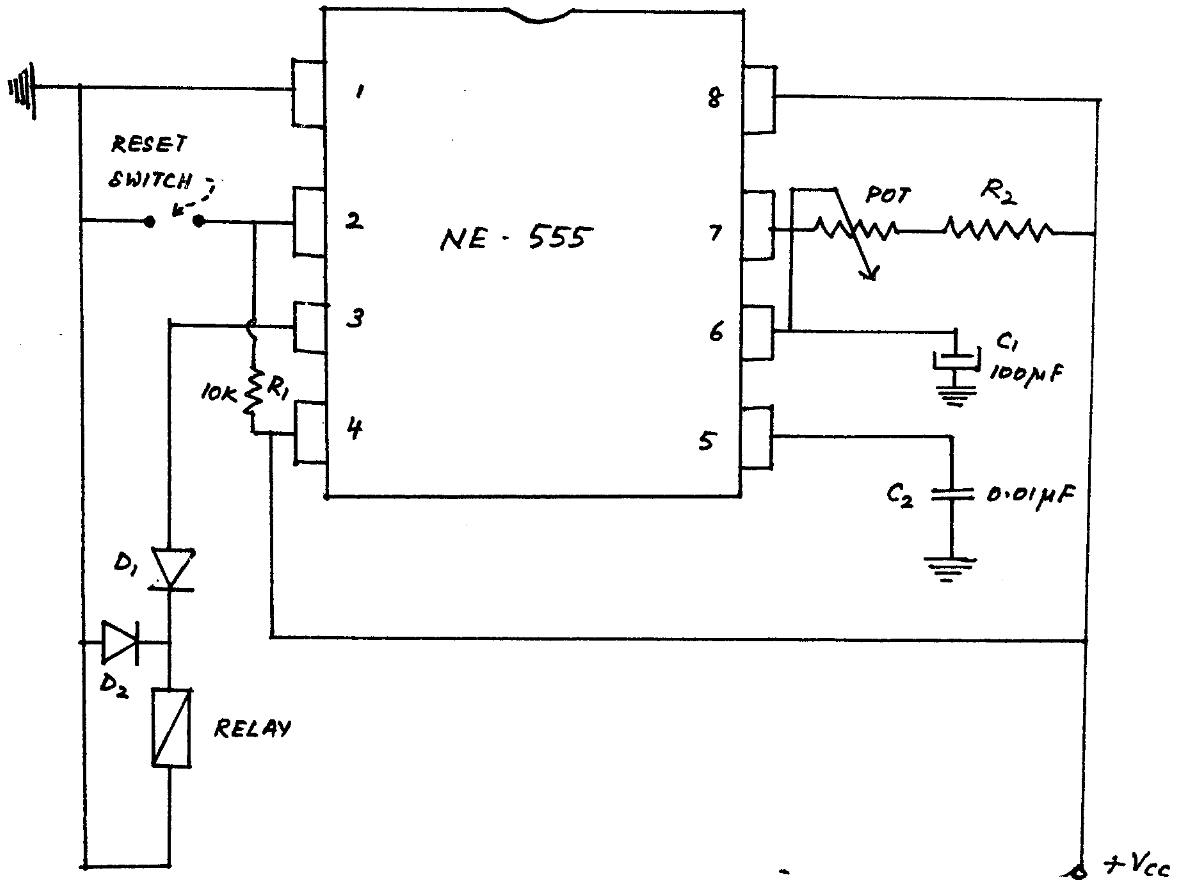

Fig 5·3 Timing Circuit Diagram.

CHAPTER VI

FABRICATION AND TESTING

6.1 Fabrication of Power circuit

The terminals MT_2 of the first set of TRIAC's are connected to the first set of Red knobs which are to be connected to the three phase supply R,Y and B respectively. The terminals MT_1 of the first set of TRIAC's are connected to the MT_2 terminals of the second set of TRIAC's through the black knobs. The second set of TRIAC's are used to form the star connection and hence the terminals MT_1 of this set of TRIAC's are shorted to obtain the star point. The terminal knobs mounted on the hylum board are used for the connection of stator windings. The heat sinks are mounted in such a manner that sufficient free space is provided between them in order to improve their efficiency. It is also to be seen that there is no bulky component nearby that would obstruct the flow of air through the heat sinks. Here heat sinks with unidirectional slots are used, and so the air flow must always pass the heat sink in the same direction as the slots are kept in order to ensure maximum dissipation of heat.

6.2 Fabrication of Control Circuit

The control circuit consists of the timing circuit and the triggering circuit which are fabricated on a Printed Circuit Board (PCB). The type of PCB used here is a single sided one. The single sided PCB's are used in entertainment packs, hobby circuits and so on. The components of the control circuit namely, the 230/12 V and 230/6 V step-down transformers, the bridge rectifier, the IC Voltage regulator, capacitors for smoothening the output, the potentiometers to vary the output of the variable voltage regulator IC LM - 317 are all placed in the appropriate places and they are soldered as per the standards. The transformer primary winding is connected to the R-phase of the supply.

The power circuit and control circuit after fabrication are mounted inside a sheet metal box with provisions for time delay knob and timer reset button.

6.3 Testing

The Star - Delta starter fabricated is tested for operation. This is done by connecting the windings A1, B1, C1 and A2, B2, C2 of the stator of a 1 HP 3-phase induction motor to the respective winding terminal knobs on the starter. The R, Y and B phases of the supply are connected to the terminal knobs A1, B1 and C1 of the starter respectively.

The time delay potentiometer is adjusted. A delay of 8 seconds for change-over of star connection of windings of stator to delta is set and the motor is started. The motor is found to run in star for a period of 8 seconds after which it is automatically connected to run in delta. The change-over is indicated by Light Emitting Diodes (LED's) for star and delta connections. The motor is tested for various values of time delay between star-delta switch over and the speeds are measured.

6.4 Advantages

Compared to the conventional type of star-delta starters using relays and contactors, this project has many advantages.

1. No moving part ensures that frictional losses and mechanical problems are eliminated.

2. A time delay knob is provided by which a manual adjustment of time delay from star connection of windings of the motor to delta connection is possible.

3. The d.c triggering voltage can be varied by adjusting the knob provided for the purpose. The change in d.c triggering voltage leads to phase control of the TRIAC. This phase control enables us to vary the speed of the Induction motor.

4. Compared to the size of the relays and contactors in the conventional type, the TRIAC's and control circuit occupy lesser area. This provides for compactness of the project.

5. Cost of manufacturing is reduced to a great extent. The project is estimated at a cost 20 to 30% lesser compared to the conventional automatic type.

6. The same power unit can be used for induction motors of different horse power ratings except that the TRIAC's of higher ratings should be provided. This is not the case in conventional star-delta starters using relays and contactors. This is due to the fact that with the increase in current rating, there is an increase in the size of the relays and contactors.

from star connection of windings to delta takes place through the TRIAC and the rest of the circuit is connected directly on line with the motor.

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