A
PROJECT REPORT
ON
SPEED CONTROL OF SINGLE PHASE INDUCTION MOTOR BY USING TRIAC

Project work submitted in partial fulfilment of the requirements

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BACHELOR OF ENGINEERING

in

ELECTRICAL ENGINEERING

BY

BAMNE SHARIQUE	**(12EE09)**
KAZI FAIZ	**(12EE18)**
DABRA GAURAV	**(12EE14)**
SAYYAD SHARUKH	**(12EE42)**

Under the guidance of

Prof. Rizwan Faradae

Professor in EE

KTC
Anjuman-I-Islam's
Kalsekar Technical Campus

DEPARTMENT OF ELECTRICAL ENGINEERING

ANJUMAN-I-ISLAMS KALSEKAR TECHNICAL CAMPUS
SCHOOL OF ENGINEERING AND TECHNOLOGY

(Approved by AICTE New Delhi, Affiliated to Mumbai University, Mumbai)

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DEPARTMENT OF ELECTRICAL ENGINEERING

CERTIFICATE

This is to certify that the Project entitled **“SPEED CONTROL OF SINGLE PHASE INDUCTION MOTOR BY USING TRIAC”** that is being submitted by **BAMNE SHARIQUE, KAZI FAIZ, DABRA GAURAV, SAYYAD SHARUKH** in partial fulfilment of the requirements for the award of degree of **BACHELOR OF ENGINEERING** in **ELECTRICAL ENGINEERING** is record of bonafide work carried out by them during the academic year 2015-2016 under our guidance and supervision.

Internal Guide	**Head of the Department**
Prof. Rizwan Faradae	**Prof. Kaleem sayed**
EXAMINER	**PRINCIPAL**

STUDENT DECLARATION

We hereby declare that the project entitled "**Speed control of single phase induction motor by using triac**" is the work done by us at **Anjuman-I-Islam Kalsekar Technical Campus School of Engineering & Technology** during the academic year 2015-2016 and is submitted in partial fulfillment of the requirement for the award of degree of Bachelor of Technology in Electrical Engineering.

BAMNE SHARIQUE
KAZI FAIZ
DABRA GAURAV
SAYYAD SHARUKH

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BAMNE SHARIQUE
KAZI FAIZ
DABRA GAURAV
SAYYAD SHARUKH

ABSTRACT

A single phase induction motor physically looks similar to that of a three phase induction motor except that its stator is provided with a single phase winding. The rotor of any single phase induction motor is interchangeable with that of a polyphase induction motor. A single phase winding would produce no rotating magnetic field and no starting torque. In the stator of a single phase motor is provided with an extra winding known as starting winding.

Single phase induction motors are small motors having a wide field of usefulness where a poly phase supply is not available. They are generally used in fans, blowers, washing machines, refrigerators, etc. The speed of the induction motor can be varied in a narrow range by varying the voltage applied to the stator winding. This method of speed control is suitable for such applications, where the load varies approximately as the square of speed, such as centrifugal pump drives, fan load.

The terminal voltage across the stator winding of the motor can be varied for obtaining the desired speed control by controlling the firing angle of the semiconductor power devices(TRIAC in our project)

For any firing angle α the average output voltage across a TRIAC is given by

$V = (2V' \cos\alpha / \pi)$;

V' is the max voltage provided.

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CHAPTER 1
INTRODUCTION

The characteristics of single phase induction motors are identical to 3-phase induction motors except that single phase induction motor has no inherent starting torque and some special arrangements have to be made for making itself starting. Though single phase induction motor is not self-starting we are using it because the 3-phase supply is not present at everywhere.

Especially in domestic purposes single phase induction motors are widely used. In many electrical appliances namely ceiling fan, refrigerator, washing machines etc . we are using this type of motor. The main reason behind using it is availability of single phase supply and one more is economical i.e., less costlier in price. So speed control of induction motor is important.

In this project we are doing single phase induction motor speed control by using Triac and 555 timer. The complete control circuitry depends on only one parameter i.e. Voltage. We know that torque developed is proportional to square of the voltage. Thus the applied voltage to induction motor stator terminals is controlled by triac and its gate pulses. When pulses to the gate are delayed then reduced voltage is applied to the induction motor stator terminals and thus as voltage and torques are proportional to each other, torque decrease and simultaneously speed of the motor gets reduced. The control circuitry consists of the following :

1. Triggering circuit
2. Triac circuit and
3. Power supply circuit.

The power supply circuit will provide DC supply 5v and 12v to the electronic devices which require the biasing voltage.The triggering circuit will generate the pulses and are given to triac as gate pulses for triggering purpose. And finally triac circuit acts as intermediate part between supply and induction motor. Therefore applied voltage from the supply to induction motor and thereby speeds are controlled.

CHAPTER 2
INDUCTION MOTOR

2.1 PRINCIPLE OF OPERATION

An induction or asynchronous motor is a type of AC motor where power is supplied to the rotor by means of electromagnetic induction, rather than a commutator or slip rings as in other types of motor. These motors are widely used in industrial drives, particularly polyphase induction motors, because they are rugged and have no brushes. Single-phase versions are used in small appliances. Their speed is determined by the frequency of the supply current, so they are most widely used in constant-speed applications, although variable speed versions, using variable frequency drives are becoming more common. The most common type is the squirrel cage motor, and this term is sometimes used for induction motors generally. In both induction and synchronous motors, the stator is powered with alternating current (polyphase current in large machines) and designed to create a rotating magnetic field which rotates in time with the AC oscillations.

In a synchronous motor, the rotor turns at the same rate as the stator field. By contrast, in an induction motor the rotor rotates at a slower speed than the stator field. Therefore the magnetic field through the rotor is changing (rotating). The rotor has windings in the form of closed loops of wire. The rotating magnetic flux induces currents in the windings of the rotor as in a transformer. These currents in turn create magnetic fields in the rotor, that interact with (push against) the stator field. Due to Lenz's law, the direction of the magnetic field created will be such as to oppose the change in current through the windings. The cause of induced current in the rotor is the rotating stator magnetic field, so to oppose this the rotor will start to rotate in the direction of the rotating stator magnetic field to make the relative speed between rotor and rotating stator magnetic field zero.

For these currents to be induced, the speed of the physical rotor must be lower than that of the stator's rotating magnetic field ( ), or the magnetic field would not be moving relative to the rotor conductors and no currents would be induced. As the speed of the rotor drops below synchronous speed, the rotation rate of the magnetic field in the rotor increases, inducing more current in the windings and creating more torque. The ratio between the rotation rate of the magnetic field as seen by the rotor (slip speed) and the rotation rate of the stator's rotating field is called "*slip*". Under load, the speed drops and the slip increases enough to create sufficient torque to turn the load. For this reason, induction motors are sometimes referred to as asynchronous motors. An induction motor can be used as induction generator, or it can be unrolled to form the linear induction motor which can directly generate linear motion.

2.2 TYPES OF INDUCTION MOTORS

Generally, induction motors are categorized based on the number of stator windings. They are:

- Single-phase induction motor
- Three-phase induction motor

Single-Phase Induction Motor:

There are probably more single-phase AC induction motors in use today than the total of all the other types put together. It is logical that the least expensive, lowest maintenance type motor should be used most often. The single-phase AC induction motor best fits this description. As the name suggests, this type of motor has only one stator winding (main winding) and operates with a single-phase power supply. In all single-phase induction motors, the rotor is the squirrel cage type.

Three-Phase AC Induction Motor:

Three-phase AC induction motors are widely used in industrial and commercial applications. They are classified either as squirrel cage or wound-rotor motors. These motors are self-starting and use no capacitor, start winding, centrifugal switch or other starting device. They produce medium to high degrees of starting torque. The power capabilities and efficiency in these motors range from medium to high compared to their single-phase counterparts. Popular applications include grinders, lathes, drill presses, pumps, compressors, conveyors, also printing equipment, farm equipment, electronic cooling and other mechanical duty applications.

2.3 SINGLE PHASE INDUCTION STARTING METHODS

The single-phase IM has no starting torque, but has resultant torque, when it rotates at any other speed, except synchronous speed. It is also known that, in a balanced two-phase IM having two windings, each having equal number of turns and placed at a space angle of (electrical), and are fed from a balanced two-phase supply, with two voltages equal in magnitude, at an angle of , the rotating magnetic fields are produced, as in a three-phase IM. The torque-speed characteristic is same as that of a three-phase one, having both starting and also running torque as shown earlier. So, in a single-phase IM, if an auxiliary winding is introduced in the stator, in addition to the main winding, but placed at a space angle of (electrical), starting torque is produced. The currents in the two (main and auxiliary) stator windings also must be at an angle of , to produce maximum starting torque, as shown in a balanced two-phase stator. Thus, rotating magnetic field is produced in such motor, giving rise to starting torque. The various starting methods used in a single-phase IM are described here.

2.3.1 Split Phase Motor

The split-phase motor is also known as an induction start induction run motor. It has two windings: a start and a main winding. The start winding is made with smaller gauge wire and fewer turns, relative to the main winding to create more resistance, thus putting the start winding's field at a different angle than that of the main winding which causes the motor to start rotating. The main winding, which is of a heavier wire, keeps the motor running the rest of the time.

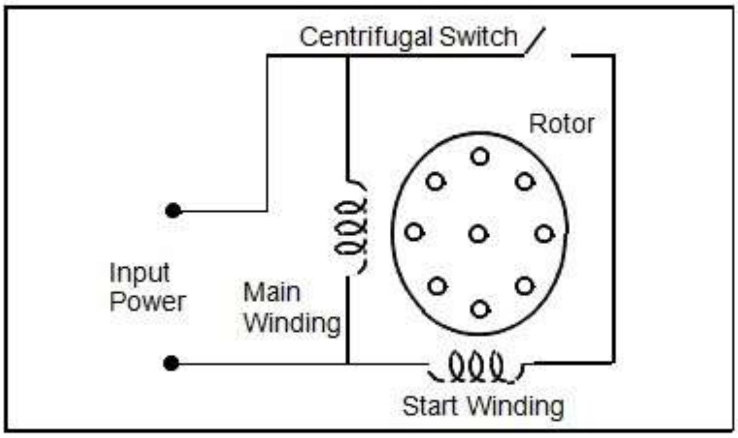


Fig 2.1: Typical Split-Phase AC Induction Motor

The starting torque is low, typically 100% to 175% of the rated torque. The motor draws high starting current, approximately 700% to 1,000% of the rated current. The maximum generated torque ranges from 250% to 350% of the rated torque . Good applications for split-phase motors include small grinders, small fans and blowers and other low starting torque applications with power needs from 1/20 to 1/3 hp. Avoid using this type of motor in any applications requiring high on/off cycle rates or high torque.

2.3.2 Capacitor Start Motor

This is a modified split-phase motor with a capacitor in series with the start winding to provide a start “boost.” Like the split-phase motor, the capacitor start motor also has a centrifugal switch which disconnects the start winding and the capacitor when the motor reaches about 75% of the rated speed. Since the capacitor is in series with the start circuit, it creates more starting torque, typically 200% to 400% of the rated torque. And the starting current, usually 450% to 575% of the rated current, is much lower than the split-phase due to the larger wire in the start circuit.
A modified version of the capacitor start motor is the resistance start motor. In this motor type, the starting capacitor is replaced by a resistor. The resistance start motor is used in applications where the starting torque requirement is less than that provided by the capacitor start motor. Apart from the cost, this motor does not offer any major advantage over the capacitor start motor.

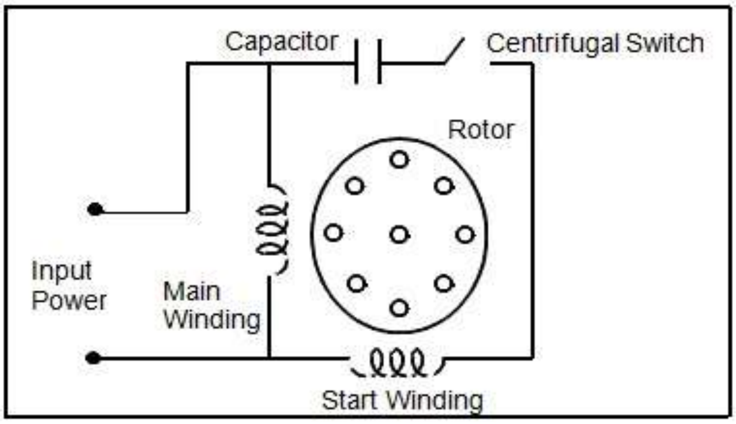


Fig 2.2: Typical Capacitor Start Induction Motor

They are used in a wide range of belt-drive applications like small conveyors, large blowers and pumps, as well as many direct-drive or geared applications

2.3.3 Permanent Split Capacitor Motor

A permanent split capacitor (PSC) motor has a run type capacitor permanently connected in series with the start winding. This makes the start winding an auxiliary winding once the motor reaches the running speed. Since the run capacitor must be designed for continuous use, it cannot provide the starting boost of a starting capacitor. The typical starting torque of the PSC motor is low, from 30% to 150% of the rated torque. PSC motors have low starting current, usually less than 200% of the rated current, making them excellent for applications with high on/off cycle rates.

The PSC motors have several advantages. The motor design can easily be altered for use with speed controllers. They can also be designed for optimum efficiency and High-Power Factor (PF) at the rated load. They're considered to be the most reliable of the single-phase motors, mainly because no centrifugal starting switch is required.

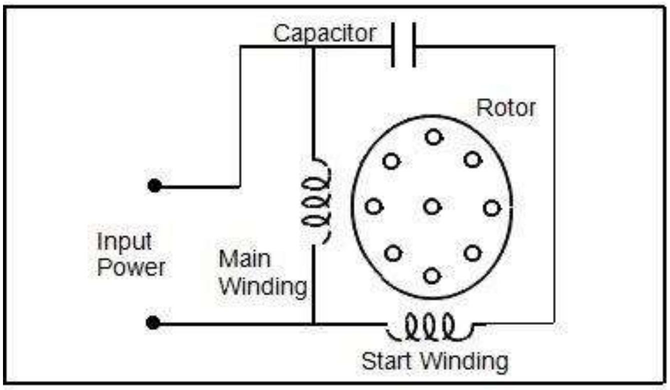


Fig 2.3: Typical Permanent Split Capacitor Motor

2.3.4 Capacitor Start And Run Motor

This motor has a start type capacitor in series with the auxiliary winding like the capacitor start motor for high starting torque. Like a PSC motor, it also has a run type capacitor that is in series with the auxiliary winding after the start capacitor is switched out of the circuit. This allows high overload torque.

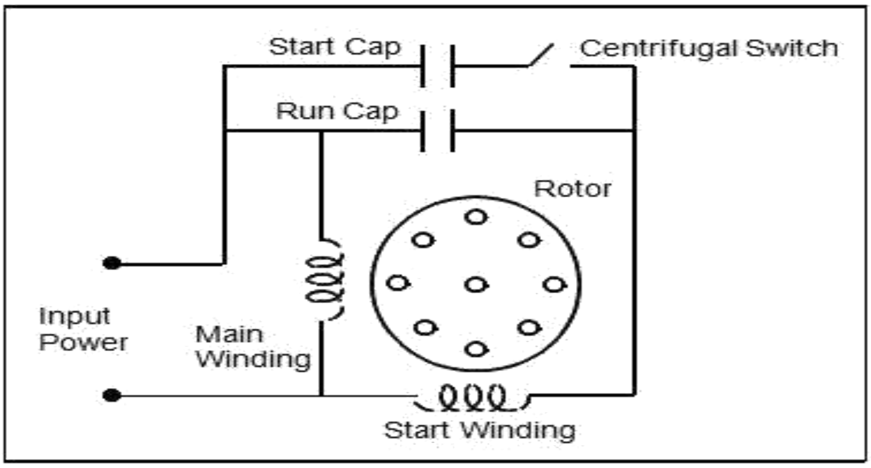


Fig 2.4: Typical Capacitor Start/Run Induction Motor

This type of motor can be designed for lower full-load currents and higher efficiency. Efficiency .This motor is costly due to start and run capacitors and centrifugal switch. It is able to handle applications too demanding for any other kind of single-phase motor. These include wood-working machinery, air compressors, high-pressure water pumps, vacuum pumps and other high torque applications requiring 1 to 10 hp.

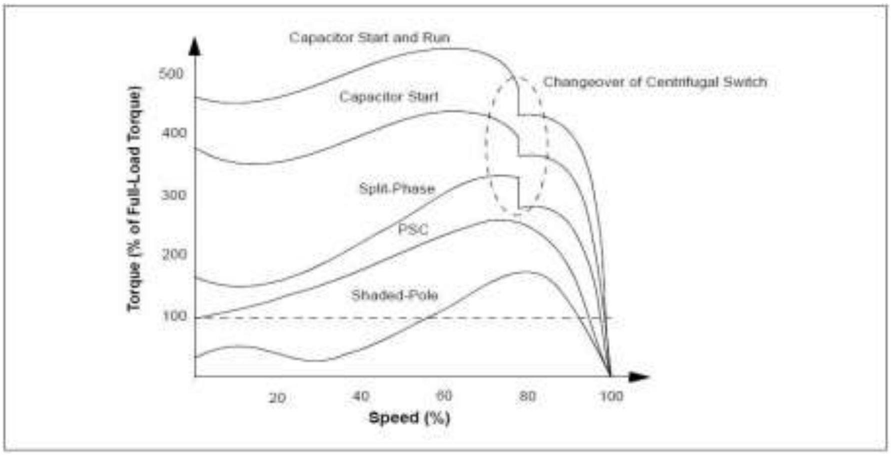


Fig 2.5: Torque-Speed Curves of Different Types of Single-Phase Induction Motors

2.4 TORQUE EQUATION

The torque produced in the induction motor depends on the following factors :

1. The part of rotating magnetic field which reacts with rotor and is responsible to produce induced e.m.f. in rotor.
2. The magnitude of rotor current in running condition.
3. The power factor of the rotor circuit in running condition.

Mathematically the relationship can be expressed as,

$$T \propto \phi I_{2r} \cos \phi_{2r} \qquad \dots (1)$$

where ϕ = Flux responsible to produce induced e.m.f.

I_{2r} = Rotor running current

$\cos \phi_{2r}$ = Running p.f. of rotor

The flux ϕ produced by stator is proportional to E_1 i.e. stator voltage.

$$\therefore \qquad \phi \propto E_1 \qquad \dots (2)$$

While E_1 and E_2 are related to each other through ratio of stator turns to rotor turns i.e. k.

$$\therefore \qquad \frac{E_2}{E_1} = k \qquad \dots (3)$$

Using equation (3) in equation (2) we can write,

$$\therefore \qquad E_2 \propto \phi \qquad \dots (4)$$

Thus in equation (1), ϕ can be replaced by E_2.

While
$$I_{2r} = \frac{E_{2r}}{Z_{2r}} = \frac{s E_2}{\sqrt{R_2^2 + (sX_2)^2}} \qquad \dots (5)$$

and
$$\cos \phi_{2r} = \frac{R_2}{Z_{2r}} = \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}} \qquad \dots (6)$$

Using equations (4), (5), (6) in equation (1),

$$T \propto E_2 \cdot \frac{s E_2}{\sqrt{R_2^2 + (sX_2)^2}} \cdot \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

$$\therefore \quad \boxed{T \propto \frac{s E_2^2 R_2}{R_2^2 + (sX_2)^2} \text{ N-m}}$$

$$\therefore \quad T = \frac{k s E_2^2 R_2}{R_2^2 + (sX_2)^2} \qquad \ldots(7)$$

where k = Constant of proportionality

The constant k is proved to be $3/2\pi\, n_s$ for the three phase induction motor.

$$\therefore \quad k = \frac{3}{2\pi n_s} \qquad \ldots (8)$$

Key Point : *n_s = Synchronous speed in r.p.s.* $= \frac{N_s}{60}$

Using equation (8) in equation (7) we get the torque equation as,

$$\boxed{T = \frac{3}{2\pi n_s} \cdot \frac{s E_2^2 R_2}{R_2^2 + (s X_2)^2} \text{ N-m}} \qquad \ldots (9)$$

So torque developed at any load condition can be obtained if slip at that load is known and all standstill rotor parameters are known .

2.5 SPEED CONTROL METHOD OF SINGLE PHASE INDUCTION MOTOR

For the speed control of single phase induction motor we have only one method called as "STATOR VOLTAGE CONTROL OF SINGLE PHASE INDUCTION MOTOR." In speed control by stator voltage control, the stator voltage is reduced from base value of rated speed to a lower value. As torque is proportional to voltage square, the torque speed characteristics goes down proportional to voltage square.

With shifting of torque characteristics the operating point will also move to give a reduce motor speed. For a well-designed machine with low value of slip the reduction in speed with reduced voltage is very small. Therefore if a large drop in speed I required with reduction in stator voltage, the motor is specially designed with high full load slip.

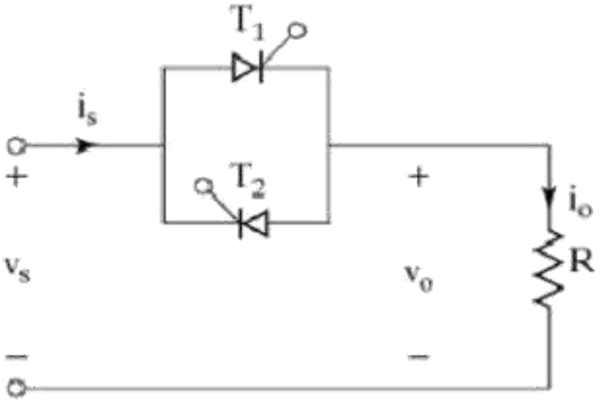


Fig 2.6: AC voltage controller

Using thyristor the control of stator voltage can be obtained by using AC voltage controller where reverse-parallel connected thyristors are used in each phase between supply and motor. The stator voltage reduced from its base value by increase of firing angle of thyristor from 0 to 180.

CHAPTER 3

POWER DEVICES

3.1 INTRODUCTION:

Power semiconductor devices constitute the heart of modern power electronic apparatus. They are used in power electronic converters in the form of a matrix of on-off switches, and help to convert power from ac-to-dc (rectifier), dc-to-dc (chopper), dc to-ac (inverter), and ac-to-ac at the same (ac controller) or different frequencies (cycloconverter). The switching mode power conversion gives high efficiency, but the disadvantage is that due to the nonlinearity of switches, harmonics are generated at both the supply and load sides. The switches are not ideal, and they have conduction and turn-on and turn-off switching losses. Converters are widely used in applications such as heating and lighting controls, ac and dc power supplies, electrochemical processes, dc and ac motor drives, static VAR generation, active harmonic filtering, etc. Although the cost of power semiconductor devices in power electronic equipment may hardly exceed 20–30 percent, the total equipment cost and performance may be highly influenced by the characteristics of the devices. An engineer designing equipment must understand the devices and their characteristics thoroughly in order to design efficient, reliable, and cost-effective systems with optimum performance. It is interesting to note that the modern technology evolution in power electronics has generally followed the evolution of power semiconductor devices. The advancement of microelectronics has greatly contributed to the knowledge of power device materials, processing, fabrication, packaging, modeling, and simulation.

Today’s power semiconductor devices are almost exclusively based on silicon material and can be classified as follows:

- Diode
- Thyristor or silicon-controlled rectifier (SCR)
- Triac
- Gate turn-off thyristor (GTO)
- Bipolar junction transistor (BJT or BPT)
- Power MOSFET

In this chapter, we will briefly study the operational principles and characteristics of these devices.

3.2 DIODES

Power diodes provide uncontrolled rectification of power and are used in applications such as electroplating, anodizing, battery charging, welding, power supplies (dc and ac), and variable frequency drives. They are also used in feedback and the freewheeling functions of converters and snubbers. A typical power diode has P-I-N structure, that is, it is a P-N junction with a near intrinsic semiconductor layer (I-layer) in the middle to sustain reverse voltage. Figure 1.1 shows the diode symbol and its volt-ampere characteristics. In the forward biased condition, the diode can be represented by a junction offset drop and a series-equivalent resistance that gives a positive slope in the V-I characteristics. The typical forward conduction drop is 1.0 V. This drop will cause conduction loss, and the device must be cooled by the appropriate heat sink to limit the junction temperature. In the reverse-biased condition, a small leakage current flows due to minority carriers, which gradually increase with voltage. If the reverse voltage exceeds a threshold value, called the breakdown voltage, the device goes through avalanche breakdown, which is when reverse current becomes large and the diode is destroyed by heating due to large power dissipation in the junction.

The turn-off voltage and current characteristics as functions of time, which are indicated in Figure 1.2, are particularly important for a diode. In the forward high-conduction region, the conduction drop (VF) is small, as mentioned before. At this condition, the P and N regions near the junction and the I-layer remain saturated with minority carriers.

If the device is open-circuited, the carriers die by a recombination process, which takes a reasonably long time. Normally, a reverse dc voltage (VR) is applied to turn off the device, as indicated in Figure 1.2. At time t = 0, the reverse voltage is applied when the current goes down linearly because of series-circuit inductance. During time t2, the current is negative and the minority carriers sweep out across the junction, but the excess carrier concentration keeps the junction saturated, and therefore, the same negative current slope is maintained. The conduction drop decreases during t1 and t2 due to the reduction of Ohmic (equivalent resistance) drop. At the end of t2, the device sustains voltage, and steady-state voltage appears at the end of t3. During t3, the reverse current falls quickly partly due to sweeping out and partly by recombination. The fast decay of negative current creates an inductive drop that adds with the reverse voltage VR as shown. The reverse recovery time trr = t2 + t3 and the corresponding recovery charge Qrr (shown by the hatched area) that are affected by the recombination process are important parameters of a diode. The snappiness by which the recovery current falls to zero determines the voltage boost Vrr. This voltage may be destructive and can be softened by a resistance –capacitance snubber,which will be discussed later.

Power diodes can be classified as follows:

- Standard or slow-recovery diode
- Fast-recovery diode
- Schottky diode

Slow- and fast-recovery diodes have P-I-N geometry, as mentioned above. In a fastrecovery diode, as the name indicates, the recovery time trr and the recovery charge Qrr (shown by the hatched area) are reduced by the minority carrier lifetime control that enhances the recombination process. However, the adverse effect is a higher conduction drop. For example, the POWEREX fast-recovery diode type CS340602, which has a dc current rating (IF(dc)) of 20 A and a blocking voltage rating (Vrrm) of 600 V, has the following ratings: VFM = 1.5 V, Irrm = 5.0 mA, trr = 0.8 µs, and Qrr = 15 µC. The standard slow-recovery diodes are used for line frequency (50/60 Hz) power rectification. They have a lower conduction drop, but a higher trr. These diodes are available with ratings of several kilovolts and several kiloamperes. A Schottky diode is basically a majority carrier diode and is formed by a metal-semiconductor junction. As a result, the diode has a lower conduction drop (typically 0.5 V) and faster switching time, but the limitations are a lower blocking voltage (typically up to 200 V) and higher leakage current. For example, the International Rectifier Schottky diode type 6TQ045 has ratings of Vrrm = 45 V, IF(AV) = 6 A, VF = 0.51 V, and reverse leakage current Irm = 0.8 mA (at 25 °C). These diodes are used in high-frequency circuits.

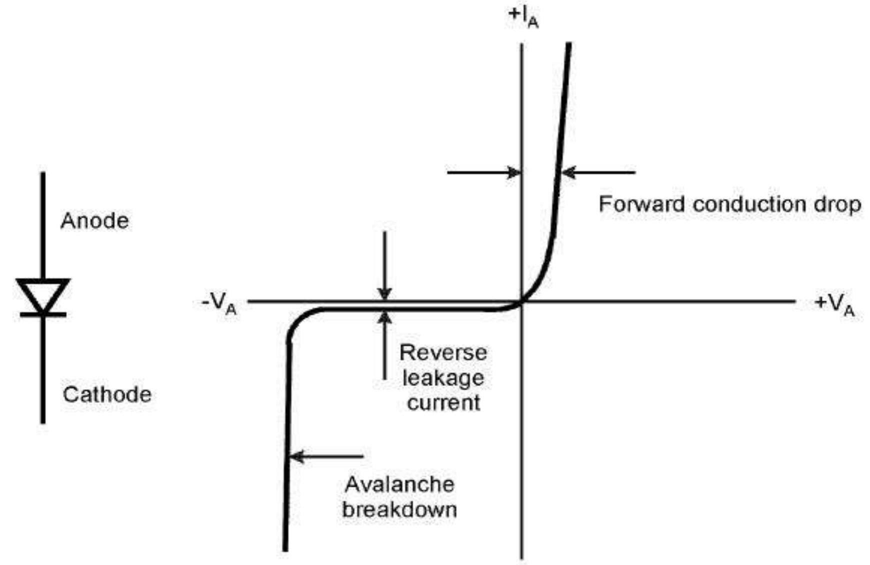


Fig 3.1: Diode symbol and volt-ampere characteristics

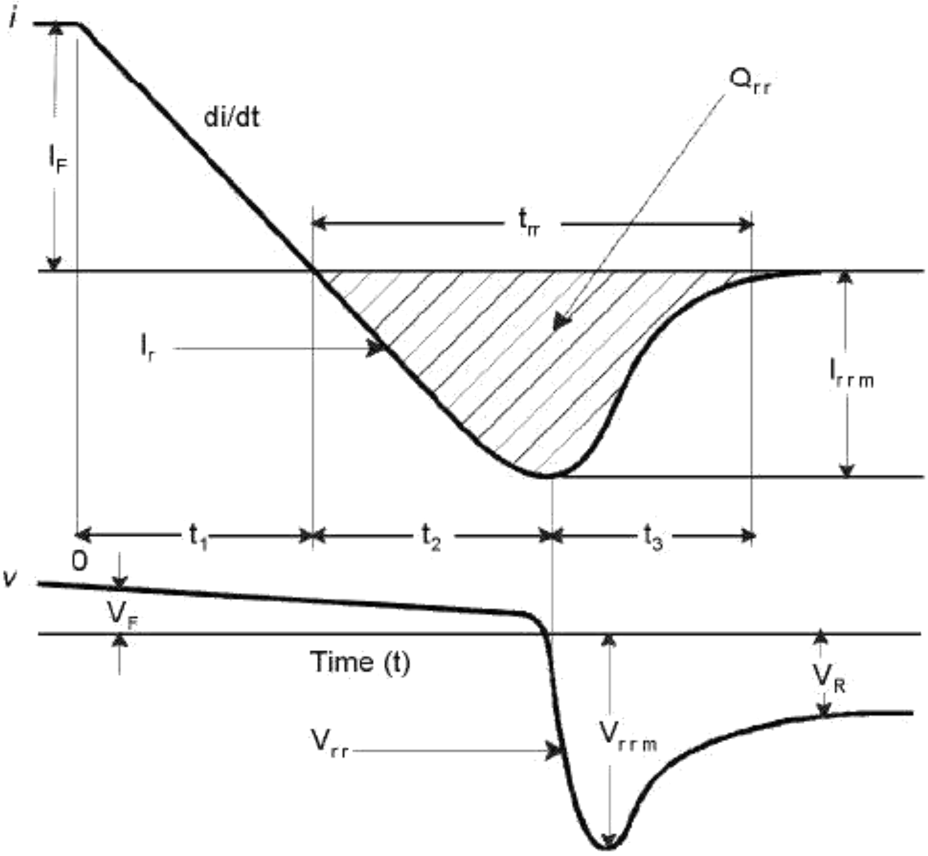


Fig 3.2: Turn-off switching characteristics of a diode

The electrical and thermal characteristics of diodes are somewhat similar to thyristors, which will be discussed next. Specific circuit applications of different types of diodes will be discussed in later chapters.

3.3 THYRISTORS

Thyristors, or silicon-controlled rectifiers (SCRs) have been the traditional workhorses for bulk power conversion and control in industry. The modern era of solid-state power electronics started due to the introduction of this device in the late 1950s. Chapters 3, 4, and 6 will discuss thyristor converters and their applications. The term “thyristor” came from its gas tube equivalent, thyratron. Often, it is a family name that includes SCR, triac, GTO, MCT, and IGCT. Thyristors can be classified as standard, or slow phase-control-type and fast-switching, voltage fed inverter-type. The inverter-type has recently become obsolete and will not be discussed further.

3.3.1 Volt-Ampere Characteristics

Figure 1.3 shows the thyristor symbol and its volt-ampere characteristics. Basically, it is a three-junction P-N-P-N device, where P-N-P and N-P-N component transistors are connected in regenerative feedback mode. The device blocks voltage in both the forward and reverse directions (symmetric blocking). When the anode is positive, the device can be triggered into conduction by a short positive gate current pulse; but once the device is conducting, the gate loses its control to turn off the device. A thyristor can also turn on by excessive anode voltage, its rate of rise (dv/dt), by a rise in junction temperature (TJ), or by light shining on the junctions. The volt-ampere characteristics of the device indicate that at gate current IG = 0, if forward voltage is applied on the device, there will be a leakage current due to blocking of the middle junction. If the voltage exceeds a critical limit (breakover voltage), the device switches into conduction. With increasing magnitude of IG, the forward breakover voltage is reduced, and eventually at IG3, the device behaves like a diode with the entire forward blocking region removed. The device will turn on successfully if a minimum current, called a latching current, is maintained. During conduction, if the gate current is zero and the anode current falls below a critical limit, called the holding current, the device reverts to the forward blocking state. With reverse voltage, the end P-N junctions of the device become reverse-biased and the V-I curve becomes essentially similar to that of a diode rectifier. Modern thyristors are available with very large voltage (several KV) and current (several KA) ratings.

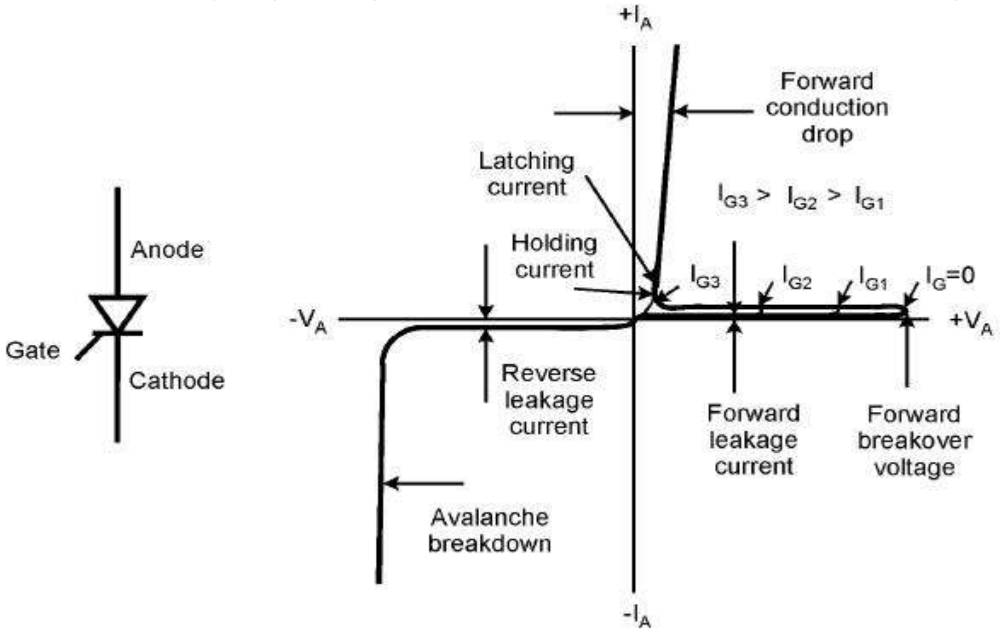


Fig 3.3: Thyristor symbol and volt-ampere characteristics

3.3.2 Switching Characteristics

Initially, when forward voltage is applied across a device, the off-state, or static dv/dt, must be limited so that it does not switch on spuriously. The dv/dt creates displacement current in the depletion layer capacitance of the middle junction, which induces emitter current in the component transistors and causes switching action. When the device turns on, the anode current di/dt can be excessive, which can destroy the device by heavy current concentration. During conduction, the inner P-N regions remain heavily saturated with minority carriers and the middle junction remains forward-biased. To recover the forward voltage blocking capability, a reverse voltage is applied across the device to sweep out the minority carriers and the phenomena are similar to that of a diode (see Figure 1.2). However, when the recovery current goes to zero, the middle junction still remains forward-biased. This junction eventually blocks with an additional delay when the minority carriers die by the recombination process. The forward voltage can then be applied successfully, but the reapplied dv/dt will be somewhat less than the static dv/dt because of the presence of minority carriers. For example, POWEREX SCR/diode module CM4208A2 (800 V, 25 A) has limiting di/dt = 100 A/µs and off-state dv/dt = 500 V/µs parameters. A suitably-designed snubber circuit (discussed later) can limit di/dt and dv/dt within acceptable limits. In a converter circuit, a thyristor can be turned off (or commutated) by a segment of reverse ac line or load voltage (defined as line or load commutation, respectively), or by an inductance- capacitance circuit-induced transient reverse voltage (defined as forced commutation).

3.3.3 Power Loss and Thermal Impedance

A thyristor has dominant conduction loss like a diode, but its switching loss (to be discussed later) is very small. The device specification sheet normally gives information on power dissipation for various duty cycles of sinusoidal and rectangular current waves. Figure 1.4 shows the power dissipation characteristics for a rectangular current wave. The reverse blocking loss and gate circuit loss are also included in the figure. These curves are valid up to 400 Hz supply frequency. The heat due to power loss in the vicinity of a junction flows to the case and then to the ambient through the externally mounted heat sink, causing a rise in the junction temperature TJ. The maximum TJ of a device is to be limited because of its adverse effect on device performance. For steady power dissipation P, TJ can be calculated as

$TJ - TA = P(\theta JC + \theta CS + \theta SA)$ (1.1) where TA is the ambient temperature, and θJC, θCS, and θSA represent the thermal resistance from junction to case, case to sink, and sink to ambient, respectively. The resistance θSA is determined by the cooling system design, and the methods of cooling may include heat sink with natural convection cooling, forced air cooling, or forced

liquid cooling. From Equation (1.1), it is evident that for a limited TJmax (usually 125°C), the dissipation P can be increased by reducing θSA. This means that a more efficient cooling system will increase power dissipation, that is, the power-handling capability of a device. An infinite heat sink is defined when θSA = 0, that is, the case temperature TC = TA.

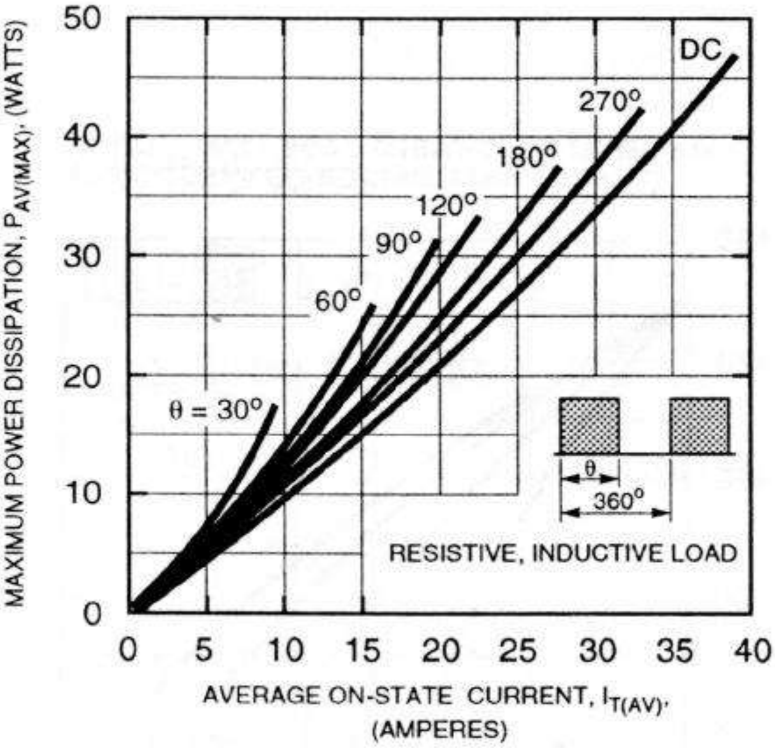


Fig: 3.4 Average on-state power dissipation of thyristor for rectangular current wave (POWEREX CM4208A2)

In practical operation, the power dissipation P is cyclic, and the thermal capacitance or storage effect delays the junction temperature rise, thus permitting higher loading of the device. The transient thermal equivalent circuit can be represented by a parallel RC circuit, where P is equivalent to the current source and the resulting voltage across the circuit represents the temperature TJ. Figure 1.5(a) shows the TJ curve for the dissipation of a single power pulse. Considering the complementary nature of heating and cooling curves, the following equations can be written.

$$TJ\,(t1) = TA + P\theta\,(t1) \qquad (1.2)$$

$$TJ\,(t2\,) = TA + P[\theta\,(t2) - \theta\,(t2 - t1) \qquad (1.3)$$

where $\theta(t1)$ is the transient thermal impedance at time t1. The device specification sheet normally gives thermal impedance between junction and case. The additional effect due to heat sink can be added if desired. Figure 1.5(b) shows typical junction temperature build-up for three repeated pulses. The corresponding TJ expressions by the superposition principle can be given as

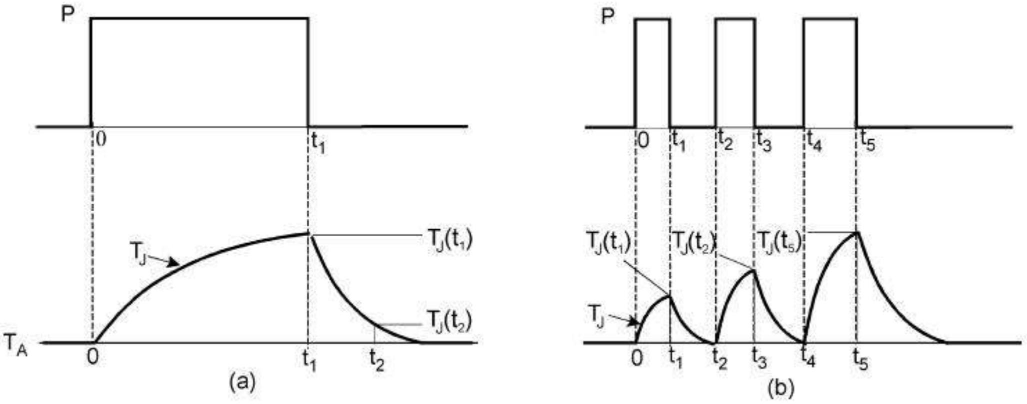


Fig 3.5: Junction temperature rise with pulsed power dissipation

(a) Single pulse, (b) Multiple pulses

$$TJ\ (t1) = TA + P\theta\ (t1) \qquad (1.4)$$

$$TJ\ (t3) = TA + P[\theta\ (t3) - \theta\ (t3 - t1) + \theta\ (t3 - t2)] \qquad (1.5)$$

$$TJ\ (t5) = TA + P[\theta\ (t5) - \theta\ (t5 - t1) + \theta\ (t5 - t2) - \theta\ (t5 - t3) + \theta\ (t5 - t4)] \qquad (1.6)$$

Figure 1.6 illustrates the transient thermal impedance curve ($\theta JC(t)$) of a thyristor (type CM4208A2) as a function of time. The device has the rated thermal resistances of $\theta JC = 0.8$ °C/W and $\theta CS = 0.2$ °C/W. Note that the device cooling and thermal impedance concepts discussed here are also valid for all power semiconductor devices.

3.3.4 Current Rating

Based on the criteria of limiting TJ as discussed above, Figure 1.7 shows the average current rating IT(AV) vs. permissible case temperature TC for various duty cycles of rectangular current wave. For example, if TC is limited to 110°C, the thyristor can carry 12 A average current for = 120°. If a better heat sink limits TC to 100 °C, the current can be increased to 18 A. Figure 1.7 can be used with Figure 1.4 to design the heat sink thermal resistance.

3.4 TRIACS

A triac has a complex multiple-junction structure, but functionally, it is an integration of a pair of phase-controlled thyristors connected in inverse-parallel on the same chip. Figure 1.8(a) shows the triac symbol and (b) shows its volt-ampere characteristics. The three-terminal device can be triggered into conduction in both positive and negative half-cycles of supply voltage by applying gate trigger pulses. In I+ mode, the terminal T2 is positive and the device is switched on by positive gate current pulse. In III- mode, the terminal T1 is positive and it is switched on by negative gate current pulse. A triac is more economical than a pair of thyristors in anti-parallel and its control is simpler, but its integrated construction has some disadvantages. The gate current sensitivity of a triac is poorer and the turn-off time is longer due to the minority carrier storage effect. For the same reason, the reapplied dv/dt rating is lower, thus making it difficult to use with inductive load. A well-designed RC snubber is essential for a triac circuit. Triacs are used in light dimming, heating control, appliance-type motor drives, and solid-state relays with typically 50/60 Hz supply frequency.

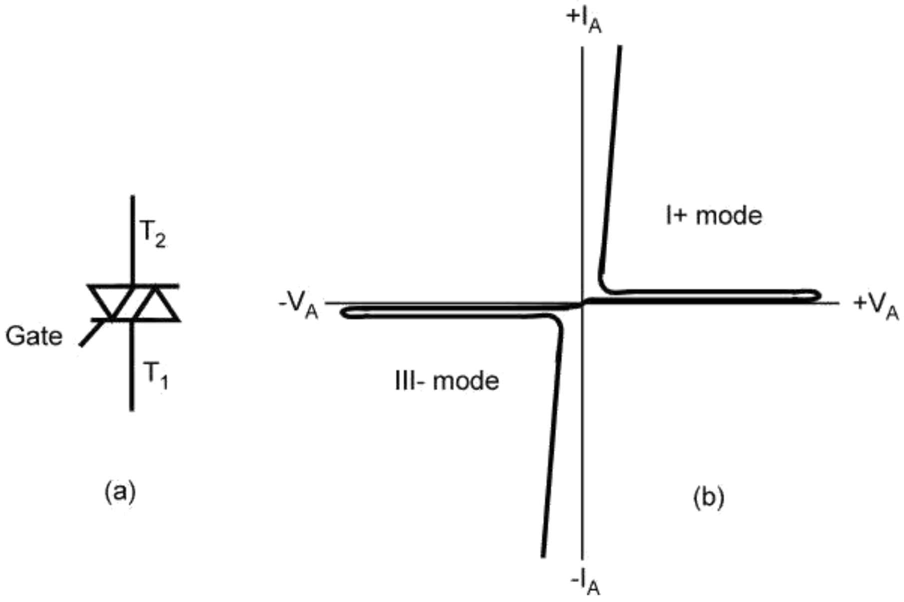


Fig 3.6: Triac symbol and volt-ampere characteristics

Figure 3.7(a) shows a popular incandescent lamp dimmer circuit using a triac and the corresponding waveforms. The gate of the triac gets the drive pulse from an RC circuit through a diac, which is a symmetric voltage-blocking device. The capacitor voltage vc lags the line voltage wave. When vc exceeds the threshold voltage ± Vs of the diac, a pulse of current in either polarity triggers the triac at angle αf , giving full-wave ac phase-controlled output to the load. The firing angle can be varied in the range α1 to α2 to control light intensity by varying the resistance R1.

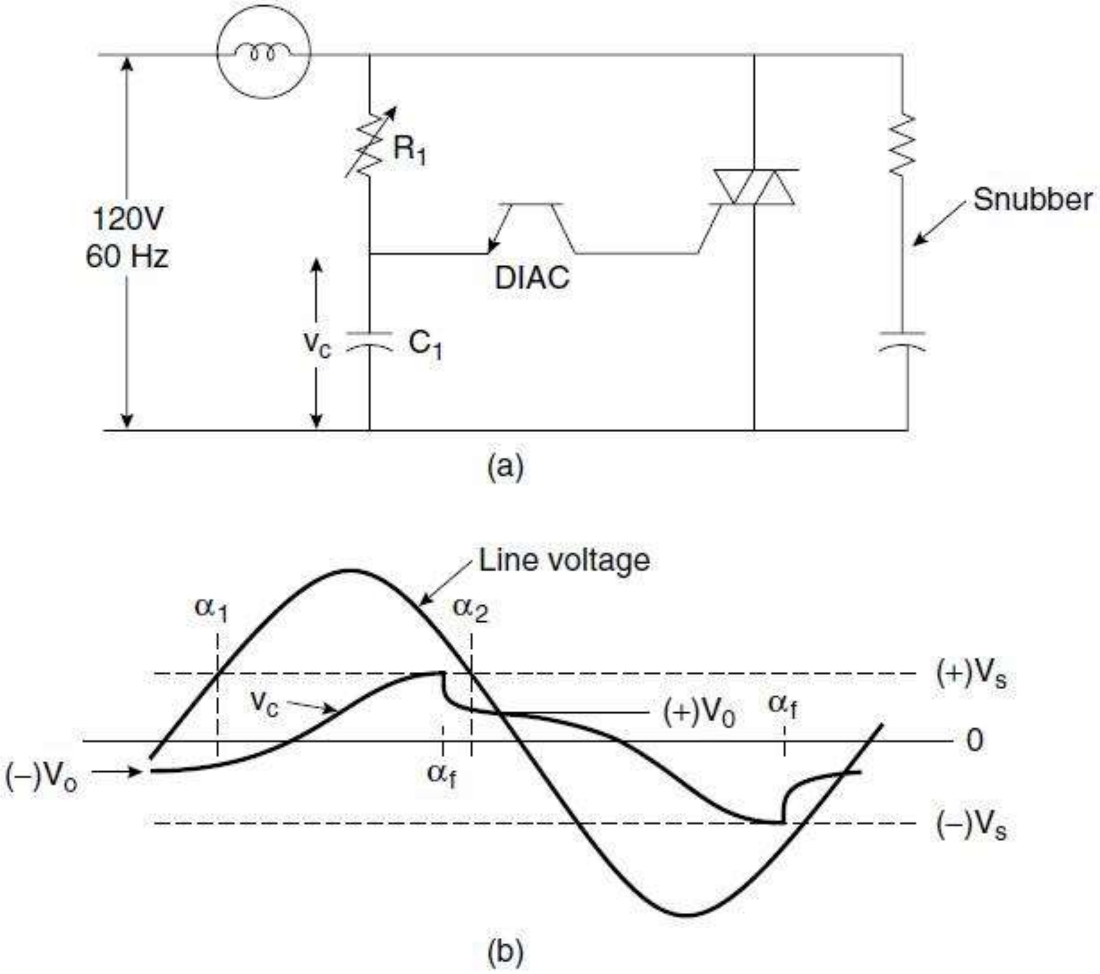


Fig 3.7: (a) Triac light dimmer circuit, (b) Control waveforms

3.5 GATE TURN-OFF THYRISTORS (GTOS)

A gate turn-off thyristor (GTO), as the name indicates, is basically a thyristor-type device that can be turned on by a small positive gate current pulse, but in addition, has the capability of being turned off by a negative gate current pulse.

The turn-off capability of a GTO is due to the diversion of P-N-P collector current by the gate, thus breaking the P-N-P / N-P-N regenerative feedback effect. GTOs are available with asymmetric and symmetric voltage-blocking capabilities, which are used in voltage-fed and current-fed converters, respectively. The turn-off current gain of a GTO, defined as the ratio of anode current prior to turn-off to the negative gate current required for turn-off, is very low, typically 4 or 5. This means that a 6000 A GTO requires as high as –1500 A gate current pulse. However, the duration of the pulsed gate current and the corresponding energy associated with it is small and can easily be supplied by low-voltage power MOSFETs.

GTOs are used in motor drives, static VAR compensators (SVCs), and ac/dc power supplies with high power ratings. When large-power GTOs became available, they ousted the force-commutated, voltage-fed thyristor inverters.

3.5.1 Switching Characteristics

The switching characteristics of GTOs are somewhat different from those of thyristors and therefore require some explanation. Figure 1.10 shows a GTO chopper (dc-to-dc converter) circuit with a polarized snubber. The snubber consists of a turn-on component (LL) called a series snubber and a turn-off component (Rs, Cs, and Ds), called a shunt snubber. This type of converter is typically used for a subway dc motor propulsion drive.

Figure 1.11 shows the turn-on and turn–off characteristics of the circuit with the snubber. The turn-on characteristics of a GTO are essentially similar to those of a thyristor. Initially, before turn-on, the capacitor Cs is charged to supply voltage Vd and the load current is flowing through the freewheeling diode. At turn-on, the series snubber limits di/dt through the device, and the supply voltage Vd is applied across the load. At the same time, Cs discharges through Rs and the GTO in series (neglecting the Ls effect), dumping most of its energy into the resistor Rs. The power dissipation Ps in the resistor is approximately given as

$$Ps = 0.5CsVd^2f \quad (1.7)$$

where f = chopper operating frequency. Obviously, the turn-on switching loss of the device is reduced because of delayed build-up of the device current.

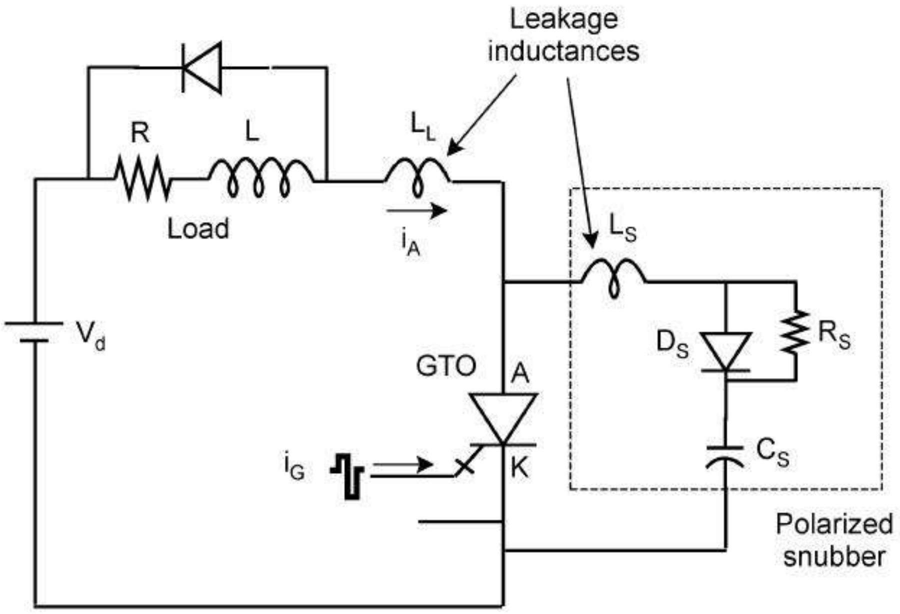


Fig 3.8: GTO chopper with polarized snubber

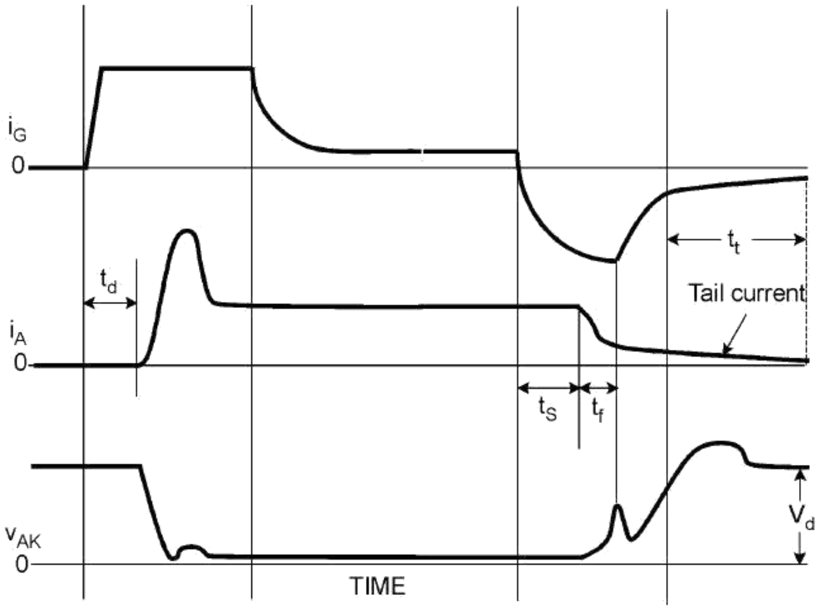


Figure 3.9 GTO turn-on and turn-off characteristics with snubber (not to scale)

When the GTO isturned off by negative gate current pulse, the controllable anode current iA begins to fall after a short time delay, defined as storage time (ts). The fall time tf is somewhat abrupt, and is typically less than 1.0 µs. As the forward voltage begins to develop, anode current tends to bypass through the shunt capacitor, limiting dv/dt across the device. The leakage inductance Ls in the snubber creates a spike voltage, as shown. A large voltage spike is extremely harmful because current concentration may create localized heating, causing what is known as second breakdown failure. This emphasizes the need to minimize the shunt snubber leakage inductance. After the spike voltage, the anode voltage overshoots due to underdamped resonance before settling to normal forward blocking voltage Vd. GTO has a long tail current, as shown, mainly due to sweeping out of the minority carriers. This tail current at large anode voltage causes large turn-off switching loss unless voltage build-up is slowed with large Cs. However, large Cs increases snubber dissipation, as given by Equation (1.7). The trade-off between snubber loss and turn-off switching loss, and the corresponding total loss curves with increasing snubber capacitance are given approximately by Figure 1.12. The curves indicate that the device-switching loss is diverted to snubber loss, and the total loss may be higher than the intrinsic switching loss of the device. Since GTO power losses are somewhat higher during switching, the converter switching frequency is low and is typically restricted within 1.0 kHz.

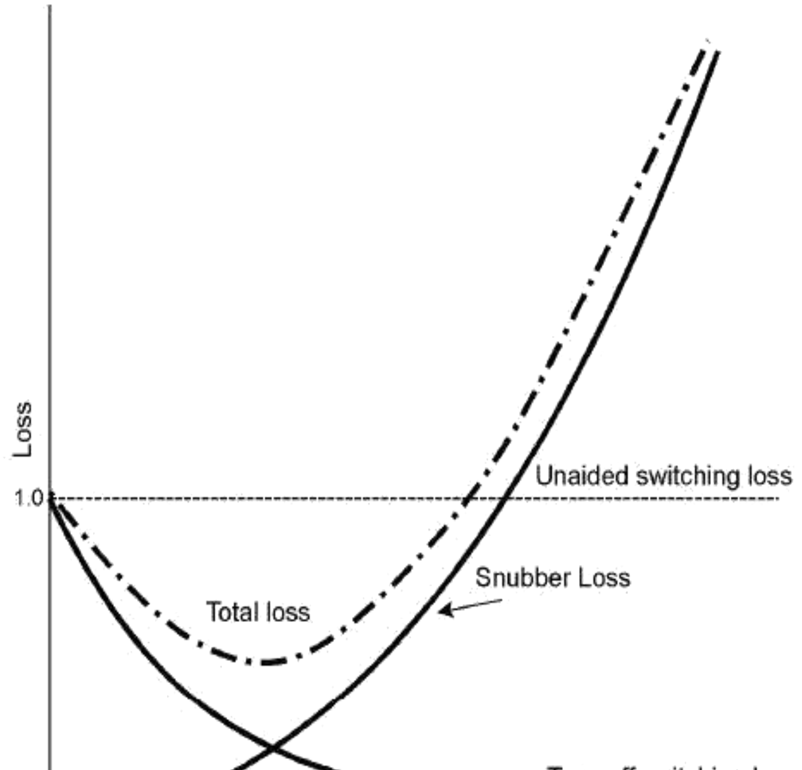


Fig 3.10: Trade-off between snubber loss and turn-off switching loss with increasing capacitor.

3.5.2 Regenerative Snubbers

The snubber loss may be substantial in a high-power and/or high-frequency converter. This, in turn, may reduce the converter's efficiency and put a burden on the cooling system. To combat this problem, various regenerative or energy recovery schemes have been proposed where the stored energy in the snubber capacitor is pumped back to the source or load. Figure 1.13(a) shows a passive energy recovery scheme. When the GTO is turned off, the snubber capacitor Cs charges to the full supply voltage, as usual. At the subsequent turn-on of the GTO, the stored energy is transferred to capacitor C resonantly through the inductance L and diode D. When the GTO turns off again, the energy in C is absorbed in the load and Cs charges again to voltage Vd. Figure 1.13(b) shows a regenerative snubber that uses an auxiliary chopper. At GTO turn-off, the snubber capacitor Cs charges to supply voltage. At subsequent turn-on of the device, the energy is resonantly transferred to capacitor C, as before. The energy in C is then pumped to the source through a dc-to-dc boost converter.

The discussion on dissipative and regenerative snubbers given in this section is also valid for other devices. The idea of a regenerative snubber appears very attractive, but its application should be carefully weighed against the extra cost, loss, complexity, and equipment reliability. High-power GTO converters normally use regenerative snubbers. Otherwise, RC snubbers are commonly used. Snubberless converters, which will be discussed later, are also possible.

3.6 BIPOLAR POWER OR JUNCTION TRANSISTORS (BPTS OR BJTS)

A bipolar junction transistor (BPT or BJT), unlike a thyristor-like device, is a two-junction, self-controlled device where the collector current is under the control of the base drive current. Bipolar junction transistors have recently been ousted by IGBTs (insulated gate bipolar transistors) in the higher end and by power MOSFETs in the lower end. The dc current gain (hFE) of a power transistor is low and varies widely with collector current and temperature. The gain is increased to a high value in the Darlington connection, as shown in Figure 1.14. However, the disadvantages are higher leakage current, higher conduction drop, and reduced switching frequency. The shunt resistances and diode in the base-emitter circuit help to reduce collector leakage current and establish base bias voltages. A transistor can block voltage in the forward direction only (asymmetric blocking). The feedback diode, as shown, is an essential element for chopper and voltage-fed converter applications. Double or triple Darlington transistors are available in module form with matched parallel devices for higher power rating.

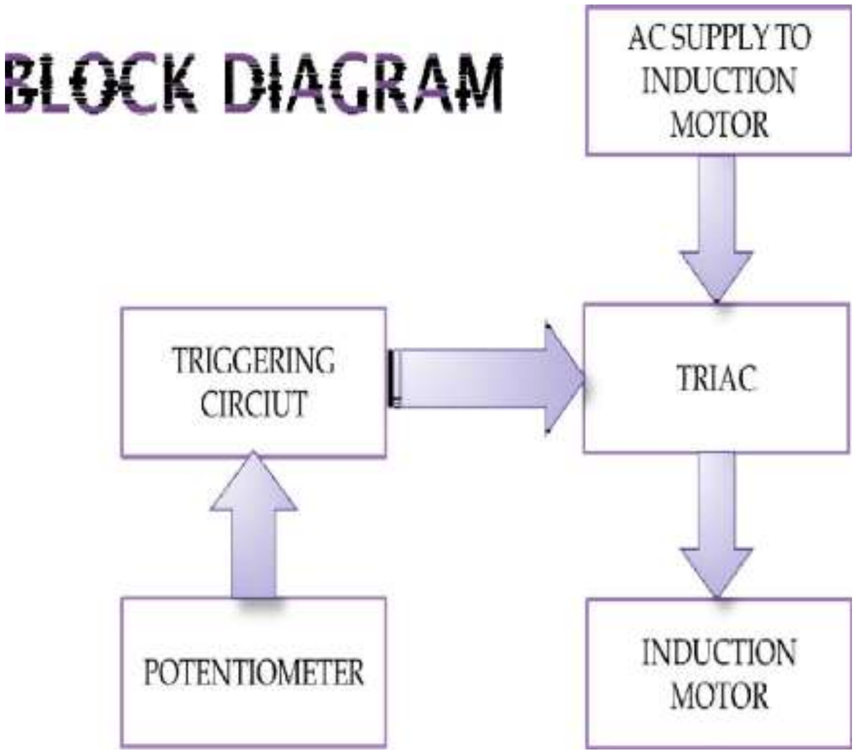
CHAPTER 4

4.1 INTRODUCTION

For the speed control of single phase induction motor we are using stator voltage supply control. In this method of control we are using an intermediate part called AC cycloconverter between the AC supply and induction motor. Therefore supply voltage is controlled by controlling the gate pulses to the cycloconverter. And thereby torque is also controlled and thus the speed of the induction motor.

4.1.1 Block diagram

The block diagram of our project is shown below:



4.2 TRIGGERING CIRCUIT OF TRIAC

The functioning of the entire triggering circuit can be studied in five parts:

1. TRANSFORMER
2. RECTIFIER
3. COMPARATOR
4. 555 TIMER
5. MOSFET
6. OPTO-ISOLATOR

4.3 TRANSFORMER

The transformer in our circuit is a step down transformer This transforms the 220V input sinusoidal voltage to 30V at 1 amp output voltage. It acts as an isolation device between the ac mains and the electronic circuit.

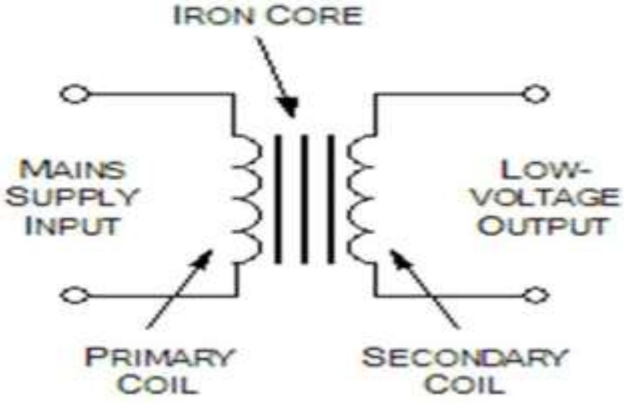


Fig 4.1: Step-down transformer

The output of the transformer is shown below:

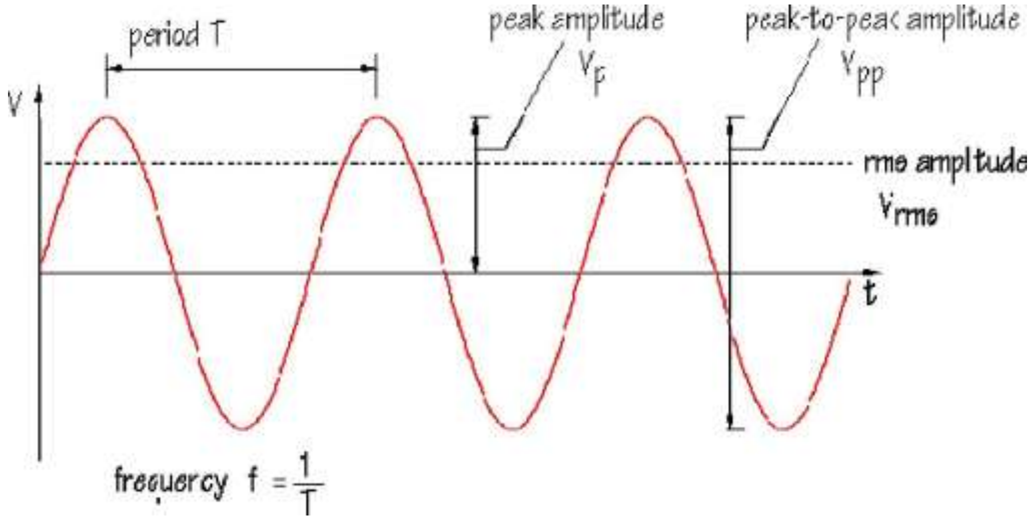


Fig 4.2: Output of the transformer

4.4 RECTIFIER

There are two bridge rectifiers used in the circuit to rectify the 30V AC . The output from one of the rectifier is filtered using the appropriate capacitors and is used as a input to positive terminal of the comparator. The output of the remaining rectifier acts as the reference to the comparator.The rectifier is formed using diodes.

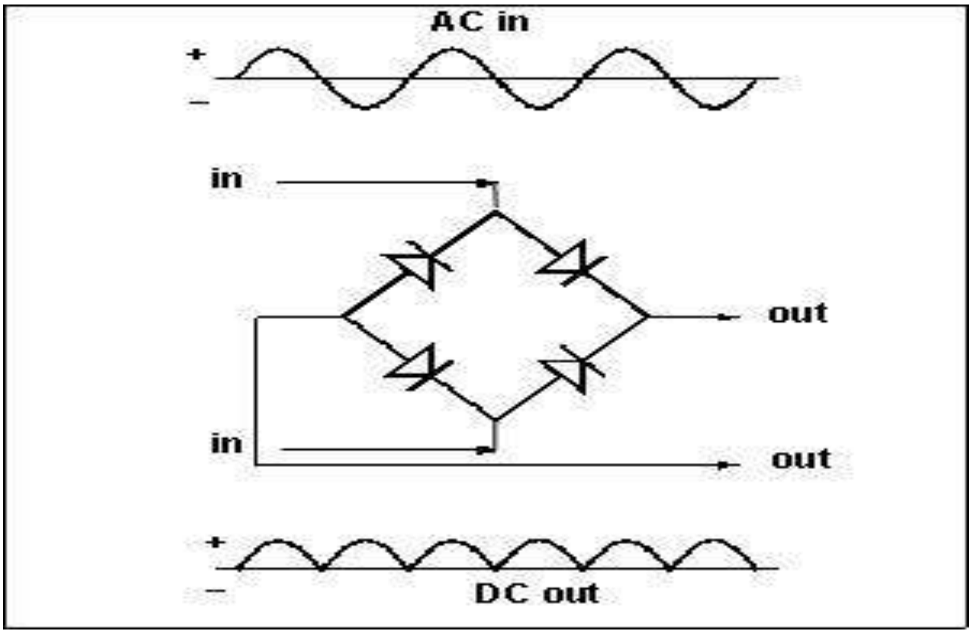


Fig 4.3: Output Waveform of rectifier

The input to the rectifier is sinusoidal step down AC voltage which is given from transformer output. It rectifies the voltage and gives the output voltage as the pulsating DC voltage. There two rectifiers used in the triggering circuit. One of the rectifiers output is given directly as one of the input to the comparator. Another input to the comparator is filtered DC (pure DC) which is generated from combination of one of the rectifiers output and capacitor filter as shown in the schematic diagram.

4.5 555 TIMER

The pin diagram, internal diagram and 555 timer pin diagram are shown below:

Fig 4.4: 555 timer IC

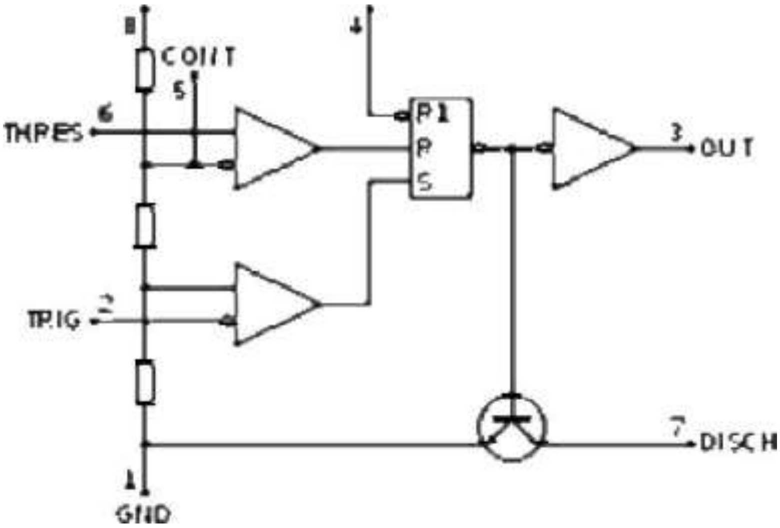


Fig 4.5: Internal diagram of 555 timer

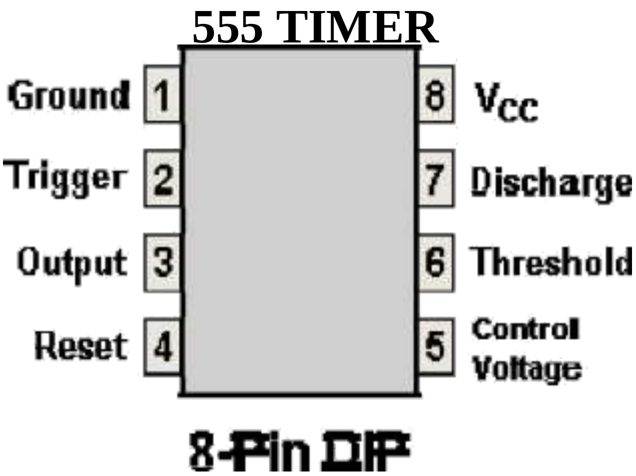


Fig 4.6: Pin diagram of 555 timer

The 555 has three operating modes:

1. Monostable mode: in this mode, the 555 functions as a "one-shot" pulse generator. Applications include timers, missing pulse detection, bouncefree switches, touch switches, frequency divider, capacitance measurement, pulse-width modulation (PWM) and so on.
2. Astable: free running mode: the 555 can operate as an oscillator. Uses include LED and lamp flashers, pulse generation, logic clocks, tone generation, security alarms, pulse position modulation and so on. Selecting a thermistor as timing resistor allows the use of the 555 in a temperature sensor: the period of the output pulse is determined by the temperature. The use of a microprocessor based circuit can then convert the pulse period to temperature, linearize it and even provide calibration means.
3. Bistable mode or Schmitt trigger: the 555 can operate as a flip-flop, if the DIS pin is notconnected and no capacitor is used. Uses include bounce-free latched switches.Pin diagram of 555 timer

The 555 timer used in our circuit is in the astable mode. The resistors R1 and R2 help in varying the frequency of the output from the comparator This helps in generating a pulse train used to trigger the gate of the triac used. The biasing voltage used in the circuit is 5V. Frequency of generated pulse

(f) = 1/[(R1+2R2)*C*ln(2)]

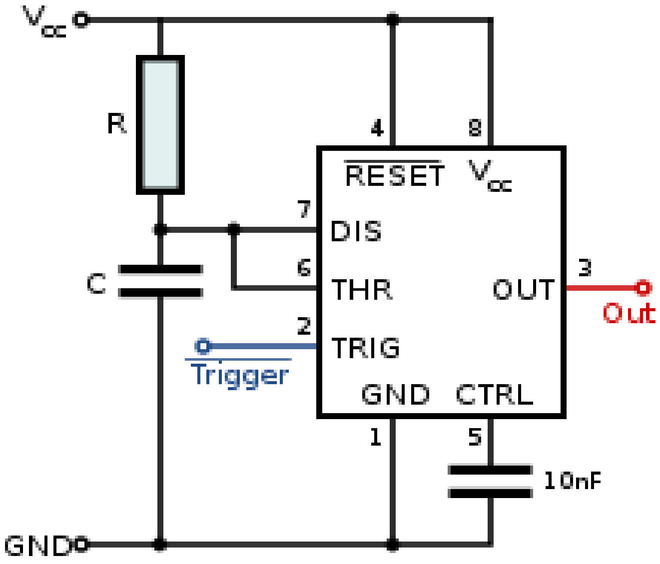


Fig 4.7: Connections of 555 timer in monostable mode

4.6 COMPARATOR

In electronics, a **comparator** is a device that compares two voltages or currents and outputs a digital signal indicating which is larger. It has two analog input terminals V_+ and V_- and one binary digital output V_o. The output is ideally

$$V_o = \begin{cases} 1, & \text{if } V_+ > V_- \\ 0, & \text{if } V_+ < V_- \end{cases}$$

A comparator consists of a specialized high-gain differential amplifier. They are commonly used in devices that measure and digitize analog signals, such as analog-to-digital converters (ADCs), as well as relaxation oscillators.

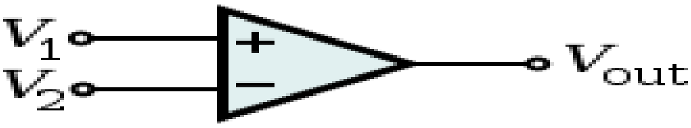


Fig 4.8: Comparator

4.7 MOSFET

The metal–oxide–semiconductor field-effect transistor (MOSFET, MOS-FET, orMOS FET) is a type of transistor used for amplifying or switching electronic signals.

Although the MOSFET is a four-terminal device with source (S), gate (G), drain (D), and body (B) terminals, the body (or substrate) of the MOSFET is often connected to the source terminal, making it a three-terminal device like other field-effect transistors. Because these two terminals are normally connected to each other (short-circuited) internally, only three terminals appear in electrical diagrams. The MOSFET is by far the most common transistor in both digital and analog circuits, though the bipolar junction transistor was at one time much more common.

The main advantage of a MOSFET over a regular transistor is that it requires very little current to turn on (less than 1mA), while delivering a much higher current to a load (10 to 50 times or more).

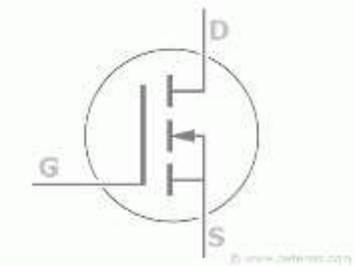


Fig 4.9 : MOSFET

The "metal" in the name MOSFET is now often a misnomer because the previously metal gate material is now often a layer of polysilicon (polycrystalline silicon).Aluminium had been the gate material until the mid-1970s, when polysilicon became dominant, due to its capability to form self-aligned gates. Metallic gates are regaining popularity, since it is difficult to increase the speed of operation of transistors without metal gates.

Likewise, the "oxide" in the name can be a misnomer, as different dielectric materials are used with the aim of obtaining strong channels with smaller applied voltages.

4.8 OPTO ISOLATOR

In electronics, an opto-isolator, also called an optocoupler, photocoupler, or optical isolator, is a component that transfers electrical signals between two isolated circuits by using light. Opto-isolators prevent high voltages from affecting the system receiving the signal. Commercially available opto-isolators withstand input-to-output voltages up to 10 kV and voltage transients with speeds up to 10 kV/μs.

A common type of opto-isolator consists of an LED and a phototransistor in the same opaque package. Other types of source-sensor combinations include LED-photodiode, LED-LASCR, and lamp-photoresistor pairs. Usually opto-isolators transfer digital (on-off) signals, but some techniques allow them to be used with analog signals.

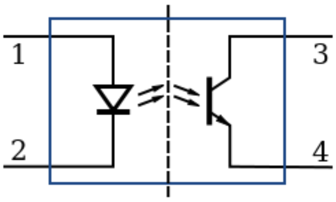


Fig 4.10 Opto Isolator

An opto-isolator contains a source (emitter) of light, almost always a near infrared light-emitting diode (LED), that converts electrical input signal into light, a closed optical channel (also called dielectrical channel), and a photosensor, which detects incoming light and either generates electric energy directly, or modulates electric current flowing from an external power supply. The sensor can be a photoresistor, a photodiode, a phototransistor, a silicon-controlled rectifier (SCR) or atriac. Because LEDs can sense light in addition to emitting it, construction of symmetrical, bidirectional opto-isolators is possible. An optocoupled solid state relay contains a photodiode opto-isolator which drives a power switch, usually a complementary pair of MOSFETs. A slotted optical switch contains a source of light and a sensor, but its optical channel is open, allowing modulation of light by external objects obstructing the path of light or reflecting light into the sensor.

In its simplest form, an optoisolator consists of a light-emitting diode (LED), IRED (infrared-emitting diode) or laser diode for signal transmission and aphotosensor (or phototransistor) for signal reception. Using an optocoupler, when an electrical current is applied to the LED, infrared light is produced and passes through the material inside the optoisolator. The beam travels across a transparent gap and is picked up by the receiver, which converts the modulated light or IR back into an electrical signal. In the absence of light, the input and output circuits are electrically isolated from each other.

Electronic equipment, as well as signal and power transmission lines, are subject to voltage surges from radio frequency transmissions, lightning strikes and spikes in the power supply. To avoid disruptions, optoisolators offer a safe interface between high-voltage components and low-voltage devices.

4.9 SUPPLY, TRIAC AND INDUCTION MOTOR

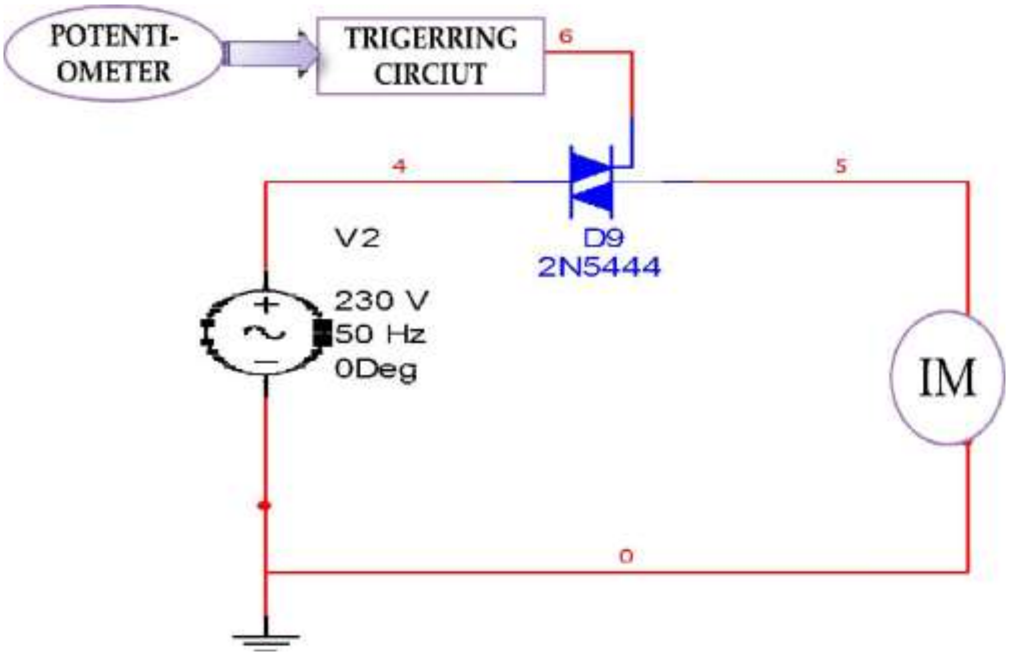


Fig 4.11: Supply, TRIAC and Induction motor.

4.10 TRIAC OUTPUT WAVEFORM

The triac output is same as the output of the AC voltage controller. Depending on the potentiometer value, the firing angle to the triac's gate is controlled and thus the output of the triac is in the form of chopped wave that is reduced in value. Therefore the reduced voltage is applied to the induction motor.

The output voltage waveform of the triac is shown in the figure below:

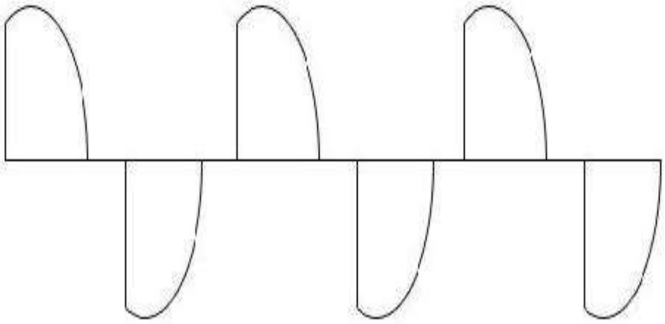


Fig 4.12: AC waveform with triac

4.11 Relationship between speed and voltage applied

From the triac output shown in the above figure, it can be seen that the sinusoidal AC voltage have chopped. Therefore the output voltage of the triac which is applied to the triac is reduced by delay angle control of the triac. The derivation of the torque equation is done in the previous chapter.

We know that the torque of the induction motor is directly proportional to the square of the applied voltage, the torque will get reduced by the reduced applied voltage. The speed of the motor depends on the torque (directly related). As the torque is reduced, the speed of the induction motor also gets reduced. Thus by controlling the delay angle of the triac, the applied voltage is controlled from it the speed is controlled.

CHAPTER 5

SOFTWARE ANALYSIS

5.1 GENERAL DESCRIPTION AND IMPORATANCE OF SOFTWARE SIMULATION

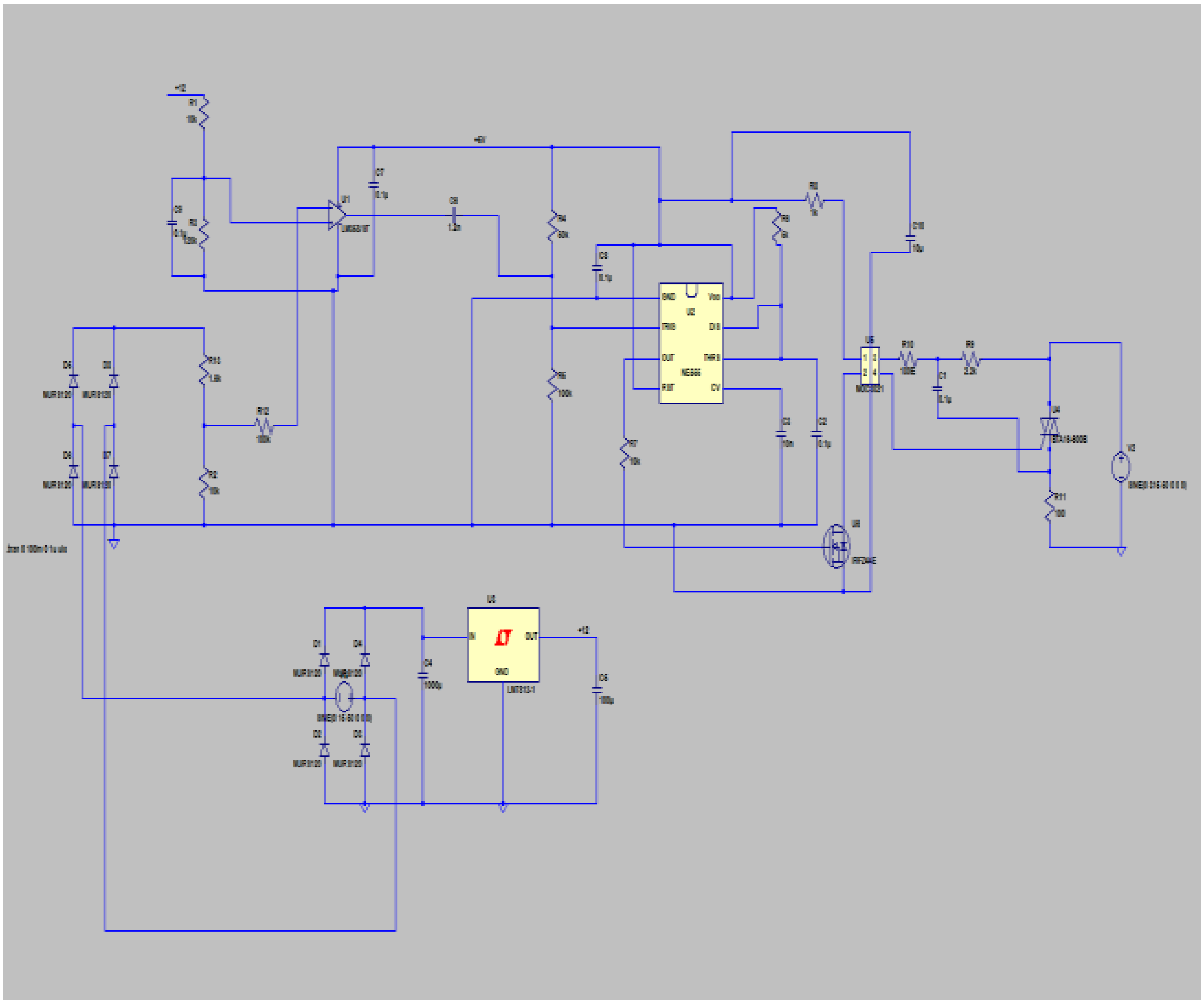
Software analysis of any hardware to be made is like or can be compared with a pre-planning sketch for house construction. The house planning is important because without it, it becomes difficult for utilizing the entire area available and few situations arises where it is difficult to decide and proceed further.

The triggering circuit, supply, triac and virtual load has to be connected and pre-executed in the software for checking the correctness of the entire circuit. For this purpose we have used software called “LT Spice”.

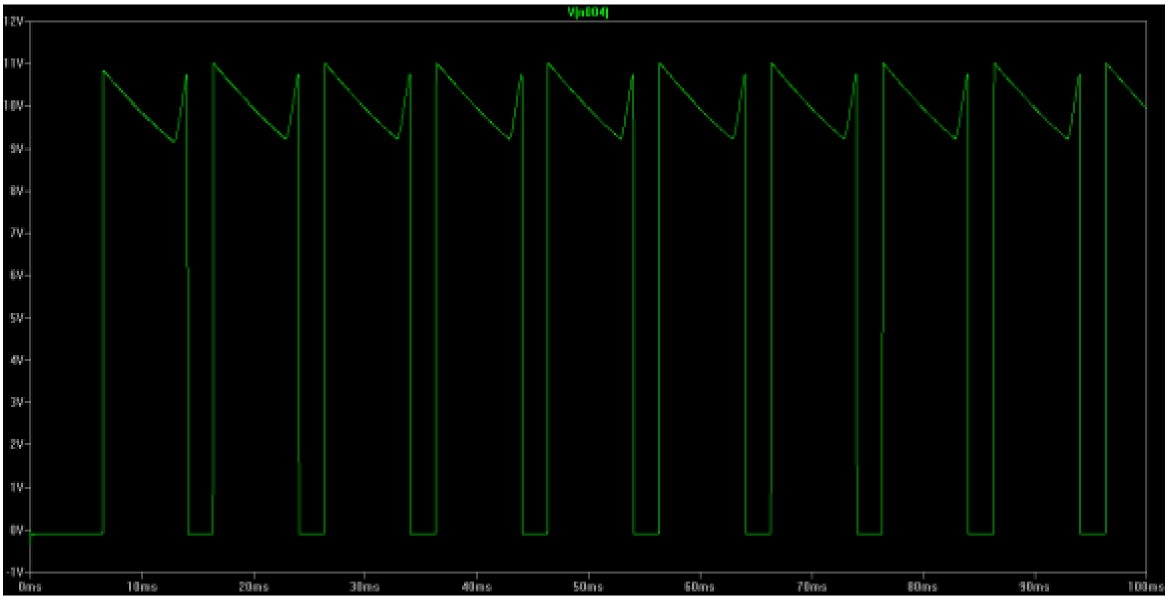
In it we have connected the entire circuit including a virtual load. The circuit comprises of the triggering circuit and triac, supply and virtual load connections. First lets discuss about the triggering circuit, as explained in previous chapters there are 5 important parts in the triggering circuit and are transformer, diode bridge rectifier, comparator, 555 timer, MOSFET, Opto-Isolator.

As it is simulation there is no need of the transformer. We can direct get the required levels of voltages. Next is diode bridge rectifier it is used for conversion of ac to dc. Now the pulsating dc and reference dc is given to comparator and in the output of comparator we get square wave. This square wave is passed through differential circuit and then positive and negative going spikes are generated. This spikes are given as input to 555 timer as for triggering of 555 timer negative going spkies are required. Then the output of 555 timer is given to MOSFET which act like switch and the output of MOSFET is given to opto-isolator which generate the pulses which are given to TRIAC as gate pulses. These pulses will trigger the triac and provides a conducting path from supply or source to load. So supply is connected to load if the triggering pulses are applied else not connected. And this how is reduced voltage is applied to the load.

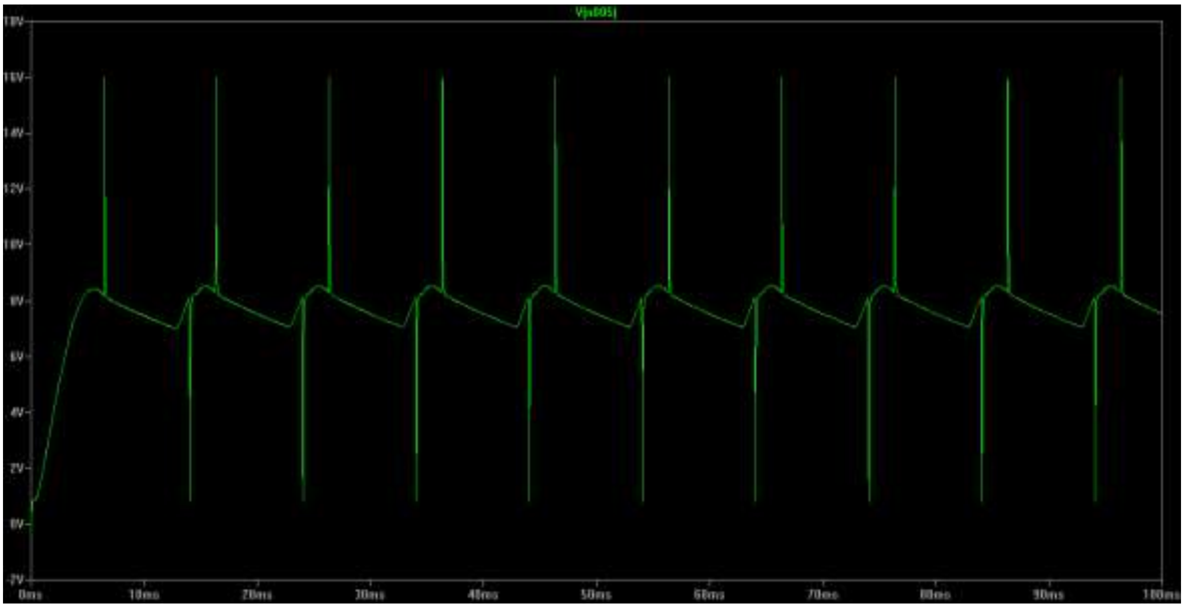
The schematic circuit diagram is shown below.



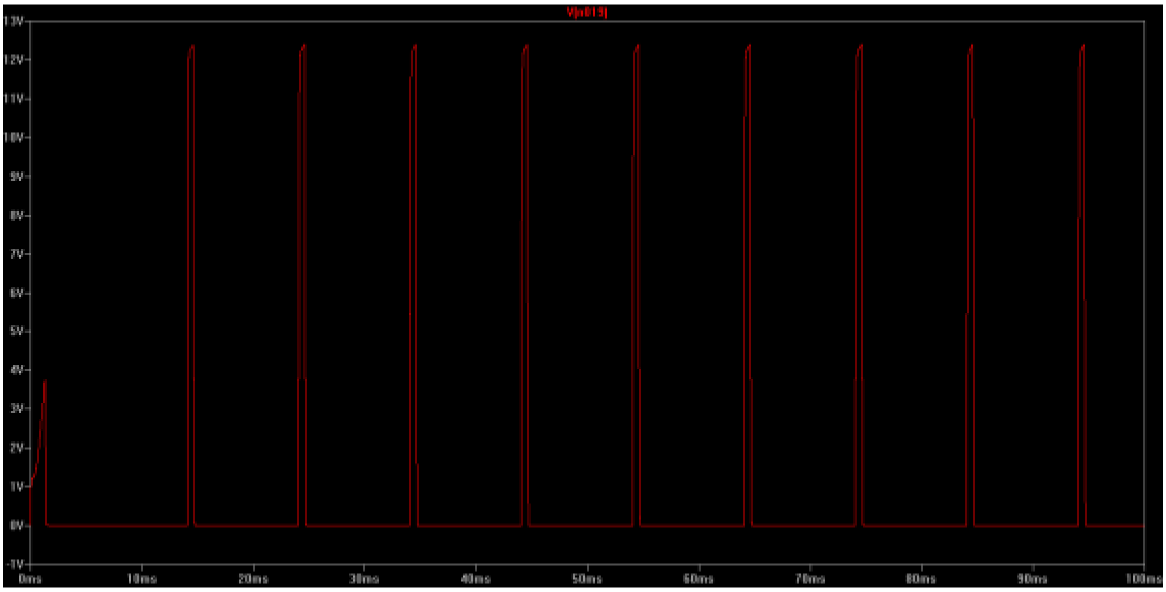
The output of the comparator(LM 358) is shown below



The input of 555 timer is shown below:



The output of the 555 timer is shown below



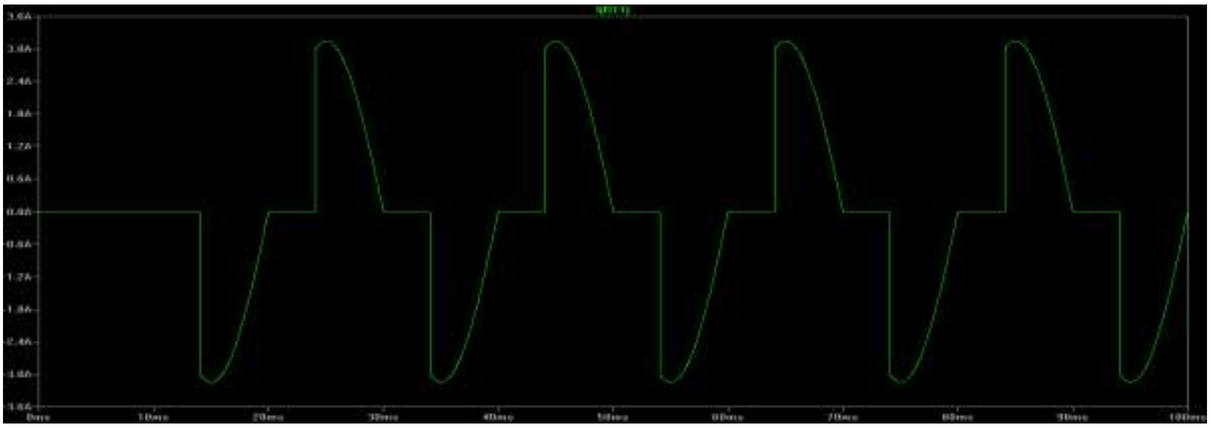
5.2 OUTPUT OF THE TRIAC (ACROSS THE LOAD)

The generated triggering pulses are given to the triac. The supply is connected to triac and load is also connected to the it. Now the pots in the triggering circuit are adjusted and thereby different triggering pulses are generated.

The following are the output waveform of the triac after triggering with different delaying angles.

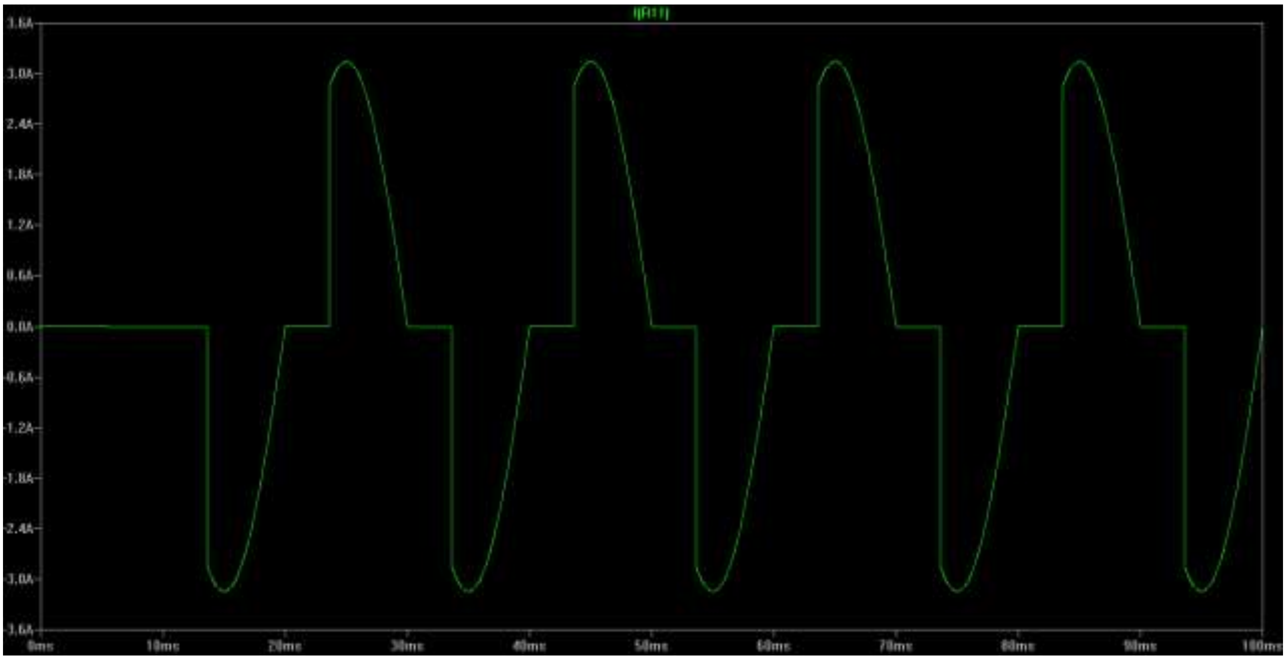
Case1:

R3=120k



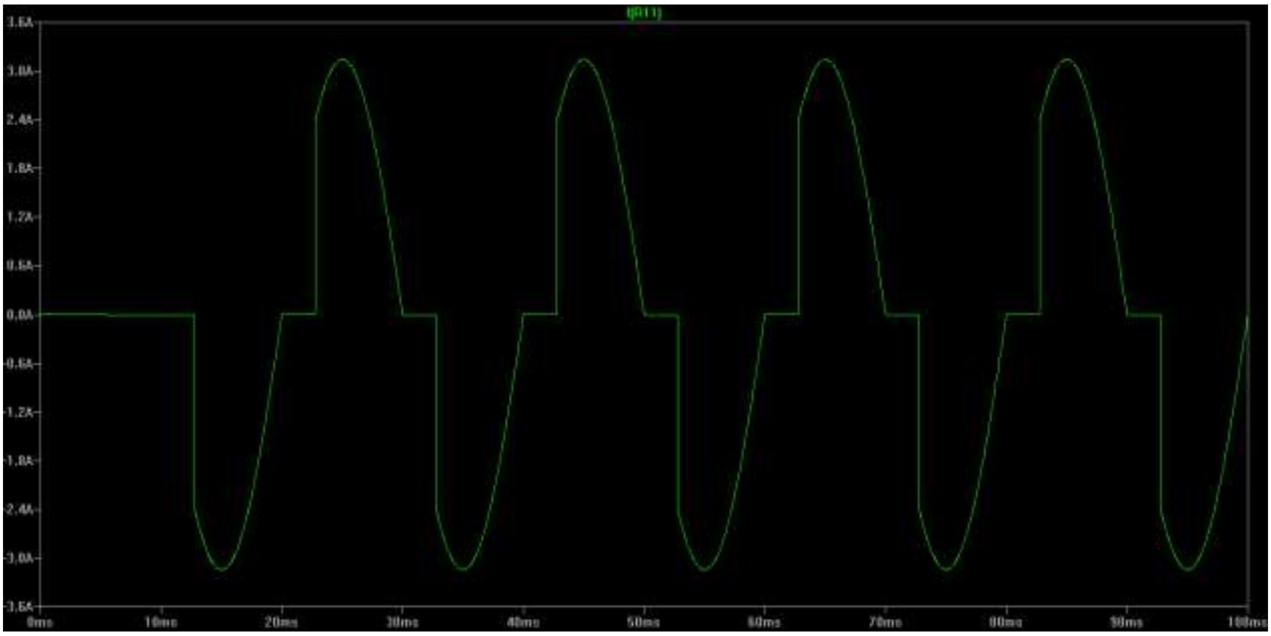
Case 2:

R3=60k



Case 3:

R3=30k



CHAPTER 6

HARDWARE DESIGN AND RESULT

6.1 WORKING OF THE HARDWARE

The main cause behind the reduction of the voltage is delay angle which can be only produced by AC voltage controllers. In this controller, the power devices used is triac. By varying the firing pulses to the triac either voltage equal to the supply or voltage less than the supply voltage are obtained.

We know when the reduced voltage is applied, the power consumed or absorbed also decreases proportionally. Hence the brightness of the lamp and also the speed of the induction motor are reduced and also can be made equal to the maximum values only.

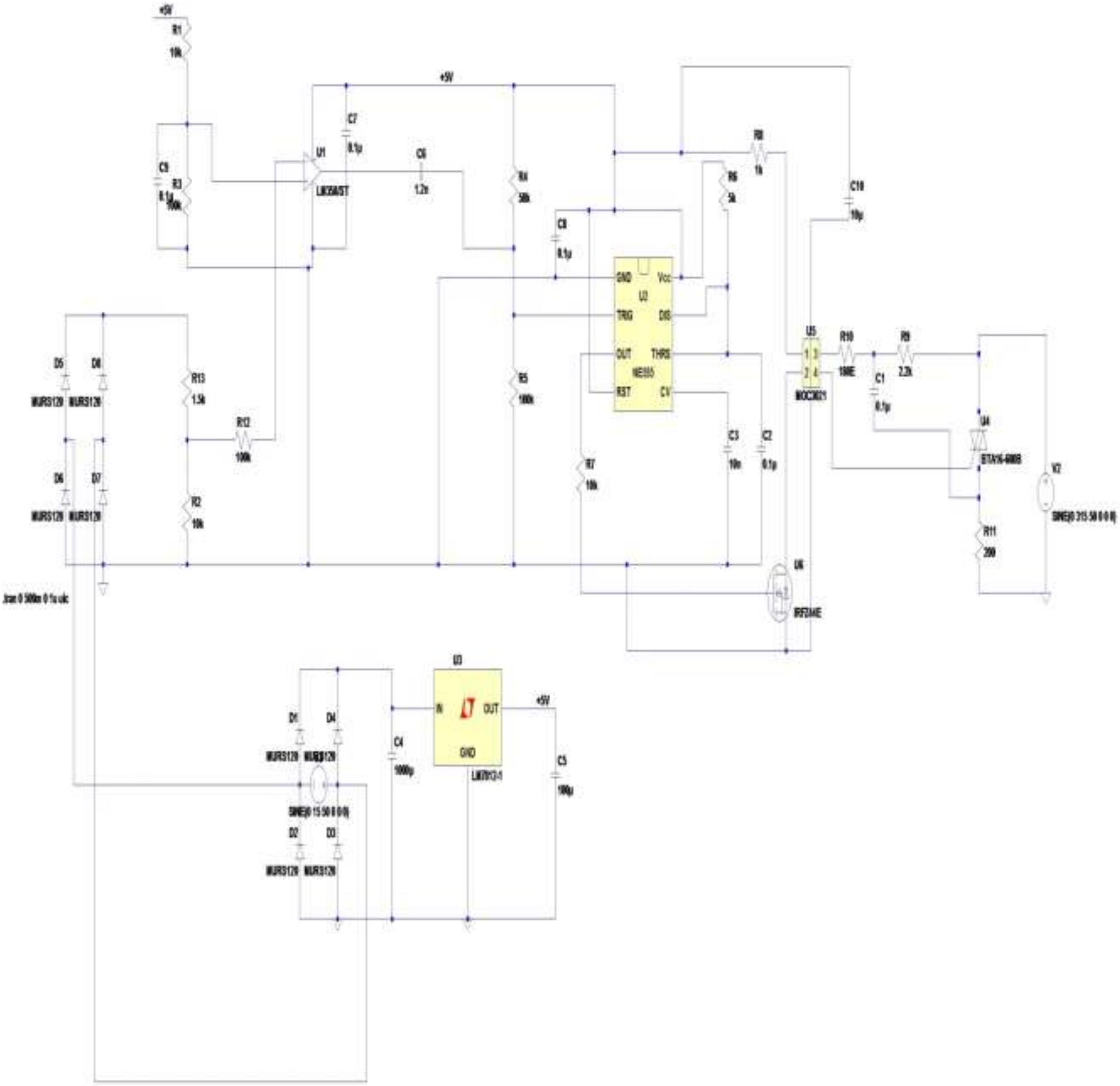
The hardware and software are very similar to each other, the only difference is that the load and circuits are real and not virtual in the hardware. There are totally 3 part in the hardware of the project. They are

1. Triggering circuit
2. Triac
3. Load.

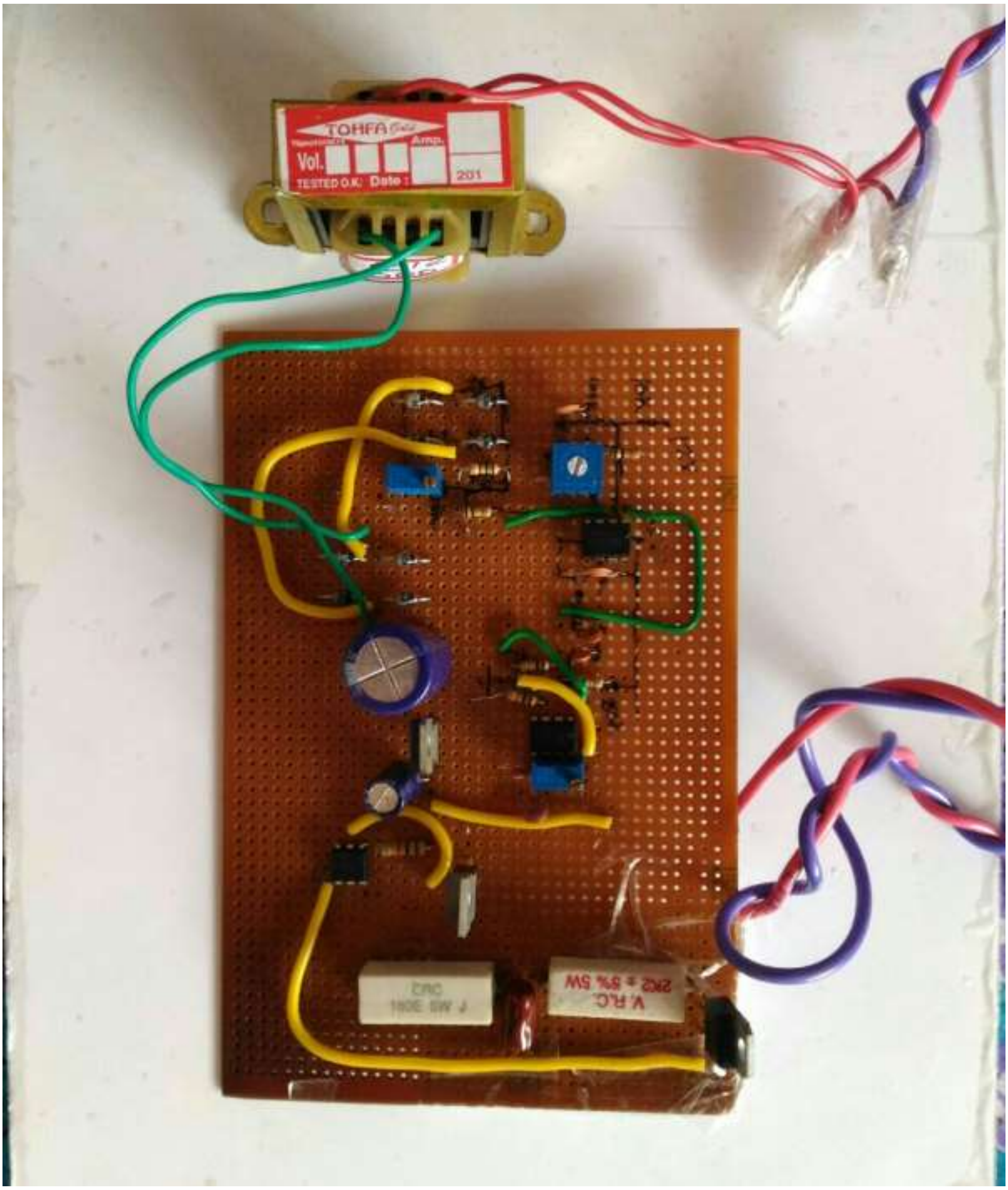
6.2 TRIGGERING CIRCUIT

The triggering circuit is first designed. On the PCB, the soldering work was being done. After the soldering work the connection of the triac, supply and load are made.

The following is the schematic circuit designed :



The PCB and the soldering made on it are been shown in the figure below



6.3 LOAD

The load which is connected to the output of the triac is induction motor .i.e. fan and as the triac is triggered, the load (fan) will be slowly starts rotating as the applied voltage increases speed also increases. At any single instant of time when triggering pulse have been given to triac, the load is shown in the figure below :

CHAPTER 7

RESULTS AND CONCLUSIONS

7.1 WORK DONE IN THIS PROJECT:

In our project the following are works has being done by us:

I. Simulation of the schematic circuit in the LTSpice software.
III. Soldering of the components on the PCB.
IV. And finally connecting all along with AC motor and performing the experiment of speed control.

7.2 FUTURE SCOPE:

In electrical regulator by using resistance the output voltage is varied simultaneously the speed is varied. But to reduce the energy losses in the resistor, electronic regulator is introduced, which uses triac to vary the output voltage by varying the firing angle and avoids loss of energy in resistor.

This model of speed control of the single phase induction motor is already existing technology. Our project(model) of speed control of the single phase induction motor is only a prototype for the existing technology.

The existing technology can be improved by doing modifications in the speed adjustment of the motor through controlling the triac triggering pulses with micro-controller. And the work is been going for the more efficient and automatic speed control of the single phase induction motor.

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