“SOFT STARTER FOR INDUCTION MOTOR”

A Major Project Report

Submitted in Partial Fulfillment of the Requirements
for the degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING
(POWER APPARATUS & SYSTEMS)

By

Vanjani Harsha B.
(04MEE021)

Department of Electrical Engineering

INSTITUTE OF TECHNOLOGY
NIRMA UNIVERSITY OF SCIENCE & TECHNOLOGY,
AHMEDABAD 382 481
May 2005-2006

CERTIFICATE

This is to certify that the Major Project Report entitled “SOFT STARTER FOR INDUCTION MOTOR” submitted by Miss Harsha Vanjani (04mee021), towards the partial fulfillment of the requirements for Master of Technology (Electrical Engineering) in the field of Power Apparatus & Systems of Nirma University of Science and Technology is the record of work carried out by her under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

Date:

Project Guides:

Industry Guide:

(1) Mr. J. B. Gajjar
Amee Power Drives.
Vatva, Ahmedabad

Institute Guide:

(2) Prof. B.B.Kadam,
Nirma Institute of Technology,
Ahmedabad.

HOD

Department of Electrical Engineering
Institute of Technology
Nirma University, Ahmedabad

Director

Institute of Technology
Nirma University, Ahmedabad

CERTIFICATE

This is to certify that the project work entitled *"Soft Starter for Induction Motor"* ***is an authentic record of the work done by*** *Ms. Harsha B. Vanjani* ***during August 2005 to April 2006 carried out under my supervision at*** *Amee Power Drives, Vatva, Ahmedabad.***.**

I further certify that the work has not been submitted either partly or fully to any university / institution for the award of any diploma / degree.

(J.B.Gajjar)

Managing Director,
Amee Power Drives,
Vatva,
Ahmedabad.

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HARSHA VANJANI

Abstract

Induction motors, when direct switched take 5 to 7 times their full load current. This current will produce large line-voltage drop, which can affect other equipments connected to line. Further more, the resistance of the squirrel cage induction motor is fixed and small. The frequency of the motor currents equals to the supply frequency. Hence the starting current of the rotor is very large in magnitude. So, torque per ampere is very poor. It is roughly 1.5 times the full load torque.

Soft starters control the voltage applied to asynchronous motors during start up, reducing the starting current and torque to provide a smooth, steeples acceleration. The problem with conventional starters is frequent start/stop of the motor cause damage to the motor shaft. Start/stop by use of soft starter eliminates damage of the motor shaft. Smooth increase in operating voltage during start up eliminates transient torque associated with conventional starting methods thereby increasing the life of driving gears such as belts, chains, couplings, gears etc. It improves input power factor. Soft Starters solve the supply and load side problems associated with the conventional starters and in addition offer other benefits better control and monitoring. Here Atmega16L Micro controller is used for control. It has RISC architecture and Analog to Digital converter inbuilt.

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CHAPTER 1: INTRODUCTION

Soft starters control the voltage applied to asynchronous motors during start up, reducing the starting current and torque to provide a smooth, steeples acceleration. The problem with conventional starters is frequent start/stop of the motor cause damage to the motor shaft. Start/stop by use of soft starter eliminates damage of the motor shaft. Smooth increase in operating voltage during start up eliminates transient torque associated with conventional starting methods thereby increasing the life of driving gears such as belts, chains, couplings, gears etc. It improves input power factor. Soft Starters solve the supply and load side problems associated with the conventional starters and in addition offer other benefits better control and monitoring. Traditional Starters are described below.

1.1 Traditional Electromechanical Starters:

A.C. Induction motors are traditionally started and stopped by applying and removing the A.C. supply. In some cases, a full voltage start is acceptable, but in many situations, the start current must be reduced, and so a reduced voltage starter is employed.

1.1.1 Direct On Line

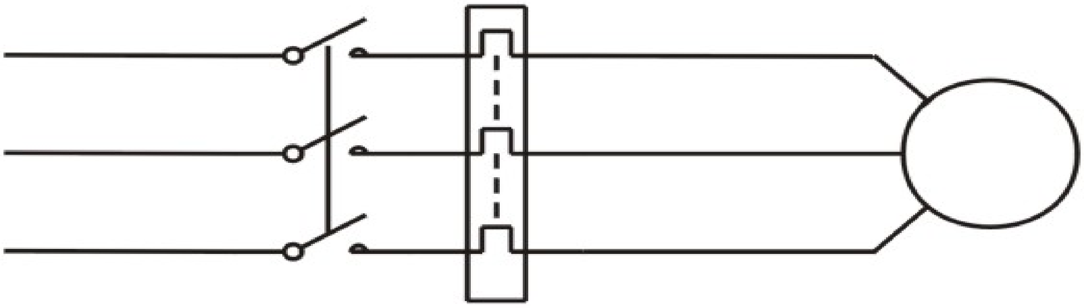


Figure 1.1 Direct On Line Starter

The simplest form of motor starter for the induction motor is the Direct On Line starter. The DOL starter comprises a switch and an overload protection relay. The switch may be a manually operated load break switch, but more commonly it would be an electromagnetic contactor, which can be opened by the thermal overload relay. Typically, separate start and stop buttons will control the contactor, and an auxiliary contact is used as a hold in contact. i.e. the contactor is electrically latched closed while the motor is operating. To start, the contactor is closed, applying full line voltage to the motor windings. The motor will draw a very high inrush current for a very short time, to establish the magnetic field in the iron, and then the current will be limited to the Locked Rotor Current of the motor. The motor will develop Locked Rotor Torque and begin to accelerate towards full speed. As the motor accelerates, the current will begin to drop, but will not drop significantly until the motor is at a high speed, typically about 85% of synchronous speed. The actual starting current curve is a function of the motor design, and the terminal voltage, and is totally independent of the motor load. The motor load will affect the time taken for the motor to accelerate to full speed and therefore the duration of the high starting current, but not the magnitude of the starting current. Provided the torque developed by the motor exceeds the load torque at all speeds during the start cycle, the motor will reach full speed. If the torque delivered by the motor is less than the torque of the load at any speed during the start cycle, the motor will cease accelerating. If the starting torque with a DOL starter is insufficient for the load, the motor must be replaced with a motor, which can develop a higher starting torque. The acceleration torque is the torque developed by the motor minus the load torque, and will change as the motor accelerates due to the motor speed torque curve and the load speed torque curve.

The start time is dependant on the acceleration torque and the load inertia. DOL starting results in maximum start current and maximum start torque. This may cause an electrical problem with the supply, or it may cause a mechanical problem with the driven load.

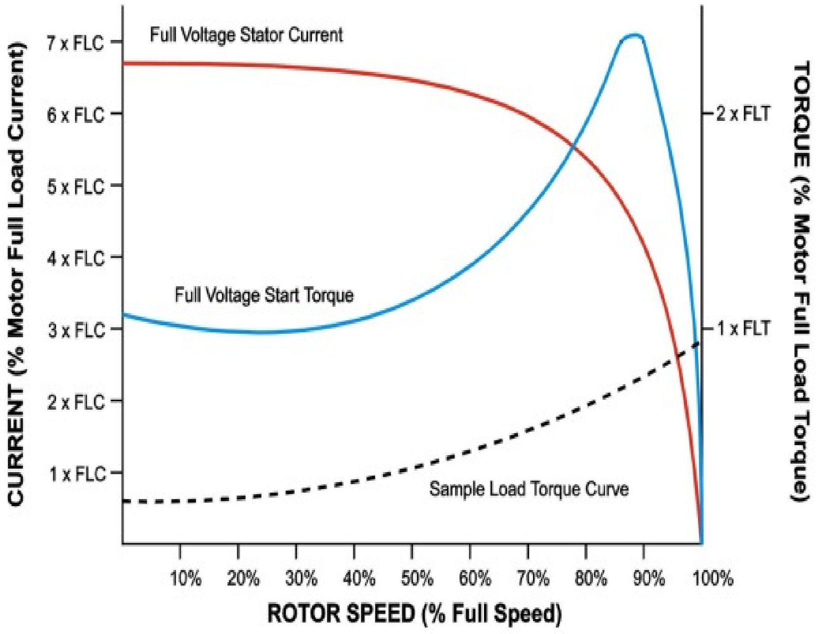


Figure 1.2 DOL Characteristics

The starting current as we have already seen may be five to eight times the full load current, and the heating of the windings is proportional to the square of the current. At starting it will therefore be 25-64 times normal. Furthermore, at the instant of start there is no windage and no radiation. Therefore a very long starting period may result in overheating.

For these reasons it is also undesirable to make repeated successive starts without intervening periods for cooling.

1.1.2 Primary Resistance

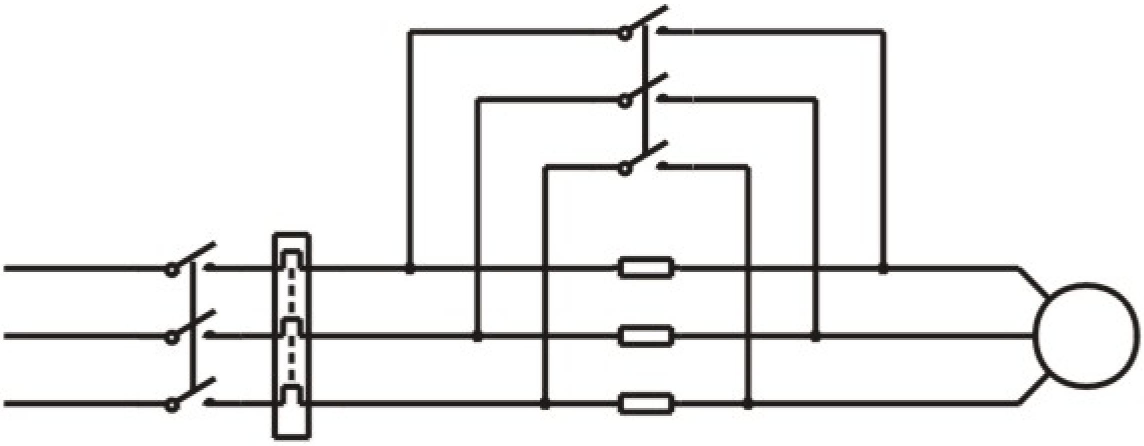


Figure 1.3 Primary Resistance Starter

The Primary Resistance starter will have one or more sets of resistors, which, during start, are connected in series with the supply to the motor. The series resistors limit the starting current drawn by the motor, and thus reduce the starting torque of the motor. Once the motor is up to full speed (or after a period of time) the resistors are bridged by a contactor to apply full voltage to the motor. If the full details of the motor starting characteristics are known, and the starting characteristics of the load are also known, it is practical to determine the correct value of the resistors to provide enough start torque for the load while minimizing the starting current. A primary resistance starter correctly designed and constructed will cause the motor to accelerate the load to almost full speed with the resistors in circuit before they are bridged out. In this case, the transition to full voltage only occurs once the impedance of the motor has risen, and the resulting current is much less than the LRC of the motor. In a poorly designed system, the transition to full voltage will occur at less than 80% full speed, and the current will then step up to almost DOL current, resulting in little gain from the use of the primary resistance starter other than the increased cost of the starter. (Advantageous to the starter supplier, not to the end user.) Improved starting characteristics with some loads can be achieved by the use of several stages of resistance and bridging out increasing amounts of resistance as the motor accelerates. With the primary resistance starter, it is not easy to alter the resistance and hence the starting characteristics once the starter is built. Therefore, it is important that the correct resistors are selected in the first place. The primary resistance starter reduces the voltage applied to the motor terminals while passing the full starting current to the motor. Consequently, there is very high power dissipation in the resistors, resulting in the requirement for very high power rated resistors. Typically, the resistors will dissipate as much as 150% - 200% the power rating of the motor for the duration of the start. The resistors may be either metallic resistors, or liquid resistors. Metallic resistors have a positive temperature coefficient and as a result, as they heat up, their resistance increases. Liquid resistors, such as saline solution, have a negative temperature coefficient and so consequently, as they heat up, their resistance reduces. The heat build up in the resistors during start, and their temperature dependant resistance characteristics, make it essential the resistors are allowed to fully cool between starts. This restricts the starting frequency and the minimum time between the starts.

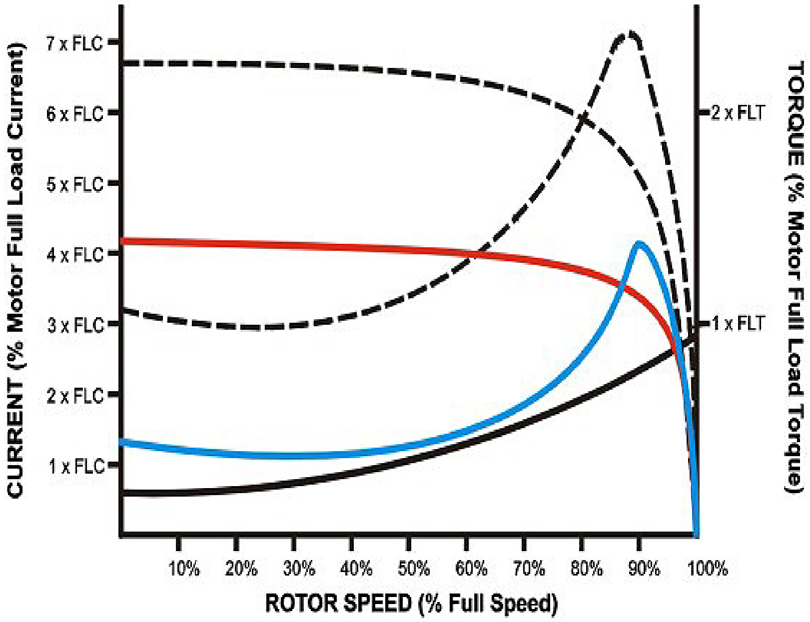


Figure 1.4 Primary Resistance Characteristics

1.1.3 Primary Reactance.

A Primary reactance starter is similar to a primary resistance starter except that the resistors are replaced by a three-phase reactor to limit the starting current. The operation of the primary reactance starter is essentially the same as that of the primary resistance starter, but the use of a three-phase reactor in place of the resistors offers the advantage of reduced heat loss and greater ease of start current setting due to the ability to change taps on the reactor.

1.1.4 Autotransformer.

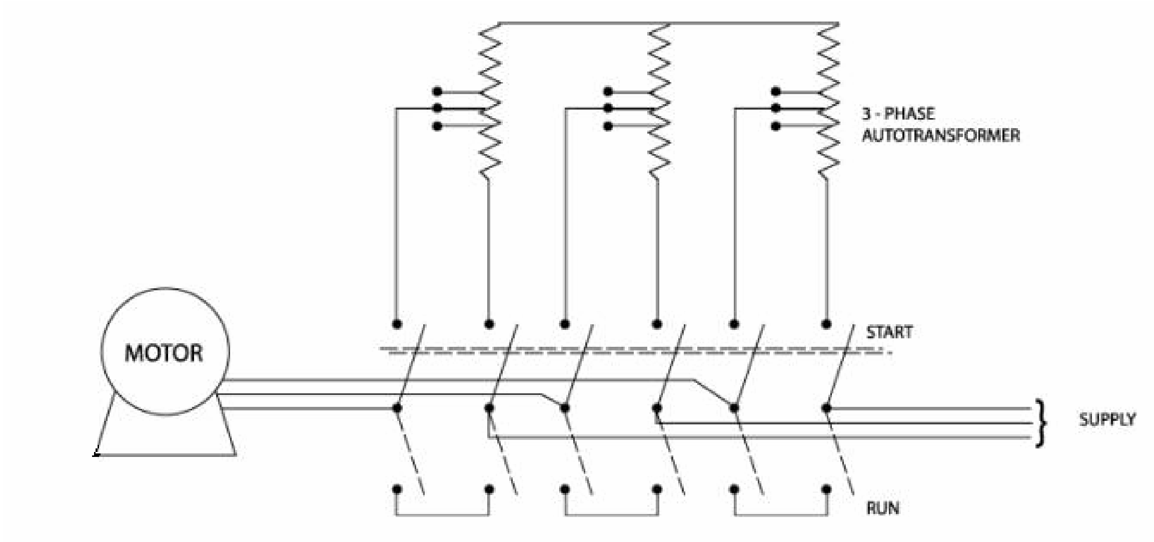


Figure 1.5 Autotransformer Starter

An Autotransformer starter uses an autotransformer to reduce the voltage applied to a motor during start. The autotransformer may have a number of output taps and be set-up to provide a single stage starter, or a multistage starter. Typically, the autotransformer would have taps at 50%, 65% and 80% voltage, enabling the motor to be started at one or more of these settings.

There are two ways of connecting an autotransformer starter, the most obvious way is to apply full voltage to the transformer via a contactor, and connect the motor to the tap by means of a contactor. When the motor has accelerated to full speed, or has run out of acceleration torque, the tap contactor opens, disconnecting the motor from the transformer and another contactor closes connecting the motor to the supply. The transformer can now be disconnected from the supply. This format is known as an open transition starter and is less than ideal due to the fact that the motor is disconnected for a short period of time during the start period. While the motor is connected and accelerating, there is a rotating magnetic field in the stator, which causes flux in the rotor and thus a rotor current to flow. At the instant the motor is disconnected, there is a magnetic field in the rotor, which is spinning with-in the stator winding. The motor acts as a generator until the rotor field decays. The voltage generated by the motor is not synchronized to the supply, and so on reconnection to the supply, the voltage across the contactor at closure can be as much as twice the supply voltage resulting in a very high current and torque transient. This open transition switching is often known as the auto-reclose effect as it yields similar characteristics to opening and closing a breaker on a supply to one or more motors. The consequences of open transition switching can be as bad as broken shafts and stripped gears. By a rearrangement of the power circuit, it is possible, at no extra cost, to build a closed transition starter and thereby eliminate the current and torque transients. The closed transition autotransformer starter is known as the Korndorffer starter. The open transition switching is achieved by reconnecting the tap contactor between the transformer and motor, to the star connection of the transformer, hard wiring the motor to the tap, and altering the sequence of contactor control. To start the machine, the main contactor and the star contactors are closed applying reduced voltage to the motor. When the motor has reached full speed, (or run out of acceleration torque) the star contactor is opened effectively converting the autotransformer starter into a primary reactance starter. Next the primary reactance is bridged by a contactor applying full voltage to the motor. At no time does the motor become disconnected from the supply. The transformer is generally only intermittent rated for the starting duty, and so the frequency and duration of the starts is limited. With a transformer starter, it is relatively easy to change taps and thereby increase the starting voltage if a higher torque is required. The auto transformer starter is a constant voltage starter, so the torque is reduced by the voltage reduction squared over the entire speed range, unlike the primary resistance or primary reactance starters which are constant impedance starters and where the start voltage is dependant on the ratio of the motor impedance to the motor plus starter impedance.

As the motor accelerates, it's impedance rises and consequently, the terminal voltage of the motor also rises, giving a small torque increase at higher speeds. Unlike the primary resistance and primary reactance starter, the current flowing into the motor is different from that flowing from the supply. The supply current flows into the primary circuit of a transformer, and the secondary current is applied to the motor. The transformer reduces the primary current by the same ratio as the voltage reduction. If the motor is connected to the 50% tap of the transformer, the voltage across the motor terminals will be 50%. Assuming an LRC of 600%, there will be 300% current flowing into the motor. If 300% current flows into the motor, then the current into the transformer will be 150%. This would suggest that the lowest starting current will be achieved by the use of an auto transformer starter. In most instances, the load will require an increasing torque as it accelerates, and so often a higher tap must be selected in order to accelerate the load to full speed before the step to full voltage occurs. If a multistage transformer starter is employed, then the primary current will certainly be lower than other forms of induction motor starter.

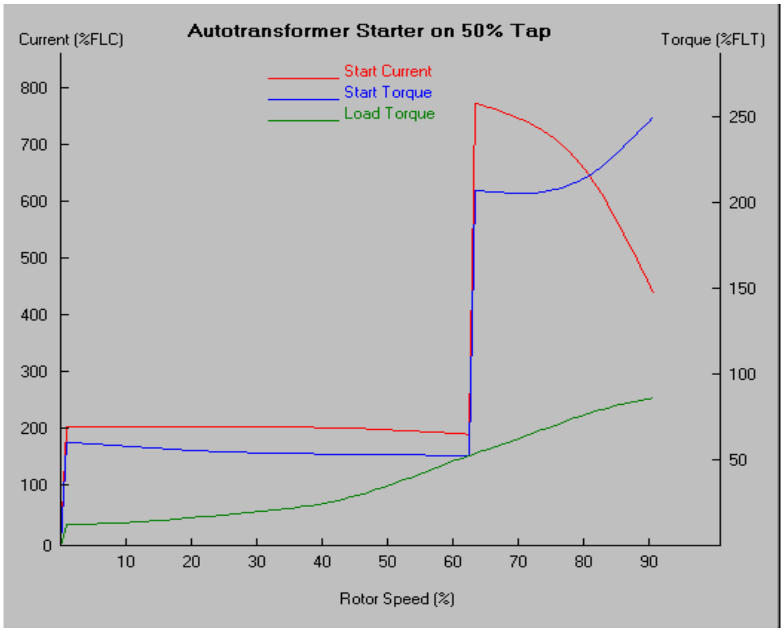


Figure 1.6 Autotransformer Characteristics on 50% tap

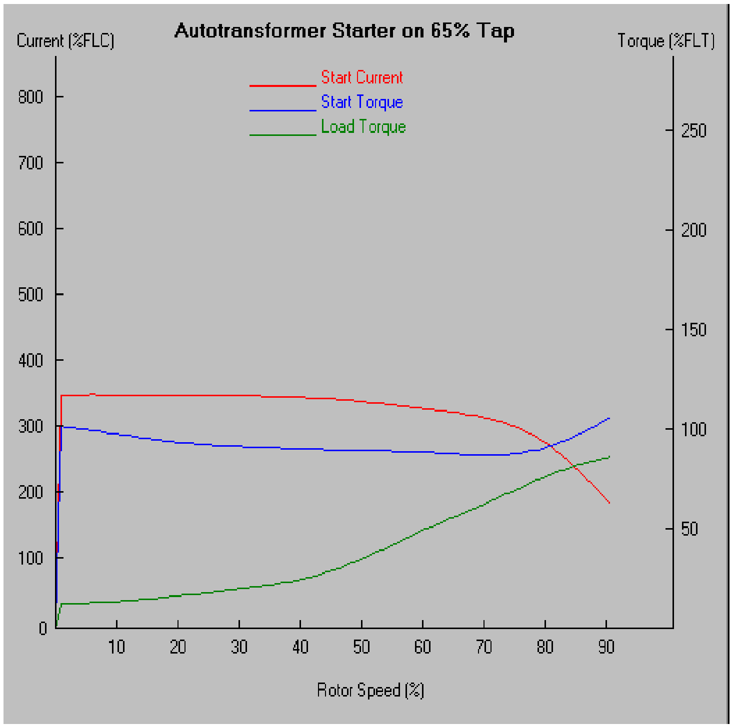


Figure 1.7 Autotransformer Characteristics on 65% tap

These starters are bulky and dissipate a lot of heat. The step jumps in current and torque cause supply current peaks and jolt in mechanical system.

1.1.5 Star Delta

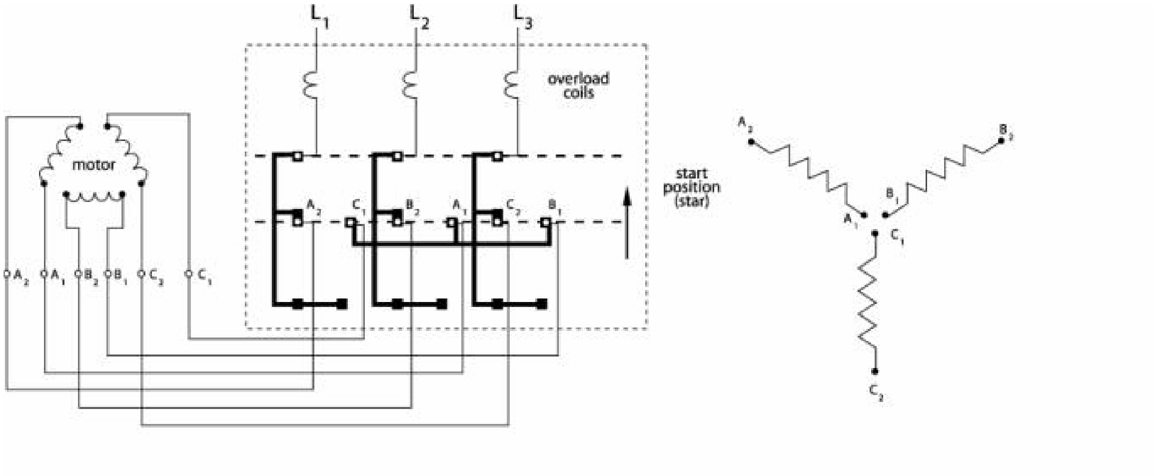


Figure 1.8 Start Position of Star Delta Starter

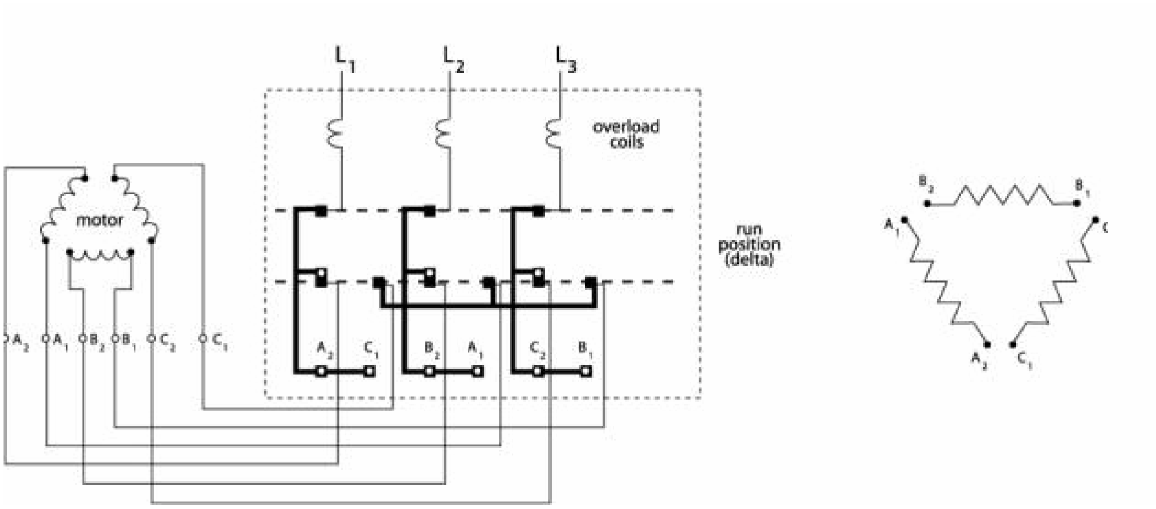


Figure 1.9 Run Position of Star Delta Starter

The Star Delta starter can only be used with a motor, which is rated for connection in delta operation at the required line voltage, and has both ends each of the three windings available individually.

At Start, the line voltage is applied to one end of each of the three windings, with the other end bridged together, effectively connecting the windings in a star connection. Under this connection, the voltage across each winding is 1/(√ 3) of line voltage and so the current flowing in each winding is also reduced by this amount. The resultant current flowing from the supply is reduced by a factor of 1/3 as is the torque. i.e. A motor which exhibits a LRC of 600% and an LRT of 180% will exhibit characteristics of: LRC$_{star}$ of 200% and LRT$_{star}$ of 60%. In some cases, this may be enough to get the motor up to full speed, but most, as this is a constant voltage starter, the transition to full voltage will occur at part speed resulting in a virtual DOL type start. To step to full opined by a very high torque and current transient. In most situations, there would be less damage to the equipment and less interference tillage, the star connection is opened, effectively open circuiting the motor, and the ends of the windings are then connected to the three phase supply in a fashion to create a delta connection. This type of starter is an open transition starter and so the switch to delta is acumen the supply if a DOL starter was employed. The star delta is not easily converted to a closed transition starter, and even the closed transition star delta starter still has the problem that the start voltage cannot be altered. If there is insufficient torque available in star, then it will go DOL. The star delta starter does get around the regulations in some countries where there is a requirement for a reduced voltage starter, but in reality, in many situations results in more severe transients than DOL. The main benefits of the star delta starter are that it puts more money in the pockets of the switchgear supplier, and it is politically correct.

These starters require 6 wires to be run to the motor implying higher installation time and cost. The step jumps in current and torque cause supply current peak and jolt in mechanical system.

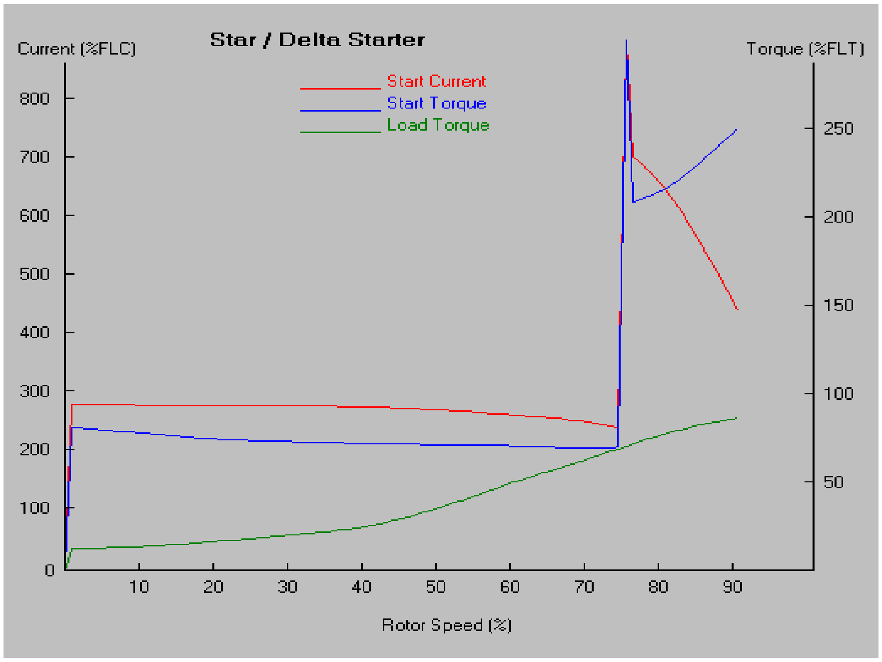


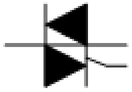
Figure 1.10 Star Delta Starter Characteristics

1.1.6 Soft Starters for Induction Motors:

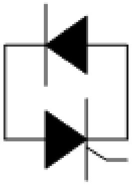
A soft starter is another form of reduced voltage starter for A.C. induction motors. The soft starter is similar to a primary resistance or primary reactance starter in that it is in series with the supply to the motor. The current into the starter equals the current out. The soft starter employs solid-state devices to control the current flow and therefore the voltage applied to the motor. In theory, soft starters can be connected in series with the line voltage applied to the motor, or can be connected inside the delta loop of a delta connected motor, controlling the voltage applied to each winding.

Voltage control is achieved by means of solid-state A.C. switches in series with each phase. These switches comprise either:

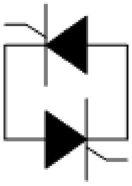
1 x Triac per phase



1 x SCR and 1 x Diode reverse parallel connected per phase.



2 x SCRs reverse parallel connected per phase.



1.2 Solid-state switches:

These Solid State Switches are phase controlled in a similar manner to a light dimmer, in that they are turned on for a part of each cycle. Varying the conduction angle of the switches controls the average voltage. Increasing the conduction angle will increase the average output voltage. Controlling the average output voltage by means of solid state switches has a number of advantages, one of the major advantages being the vast improvement in efficiency relative to the primary resistance starter, due to the low on state voltage of the solid state switches. Typically, the power dissipation in the starter, during start, will be less than 1% of the power dissipated in a primary resistance starter during start. Another major advantage of the solid-state starter is that the average voltage can be easily altered to suit the required starting conditions. By variation of the conduction angle, the output voltage can be increased or reduced, and this can be achieved automatically by the control electronics. The control electronics can be preprogrammed to provide a particular output voltage contour based on a timed sequence (open loop), or can dynamically control the output voltage to achieve an output profile based on measurements made of such characteristics as current and speed (closed loop).

1.3 Switching Elements:

The switching elements must be able to control the current applied to the motor at line voltage. In order to maintain a high level of reliability on a real industrial type supply, the switching elements need to be rated at least 3 times the line voltage. On a 400-volt supply, this means that the requirement is for 1200 Volt devices, and 600 Volt devices on a 200-volt supply. It is also important that the switching elements have a good transient current overload capacity. 1200 Volt triacs with good current transient overload characteristics are not readily available, and so the choice is really between the SCR-Diode and SCR-SCR. There are some triacs, which are suitable for this operation, but they are not easily attainable. The major differences between the SCR-SCR and the SCR-Diode options are price, and the harmonic content of the output voltage.

The SCR-SCR method provides a symmetrical output which is technically desirable from the point of supply disturbances and harmonics, while the SCR-Diode method is inferior technically, it is commercially more effective and easier to implement. Harmonics awareness and paranoia has drastically reduced the number of SCR-Diode type soft starters on today's market, but they do still exist. The technology is not always easily recognizable as such with terms such as three pulse technology being used to describe SCR-Diode systems as opposed to six pulse technology describing SCR-SCR systems.

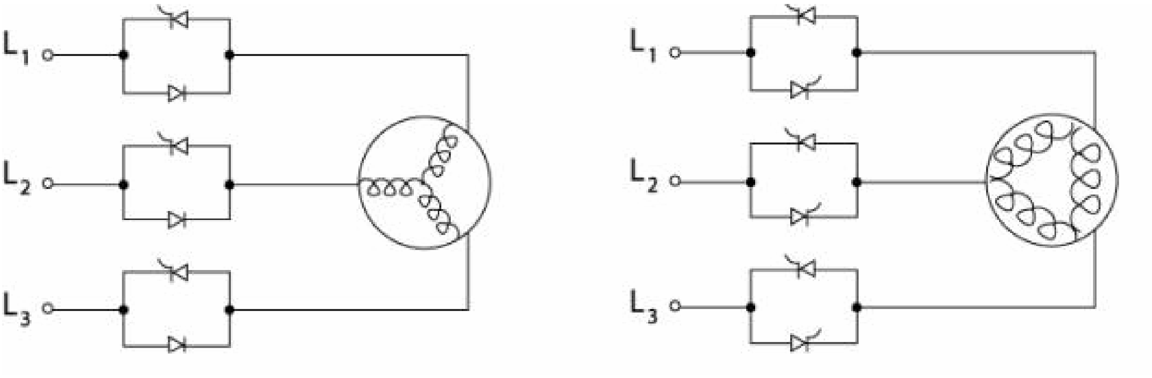


Figure 1.11 Electronic Soft Starter

The advantages of using an electronic Soft Starter can briefly be summarized as follows:

1. The elimination of current transients
2. The elimination of torque transients
3. Extended life from mechanical drive systems
4. Reduced stresses in the motor
5. Possibility of electronic stopping and starting (leaving the contactor closed) where rapid switching is required.
6. Reduced maintenance costs
7. The ability to soft stop a motor as in pumping applications.

1.4 Induction Motor:

Since its invention one hundred years ago, the standard 3-phase induction motor has become one of the most familiar items of industrial equipment ever known. Due to its simplicity of construction, low cost, reliability and relatively high efficiency, it is likely to remain the prime source of mechanical energy for industrial applications.

1.4.1 Introduction

The conversion of energy from the electrical supply to rotating mechanical energy, is the primary purpose of all motors. To regulate energy flow, most motor circuits require a mechanism to connect and disconnect them from their electrical power source and, electro-mechanical switches, known as 'Contactors', are the standard means of achieving this control. Even today, more than one hundred years after their introduction, contactor-based systems remain the most widely used method of motor control. Nevertheless, there is a definite trend towards more sophisticated electronic systems of control being applied to fixed-speed motor drives and here we discuss the newest form of control - namely, electronic, microprocessor-controlled, optimising soft-starters.

In order to appreciate the benefits of using an electronic controller, it is important to have some understanding of the characteristics and limitations of the induction motor and the electro-mechanical systems currently used to control them.

The standard, fixed-speed induction motor has to fulfill two basic requirements: -

1. To accelerate itself and its load to full speed (or speeds in the case of multi-speed motors)
2. To maintain the load at full speed efficiently and effectively over the full range of loadings.

As mentioned earlier, motors convert electrical energy drawn from the power supply into a mechanical form, usually as a shaft rotating at a speed fixed by the frequency of the supply. The power available from the shaft is equal to the torque (moment) multiplied by the shaft speed (rpm). From an initial value at standstill, the torque alters, up or down, as the machine accelerates, reaching a peak at about two-thirds full speed, finally to become zero at synchronous speed. This characteristic means that induction motors always run at slightly less than synchronous speed in order to develop power - the ’slip speed’ and, hence the term asynchronous. The graph below, which shows an induction motor torque/speed curve, illustrates this most important characteristic. The induction motor can be treated essentially as a transformer for analysis. The induction motor has stator leakage reactance, stator copper loss elements as series components, and iron loss and magnetizing inductance as shunt elements. The rotor circuit likewise has rotor leakage reactance, rotor copper (aluminum) loss and shaft power as series elements.

The transformer in the center of the equivalent circuit can be eliminated by adjusting the values of the rotor components in accordance with the effective turns ratio of the transformer.

Torque/Speed curve for the induction motor :

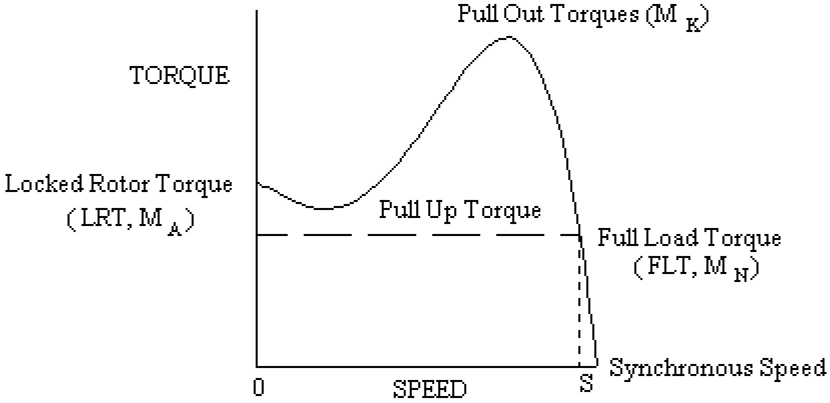


Figure 1.12 Torque/Speed curve for the induction motor

The acceleration of a motor-load system is caused by the difference between the developed torque (motor) and the absorbed torque (load) and is shown by the shaded area in the next figure:

Torque/Speed Curve - Accelerating Torque

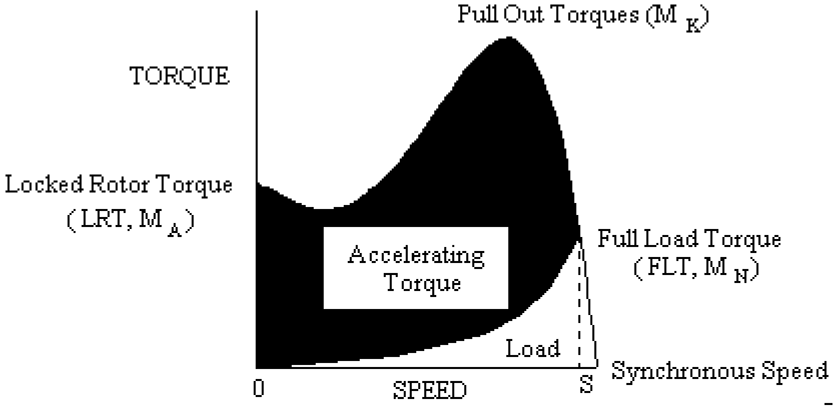


Figure 1.13 Torque/Speed Curve - Accelerating Torque

Torque/Speed Curve - High starting torque/High efficiency motor

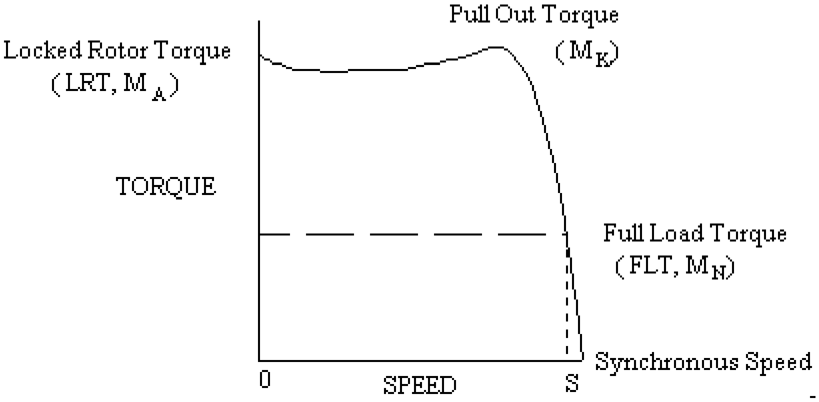


Figure 1.14 Torque/Speed Curve - High starting torque/High efficiency motor

1.4.2 Equivalent Circuit.

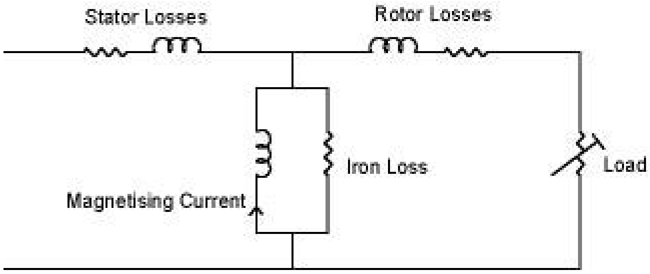


Figure 1.15 Equivalent Circuit

From the equivalent circuit and a basic knowledge of the operation of the induction motor, it can be seen that the magnetizing current component and the iron loss of the motor are voltage dependant, and not load dependant. Additionally, the full voltage starting current of a particular motor is voltage and speed dependant, but not load dependant. The magnetizing current varies depending on the design of the motor. For small motors, the magnetizing current may be as high as 60%, but for large two pole motors, the magnetizing current is more typically 20 - 25%. At the design voltage, the iron is typically near saturation, so the iron loss and magnetizing current do not vary linearly with voltage with small increases in voltage resulting in a high increase in magnetizing current and iron loss.

1.4.3 Starting Characteristics.

In order to perform useful work, the induction motor must be started from rest and both the motor and load accelerated up to full speed. Typically, this is done by relying on the high slip characteristics of the motor and enabling it to provide the acceleration torque.

Induction motors at rest, appear just like a short-circuited transformer, and if connected to the full supply voltage, draw a very high current known as the "Locked Rotor Current". They also produce torque, which is known as the "Locked Rotor Torque". The Locked Rotor Torque (LRT) and the Locked Rotor Current (LRC) are a function of the terminal voltage to the motor, and the motor design. As the motor accelerates, both the torque and the current will tend to alter with rotor speed if the voltage is maintained constant.

The starting current of a motor, with a fixed voltage, will drop very slowly as the motor accelerates and will only begin to fall significantly when the motor has reached at least 80% full speed. The actual curves for induction motors can vary considerably between designs, but the general trend is for a high current until the motor has almost reached full speed. The LRC of a motor can range from 500% Full Load Current (FLC) to as high as 1400% FLC. Typically, good motors fall in the range of 550% to 750%FLC.

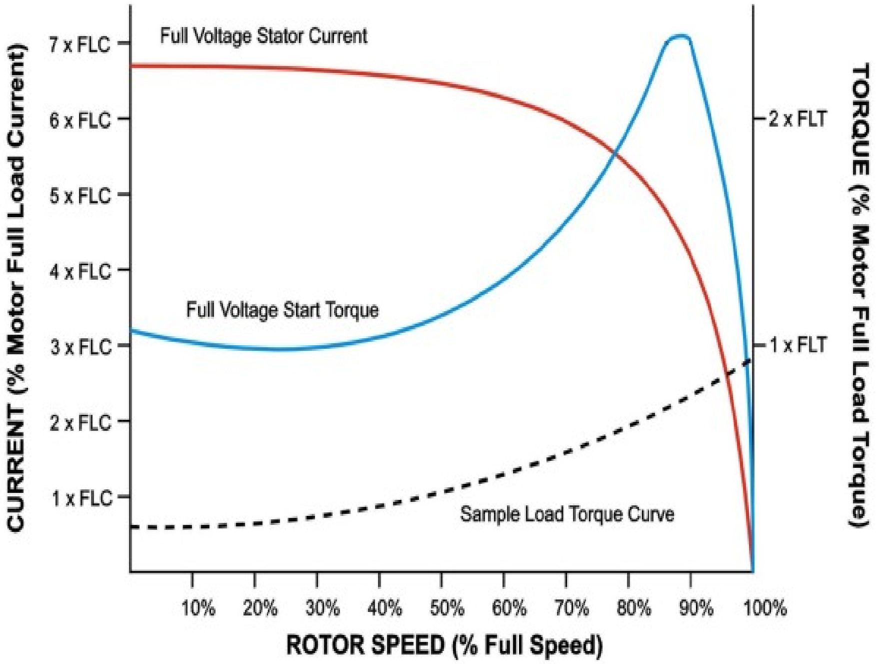


Figure 1.16Starting Characteristics

The starting torque of an induction motor starting with a fixed voltage, will drop a little to the minimum torque known as the pull up torque as the motor accelerates, and then rise to a maximum torque known as the breakdown or pull out torque at almost full speed and then drop to zero at synchronous speed.

The curve of start torque against rotor speed is dependant on the terminal voltage and the motor/rotor design.

The LRT of an induction motor can vary from as low as 60% Full Load Torque (FLT) to as high as 350% FLT. The pull-up torque can be as low as 40% FLT and the breakdown torque can be as high as 350% FLT. Typical LRTs for medium to large motors are in the order of 120% FLT to 280% FLT.

The power factor of the motor at start is typically 0.1 - 0.25, rising to a maximum as the motor accelerates, and then falling again as the motor approaches full speed. A motor, which exhibits a high starting current, i.e. 850%, will generally produce a low starting torque, whereas a motor, which exhibits a low starting current, will usually produce a high starting torque. This is the reverse of what is generally expected. The induction motor operates due to the torque developed by the interaction of the stator field and the rotor field. Both of these fields are due to currents which have resistive or in phase components and reactive or out of phase components. The torque developed is dependant on the interaction of the in phase components and consequently is related to the I^2R of the rotor. A low rotor resistance will result in the current being controlled by the inductive component of the circuit, yielding a high out of phase current and a low torque.

Figures for the locked rotor current and locked rotor torque are almost always quoted in motor data, and certainly are readily available for induction motors. Some manufactures have been known to include this information on the motor nameplate. One additional parameter, which would be of tremendous use in data sheets for those who are engineering motor, starting applications, is the starting efficiency of the motor. By the starting efficiency of the motor, I refer to the ability of the motor to convert amps into newton meters. This is a concept not generally recognized within the trade, but one, which is extremely useful when comparing induction motors.

The easiest means of developing a meaningful figure of merit, is to take the locked rotor torque of the motor (as a percentage of the full load torque) and divide it by the locked rotor current of the motor (as a percentage of the full load current).

Starting efficiency = Locked Rotor Torque/ Locked Rotor Current

If the terminal voltage to the motor is reduced while it is starting, the current drawn by the motor will be reduced proportionally. The torque developed by the motor is proportional to the current squared, and so a reduction in starting voltage will result in a reduction in starting current and a greater reduction in starting torque. If the start voltage applied to a motor is halved, the start torque will be a quarter, likewise a start voltage of one third will result in a start torque of one ninth.

1.4.4 Runnng Characteristics:

Once the motor is up to speed, it operates at low slip, at a speed determined by the number of stator poles. The frequency of the current flowing in the rotor is very low. Typically, the full load slip for a standard cage induction motor is less than 5%. The actual full load slip of a particular motor is dependant on the motor design with typical full load speeds of four pole induction motor varying between 1420 and 1480 RPM at 50 Hz. The synchronous speed of a four-pole machine at 50 Hz is 1500 RPM and at 60 Hz a four-pole machine has a synchronous speed of 1800 RPM.

The induction motor draws a magnetizing current while it is operating. The magnetizing current is independent of the load on the machine, but is dependant on the design of the stator and the stator voltage. The actual magnetizing current of an induction motor can vary from as low as 20% FLC for large two pole machines to as high as 60% for small eight pole machines. The tendency is for large machines and high-speed machines to exhibit a low magnetizing current, while low speed machines and small machines exhibit a high magnetizing current. A typical medium sized four pole machine has a magnetizing current of about 33% FLC.

A low magnetizing current indicates a low iron loss, while a high magnetizing current indicates an increase in iron loss and a resultant reduction in operating efficiency. The resistive component of the current drawn by the motor while operating, changes with load, being primarily load current with a small current for losses. If the motor is operated at minimum load, i.e. open shaft, the current drawn by the motor is primarily magnetizing current and is almost purely inductive. Being an inductive current, the power factor is very low, typically as low as 0.1. As the shaft load on the motor is increased, the resistive component of the current begins to rise. The average current will noticeably begin to rise when the load current approaches the magnetizing current in magnitude. As the load current increases, the magnetizing current remains the same and so the power factor of the motor will improve. The full load power factor of an induction motor can vary from 0.5 for a small low speed motor up to 0.9 for a large high-speed machine. The losses of an induction motor comprise: iron loss, copper loss, windage loss and frictional loss. The iron loss, windage loss and frictional losses are all essentially load independent, but the copper loss is proportional to the square of the stator current. Typically the efficiency of an induction motor is highest at 3/4 load and varies from less than 60% for small low speed motors to greater than 92% for large high speed motors. Operating power factor and efficiencies are generally quoted on the motor data sheets.

CHAPTER 2: POWER CONTROLLER

The switching characteristics of power devices permit the control and conversion of electric power from one form to another. These converters are called static power converters and consist of a matrix of switches. Using a combination of these devices allows us to create circuit configurations that allow us to convert between a.c. and d.c. signals.

The resulting power electronic circuits are classified into six types:

1. ac-dc converters (controlled rectifiers)
2. ac-ac converters (ac voltage controllers)
3. dc-dc converters (dc choppers)
4. dc-ac converters (inverters)
5. static switches

2.1 Introduction

By connecting a parallel pair of thyristor between a.c. supply and load, the voltage applied to load can be controlled. This type of power controller is known as an a.c. voltage controller or power controller. Therefore, a.c. voltage controller converts fixed mains voltage directly to variable alternating voltage without a change in frequency. The important applications of voltage controller are,

- ☐ Speed control of poly phase induction motor
- ☐ Domestic and Industrial heating , Electroplating
- ☐ On load transformer tap changing

- Static reactive power compensation

2.2 Classification of Power Controller:

- Single phase Voltage Controller
  - Half Wave Voltage Controller
  - Full Wave Voltage Controller
- Three phase Voltage Controller
  - Half Wave Voltage Controller
  - Full Wave Voltage Controller
- Single phase half wave Voltage controller

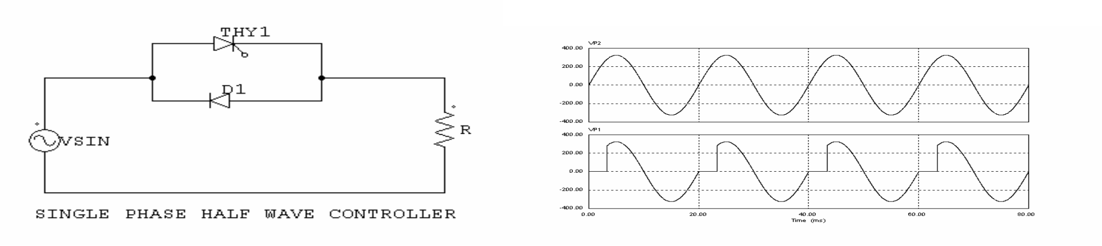


Figure 2.1 Single-phase half wave Power controller

- Single phase full wave Voltage controller

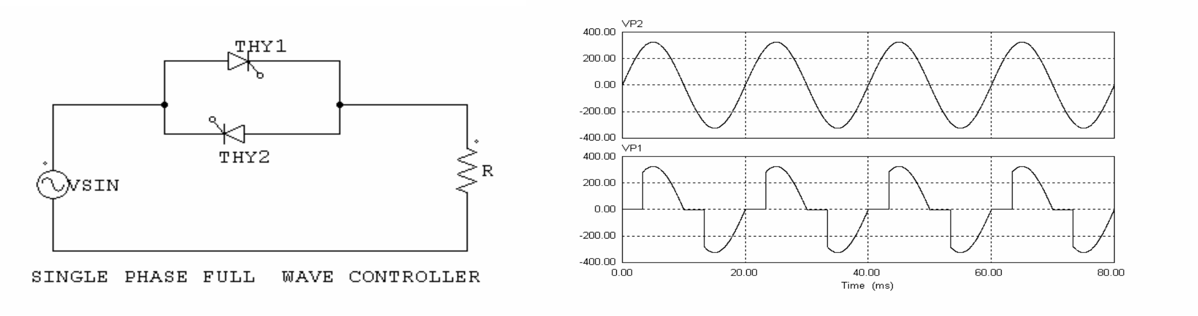


Figure 2.2 Single-phase full wave Power controller

- Three phase half wave Voltage controller

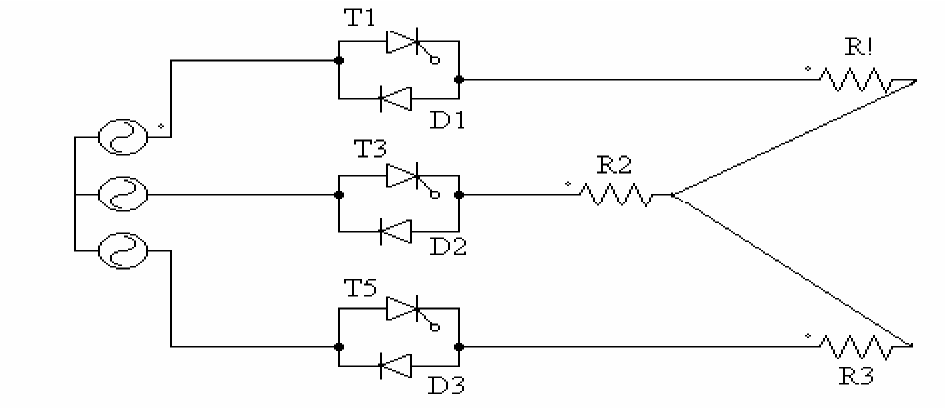


Figure 2.3 Three phase half wave Power controller

- Three phase full wave Voltage controller

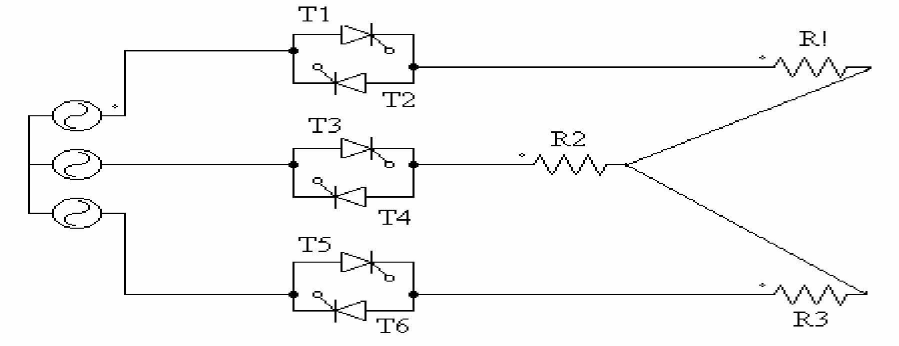


Figure 2.4 Three phase full wave Power controller

2.3 Control Methods:

SCR Power Controllers are available either as Zero Fired (for resistive loads) or Phase Angle Fired (for transformer coupled loads and some heating loads which change resistance dramatically with temperature or time), and single or 3 phase loads.

- Zero Fired

  Most power control applications involve simple resistive heating loads which require little in the way of sophistication..

They undergo negligible resistance change as they heat, and they operate at or near available line voltages

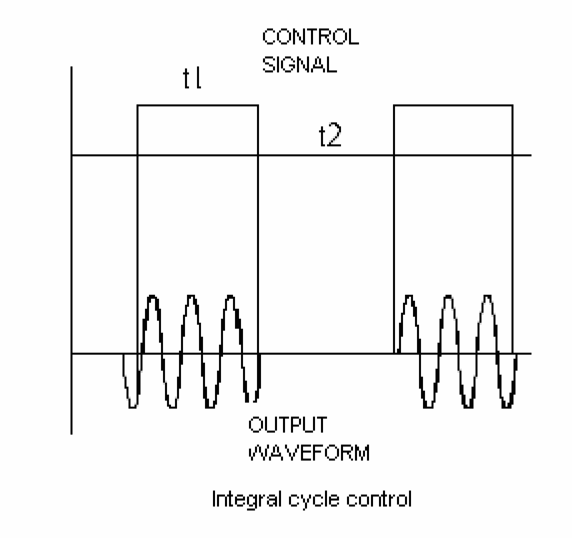


Figure 2.5 Zero fired Control

Here, the output power is varied by t1 and t2. Generally the cycle time (t1+t2) is kept constant and the ON time t1 is varied in proportion to the power demanded.

$$\text{Output Power} = \frac{t1}{(t1+t2)} \text{ x Max. Power} = \frac{t(on)}{t(cycle)} \text{ x Max. Power}$$

- Single phase Control

By controlling the number of cycles of a fixed time period (microseconds in some units), the control signal to the SCR will cause the SCR to be gated on for a certain time period and then off for a given time period. For example, at 50% power, it will be on for 10 cycles and off for 10 cycles. At 10% power, it will be on for 2 cycles and off for 18, etc. It is important to note that zero fired SCR's control average power to the load. There is no voltage or current control as in phase control (although this is available in some controllers). It is, therefore, not practical to current limit zero fired SCR's. Of course, with purely resistive loads, there is no need for current limiting. More exotic SCR's offer Fast Cycle, Half Cycle or Single Cycle firing.

- ❑ Three Phase Control

Confusion occasionally results when users notice that three phase zero fired SCR's often control only two legs of the three phases. This is standard practice throughout the industry and results from the fact that in common wye or delta connected loads, current flow through the third leg must also flow through the other controlled legs. This effectively controls all power to the load, and results in some cost saving.

- ❑ Two leg control
  - o Star or delta load
  - o Not used with four wire loads, neutral is floating

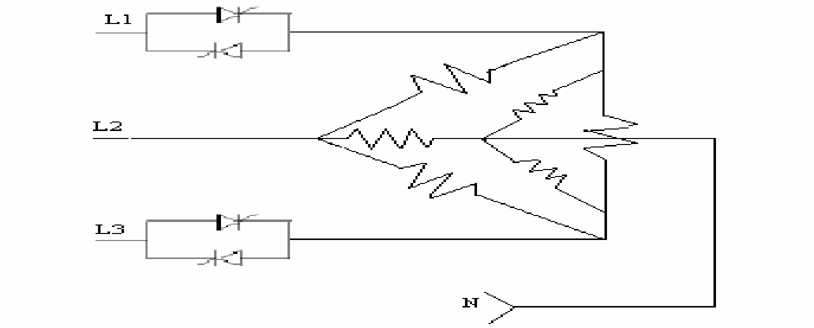


Figure 2.6 Three phase Two leg Control

- ❑ Three leg Control
  - o Cost is increased
  - o Low RFI is retained

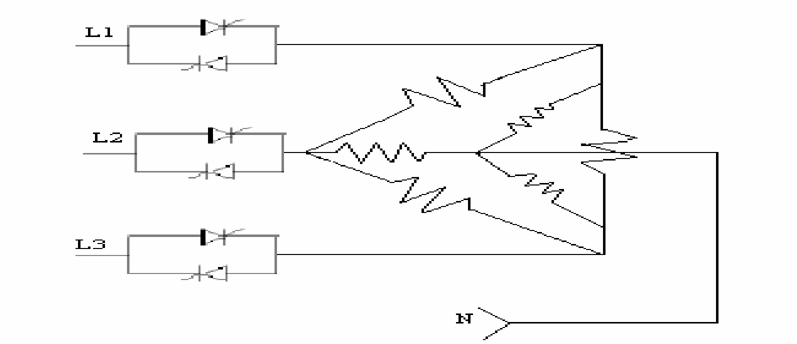


Figure 2.7 Three phase Three leg Control

- Prohibited Load

Transformers head the list as prohibited for most Zero Fired devices. As a power transformer is energized, a magnetizing current flows into the primary winding to set up flux lines within the transformer so that power may be taken from the secondary. This inrush of current may be several times the surge current rating of the SCR and fusing. This is why "soft start" or "ramping on startup" features are specified with controllers dealing with phase controlled SCR's. The voltage is started at a small percentage of the line voltage and is slowly brought up to the line value, so that inrush currents can never exceed ratings. Units turn fully on at zero, and therefore, cannot be prevented from impressing the entire inrush current upon the transformer. The inevitable result is a blown fuse or a damaged SCR and transformer.

Four wire wye loads also present problems. Think of them as three separate and independent loads. A four-wire wye (or "star") load has each phase connected to a neutral point; therefore, the voltage across the leg is the line voltage divided by 1.732. That is, on a 480V 3 Phase system connected 4 wire Wye, three 277 volt units must be used. They will be connected from line to neutral. Some SCR's, however, are designed for use with 3 or 4 wires Wye, open or closed Delta, 3 wire Delta and Star loads. Just make extremely sure that they are designed for this purpose.

Any heating element, which requires current limiting may not be controlled by standard zero, fired devices. Such elements include: molybdenum, tantalum, silicon carbide (globars), super kanthal, and platinum. This entire exhibit a significant resistance changes over time and temperature, usually from 2 or 3:1 to 20:1. These nearly always have an interposing transformer in the system and as such will be eliminated from zero fired consideration.

Any load, such as a tungsten lamp, which has a minimal resistance change, but which has a very fast response time, may not be zero fired. Generally speaking, any three phase load which tends to be unbalanced, or any resistance load with a high temperature coefficient and significant thermal mass, cannot be operated zero fired.

- ❑ Phase Angle Fired

Basically, motors or transformer-coupled loads must be fired by a phase angle gating device because at start-up, lots of power is necessary to energize the coil before any work can be done. The inrush of current for this would blow the fuses of a zero-fired device, or even blow it up. Certain electrical connections and heating elements also must be phase angle fired. Any prohibited load for a zero fired device is a candidate for phase angle firing.

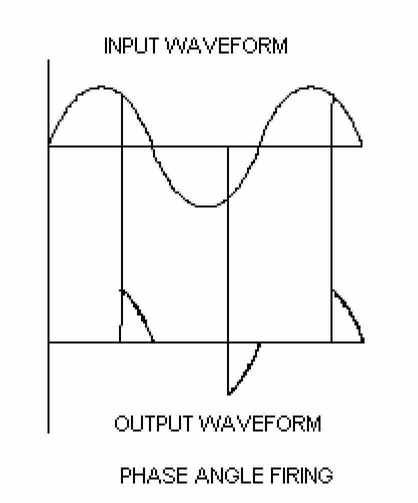


Figure 2.8 Phase Angle Control

- ❑ Six SCR in line for Delta Connection
    - o Inductive load

  - Balanced resistive Load
  - Transformer coupled load

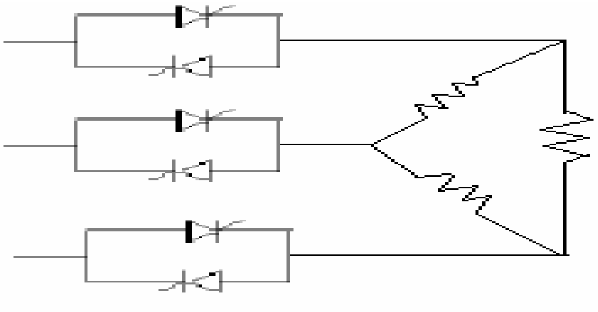


Figure 2.9 Phase Angle Control with Delta connected load

- Six SCR in line for Star Connection
  - Unbalanced load
  - Reduced Voltage Rating

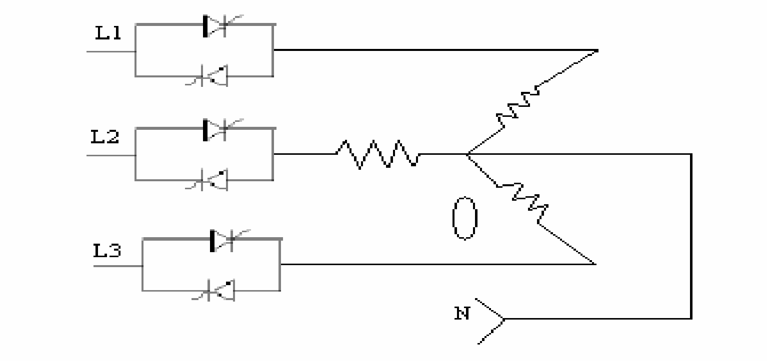


Figure 2.10 Phase Angle Control with Star connected load

Whereas zero fired devices turn on at each zero crossing point in the AC sine wave, and control by regulating bursts of whole sine waves to the load, phase angle fired devices may be turned on at any point within the half cycle. This controls the RMS voltage out of the SCR, and thus the power. The ability to choose any of an infinite number of firing points is sometimes called stepless control. This allows Phase Angle Fired SCR's to replace Saturable Reactors, Variacs, Stepper Switches, Contactors, Ignatrons, and Thyratrons with a much more stable, reliable, efficient and acoustically quieter device.

When an SCR is fired at some conduction angle other than zero, let's say 90°, large amounts of power are being switched under load. If the SCR is driving a transformer, this steep waveform will permit a very large inrush current to flow into the transformer primary. This may be several times the surge current rating of the SCR, fuse and transformer. Similarly, if under steady state operation, the power line drops out for a few cycles, the power may be reapplied to the transformer when the flux is at an extreme in the hysteresis curve; this may drive a transformer into saturation. Again, this saturation will cause very large and potentially damaging currents to flow.

Instead of impressing the full line voltage on the transformer, the SOFT START feature of a phase angle SCR will slowly increase its output from zero to full line voltage over a 12 cycle period, so that the transformer core has time to magnetize before taking full power from the secondary. This occurs each time the power control is turned on, each time there is a momentary outage on the power line, say a soft start reset, or even after a very large step change in the control signal.

To protect the load, current limiting should be considered with a phase fired power control. This feature overrides any other control signal over a selectable range and shuts the system down if the watt density rating of the heater load is exceeded by the power flowing into it. Fast gating limit monitors currents above a prescribed level and limits gate pulses to the SCR to prevent damaging currents.

2.4 Comparison of Zero fired and Phase Angle fired Methods:

PARAMETER	**PHASE ANGLE**	**ZERO FIRED**
Cost (1-Φ)	Relatively more	Relatively less
Cost (3-Φ)	Relatively more	2 leg control less
Type of Load	Transformer coupled, fast Resounding, Temperature dependent load	Temperature independent resistive load
Power factor	Low	Unity
Harmonics	Higher	Lower
Reliability	Relatively Less	Relatively high
EMI	High	Low
Control	More Precise	Less Precise

Table 1 Comparison of Zero fired and Phase Angle fired Methods

2.5 Power Circuit of Soft Starter:

Power circuit of soft starter is nothing but an a.c. voltage controller, which can control supply voltage. It consists of six antiparallel thyristors. By controlling the firing angle of the thyristors voltage control is possible. Figure given below shows the power circuit and waveform.

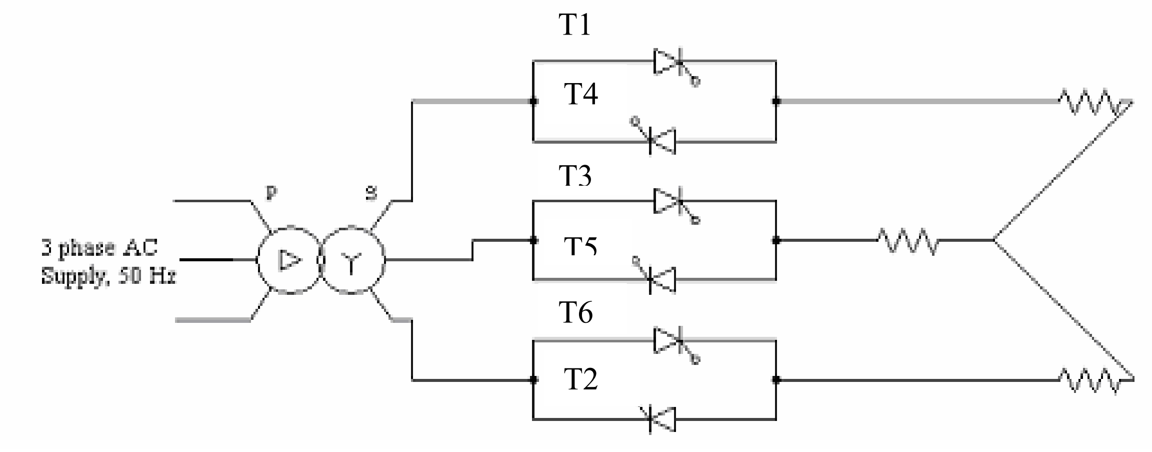


Figure 2.11 Power Circuit of Soft Starter

From the microcontroller one pulse is sent to each thyristor: a first pulse when the alpha angle is reached, then a second pulse 60 degrees later, when the next thyristor is fired. The figures below display the synchronization of the six pulses for an alpha angle of 0 degrees. The pulses are generated exactly at the zero crossings of the synchronization voltages.

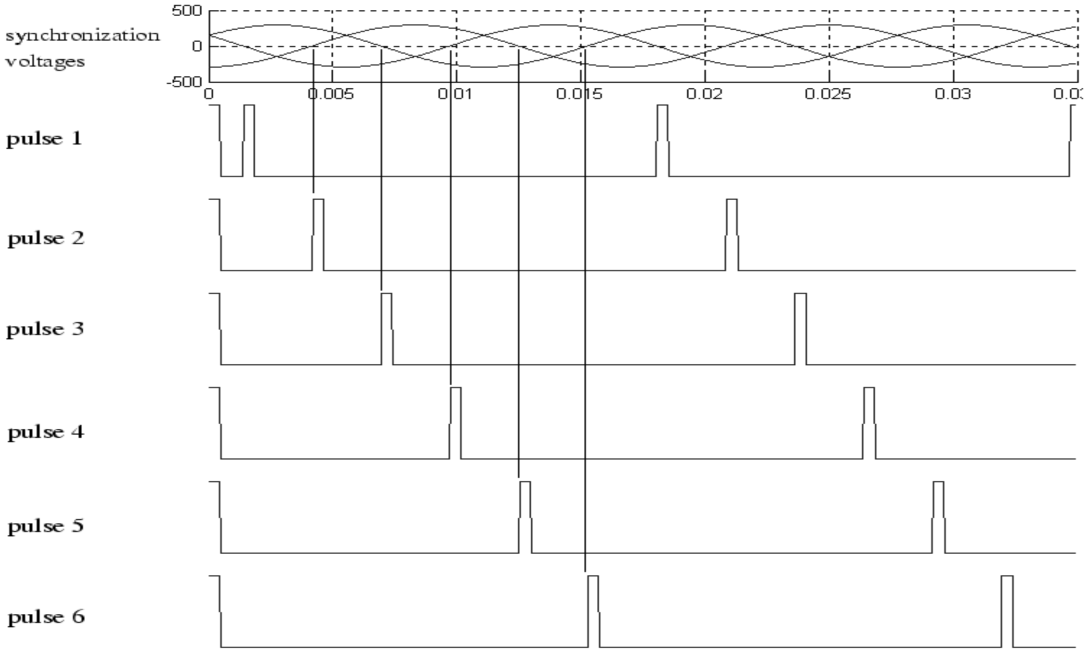


Figure 2.12 6-Pulse configuration from microcontroller

CHAPTER 3: ATMEGA16L MICROCONTROLLER

3.1 Introduction:

- High Performance, Low-Power AVR 8-bit Micro controller.
- Advanced RISC Architecture.
- 8-Channel, 10 bit ADC.
- Operating voltages 2.2V-5.5V.
- 0-8MHz for Atmega16L.

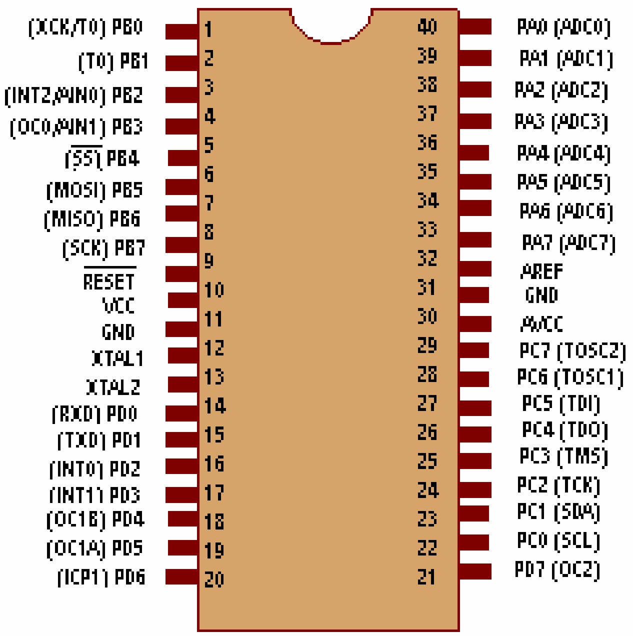


Figure 3.1 Pin Diagram of Atmega16L Micro controller

The Atmega16L features a 10-bit successive approximation ADC. The ADC is connected to an 8-channel Analog Multiplexer, which allows 8 single ended voltage inputs constructed from the pins of Port A. The ADC has a separate analog supply voltage pin, AVCC. AVCC must not differ more than ±0.3V from Vcc.

3.2 Micro controller Programmer Circuit:

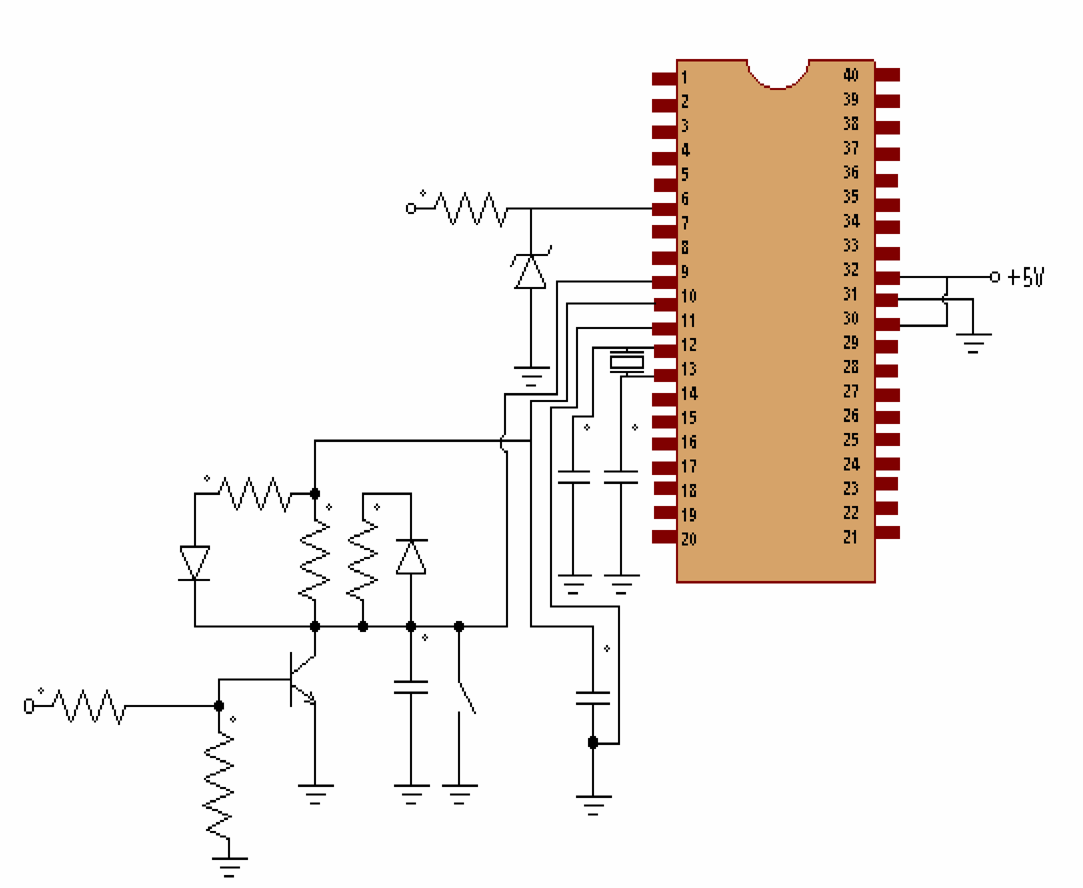
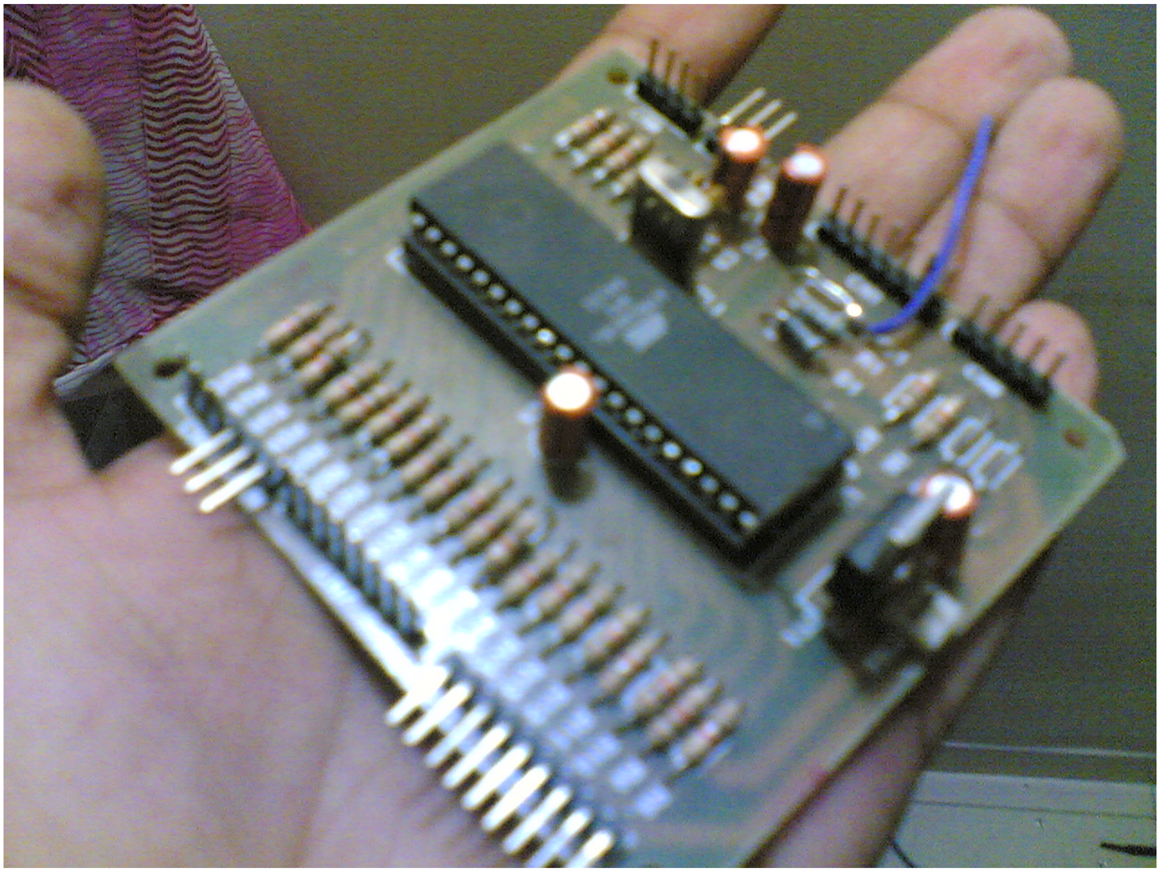


Figure 3.2 Programmer Circuit of Atmega16L



CHAPTER 4: ABOUT THE PROJECT

4.1 Features:

- Working Voltage: 415 V
- Load Current: 50 A
- Operating Mode: Phase angle control
- Type of Load: Resistive
- Over Current protection
- Thermal protection

4.2 Basic Steps:

HARDWARE PART

- POWER MODULE
- POWER SUPPLY DESIGN (±12 V)
- CURRENT SENSER DESIGN
- TEMPERATURE SENSER DESIGN
- DRIVER CIRCUIT DESIGN

SOFTWARE PART

- PROGRAMMING
- ITS IMPLIMENTATION

4.3 Basic Block Diagram:

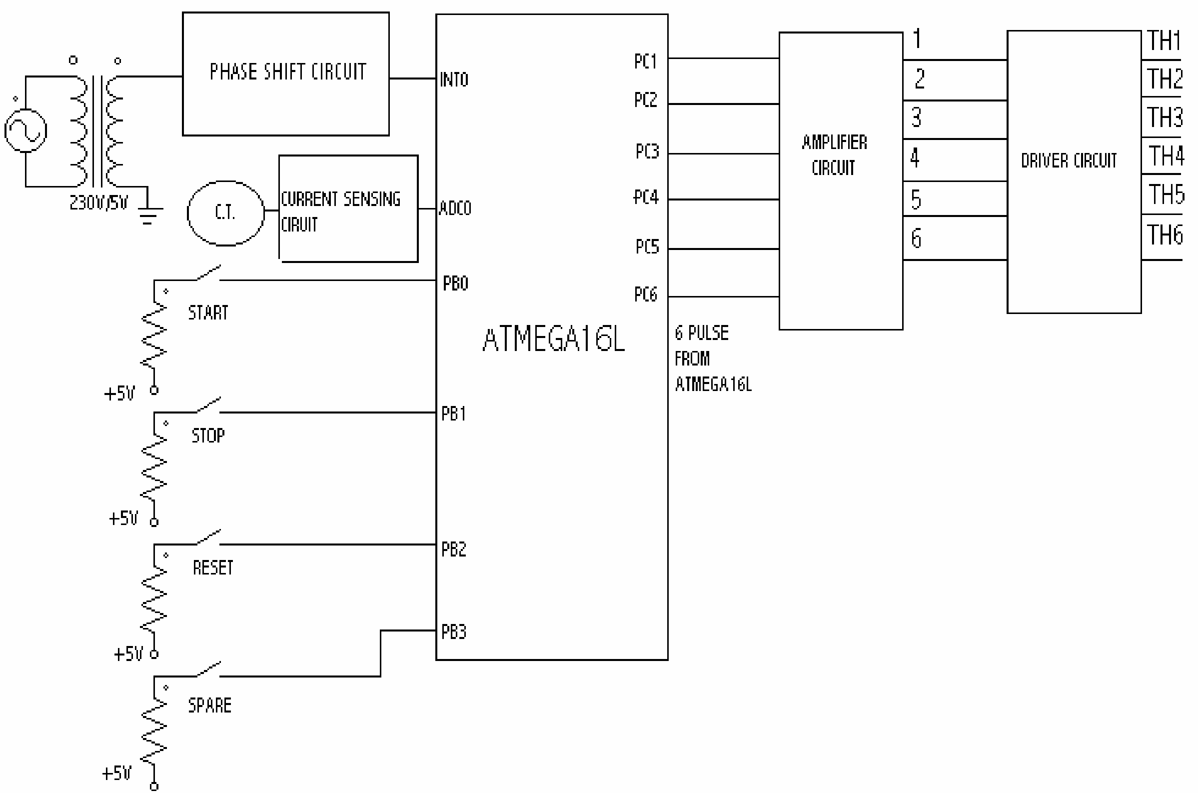


Figure 4.1 Block Diagram of Firing Circuit

Step 1: Convert AC line signal to Square wave by phase shift circuit.

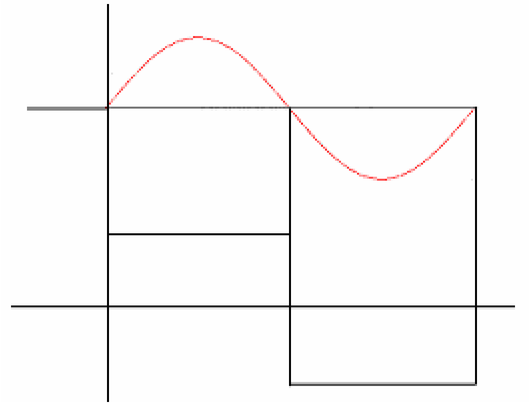


Figure 4.2 sine to square wave

Step 2: That square wave is of 20 ms; this square pulse is input of Micro controller.

Step 3: Give 0 –5 V dc analog signals to the Micro controller analog input from current sensing circuit.

Step 4: From Micro controller give pulses to Amplifier circuit.

Step 5: from Amplifier circuit give pulses to Driver card.

Step 6: From Driver card give pulses to Thyristor.

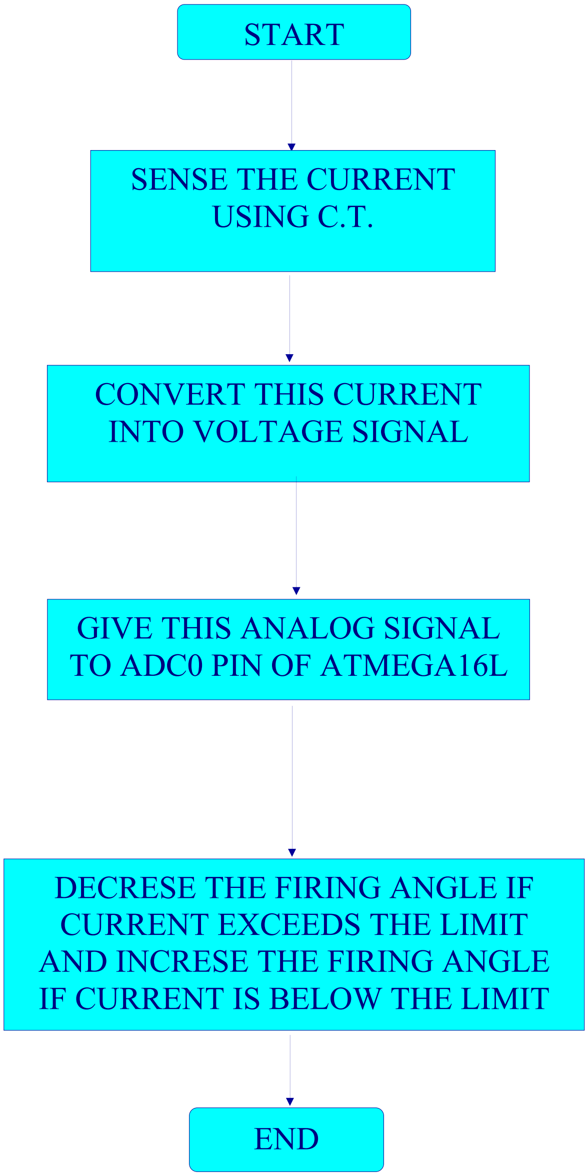
4.4 Control Loops In ATmega16L

There are three loops in the program of the Microcontroller, which will control the current as well as decide the thyristor firing sequence.

1. Current control loop.
2. Thyristor loop.
3. Firing sequence loop.

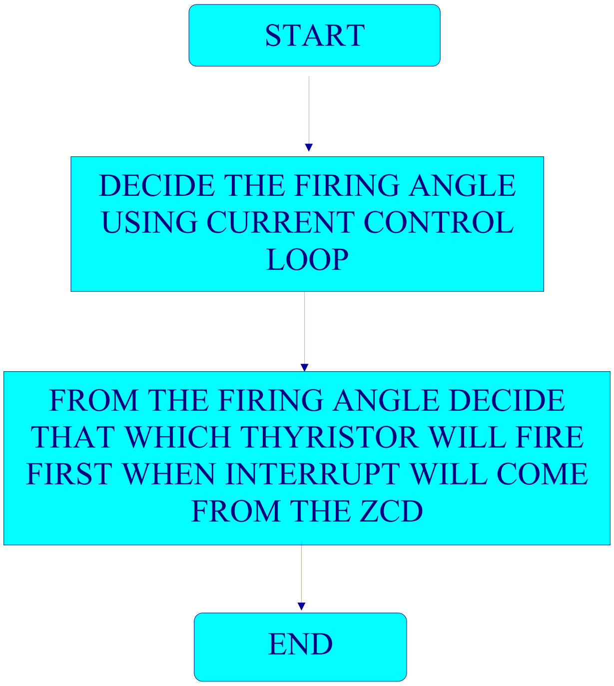
1. Current control loop:

This loop will control current, which is sensed by current transformer. This current is converted into voltage using current sensing circuit. This voltage is given to the ADC0 pin of the Micro controller. This will convert Analog signal into Digital signal. If this Digital signal value is higher than the permissible value, then firing angle will decrease and if this value is less than the permissible value then firing angle will increase. Ultimately, this loop will decide firing angle.



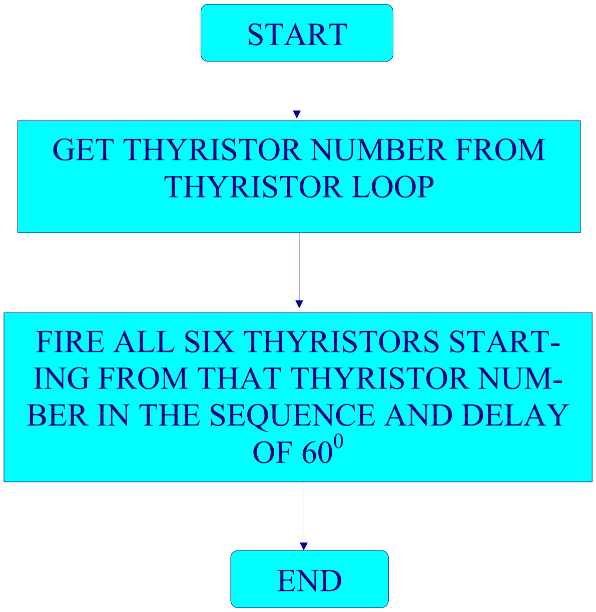
2. Thyristor loop:

This loop will decide that which number of thyristor will fire out of six thyristors when signal will come from zcd. Firing angle will be decided by current control loop. From this firing angle, using the equation given in the program number of the thyristor will be decided by this loop.

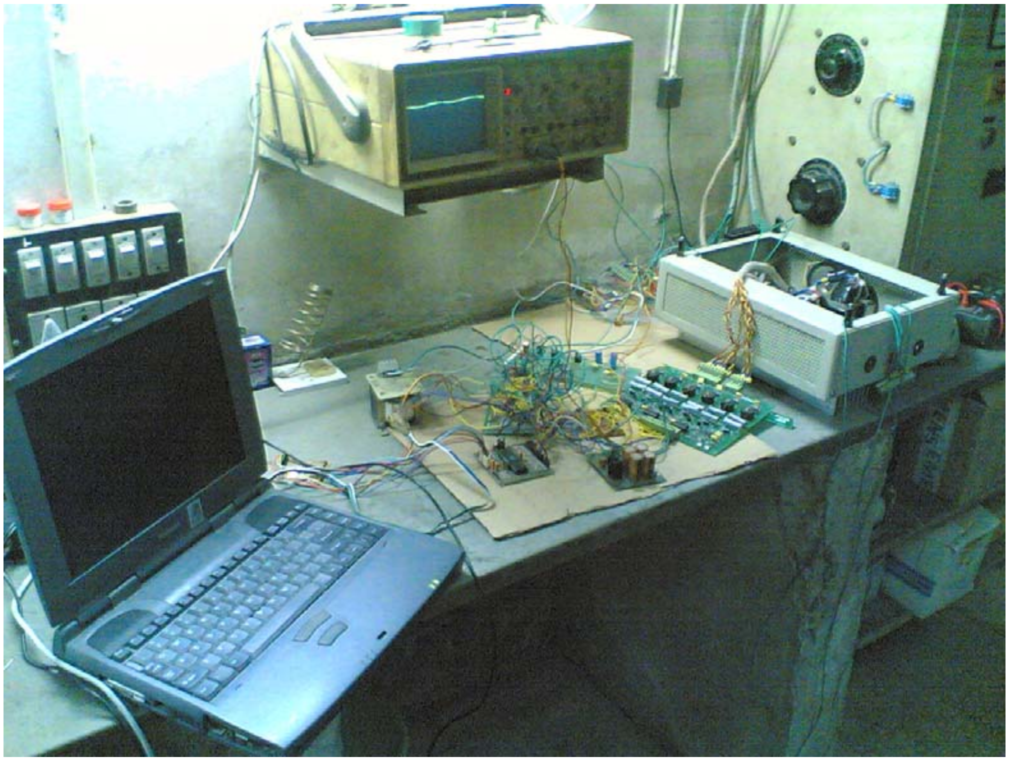


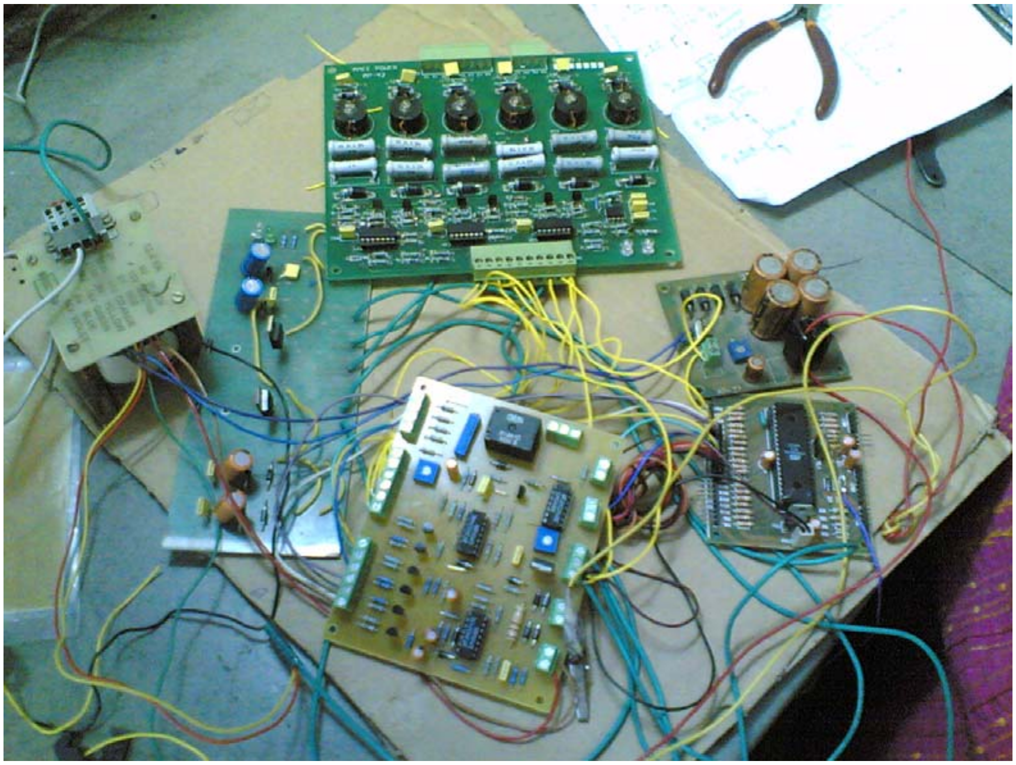
3. Firing sequence loop:

This loop gives firing sequence command from the thyristor loop. It will get the number of the thyristor, which will fire, first according to the firing angle. After that thyristor all six thyristor will fire according to the sequence with the delay of 60 ^{o}.



Experimental set-up





CHAPTER 5: HARDWARE PART

5.1 Power Supply Design :

For opamp LM348 we need power supply of ± 12 V dc. For this purpose center tap single-phase transformer is used. Transformer Secondary voltage can be calculated as follow, we want total 24 V dc at output, considering 10% variation at output side the output voltage is 28 V,

As we know for full wave rectifier,

$$V_{dc} = 2\ V_m / \prod$$

Putting Vdc = 28 V,

Secondary Peak Voltage, Vm = 44 V

V rms = 31.11 V

Considering 10% variation at secondary side we get,

$$Vosec = 31.11 + 10\% \text{ of } 31.11$$
$$= 34.22\ V$$

so using transformer whose secondary is 17 – 0 – 17 V ,

Capacitor Design,

Control circuit required current 500 mA and 24 V dc

Considering ripple factor 2.5%

$$\text{Ripple Voltage} = \text{Ripple factor} \times V\ dc$$
$$= 2.5/100 \times 24$$
$$= 0.6\ V$$

$$Erp \text{ peak to peak} = 2 * 1.41 * Er$$
$$= 1.697\ V$$

$$\text{Now, } C = I / (2 \prod f * Erp)$$
$$= 0.5 /(2 *3.142 * 50* 1.697)$$

=937.89uf

so by using two 470uf capacitor we can ripple free output voltage. IC 7812 used to get regulated + 12 V dc and IC 7912 used for -12 V. The datasheet is given in appendix. The power supply is as shown in figure below.

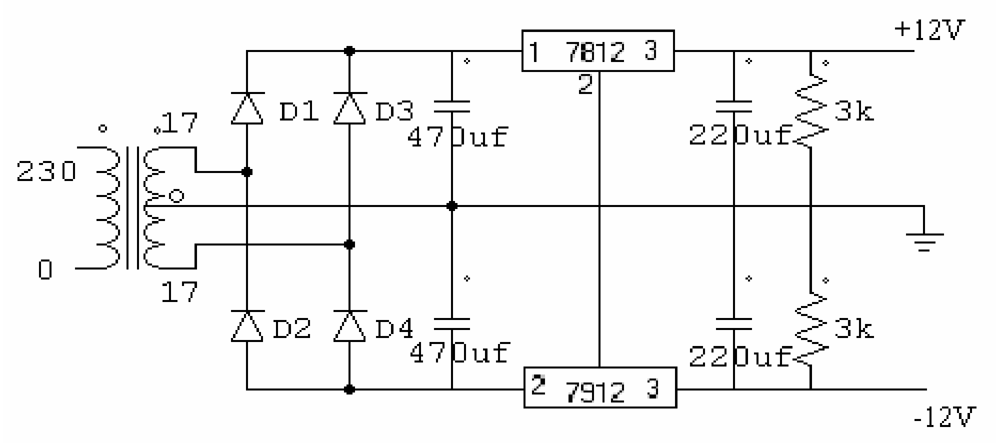


Figure 5.1 Power Supply of Power ± 12 V

5.2 Line Sensing and Synchronization Function:

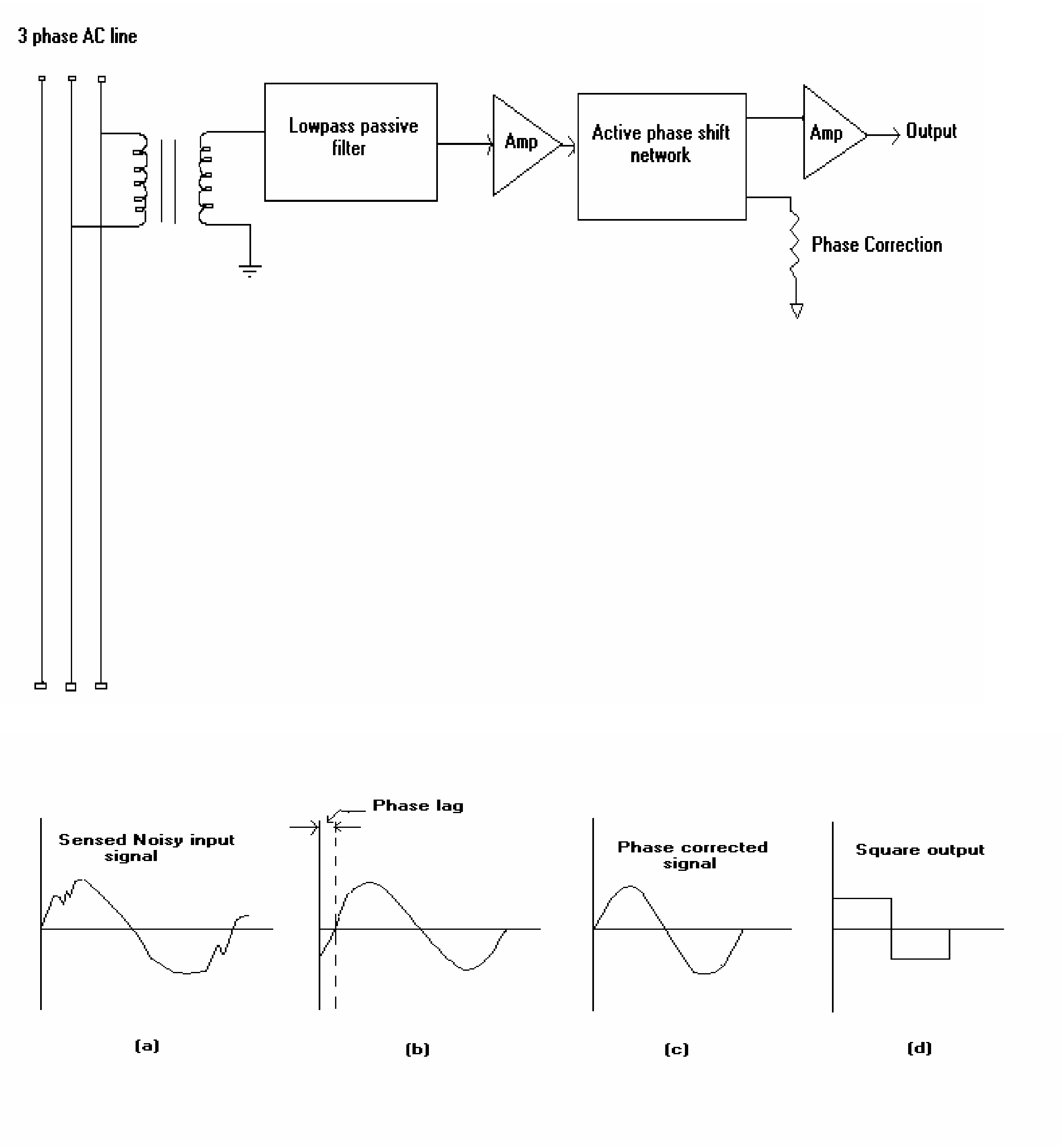


Figure 5.2 Simplified Block Diagram of Line Sensing and Synchronization Function

Line sensing and synchronization faction is comprised of the circuitry shown in figure. A.C line voltage from only one phase is sensed through a step down transformer and brought in to combine filter and phase shifting circuit. The filter an RC type low pass passive network removes high frequency components, line distortion and harmonic from sensed voltage and provide a clean well filtered AC waveform for the later generation of the firing angle. Phase shift caused by the passive filter is corrected by the following active phase shift circuit and synchronizes the filtered output with sensed AC line signal. This assures that any gate trigger pulse will be synchronized to zero crossing point of the line waveform. The phase shift circuit also corrects for any other phase shift in other portions of the firing circuit as to correct for phase corrections required where star delta connected transformers in the AC system introduces a fixed phase shift. The change of a single resistance in phase shifting network will vary the phase to the appropriate amount. In any system configuration design this will be a fixed value.

The phase shift network is followed by an op- amp type comparator circuit which square the input sine wave resulting in well designed signal that has definite zero crossing point that is synchronized with the sensed line signal. This square signal provides the appropriate waveform, which is independent of the sensed input amplitude, and therefore the gating action to the SCR's is immune to sags and surges of the input power. This independence is a decided advantage where the system is operated from poorly regulated lines.

Design Steps

- ALL-PASS FILTER

  To remove phase shift occur due to delta-star transformer.
- FILTER CIRCUIT

  To remove harmonics.
- SQUARE WAVE GENRATOR

Because of delta/ star transformer phase shift of 30 degree occur

$$¢ = -2\tan^{-1}(2\Pi fRC)$$

if we chose C = .1 uf

By calculation,

R= 125 kΩ

So if chose , R= 125 kΩ

C= .1 uf

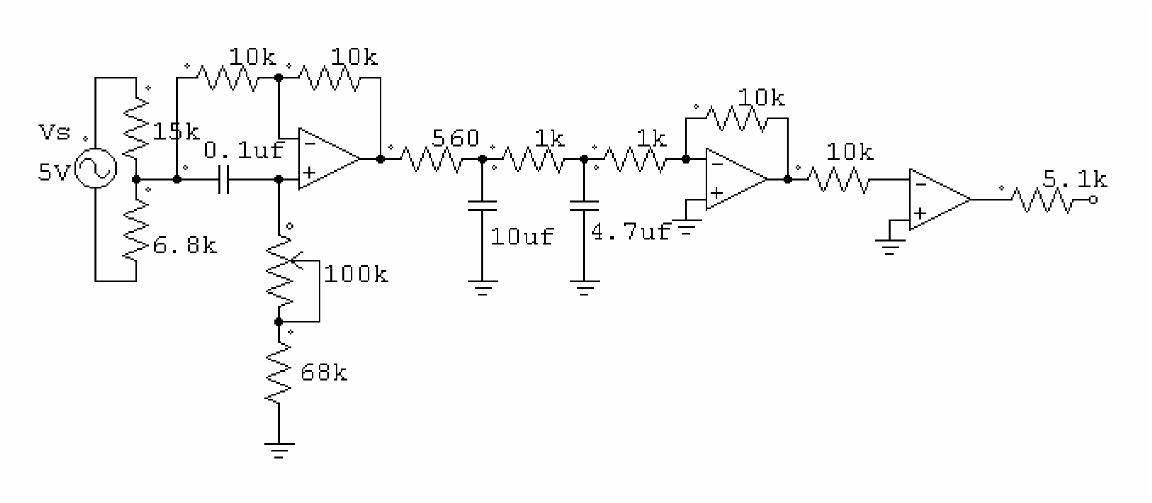


Figure 5.3 Phase Shift Circuit

Line sensing and synchronizing function is comprised of the circuitry shown in figure.

- AC line voltage from only one phase of the system is sensed through a step down transformer and brought into a combined filter and phase shifting circuit.
- This filter an RC type low pass network, removes high frequency components, line distortion and harmonics from the sensed voltage and provides a clean well filtered AC waveform for the latter generation of the firing an angle.
- Phase shift caused by the passive filter are corrected by the following active phase shift ckt and synchronizes the filtered output with the sensed AC line signal.
- This assures that any gate higher pulses will be synchronized to the zero crossing point of the line waveform.
- This phase shift ckt also corrects for any other phase shift in other portions of the firing ckt or to correct for phase correction required where way-delta connected transformer in the AC system introduces a fixed phase shift.
- The change of the value of a single resistance in the phase shifting network will vary the phase to the appropriate amount.

- In any system configuration design this will be a fixed value.
- The phase shift network is followed by an op-amp type comparator which squares the input sine wave resulting in a well defined signal that has a definite zero crossing point that is synchronized with the sensed line signal.
- This square signal provides the appropriate waveform is amplitude and therefore the gating action to the SCR's immune to sags and surge of the input power.
- This independent is a decided advantage where the system is advantage from a poorly regulated line.
- Output of this line sensing is next delivered to the firing angle generation function.

A list of the sensors that can be used to feedback information to a microcontroller are listed below:

- Shunt resistor
- Current-sensing transformer
- Hall effect current sensor

Shunt resistors are popular current sensors because they provide an accurate measurement at a low cost.

Hall Effect current sensors are widely used because they provide a non-intrusive measurement and are available in a small IC package that combines the sensor and signal-conditioning circuit. Current-sensing transformers are also a popular sensor technology, especially in high current or AC line monitoring applications. A summary of the advantages and disadvantages of each of the current sensors is provided in Table 2.

Current Sensing Method	Shunt Resistor	Hall Effect	Current Sensing Transformer
Accuracy	Good	Good	Good
Accuracy vs. Temperature	Good	Poor	Good
Cost	Low	High	Medium
Isolation	No	Yes	Yes
High Current Measuring Capacity	Poor	Good	Good
Saturation/Hysterisis Problem	No	Yes	Yes
Power Consuption	High	Low	Low
AC/DC Measurements	Both	Both	Only AC

Table 2: Comparisons of Current Sensing Methods

Advantages of Shunt resistors

- Low cost
- Good accuracy

Disadvantages of shunt resistors

- Impractical for more than 20A because of power dissipation
- High I^2R loss

5.3 Current Transformer:

The current transformer is used with its primary winding connected in series with the carrying current to be measured and, therefore, the primary current is dependant upon the load (burden) connected on the secondary winding of the current transformer. The primary winding consists of very few turns and, therefore, there is no appreciable voltage drop across it. The secondary winding of the current transformer has larger number of turns, the exact number being determined by the turns ratio. The ammeter or wattmeter current coil, are connected directly across the secondary winding terminals. Thus a current transformer operates its secondary winding nearly under short circuit conditions. One of the terminals of the secondary winding is earthed so as to protect equipment and personnel in the vicinity in the event of an insulation breakdown in the current transformer.

These transformers are used with low range ammeters to measure currents in high voltage alternating currents ckts where it is not practicable to connect instruments and meters directly to the lines. In addition to insulating the instrument from the high voltage line, they step down the current in a known ratio. As regards voltage, the transformer is of step-up variety but it is obvious that current will be stepped down. Thus, if the current transformer has primary to secondary current ratio of 100:5 then it steps the voltage 20 times whereas it steps down the current to 1/20th of its actual value hence if we know current ratio (I1/I2) of the transformer and the reading of the a.c ammeter, the line current can be calculated.

5.4 Current limiting circuit:

Current Transformer does current sensing, which give the signal of zero to 10mA. This circuit converts this signal in to 0 t0 10 V dc voltage signal. This circuit consists of op-amp rectifier and filtering circuit.

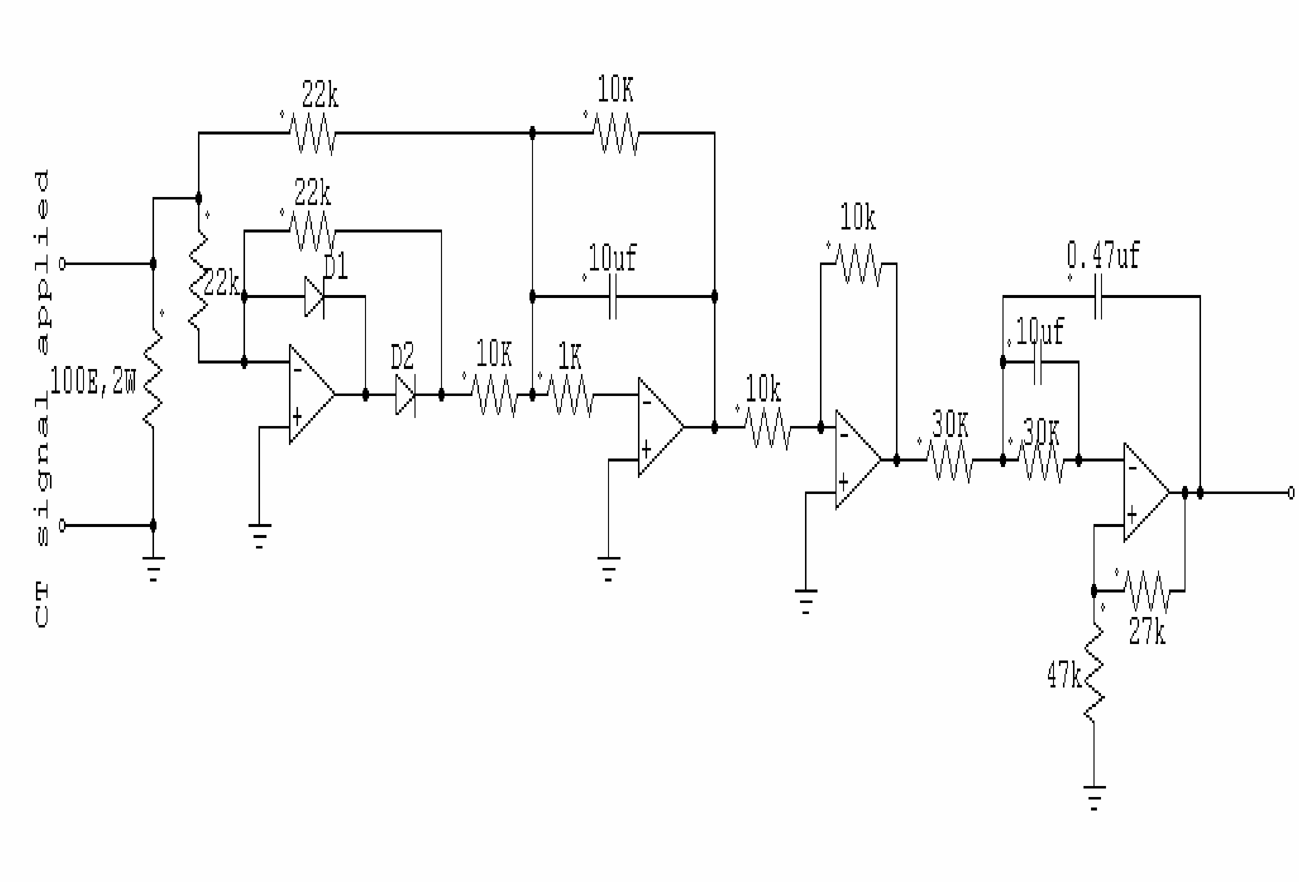


Figure 5.4 Current limiting Circuit

5.5 Amplifier Circuit:

We are getting six pulses from Micro controller. We have to amplify these pulses before giving into driver circuit. Transistor based amplifier circuit is given below. Inputs are PC1 to PC6. They are given in the base of the transistor and outputs are taken from 1 to 6.

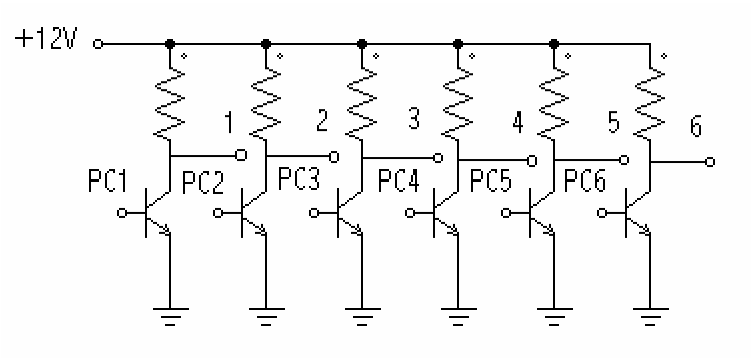


Figure 5.5 Amplifier circuit

5.6 Driver Circuit design:

As we know power controller required six Thyristor connect anti parallel. By using Micro Controller as controlling Unit of the firing of Thyristor we get the firing pulse for six Thyristor. These pulses cannot used directly to fire Thyristor because power level is not sufficient to trigger the Thyristor, so we need Amplifier circuit as well as Driver circuit for it.

Driver circuit uses Pulse Transformer for isolation between controlled circuit and power circuit, which prevent the accidental damage to the control circuit. Power Transformer can be used for Frequency range from 5KHz to 20KHz.

To get this high frequency we used 555 Timer in Astable Mode we get this frequency.

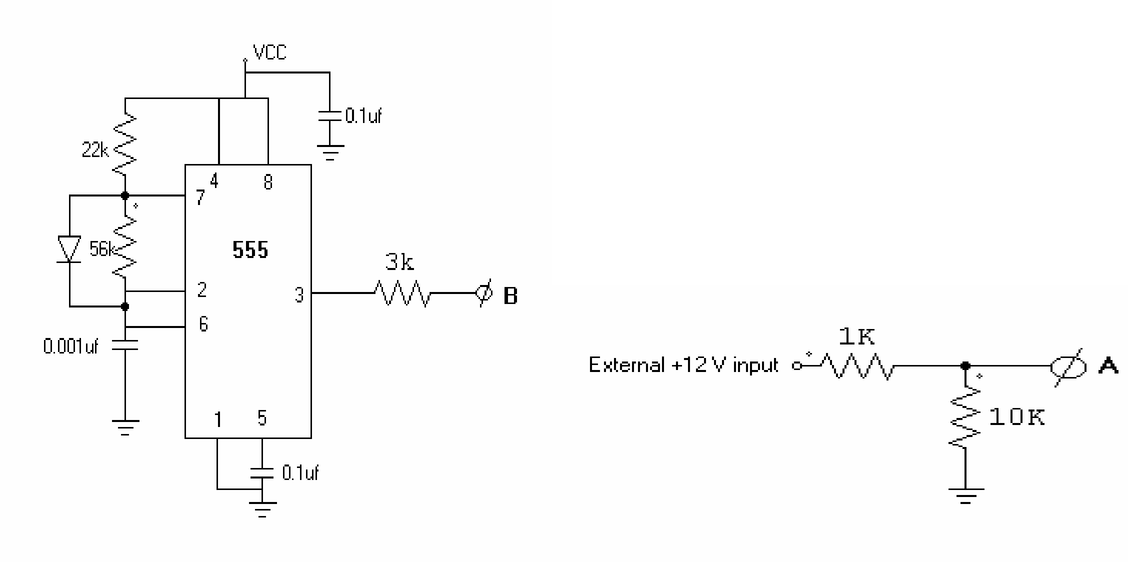


Figure 5.6 Timer in Astable Mode

As we know for astable mode,

$$fo = \frac{1.45}{(Ra+2Rb)C}$$

Using C = 0.001uf,

Ra=22K

Rb=56K

$$fo = \frac{1.45}{(22+2(56))0.001}$$

$$fo = 10.82\ KHz$$

Using IC 4082, which contain two AND gate with four input, we gate the High input at

Pin number 1 and 13 as shown in figure.

This pulse is down by resistance and given to Transistor Base whose collector is connected to the PFR fast switching diode to GPS which fulfill the gate power requirement. Transistor used which boost the current level to providing proper triggering.

As some isolation is needed to separate power circuit and control circuit for the protection purpose. Here we used Pulse Transformer for the same.

In pulse Transformer here we used 18 X 11 Pot core,

Core factor (le/Ae) = 0.597 mm'

Effective Length = 26.00 mm

Effective Area = 43 mm^2

Effective Volume = 1120.00 mm^2

Wire gauge No. 28 with nominal diameter 0.3759 mm

Nominal c/s Area = 0.09372mm

Nominal Resistance per unit length = 0.1526 ohm/ meter

Current carrying capacity = .2064 A

Here PFR diode is used as freewheeling diode for the fast switching purpose. And two 22Ω, 2W resistor are used for the Pulse Transformer Protection. Parallel RC component used for the Filtering purpose.

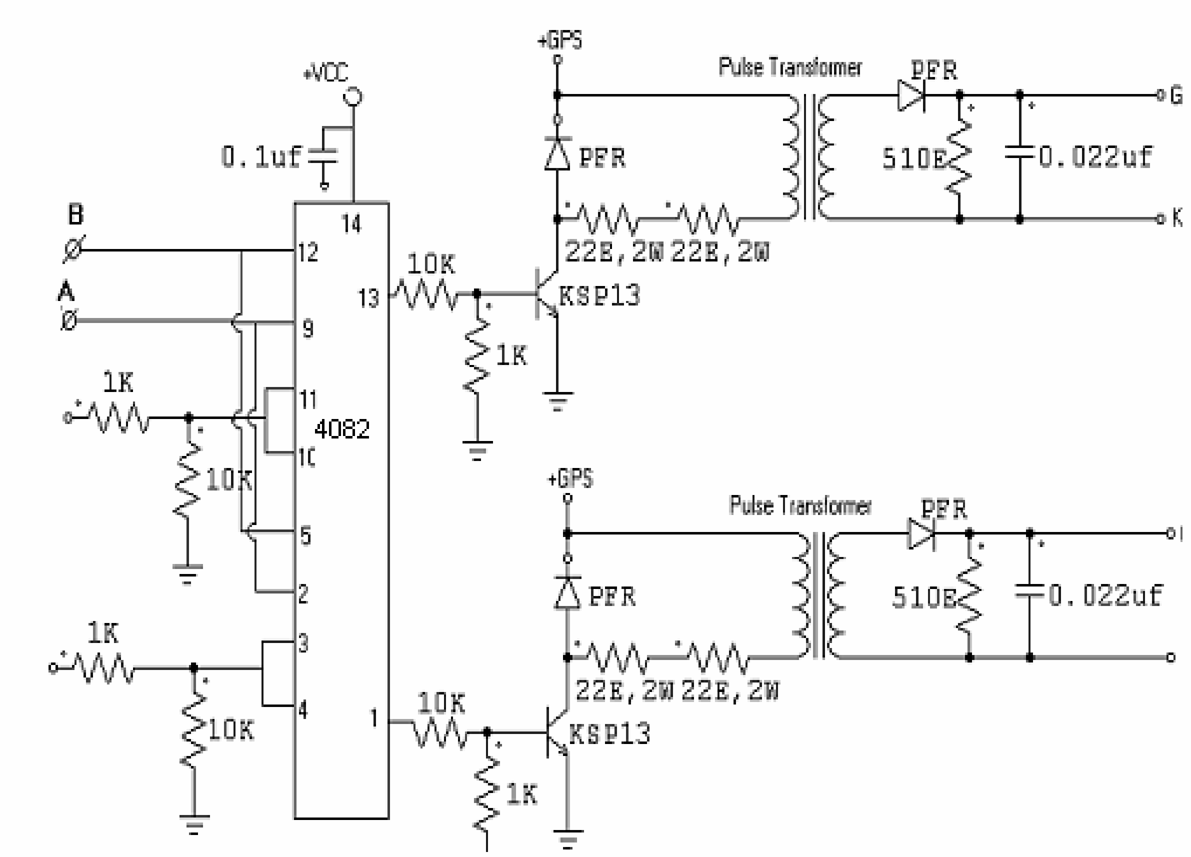
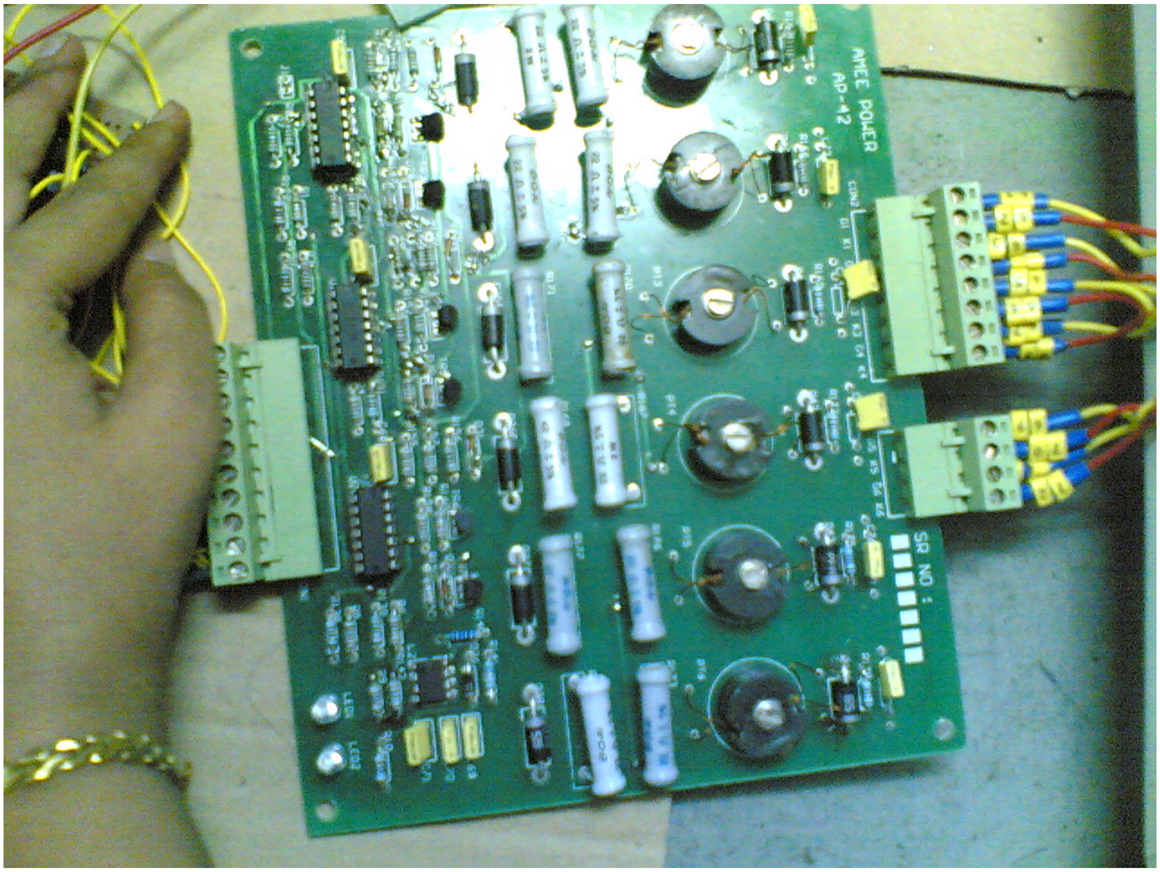


Figure 5.7 Pulse amplifier circuit



Pulse amplifier circuit

5.7 Design of Temperature sensing Circuit:

5.7.1 Thermal Sensor

The temperature sensor is the "nervous system" of the controller. Just as you rely on your sense of touch, so a temperature controller relies completely on the sensor. The controller uses the sensor signal to decide whether to turn the heater on or off to maintain the desired set point temperature,

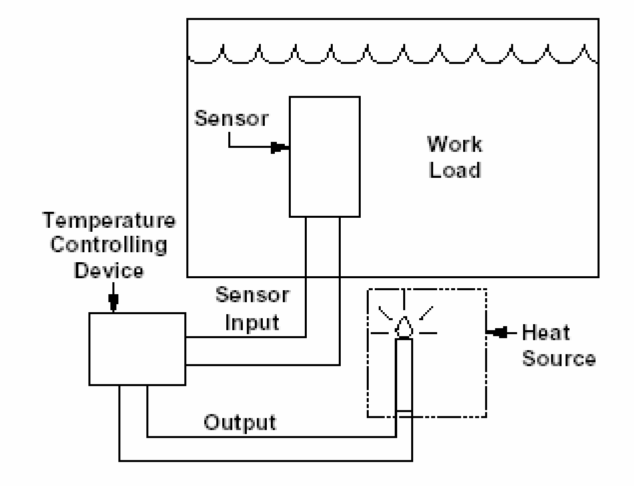


Figure 5.8 Temperature Sensor

What happens, then, if the sensor signal is inaccurate? The controller has ***no way of knowing*** that a sensor's signal is inaccurate. Therefore, it will control the thermal system based on that "bad" signal. To prevent those "bad" signals, let's jump in and explore the world of temperature sensors. The four categories of temperature sensors are:

- Thermocouples,
- Resistance temperature devices (RTD),
- Thermistors and
- Infrared sensors.

5.7.2 Thermocouple

The Thermocouple is a thermoelectric temperature sensor which consists of two dissimilar metallic wires, e.g., one chromel and one constantan. These two wires are connected at two different junctions, one for temperature measurement and the other for reference. The temperature difference between the two junctions is detected by measuring the change in voltage (electromotive force, EMF) across the dissimilar metals at the temperature measurement junction.

Working of Thermocouple

Thermocouples manipulate the fact that the electromotive force (EMF) between two dissimilar metals is a function of their temperature difference (gradient). However, three major effects are involved in a thermocouple circuit: the Seebeck, Peltier, and

Thomson effects. The Seebeck effect describes the electromotive force (EMF) existing between two dissimilar metallic materials. The change in material EMF with respect to a change in temperature is called the Seebeck coefficient or thermoelectric sensitivity. This coefficient is usually a nonlinear function of temperature. EMF that is reversible and associated with changes in temperature is called the Peltier effect. Finally, the Thomson effect relates the reversible thermal gradient and EMF in a homogeneous conductor.

ADVANTAGES OF TERMOCOUPLE

- Simple, Rugged
- High temperature operation
- Low cost
- No resistance lead wire problems shielded
- Point temperature sensing
- Fastest response to temperature changes

DISADVANTAGES OF TERMOCOUPLE

- Least stable, least repeatable
- Extension wire must be of the same thermocouple type
- Wire may pick up radiated electrical noise if not
- Lowest accuracy
- Low sensitivity to small temperature changes

5.7.3 Resistance Temperature Detector (RTD):

RTDs are precision temperature sensors. They are used in industrial applications as well as laboratories. RTD elements are typically more accurate than thermocouple elements and maintain that accuracy over a longer period of time. The Resistance Temperature Detector (RTD) or resistance thermometer uses the fact that the resistance of metals increases with temperature. Examples are RTD's are shown schematically below:

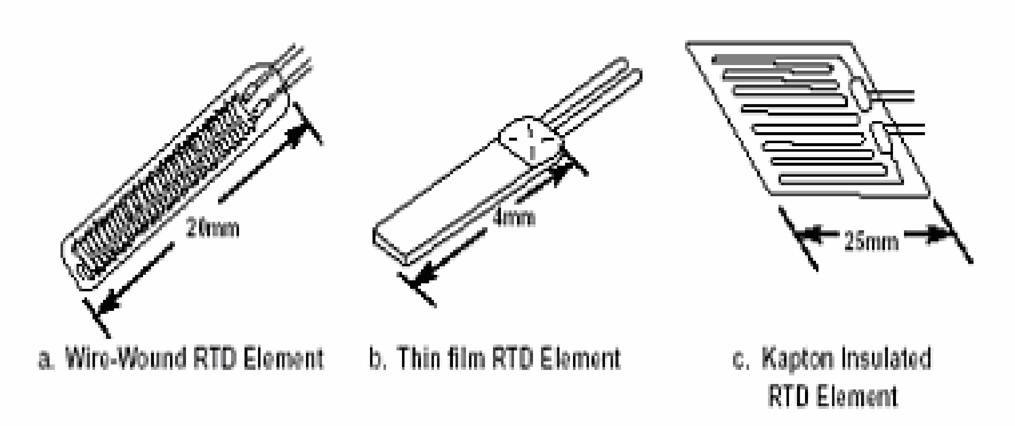


Figure 5.9 Resistance Temperature Detector

The resistance of commercially available RTDs ranges from 10 to 25,000 W. More common ones are 100, 200, and 1000 W strain-free platinum (>99.999%) probes and 10 W copper probes. Generally, the higher the resistance, the less affected the RTD will be due to small resistance/voltage fluctuations in the lead wires and circuit.

Common metals used in RTDs include platinum, copper, nickel, Balco^{TM} (70% Ni-30% Fe), and tungsten. Their temperature ranges are listed in the following table.

The resistance-temperature (R-T) relationship plays a central role in resistance temperature detectors (RTDs). The R-T relationship of some common RTD materials are illustratrated in the following schematic where the *y*-axis is the normalized resistance with respect to resistance at 0 °C (32 °F), *x*-axis is the temperature.

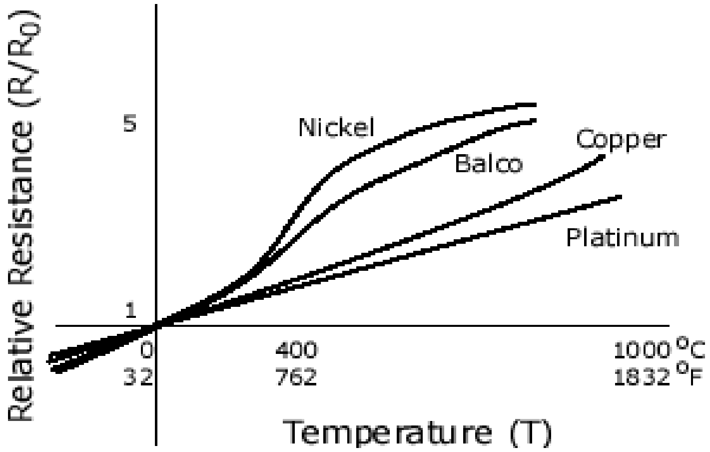


Figure 5.10 Resistance-Temperature Relationship for some RTD materials

Some materials have an almost linear R-T relationship within a certain temperature range, $T_1 < T < T_2$. Such a linear function would take the form,

$$R = R_{Ref}\left[1 + a\left(T - T_{Ref}\right)\right]$$

Rearranging to bring temperature out gives,

$$T = T_{Ref} + \frac{\left(R/R_{Ref}\right)+1}{a}$$

where a is the average temperature coefficient of resistance in the (T_1,T_2) temperature range, i.e., a is the slope of the R-T line.

Both the measured temperature and the reference temparature should be within the (T_1,T_2) temperature range, $T_1 < \{T, T_{Ref}\} < T_2$

ADVANTAGES OF RTDs :

- Stable and accurate.
- Linearity is better than thermocouples.
- Higher signal-to-noise ratio.

DISADVANTAGES OF RTDs :

- Higher signal-to-noise ratio.
- Self heating.
- Requires a current source.
- Response time may not be fast enough for some applications

5.7.4 Pyrometer:

A Pyrometer, or radiation thermometer, is a non-contact instrument that detects an object's surface temperature by measuring the temperature of the electromagnetic radiation (infrared or visible) emitted from the object.

An object also radiates energy across many wavelengths. These particular wavelengths are called “infrared radiation” or “infrared waves.” An infrared sensor intercepts a portion of the infrared energy radiated by an object. The radiation it intercepts is typically in the 8 - 14 micron wavelength range. The infrared waves are focused through a lens (or optical system) on to an infrared detector. The detector absorbs the radiation striking it and converts this into an electric output signal.

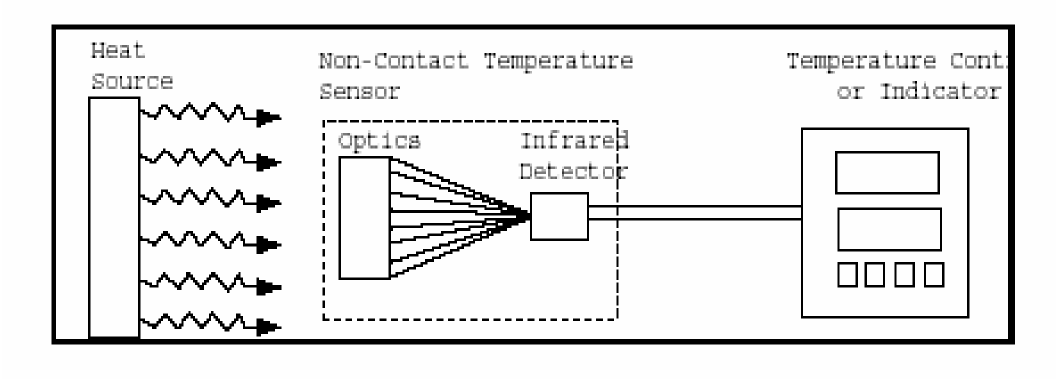


Figure 5.11: Pyrometer

The electric output signal is proportional to the amount of radiation striking it. So, as more infrared energy strikes the detector, more electrical energy is produced. This output signal is then amplified and conditioned by support electronics (and/or temperature controller) and converted into a temperature value.

Pyrometry literally means "fire" (pyros) "measuring" (metron). Pyrometers manipulate the fact that all objects above absolute zero temperature 0 K (-273.15 °C; -459.67 °F) radiate and absorb thermal energy. If the relationship between the radiation intensity and wavelength and the temperature can be established, the temperature can be found from the radiation.

Two principal theories are employed by pyrometry: Planck's law and the Stefan-Boltzmann law. Planck's law is used in narrow-band pyrometers, where only one or a few specific wavelengths are targeted. The Stefan-Boltzmann law is used in broad-band pyrometers, where a wide range of wavelengths are measured.

When electromagnetic radiation impinges upon a surface of an object, the radiation is partially absorbed, partially reflected, and partially transmitted. If all of the electromagnetic radiation is absorbed by the object, the object is called a blackbody. The emittance e is introduced to describe the difference in radiation absorption between common objects and blackbodies. Another term called *emissivity* is similar to emittance in describing the difference in radiation intensity between real materials and blackbodies. However, emissivity is a material property usually defined only for highly polished surfaces or controlled conditions. In other words, emittance is the general concept of the radiation mismatch between an object and a blackbody, whereas the emissivity is the emittance of a particular material under a certain condition.

The wavelength of thermal radiation ranges from 0.1 to 100 µm (4 ~ 4,000 µin), i.e., from the deep ultraviolet (UV) across the visible spectrum to the middle of the infrared region (IR).

Common pyrometers include:

1. Optical Pyrometer:
   - Designed for thermal radiation in the visible spectrum
   - Utilizes a visual comparison between a calibrated light source and the targeted surface. When the filament and the target have the same temperature, their thermal radiation intensity will match causing the filament to *disappear* as it blends into the targeted surface in the background.
   - When the filament disappears, the current passing through the filament can be converted into a temperature reading
2. Infrared Pyrometer:
   - Designed for thermal radiation in the infrared region (0.75 ~ 1000 µm; 30 µin ~ 0.04 in) usually 2 ~ 14 µm (80 ~ 550 µin)
   - Constructed from pyroelectric materials, e.g., triglisine sulfate (TGS), lithium tantalate (LiTaO3), or polyvinylidene fluoride (PVDF).

- Similar to the charge generated by stressed piezoelectric materials, a pyroelectric charge dissipates in time. Hence, a rotating *shutter* is required to interrupt the incoming radiation to obtain a stable output.

ADVANTAGES OF PYROMETER:

- Non-contact measurement
- Fast response time
- Good stability

DISADVANTAGES OF PYROMETER:

- Expensive
- Accuracy maybe affected by suspended dust, smoke, and thermal background radiation

5.7.5 Thermistor:

Similar to Resistance Temperature Detectors (RTD), the **Thermistor** (Bulk Semiconductor Sensor) uses resistance to detect temperature. However, unlike an RTD's metal probe where the resistance increases with temperature, the thermistor uses ceramic semi conducting materials which respond inversely with temperature. Examples of thermistors are shown in the following schematic:

Typical thermistor sensors can measure temperatures across the range of -40 ~ 150 ±0.35 °C (-40 ~ 302 ±0.63 °F). The shape of the thermistor probe can take the form of a bead, washer, disk, or rod as illustrated in the above figure. Typical operation resistances are in the k range, although the actual resistance may range from several MΩ to several ohms.

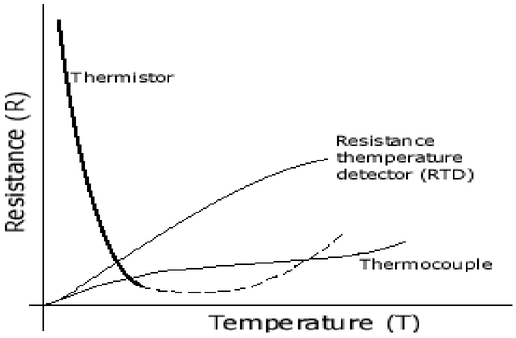


Figure 5.12: Characteristics of Three Temperature Transducers

The thermistor is a resistance thermometer. The relationship between its resistance and the temperature is highly nonlinear. Furthermore, the resistance changes negatively and sharply with a positive change in temperature, as shown schematically below. There are two types of termistor

- NTC (Negative temperature coefficient)
- PTC (positive temperature coefficient)

5.7.6 PTC thermistor:

Positive Temperature Coefficient (PTC) thermistors exhibit a high positive temperature coefficient of resistance between certain temperatures. PTC thermistors are made of semiconductive ceramics based on solid solution of $BaTiO_3$. During the cooling period after firing process, PTC can be obtained in an oxygen atmosphere. By their nature, grain boundaries represent inhomogeneities in structure and composition. These grain boundary defects and impurities give rise to a distribution in energy of a planar array of localized interface states. This forms potential barriers in the space charge region. These barriers can be expressed by the formula:

$$R=R_0\exp(eV_b)/kT$$

Where V_b is potential barrier height. Since V_b is inversely proportional to the value of the dielectric constant of the crystals, R is dependent on dielectric constant. In case of ferroelectric compound like $BaTiO_3$, dielectric constant obeys the Curie-Weiss law.

$$\varepsilon = \frac{C}{T-\theta}$$

If the temperature exceeds Curie temperature (θ), the dielectric constant decreases with the temperature. As a result, the resistance increases rapidly just above the Curie temperature. Below the Curie temperature, the barriers are weak or absent partly as a result of the spontaneous polarization of the crystals which may compensate the boundary changes. The electrons are captured at the boundaries and gradually liberated in proportion with the increase in body temperature of the PTC thermistor with respect to its Curie point, causing the potential barriers to decrease in strength. This means that the PTC thermistor loses its properties and may eventually respond in a similar fashion to a NTC if the temperature becomes too high.

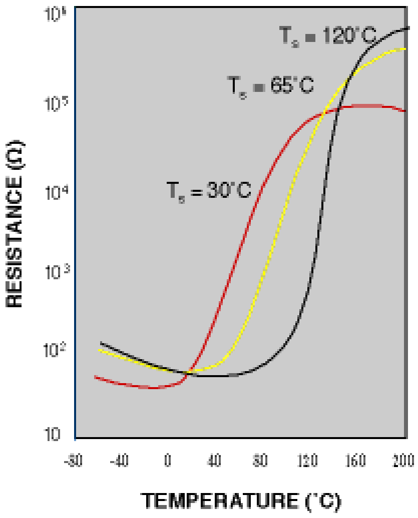


Figure 5.13: Typical PTC Resistance versus Temperature Curves

By altering the major elements and levels of dopants the T_S can be modified. Most PTC's have a T_S from around 50ºC to 160ºC, although it is possible to manufacture parts with T_S as low as 0ºC and as high as 300ºC. In addition, the resistance level of the parts can be altered over a limited range. The graph above shows a typical resistance versus temperature curve for a PTC thermistor.

Electrical characteristics of PTC thermistors:

The electrical characteristic of PTC thermistors can be described by utilizing a number of parameters. Because no single equation has been developed for the PTC thermistor, these parameters serve to define the resistance versus temperature characteristics of the PTC.

Resistance at 25ºC (R_{25}):

This resistance is a zero power resistance that serves as a baseline for the normal resistance of the part in a circuit. The resistance is measured with no appreciable current flowing through the thermistor. This is done so as to not self-heat the thermistor, which could cause errors in the measured value. A typical specification for the maximum measuring power is 0.1 mW.

Minimum resistance (R_{min}):

The minimum resistance of a PTC thermistor is defined as the lowest zero power resistance value that can be measured. It is the point on the resistance versus temperature curve where a relative minimum occurs. R_{min} is often used as a baseline for the measurement of the switch temperature of a PTC. It also will indicate what the maximum current that will flow through the circuit before the PTC starts to limit its flow. Normally, the actual value attained is not tabulated but for most values of T_s, the value of R_{min} will be similar to the value of R25.

Unlike the NTC thermistor with its ability to sense temperature accurately over a wide temperature range, the PTC thermistor is only useful as a temperature measuring device over a relatively short range of temperatures near the switch temperature. Because the resistance versus temperature characteristic of the PTC thermistor does not lend itself to an equation, most specifications are for the PTC thermistor to be a resistance value at some specific temperature plus or minus some tolerance. When the PTC is being used as a temperature sensor, the amount of current through the PTC must be small so as not to self-heat the thermistor and cause errors. Normally, it is not possible to use a PTC thermistor as a temperature sensor when it is in a self-heated mode of operation.

ADVANTAGES OF THERMISTOR:

- High sensitivity to small temperature changes
- Temperature measurements become more stable with use
- Copper or nickel extension wires can be used

DISADVANTAGES OF THERMISTOR:

- Limited temperature range
- Fragile
- Some initial accuracy “drift”
- Decalibration if used beyond the sensor’s temperature ratings
- Lack of standards for replacement

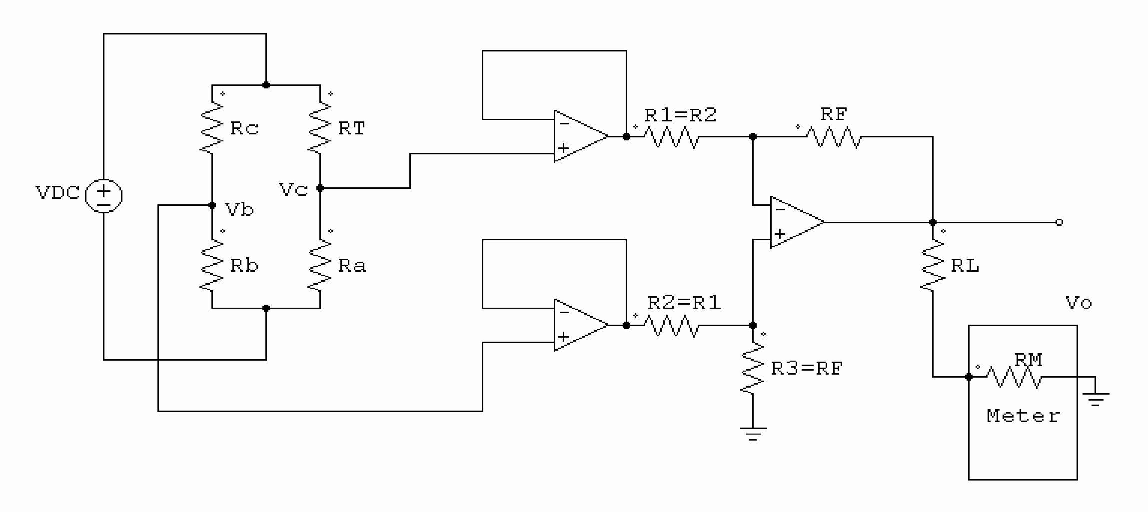


Figure 5.14: Temperature Sensing Circuit

In the circuit there is resistance bridge form Ra, Rb, Rc are the resistance and RT is temperature sensing device like RTD or Thermistor, which change its resistance as temperature change and output voltage is changed accordingly.

For balance condition,

$$Vb = Vc$$

$$Rb * Vdc / (Rb+Rc) \quad = \quad RT * Vdc / (RT+Ra)$$

If there is any change in temp. than RT changes its value by $\underline{\Delta}RT$,

$$Va = \; Ra * Vdc / (Ra+RT+ \underline{\Delta}RT)$$

$$Vb = \; Rb * Vdc / (Rb+Rc)$$

$$\text{If } Ra = Rb = Rc = RT = R,$$

$$Vab = Va - Vb$$

$$Ra * Vdc / (Ra+RT+ \underline{\Delta}RT) - Rb * Vdc / (Rb+Rc)$$

$$\text{If } \; Ra = Rb = Rc = RT$$

$$Vab = \; - \underline{\Delta}R * Vdc / 2*(2R+\underline{\Delta}R)$$

$$Vo = Vab * (- RF / R1)$$

$$Vo = \underline{\Delta}R * Vdc / 2*(2R+\underline{\Delta}R) \; * (RF / R1)$$

$$2R+\underline{\Delta}R = = 2R$$

$$Vo = (RF / R1) * (\underline{\Delta}R / 4R) * Vdc$$

CHAPTER 6: USE OF POWER MODULE

Thyristor Selection:

Power of the Motor: 5 H.P.

Supply Voltage: 415V

From the equation $P=\sqrt{3}\ VI\cos\phi$

Assuming $\cos\phi=0.8$

So, I=6.4A

Considering full load current, I=26A.

We have selected IRK26 Thyristor.

Power module consists of six Thyristor connected anti parallel to each other. Here we used IRK 26 Thyristor for application. To design complete Power module for three phase power controller we need to design Heat sink, Sunbber circuit and current Transformer for measuring of load current.

6.1 Heat Sink Design:

In our country, summer temperature can go up to 45 C where all manufacturer of semiconductor devices (diode, transistor, Thyristor, ICs, etc.) specify the power handling capacity at a device case temperature of only 25^0 C. The power handling capacity is of the device is decreases rapidly with the temperature and become zero at case temperature of around 125^0 C. Heat destroys devices and reduces device life in three way,

- Thermal Runaway

A small rise in temperature decreases Semiconductor resistance, leading to higher current flow. Heat generated in proportion to the square of the current raises the temperature still further, and this cycle repeats till the device is burnt.

- Hot Spots

An uneven p-n junction profile has a low resistance path with high current density. The excessive heat built up at the spot damages the device. Such hotspot are possible if heat is not uniformly taken away from the device surface.

- Aging/Thermal Fatigue

Normally, semiconductor devices experience cycle of heating and cooling due to switching ON and OFF. Over long period, the expansions and contractions due to these cycles, lead to fatigue of the joints between the chip and its contact leads.

Semiconductor devices performance is very sensitive to temperature. Frequency Response, gain, leakage current, and forward and reverse blocking capabilities all vary with temperature leading to circuit drift, calibration problem, and malfunctioning. Such effect also affects symmetric/balanced circuit such as push pull amplifier, differential amplifier and flip-flop, where two devices must be at the same temperature for proper operation.

- **Factors should be considered:**

RESISTANCE TO THE FLOW OF HEAT AWAY FROM THE DEVICE:

The major obstacles to the flow of heat are interface between,

1. The semiconductor junction and device case (Thermal resistance θ_{jc})
2. The device case and the heat sink surface (Thermal resistance θ_{cs})
3. The heat sink surface and surrounding air(Thermal resistance θ_{sa})

θ_{jc} is specified in the device manufacturer's datasheet and is a fixed value. θ_{cs} depend on the surface area of and the nature of contact between the device case and the heat sink. θ_{sa} depend upon the design of heat sink and is the most important parameter of the heat sink. Among the various factors that contribute to θ_{sa}, the important factors are,

(a) The material used
(b) The surface area of heat sink
(c) Inter fin space for air circulation.
(d) Emissivity of the heat sink surface.
(e) Method of mounting

- **Heat sink design for Thyristor IRK 26:**

Some power loss in Thyristor during its working.

(a) Forward Conduction loss
(b) Loss due to leakage current during forward and reverse blocking,
(c) Switching losses at turn on and turn off
(d) Gate triggering loss

At industrial power frequencies between zero to 400 Hz, the Forward Conduction loss is major component. But switching losses become dominant at high operating frequencies. These electrical losses produce Thermal heat, which must be removed from the junction region. The thermal losses and hence temperature rise of device increases with the Thyristor rating. Thyristor heating and hence its junction temperature rise is depend primarily on current handled by the device during its working.

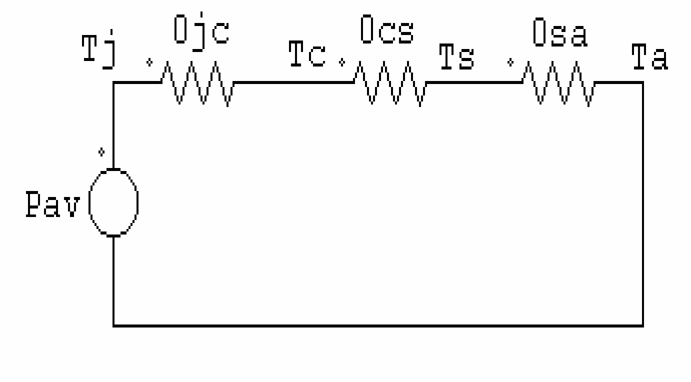


Figure 6.1 Thermal equivalent circuit for Thyristor

Where, θ_{jc} Thermal resistance between junction temperature Tj and case temperature Tc.

θ_{cs} Thermal resistance between case temperature Tc and sink temperature Ts.

θ_{sa} Thermal resistance between sink temperature Ts and ambient temperature Ta.

Pav is power loss in watts.

$$Pav = \frac{Tj - Ta}{0ja}$$

$$0ja = 0jc + 0cs + 0sa$$

$$Tj - Ta = Pav(0jc + 0cs + 0sa)$$

For Thyristor IRK 26,

$I_{TAV} = 27$ A

From graph Pav = 35 W

$$0sa = \frac{Tj - Ta}{Pav} - (0jc + 0cs)$$

From datasheet of IRK 26,

$\theta_{jc} = 0.31$ K/W

$\theta_{cs} = 0.1$ K/W

$$0sa = \frac{125 - 40}{35} - 0.41$$

= 2.01 K/W

Ts- Ta = Pav * θ_{sa}

= 70.64 K

for Ts – Ta = 20.64 and Pav = 35 W,

From graph of standard Heat sink rating of aluminum,

Sink of Dimension approximately 3.2 X 10 X 12.5 cms is used.

6.2 Sunbber Circuit Design:

From datasheet of IRK 26,

di/dt = 150 A/us

dv/dt =500 V/us

Using safety factor 2,

di/dt = 75 A/us

dv/dt =250 V/us

Using Maximum supply voltage is 415 V,

$$Ls = \frac{Vs}{(di/dt)max}$$

$$Ls = (415 / 75) *10^{-6}$$

$$Ls = 5.55\ uH$$

$$Rs = \frac{L}{Vs}\ (dv/dt)max$$

$$Rs = 10\ \Omega$$

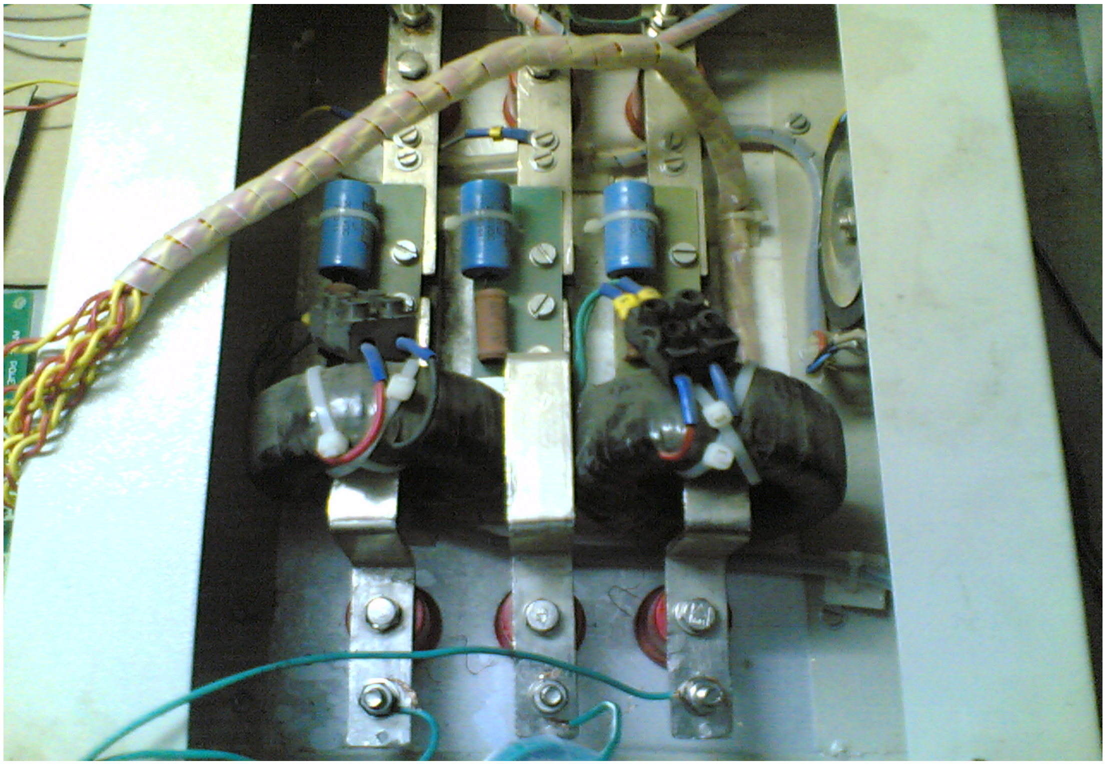
Using $\zeta = 0.65$

$$Cs = (2\zeta / Rs)^{2}\ Ls$$

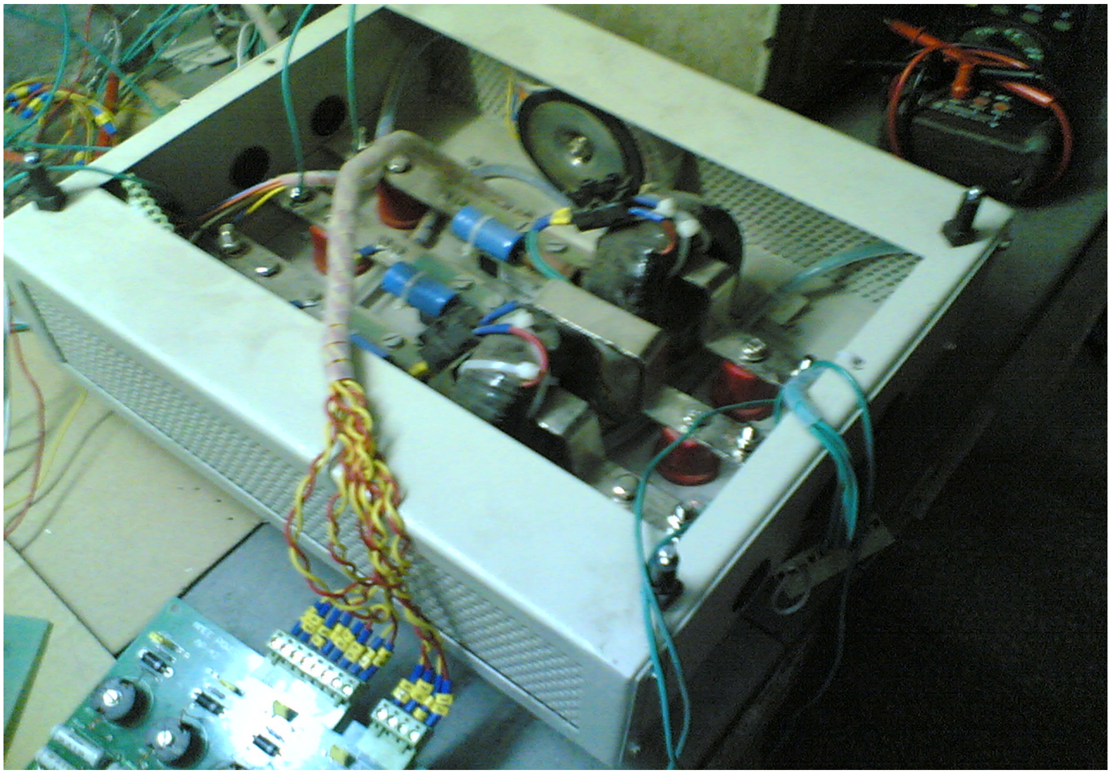
$$Cs = 0.1\ uf,\ 2000\ V$$

So using the Rs = 10 Ω, 5 W, and Cs = 0.1 uf, 2000V we can give the protection to the Thyristor.

The power module with Heat Sink, Sunbber Circuit and Current transformer is as shown.



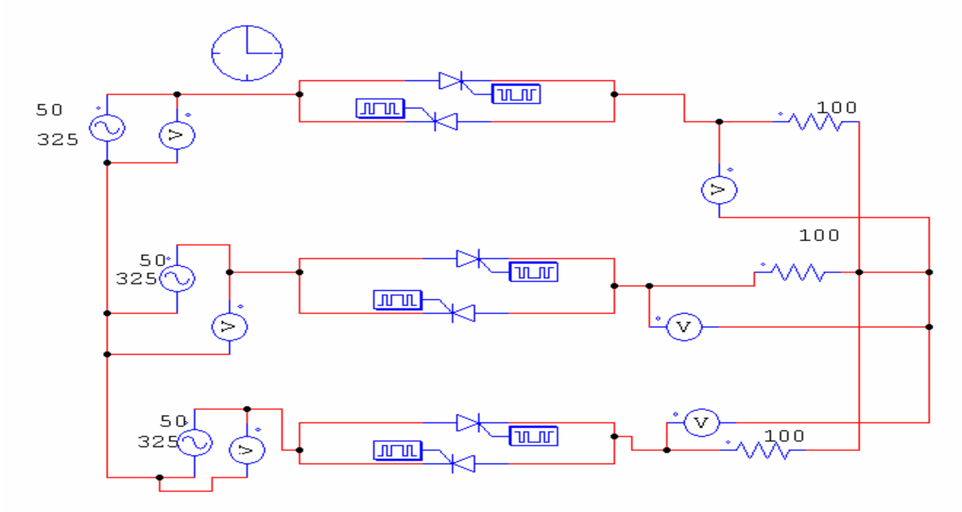
Power module of Three Phase Controller

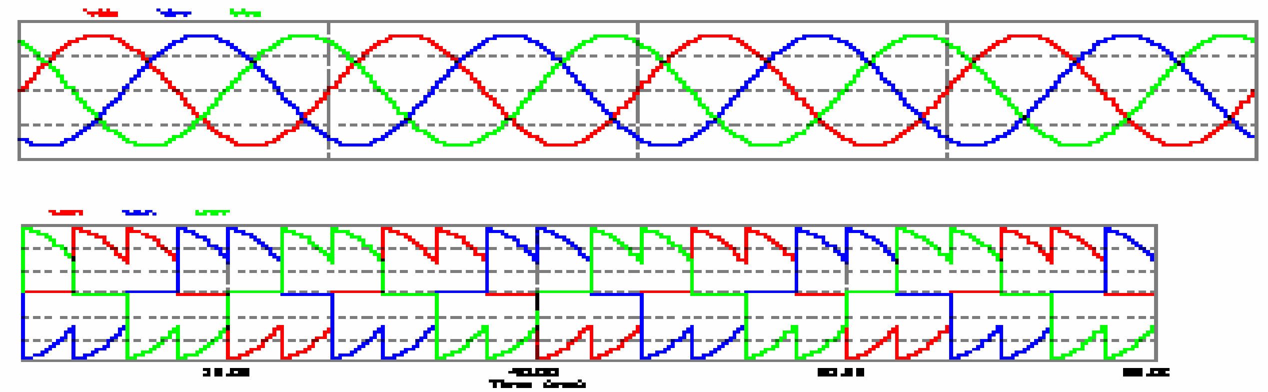


Power module of Three Phase Controller

CHAPTER 7: SIMULATION RESULTS OBTAINED

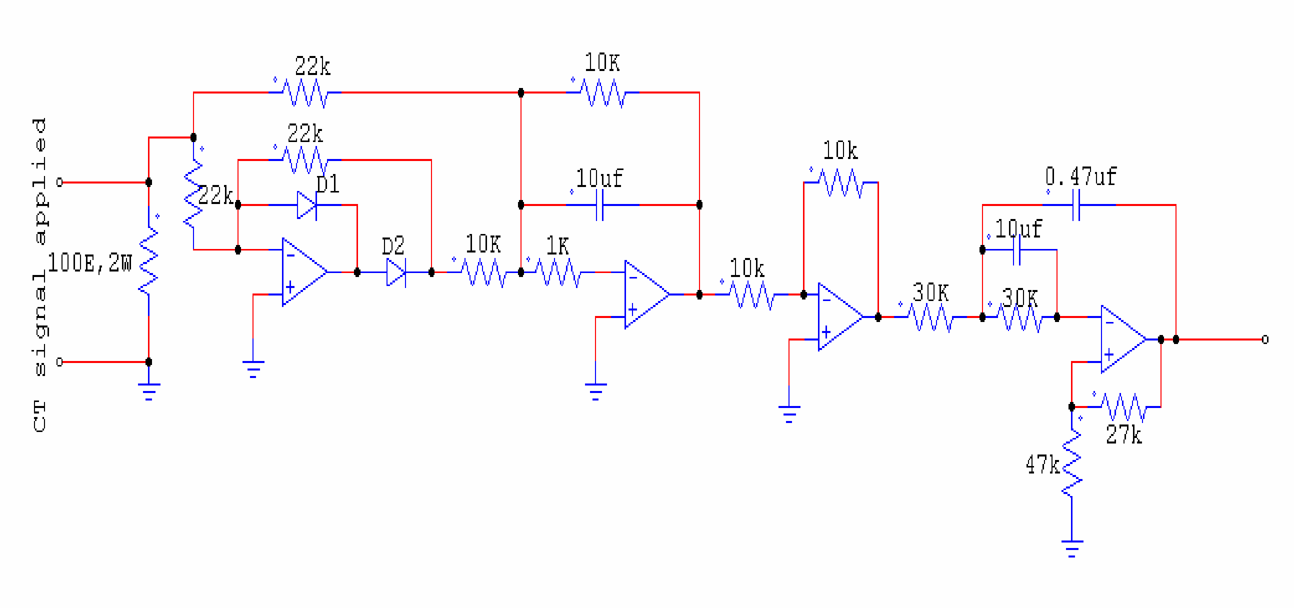
7.1 Simulation of Power circuit:

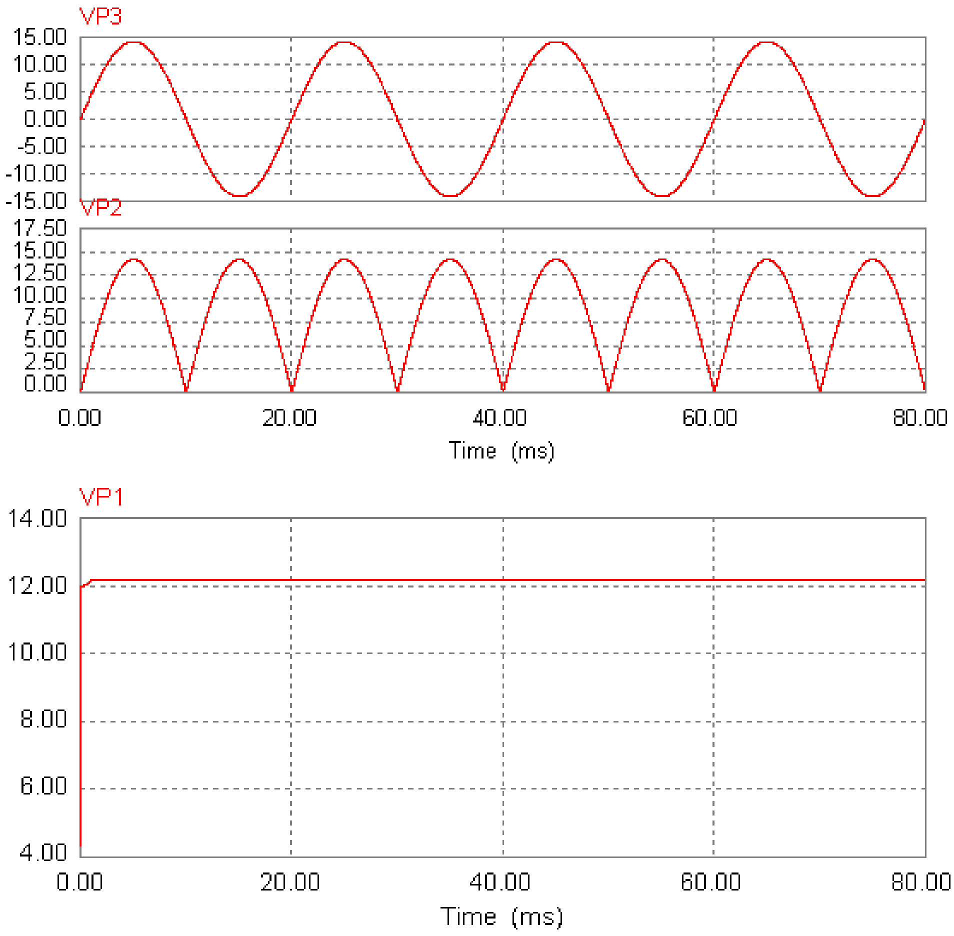




Waveform of Power circuit
Waveform of Temperature Sensing Circuit

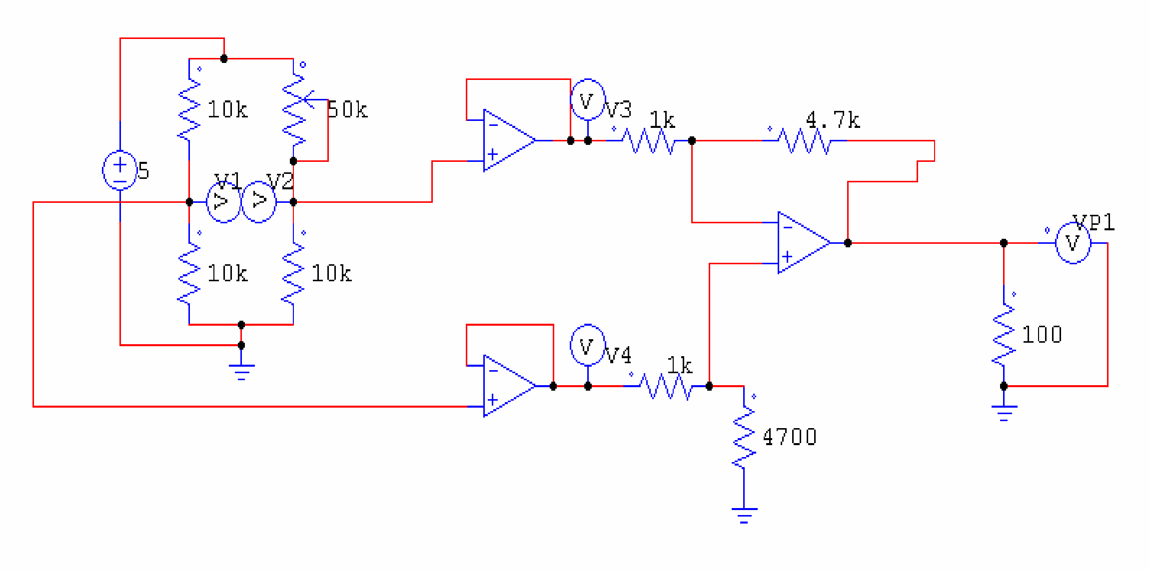
7.2 Current Limiting circuit:



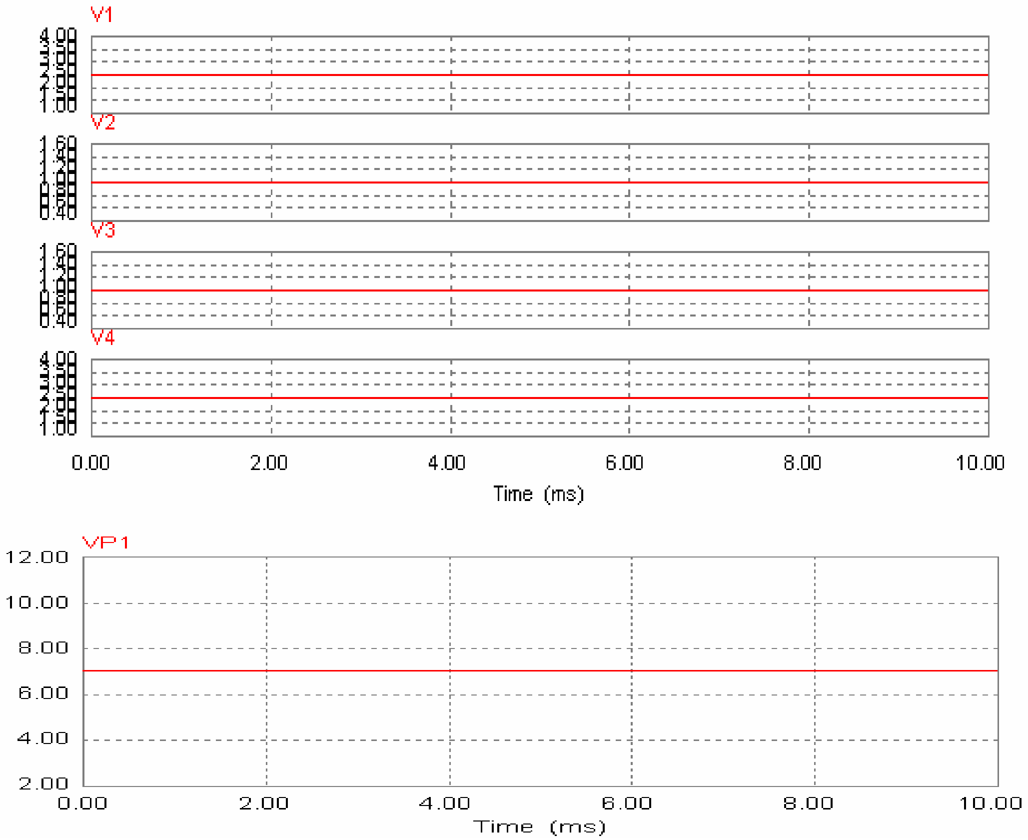


Waveform of current sensing circuit

7.3 Temperature Sensing Circuit:



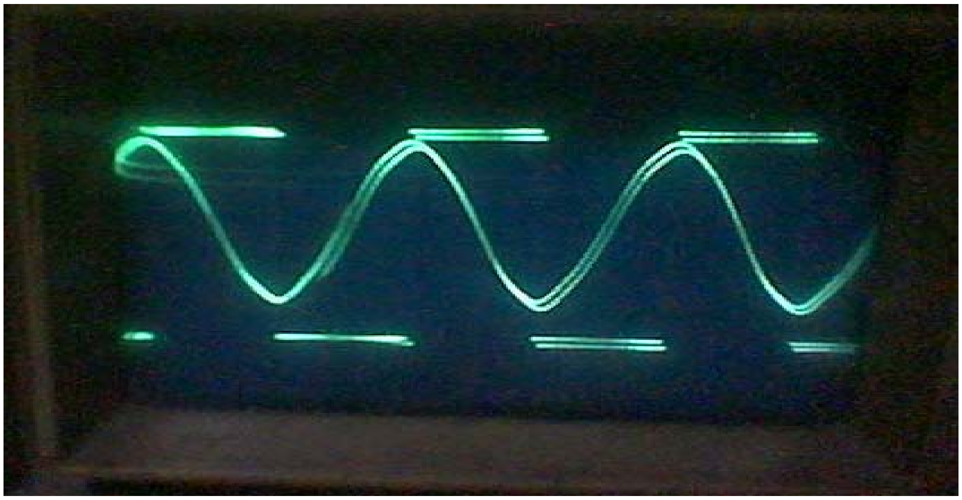
When 50K pot at 0.8 tap,



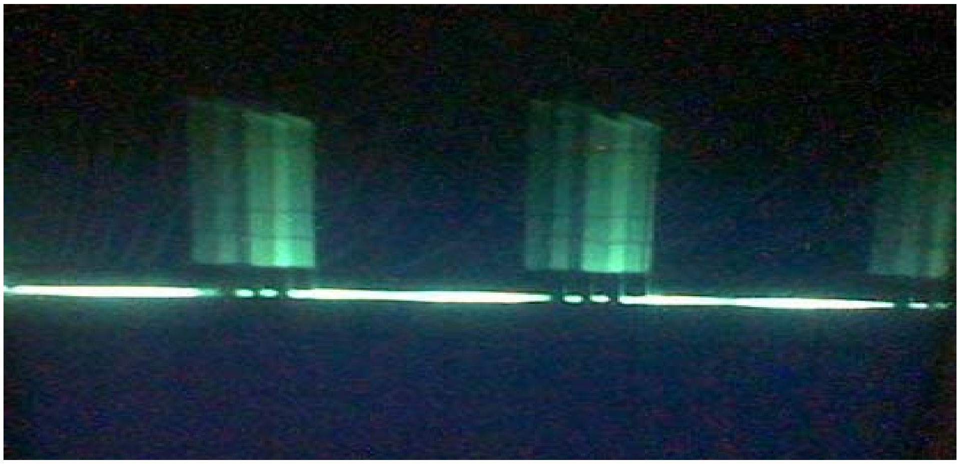
Wave form of Temperature Sensing Circuit

CHAPTER 8: WAVEFORMS AND TEST PHOTOGRAPHS WITH RESULT

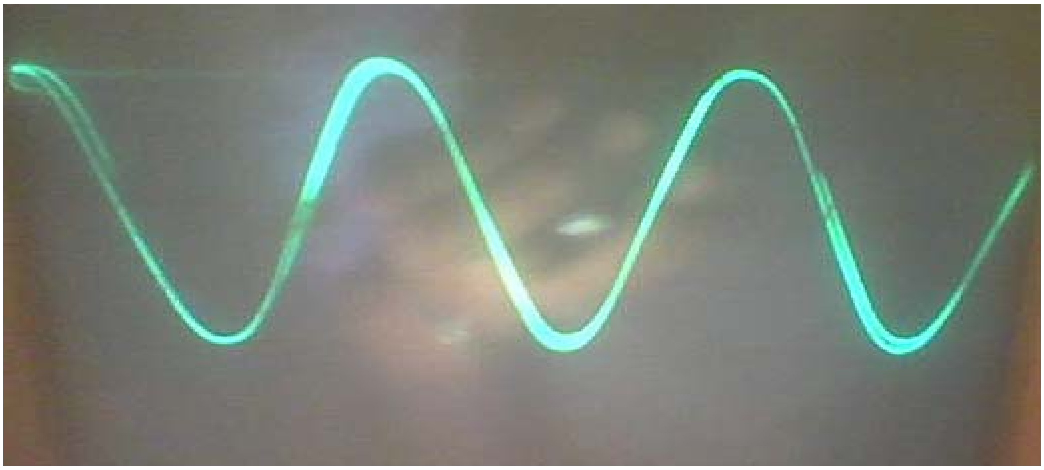
8.1 Square wave output from Synchronization circuit:

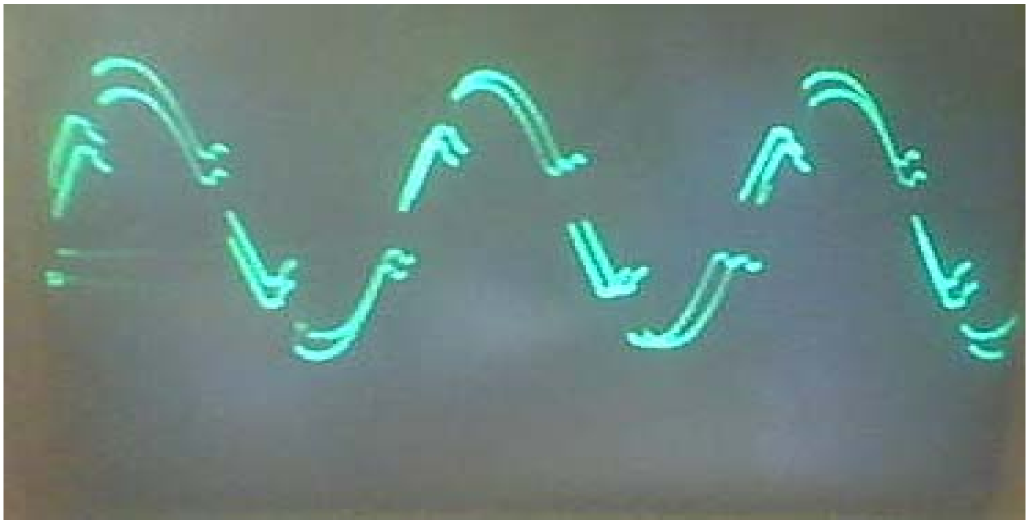


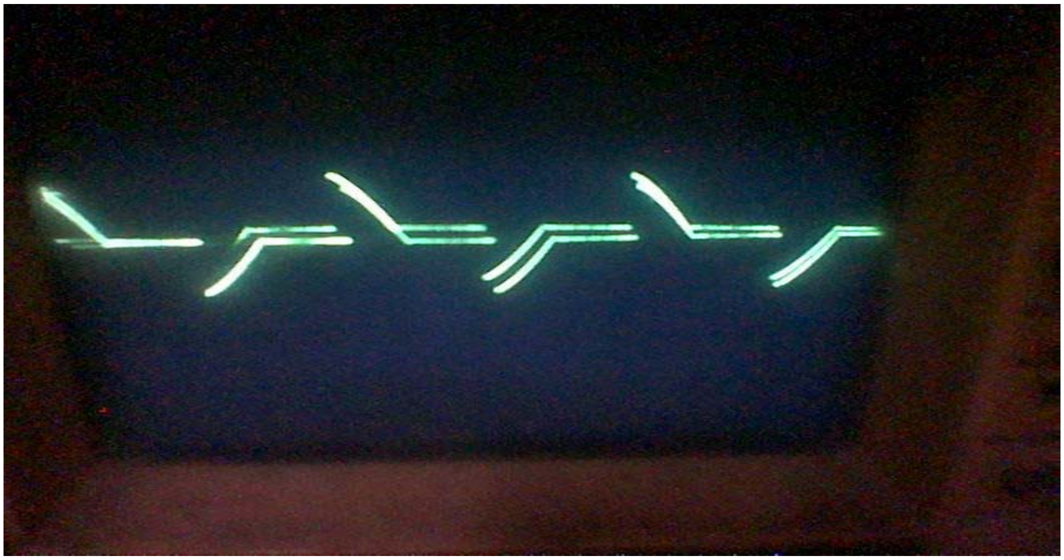
8.2 Pulse output from Driver circuit:



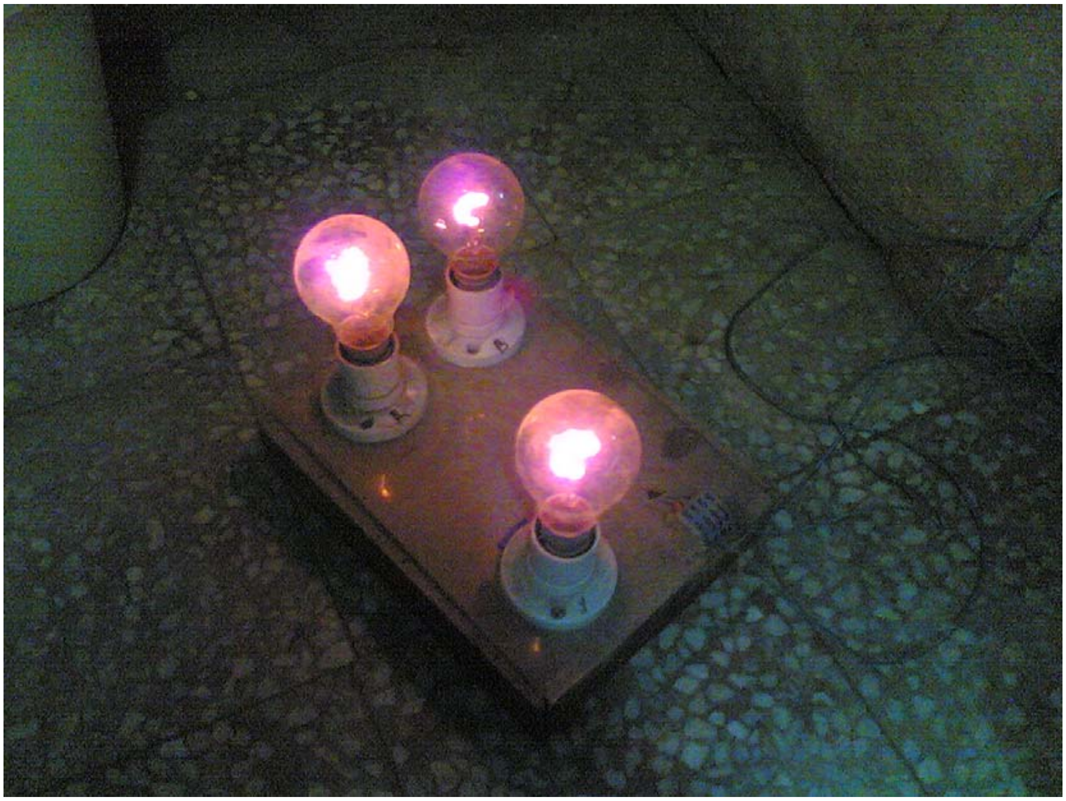
8.3 Load Voltage Waveforms for different firing angle:

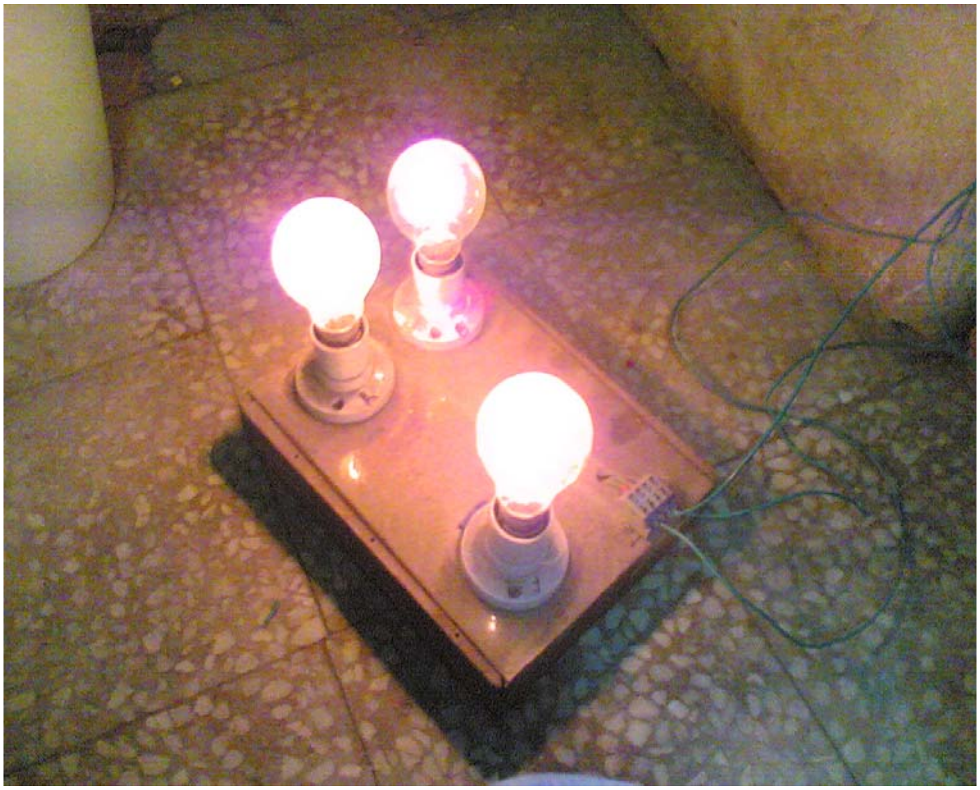






Results of soft starting experiment on Lamp load:





FUTURE SCOPE

By using Atmega16L Micro controller to control the Three Phase AC Voltage controller that is to trigger Thyristor as per requirement we can get higher accuracy, faster response and better reliability. The Hardware part and software Program resistive Load is developed. Interface between Hardware part and Software part was also carried out. For Inductive load doing changes accordingly we can program it. In case of inductive load comparison to the resistive load, voltage drop is there. So, simply by changing the reference values in the software program we can get desired result. It has been checked on AC and DC both thyristor bridges.

CONCLUSIONS

Atmega16L Micro controller has RISC architecture that has been developed to take advantage of semiconductor integration and software capabilities. High-level languages are rapidly becoming the standard programming methodology for embedded micro controllers due to improved time-to-market and simplified maintenance support. The AVR architecture was developed in conjunction with C language experts to ensure that the hardware and software work hand-in-hand to develop highly efficient, high-performance code.

Using this micro controller we found following advantages of this soft starter relative to analog soft starter:

- It has soft start and soft stop facility.
- It has Digital control using micro controller.
- Programming is in C language.
- Ramp up time can be adjust as per requirements.
- We can connect LCD for display purpose.
- Size is compact.
- Response is fast.
- Better Reliability.
- Higher Accuracy.

In addition to that other applications of this soft starters are as given below:

1. It can be used as power controller.
2. It can be used with AC and DC both thyristor bridges for AC and DC drive.

LIST OF THE COMPONENTS USED:

Component	**Quantity**
Resistor	50
Capacitor	20
Variable resistor	4
Diode	22
7805 IC	2
7912 IC	1
7812 IC	1
Push button	4
Microcontroller	1
Crystal	1
IRK26 Thyristor	6
Snubber circuit	3
Current Transformer	3
Heat sink	1
Transistors	16
Pulse Transformer	6

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[1] New Strategy to Improve Electromagnetic Torque at Starting in Thyristor Controlled Induction Motors, Zhao Kaiqi Xu Dianguo, member, IEEE Wang Yi Dept. of Electrical Engineering Harbin Institute of Technology.

[2] A comparative study of Energy Saving Benefits in Softstarters for Three-phase Induction Motors. Frede Blaabjerg, John K. Pedersen, Soren Rise and Hans-Henrik Hansen.

[3] Analysis of A Novel Topology of Soft Starter for Induction Motors. Lu Guangqiang, Ji Yanchao, YU Hongxiang, and Zhang Ke.

Websites:

http://en.wikipedia.org/wiki/Semiconductor_device
http://en.wikipedia.org/wiki/Zero_cross_circuit
http://www.lmphotonics.com/m_control.htm
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http://www.atpsensor.com/ptc
http://www.mathworks.com/

Appendix-1

C Program of Atmega16L for six pulse generation:

```
#include <inttypes.h>
#include <avr/io.h>
#include <avr/interrupt.h>
static volatile unsigned char input;
static volatile unsigned int angle;
static unsigned volatile calibration;
SIGNAL(SIG_INTERRUPT1)
{
        TCNT1 = ((angle) % 20000);
        input = 4 + ((angle) / 20000);
        //angle += 50;
}
#defineoutb(addr, data)         addr = (data)
#defineinb(addr)                        (addr)
#define BV(bit)                         (1<<(bit))
#define cbi(reg,bit)     reg &= ~(BV(bit))
#define sbi(reg,bit)     reg |= (BV(bit))
# define TIMER_PRESCALE_MASK                    0x07
#define TIMER_CLK_DIV               0x01
#define TIMER_INTERRUPT_HANDLER             SIGNAL
void timer_init()
{
        outb(TCCR1B, (inb(TCCR1B) & ~TIMER_PRESCALE_MASK) |
TIMER_CLK_DIV);
        OCR1A = 20000;
        TCNT1=0;
        sbi(TIMSK, TOIE1);
        sbi(TIMSK, OCIE1A);
}

TIMER_INTERRUPT_HANDLER(SIG_OUTPUT_COMPARE1A)
```

```
{
        TCNT1 = 0;
        input %= 6;
        switch(input)
        {
                case 0:PORTC = (63-1)<<1;break;
                case 1:PORTC = (63-32)<<1;break;
                case 2:PORTC = (63-4)<<1;break;
                case 3:PORTC = (63-2)<<1;break;
                case 4:PORTC = (63-16)<<1;break;
                case 5:PORTC = (63-8)<<1;break;
        }
   //if(angle < 20000){
   //while(TCNT1 < (angle-2000));
   //PORTC = 0xff;}
        input++;
}
int main(void)
{
   DDRC  = 0xff;
        DDRC = 0xff;
   DDRD  = 0x00;
   PORTD = 0xff;
   GICR = _BV(INT1);
        MCUCR = _BV(ISC11);
   timer_init();
        // Activate ADC with Prescaler 16 --> 1Mhz/16 = 62.5kHz
        angle = 20000;
   sei();
        unsigned int x = 0;
   int count;
 // Activate ADC with Prescaler 16 --> 1Mhz/16 = 62.5kHz
 //ADCSRA = _BV(ADEN) | _BV(ADPS2);
 count = 0;x=0;
 ADCSRA = _BV(ADEN) | _BV(ADPS2);
  for (;;) {
   // Select pin ADC0 using MUX
   ADMUX = 0;

   //Start conversion
   ADCSRA |= _BV(ADSC);

   // wait until converstion completed
   while (ADCSRA & _BV(ADSC) ) {}

   // get converted value
```

```
    x += ADCW;
    count++;
            if(count > 13){angle = (x*4);x=0;count=0;}
  }
}
```