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ELECTRONIC STARTER FOR SINGLE PHASE INDUCTION MOTOR

PROJECT INDEX: PRJ 104

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I hereby declare that I carried out the work reported in this report in the Department of Electrical Engineering, The University of Nairobi, under the supervision of Dr. Wekesa. I solemnly declare that to the best of my knowledge, no part of this report has been submitted here or elsewhere in a previous application for award of a degree. All sources of knowledge used have been duly acknowledged.

Signed:

Dated:

Abstract

Although we take starter motors for granted today, the so called self-starter was not even conceived of until several decades after arrival of the horseless carriage. Early automobiles were often selected with hand cracks, but various automobiles utilized everything from springs to gun powder to start engines. The archetypal image of a pioneering aviator spinning the prop of his aviator to get it going is an example of the human pioneered starter motor.

Modern internal combustion engines typically lack the ability to self-start, and the engines used in the first automobile were no different. Starting methods utilized, include the hand crank which was the most common engine starter in the early days of automobile. They were essentially crank handles that were temporarily coupled with engine crankshaft. The driver would literally crank the engine by turning the handles which would allow the process of internal combustion to begin. After a given number of cranks the engine would begin to run on its own and the crank would be removed.

Although the hand crank was simple and reliable, they suffered from a handful of drawbacks. The main issue with this method of starting is that it is inherently dangerous to the operator. For instance, if an engine were to kick back during the cranking process, the operator would be severely injured.

While there was a need of starter, as in 1899, Charles F. Kettering of Dayton Engineering Laboratories Company (DELCO) invented and filed for U.S. Patent 1,150,523 for the first useful electric starter. One aspect of the invention lay in the realization that a relatively small motor, driven with higher voltage and current than would be feasible for continuous operation, could deliver enough power to crank the engine for starting. The electric starter ensured that anyone

could easily start and run an internal combustion engine car, and this made it the design of choice for car buyers from that day forward. (Laukkonen)

This project investigates the electronic starter for the single phase induction motor that incorporates both short circuit and overload protection. The starter is used for switching and protecting the electric motor from the dangerous overloads by tripping. It reduces the starting current to the AC induction motors and also reduces the motor torque.

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Acknowledgements

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Last, but not least, I would like to thank the Almighty God for guiding me throughout my studies till the accomplishment of this project.

A project of this nature could never have been attempted without reference to and inspiration from the works of others whose details are mentioned in reference section. I also acknowledge all of them.

Dedication

I dedicate this project to my mother, Nancy Nyambura Kuria and my nephew Liam Gitari. Thank you for your unwavering love and support.

1. INTRODUCTION

1.1 Background

[redacted]Necessity for Motor Protection

It could be assumed that properly planned, dimensioned, installed, operated and maintained drives should not break down. However, in real life, these conditions are hardly ever ideal. The frequency of different motor damage differs since it depends on different specific operating conditions. (Rockwell Automation)

The induction motor is the most widely used motor in the industry due to its simple and rugged construction. It requires least maintenance as compared to other electrical motors. Therefore, induction motor protection plays an important role in its long life service.

Researchers have done costly and limited protection for stator winding protections, broken rotor bars protection, thermal protection etc. Mainly the induction motor needs protection from variation of the input supply for small motors which is in common use, not only in big industry but also in small scale industries. The small scale industries are not able to provide costly protection to the drives in use as it will increase their capital cost. Therefore a cheap and compact design has been done for protection of induction motors against unbalanced voltages, under voltages, short circuits etc.

Statistics show that annual down times of 0.5%...4% have to be expected. Most breakdowns are caused by an overload, insulation faults leading to earth faults, turn-to turn or winding short circuits are caused by excess voltage or contamination by dampness, oil, grease, dust and chemicals. (Rockwell Automation)

The approximate percentages by these individual faults are:

Table 1-1 Breakdown in Motors

Overload	30%
Insulation damage	20%
Phase Failure	14%
Bearing	13%
Ageing	10%
Rotor damage	5%
Others	8%

1.2 Problem Statement

To guarantee fault-free operation of an electrical drive the following points must be observed: (Rockwell Automation)

1. Correct design: a suitable motor has to be selected for each application
2. Professional operation: professional installation and regular maintenance are preconditions for fault-free operation
3. Good motor protection: this has to cover all possible problem areas.
    - It must not be tripped before the motor is put at risk
    - If the motor is put at risk, the protection device has to operate before any damage occurs.

- If damage cannot be prevented, the protection device has to operate quickly in order to restrict the extent of the damage as much as possible.

1.3 Problem Objective

The objective of this project is to;

1. Design an electronic starter for 370Watt single phase induction motor.
2. Incorporate both overload and short circuit protection to the electronic starter.

2. LITERATURE REVIEW

A motor is an electronic device that has brought about one of the biggest advancements in the field of engineering and technology ever since invention of electricity.

A motor is an electromechanical device that converts electrical energy to mechanical energy. It is because of motors, life is what it is today in the 21st century. Without motors we would have still been living in Sir Thomas Edisonǿs Era where the only purpose of electricity would have only been to glow bulbs. (electrical4u)

Basic principle of the functioning of an electrical motor lies on the fact that **force is experienced in direction perpendicular to the magnetic field and current** (Faradayǿs Right Hand Rule) **when field and current are made to interact with each other.**

2.1 Types of Motors

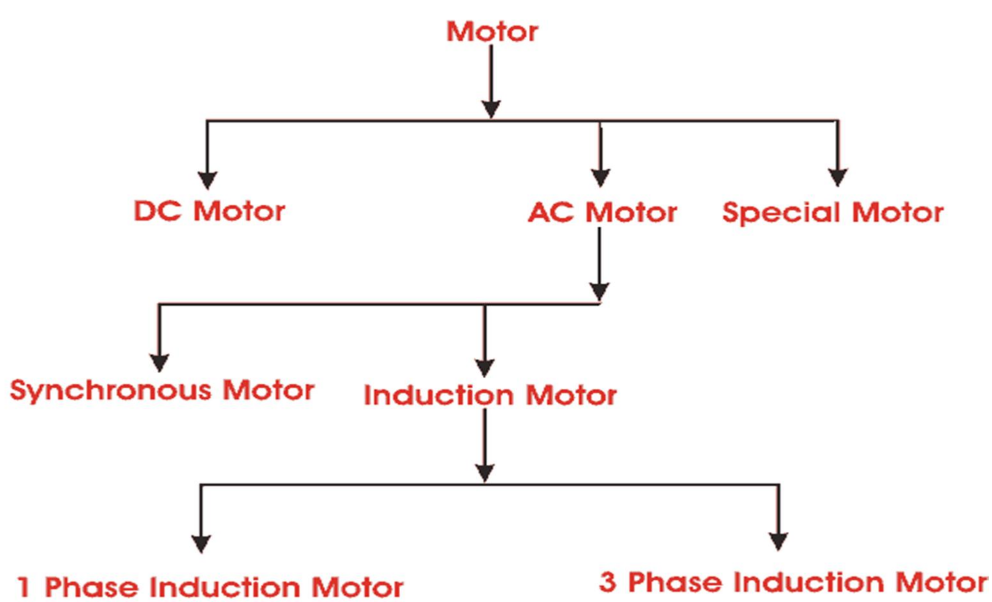

Figure 2:1 Types of Motors

2.2 History of Motors

In the year 1821, British Scientist Michael Faraday explained the conversion of electrical energy into mechanical energy by placing a current carrying conductor in a magnetic field which resulted in rotation of conductor due to torque produced by mutual action of current and field. Based on his principal, the most primitive of machines a D.C. (direct current) machine was designed by another British Scientist William Sturgeon in the year 1832.But his model was overly expensive and it was not used for any practical purpose. Later in the year 1886, the first electrical motor was invented by scientist Frank Julian Sprague that was capable of rotating at a constant speed under varied range of load and this derived motoring action. (electrical4u.com)

Among the four basic classification of motor, the DC motor as its name suggests is the only motor driven by direct current. It is the most primitive of electric motors where the rotating torque is produced due to flow of current through conductor inside a magnetic field.

The rest are all AC electric motors and are driven by alternating current e.g. the synchronous motor which always runs at synchronous speed. Here the rotor is an electromagnet which is magnetically locked with stator rotating magnetic field and rotates with it .Speeds of this machines are varied by varying frequency and the number of poles (P)

$$N_s = 120f/P \tag{2.1}$$

In another type of AC motor, rotating magnetic field cuts rotor conductors, hence circulating current is induced in this short circuited rotor conductor. Due to this interaction of magnetic field and this circulating current, rotor starts rotating .This is the induction motor also known as asynchronous motor.

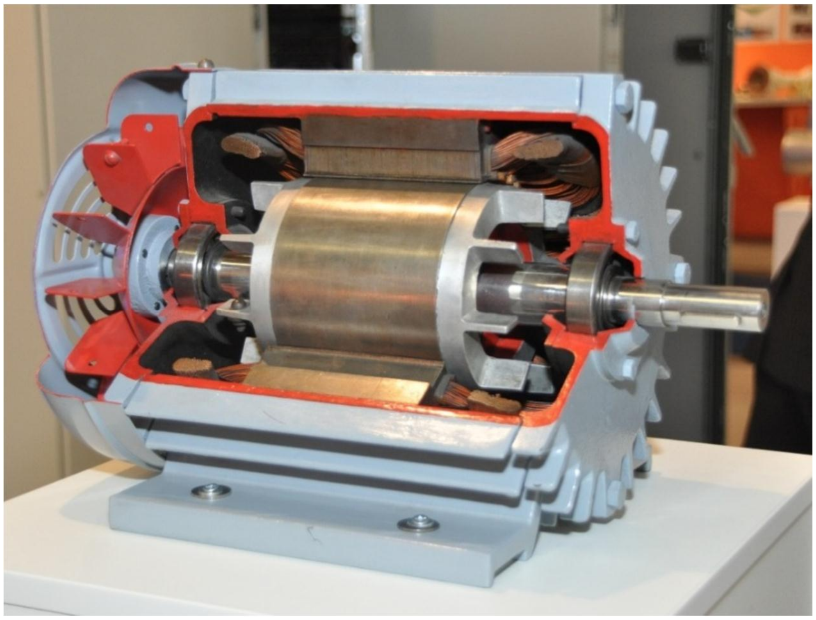

Figure 2:2 Cutaway view through stator of the Induction Motor

2.3 Starters

A starter is a device that controls the use of electrical power to equipment usually a motor.

As the name implies, starters ‘*start*’ motors. They can also stop them, reverse them, accelerate them and protect them. Starters are made from two building blocks, **contactors** and **overload protection.**

Contactors control the electric current to the motor. Their function is to repeatedly establish and interrupt an electric power circuit.

Overload Protection protects the motor from drawing too much current and overheating, from literally “burning out”.

[redacted]Contactor

A contactor can stand on its own as a power control device, or as part of a starter. Contactors are used in applications ranging from the light switch to the most complex, automated industrial equipment to control high voltages and currents.

Contactors are used by electrical equipment that is frequently turned off and on (opening and closing the circuit), such as lights, heaters, and motors. Whatever the application, the function of the contactor is always the same: **to make and break all power supply lines running to a load** or, as defined by NEMA, to repeatedly establish and interrupt an electrical power circuit.

[redacted]History

2.3.2.1 Knife Blade Switch

The first device used to stop and start electric motors was a simple knife blade switch. This was a lever that would drop a strip of metal onto a contact to make the electric circuit. In the late 1800ĝs, ñthrowing the switchò meant exactly that ï someone had to stand next to the knife blade switch and lever it into the closed position. When industry began to demand more powerful electric motors, the knife blade switch quickly became obsolete and was no longer used because engineers discovered that the contacts wear out because humans could not open and close the switch fast enough to prevent arcing. (**Arcing is a condition where a high voltage leaps across the open source as contacts closed in or pulled away from the switch, corroded the soft copper switches with pits. Dirt and moisture compounded the problem.)**

Figure 2:3 Knife Blade Switch

More importantly as motors became larger, currents to operate them also became larger, creating a serious safety concern. It was physically dangerous to handle the switch .Willing knife blade switch operators became harder and harder to find. (Cutler-Hammer)

From the knife blade switches, mechanical improvement was made and issues listed were taken care of;

- Speed of operation
- The contactor life
- Protection for the motor
- Protection for the person who operates the switch

2.3.2.2 Manual Contactor

The manual controller was the next step up the evolutionary ladder, offering several important new features.

- Unit is encased and not exposed.
- Double break contacts are used instead of single break
- Unit is physically smaller
- Unit is much safer to operate

Figure 2:4 Manual Controller

Double-break contacts open the circuit in two places simultaneously. Dividing the connection over two sets of contacts allows you to work with more current in a smaller space than you get with a single break contact. In addition, the mechanical linkage moves quickly and consistently opens and closes the circuit sparing the metal from some of arcing experienced under knife blade switches

With a manual controller, operator presses a button or switch that is integral to the electrical equipment being run. When the operator activates a manual controller, the power circuit engages carrying the electricity to the load.

2.3.2.3 Magnetic Contactors

Magnetic contactors eventually made a breakthrough as they are operated electromechanically without manual intervention. Magnetic contactors use a small control current to open and close the switch.

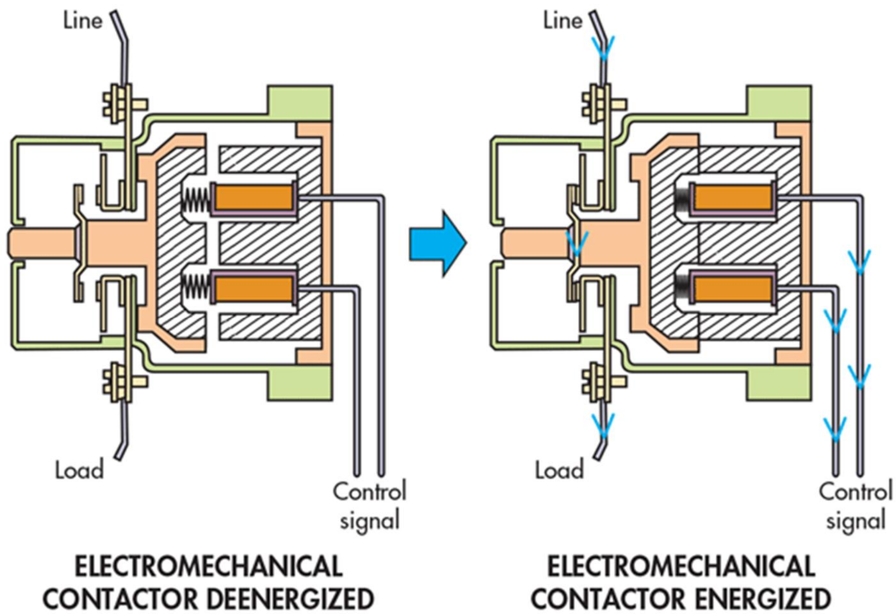

Figure 2:5 Magnetic Contactors

Main components of contactor are

1. Electromagnetic E frame
2. Armature
3. Coil

4. Spring

5. Two sets of contacts.

How exactly does the contactor open and close? The E frame when energized by the coil becomes an electromagnet. The companion to the E Frame is connected to a set of contacts. The armature is movable but is held by a spring. When the coil is energized, the movable contacts are pulled towards the stationary contacts because the armature is pulled towards the E Frame .Once the two sets of contactors meet, power can flow through the contactor to the load. When the coil is de energized, the magnetic field is de-energized and the spring forces the two sets of contacts open. (Cutler-Hammer)

Contactors are used when no load overprotection is necessary and at lower levels of electrical current. Applications include lighting circuits, heaters and transformers.

Contactor Life Arcing

A major customer concern is the life expectancy of a contactor. The more the contacts are opened and closed, the shorter the life of the contactor. As contacts open and close, an electrical arc is created between them. The arc provides additional heat which can damage the contact surfaces. Eventually the contacts become blackened with burn marks and pitting made by electrical arcs. This is not a reason for contact replacement as the oxide deposit helps them make a better óseatôto conduct electricity.

However contacts need to be replaced once the contacts are badly corroded or worn away.

In summary, the faster the contact closes, the sooner the arc is extinguished and the life expectancy of the contacts. However modern contacts have been designed to close so quickly, and with such energy, contacts slam against each other and rebound causing a bouncing action. This is referred to as **contact bounce .**Contact bounce causes secondary arcing. Contacts slam together again and again each time the bouncing arcing become less and less. So in addition to closing the contacts as fast as possible, you also want contacts to bounce as little as possible to reduce secondary arcing and wear.

[redacted] Overload

Definition- An overload occurs when too many devices are connected to a circuit or when electrical equipment is made to work beyond its rated capabilities. For example, if a conveyor jams, its motor may draw two or more times itös rated current.

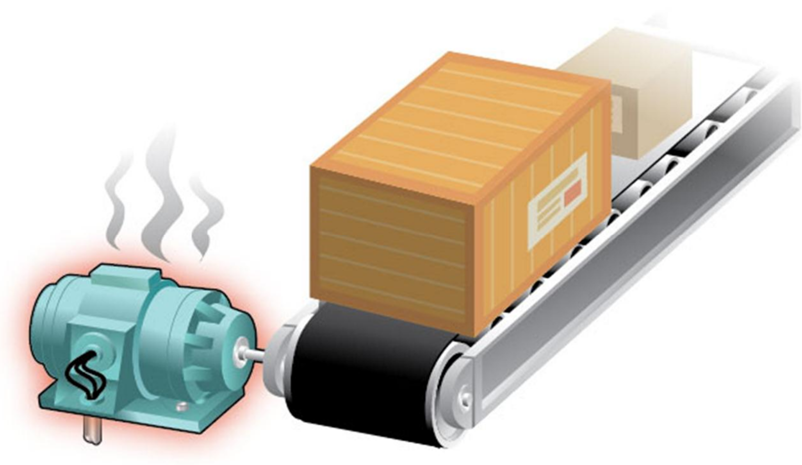

Figure 2:6 Overload of Motor

A motor is defined to run at a certain speed that is, synchronous speed. Suppose the load on the motor increases, the motor draws more current to continue running at its synchronous speed. It is quite possible to put so much load on a motor that it will draw more and more current without being able to reach synchronous speed. If this happens for a long time, the motor can melt its insulation and burn out. This condition is called an overload.

In fact, the motor could stop running altogether (locked) under a large enough load. This is another example of an overload condition. Even though the motor shaft is unable to turn, the motor continues to draw current to reach its synchronous speed. While the running motor may not draw enough current to blow the fuses or trip the circuit breaker it can produce sufficient heat to burn up the motor .This heat generated by this excessive current in the windings causes the insulation to burn out and the motor to fail.

An overload protection device therefore does not open the circuit while the motor is starting, but opens the circuit if the motor gets overloaded.

2.3.3.1 Overload Protection

As mentioned earlier overload protection prevents an electric motor from drawing too much current, overheating and literally ǒburning outô

How does a motor work and when is overload protection needed?

1. Resting
2. Starting
3. Operating under load

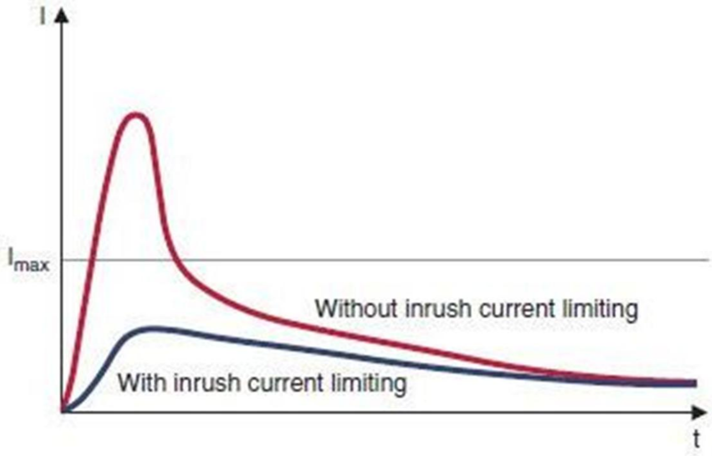

Figure 2:7 Operation of Motor

Motor at rest requires no current because circuit is open. But when the circuit is closed, motor starts drawing a tremendous inrush current as much as 6 to 8 times itøs running current. Here is the problem-this large inrush current can cause immediate tripping of the circuit breaker**.** A fuse or circuit breaker sized to handle the normal running load of the motor will open the circuit during startup, but this would not solve the problem .Suppose the motor was running, only the most extreme overload would open the circuit. Smaller overloads would not trip the circuit breaker and the motor would øburn outö. (Cutler-Hammer)

[redacted] Overload Relay

Overload relays are the heart of motor protection

Overload relays are used in starters for motor overload protection. It limits the amount of current drawn to protect the motor from overheating. It does not provide short circuit protection. This is the function of the short circuit protective equipment like fuses and circuit breakers, generally located in the disconnecting switch enclosure. Motors draw a high inrush current when starting and conventional fuses have no way of distinguishing between this temporary and harmless inrush current and a damaging overload.

The ideal and easiest way for overload protection for a motor is an element with current sensing properties very similar to the heating curve of the motor which would act to open the motor circuit when full load current is exceeded.

Overload relay consists of:

1. Current sensing unit
2. Mechanism to break the circuit either directly or indirectly

To meet motor protection needs, overload relays have a time delay to allow harmless temporary overloads without breaking the circuit. They also have a trip capability to open the control circuit if mildly dangerous currents (that could result in motor damage) continue over a period of time.

All overload relay have a means of resetting the circuit once the overload is removed.

Types of overload relay

1. Thermal relays
   i. Eutectic(melting alloy)
   ii. Bimetallic
2. Electronic relays
   i. Solid state

Thermal relays as the name implies, rely on the rising temperatures caused by the overload current to trip the overload mechanism

2.3.4.1 Eutectic Overload Relays

The melting alloy overload relay consists of a heater coil, a eutectic alloy and a mechanical mechanism to activate tripping device when an overload occurs. The relay measures temperature of the motor by measuring the amount of current being drawn. This is done indirectly through a heater coil. A heater coil converts excess current into heat which is used to determine if the motor is in danger. The magnitude of current and the length of time it is present determines the amount of heat registered in the heater coil.

Usually a eutectic alloy tube is used in combination with a ratchet wheel to activate tripping device when an overload occurs. A eutectic alloy is a metal that has a fixed temperature at which it changes directly from solid to liquid .The heat melts the alloy freeing the ratchet wheel and allowing it to turn .This action opens the normally closed contacts in the overload relay.

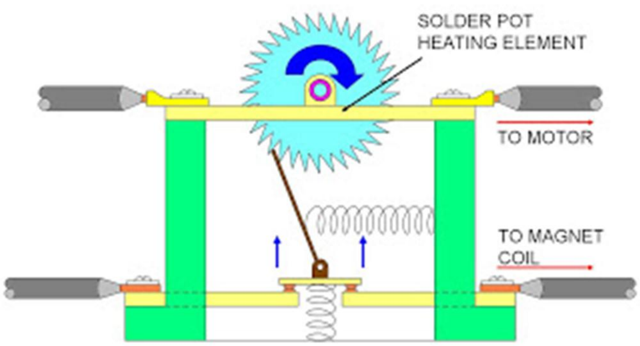

Figure 2:8 Eutectic Overload Relay

2.3.4.2 Bimetallic Overload Relay

A bimetallic device is made up of two strips of different metal. The dissimilar metal are joined together. Heating the bimetallic strip causes it to bend because the dissimilar metals expand and contract at different rates. The bimetallic strip applies tension to a spring on contact. If temperature begins to rise, the strip bends and the spring pulls the contacts apart, breaking the circuit. Heat generated due to overheating comes from either:

1. The motor
2. Heat present in where the motor operates (ambient temperature)

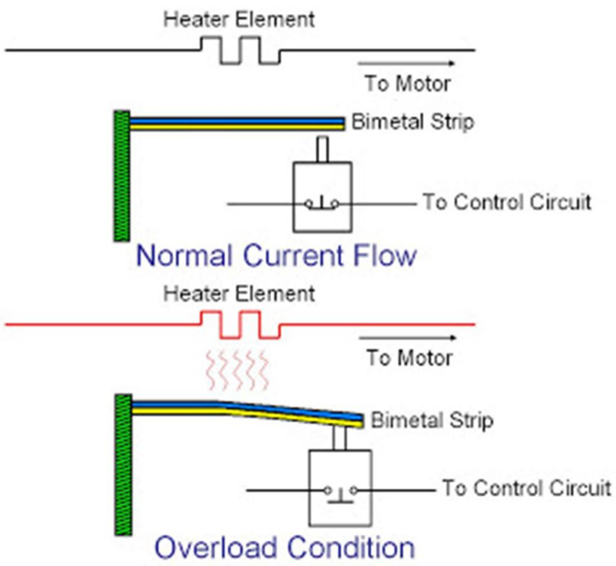

Figure 2:9 Bimetallic Overload Relay

Although ambient temperature contributes a small portion of the total heat, it has significant effects on the operation of the overload relay bimetal. A properly designed ambient compensating element reduces effects of ambient temperature change on the overload relay.

Bimetallic overload relays are commonly found in applications e.g. walk in meat coolers, remote pumping stations and some chemical process equipment where the unit is operated in environments with varying ambient temperature.

2.3.4.3 Solid State Overload Relay

These active semiconductor devices use light instead of magnetism to actuate a switch. The light comes from an LED, or light emitting diode. When control power is applied to the deviceôs output, the light General Purpose Relay is turned on and shines across an open space. On the load side of this space, a part of the device senses the presence of the light, and triggers a solid state switch that either opens or closes the circuit under control. Often, solid state relays are used where the circuit under control must be protected from the introduction of electrical noises. Advantages of Solid State Relays include low EMI/RFI, long life, no moving parts, no wastage of energy generating heat, no contact bounce, and fast response. The drawback to using a solid state relay is that it can only accomplish single pole switching.

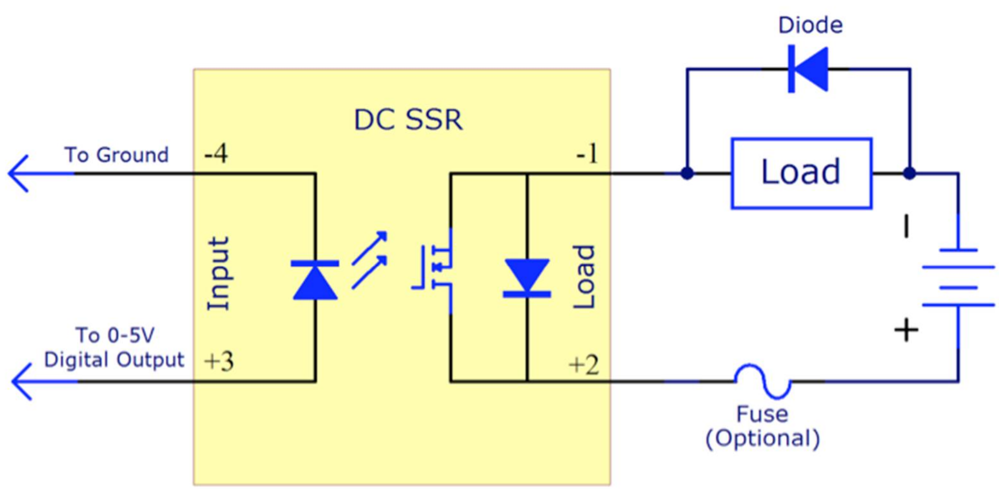

Figure 2:10 Solid State Overload Relay

Selection of overload relays is based upon the time taken for them to respond to an overload in the motor. The overload relay itself will have markings to indicate which class it belongs to.

These include class 10, 20 and 30.The class number indicates the response time in seconds. An unmarked overload relay is always class 20.

[redacted]Tripping

Many overload protection devices have a trip indicator built into the unit to indicate to the operator that an overload has occurred. Overload relays can either have a manual or an automatic reset. A manual reset require that the operator intervention such as pressing a button to restart the motor. An automatic reset allows the motor to restart automatically. Usually after a ćcooling offô period in the case of the bimetallic strip.

Overload relays also have an assigned trip class. The trip class is the maximum time in seconds at which the overload relay will trip when carrying current is at 600% of its current rating. Bimetallic overload relays can be rated as class 10 meaning they can be counted on to back the circuit no more than 10 seconds after a locked rotor condition begins. Melting alloy overload relays are generally class 20.

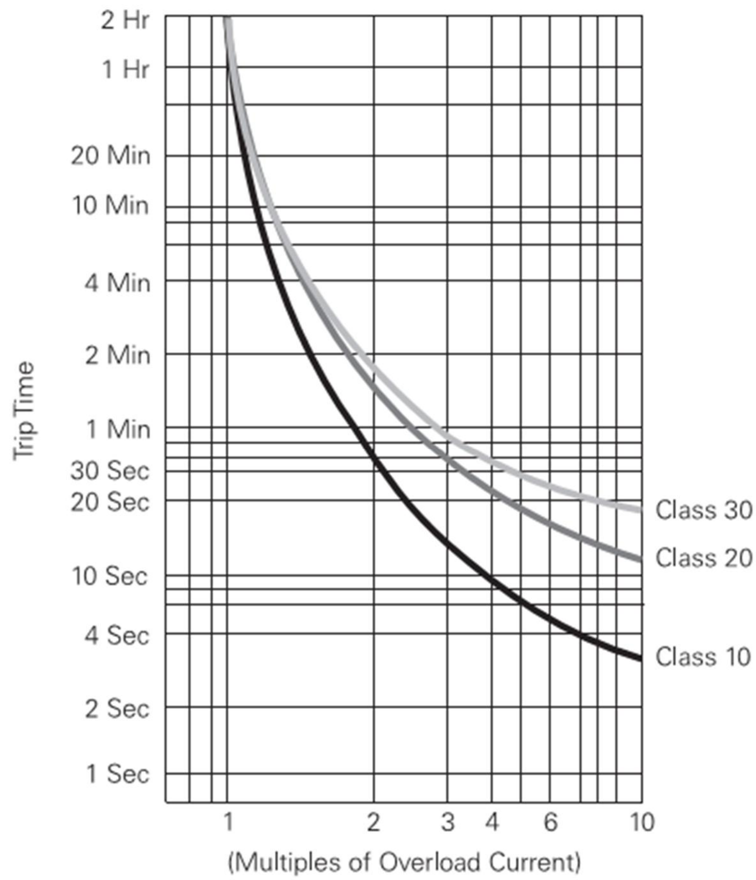

Figure 2:11 Trip Class for Overload Relay

2.3.5.1 Tripping Action

You will get motor protection with either manual or magnetic starter. When a manual starter experiences an overload. An overload trips a mechanical latch causing the contacts to open and disconnect the motor from electrical line. In a magnetic motor starter an overload results in the opening of a set of contacts within the overload relay itself. This set of contacts is wired in series with the starter coil in the control circuit of the magnetic motor starter. Breaking the coil circuit causes the starter contacts to open disconnecting the motor from the line. The motor is hence stopped and saved from "burning out". (Cutler-Hammer)

2.4 Starter Circuitry

The motor starter has two circuits;

1. The power circuit
2. Control circuit

For the three phase, full voltage, non-reversing magnetic starter shown below, the thick lines indicate the power circuits and the thin lines are the control circuit.

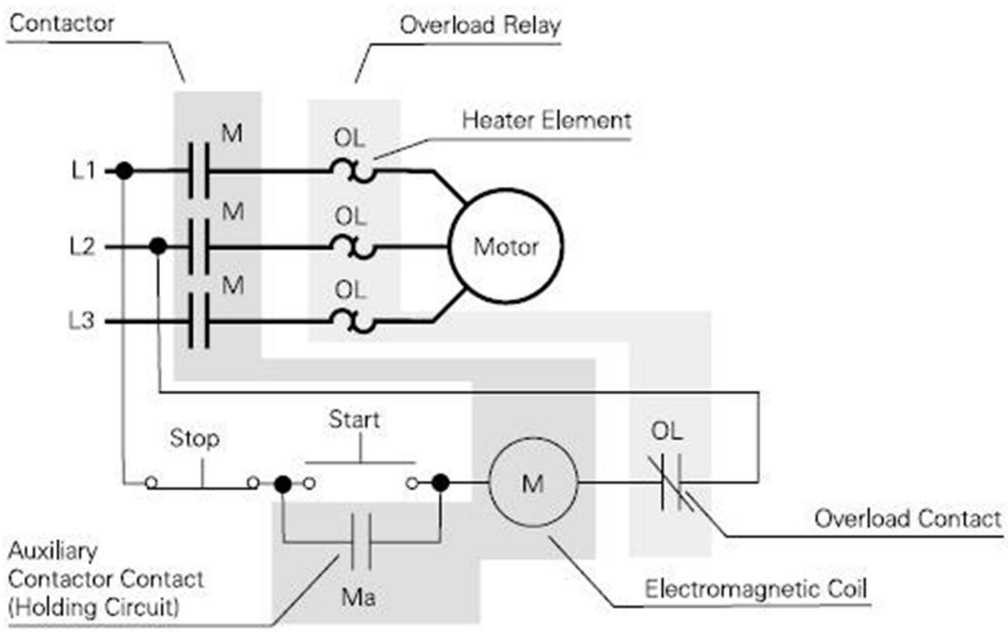

Figure 2:12 Starter Circuitry

Power circuit runs from the line to the motor. Electricity passes through contacts of a starter, the overload relay and out of the motor. The (power mains) contacts carry motor current.

The control circuit operates the contactor (ON/OFF) as shown in the figure. It controls the distribution of power. The contacts that interrupt or allow the main current to flow to the motor are controlled by opening or closing the contacts in the control circuit. The control circuit energizes the coil creating an electromagnetic field that pulls the power contacts closed, thereby connecting the motor to the line. The control circuit gets power from the same source as the motor, this is termed the common control.

2.5 Starters for Single Phase Induction Motor

The single phase induction motor is not self-starting and it is undesirable to resort to mechanical spinning of the shaft or pulling a belt to start it. The single phase stator winding produces a magnetic field that pulsates in strength in a sinusoidal manner. The field polarity reverses in strength after each half cycle but the field does not rotate. Consequently, the alternating flux cannot produce rotation in a stationary squirrel cage rotor. This strange behavior of the single phase induction can be explained on the basis of double-field revolving theory.

[redacted] Double Field Revolving Theory

According to double field revolving theory, any alternating quantity can be resolved into two components each component has a magnitude equal to half of the maximum magnitude of the alternating quantity and both these component rotates in opposite direction to each other. For example a flux Ů, can be resolved into two components;

+Ů/2 and ï Ů/2

Each of these components rotates in opposite direction, that is, one Ů/2 is rotating in clockwise direction and the other in anticlockwise direction.

When a single phase ac supply is given to the stator winding of single phase induction motor, it produces its flux of magnitude ǓAccording to the double field revolving theory, this alternating flux alpha is divided into two components of magnitude Ǔ/2.Each of these components will rotate in opposite direction, with the synchronous speed Ns. These two components of flux, forward component of flux, and backward component of flux at any instant of time, gives the value of instantaneous stator flux at that particular instant.

That is, Ǔ/2+ Ǔ/2 = Ǔresultant = Ǔf + Ǔb

Now, at starting both forward and backward components of flux are exactly opposite to each other. Also both of these components are equal in magnitude, so they cancel each other and hence the net torque experienced by the rotor at starting is zero. So, the single phase induction motors are not self-starting motors. (Mehta)

[redacted]Self-Starting Methods

Therefore, to make a single phase induction motor self-starting, we should somehow produce a revolving stator magnetic field. This may be achieved by converting a single phase supply into a two phase supply through the use of an additional winding (start windings). These two alternating flux, have some phase difference angle between them. When these fluxes interact with each other, they will produce a resultant flux. This resultant flux is rotating in nature and rotates in space in one particular direction only. The rotor quickly accelerates until it reaches a speed slightly below the synchronous speed and the additional flux can be removed. The motor will continue to run under the influence of the main flux only. Depending upon the methods of making asynchronous motor as self-starting motor, there are mainly four types of single phase induction motor namely: (Mehta)

1. Split Phase Induction Motor
2. Capacitor Start Induction Motor
3. Capacitor Start Capacitor Run Induction Motor
4. Permanent Capacitor Induction Motor
5. Shaded Pole Induction Motor

2.5.2.1 Split Phase Induction Motor

The stator of a split-phase induction motor is provided with an auxiliary or starting winding S in addition to the main winding M. The starting winding is located 90 degrees electrical from the main windings and operates only during the brief period when the motor starts up. The two windings are so designed that the starting winding S has a high resistance and small reactance while the main windings M has relatively low resistance and high reactance. Phase angle between I_s and I_m is made as large as possible the starting torque is proportional to sin Ŭas shown in the schematic below.

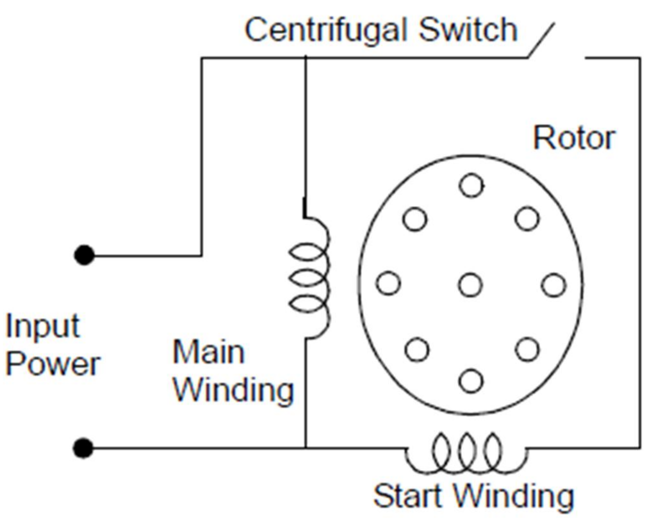

Figure 2:13 Split Phase Induction Motor

Operation

When the two stator windings are energized from a single phase supply, the main windings carries current I_m while the starting windings carries current I_s.

Since the main windings is made highly inductive while the starting winding is highly resistive, the currents I_m and I_s have a reasonable phase angle Ŭ(25 degrees to 30 degrees). Consequently, a weak revolving field approximating to that of a 2 phase machine is produced which starts the motor. The starting torque is given by;

$$T = k \times I_m \times I_s \times \sin\alpha \tag{2.2}$$

Where k is a constant whose magnitude depends upon the design of the motor.

When the motor reaches 75% of the synchronous speed, the centrifugal switch opens the switch of the starting windings. The motor then operates as a single phase induction motor and continues to accelerate till it reaches the normal speed. The normal speed is below the synchronous speed and depends upon the load of the motor.

During starting when I_m is large the centrifugal switch closes thereby allowing I_s to flow allowing the motor to start as usual. After the motor has attained 75% of synchronous speed, I_m drops to a value low enough to open the switch.

Characteristics

1. The starting torque is 1.5 to 2 times the full load torque and the starting current is 6 to 8 times the full load current.
2. Due to their low cost, split phase induction motors are the most popular single phase motors in the market.

3. Since the starting winding is made of fine wire, the current density is high and the winding heats up quickly. If starting winding exceeds 5 seconds, the winding may burn out unless the motor is protected by built in thermal relay.

4. They are constant speed motors, that is, their speed variation is 2-5% from no load to full load.

5. These motors are suitable where a moderate starting torque is required and where starting period are infrequent e.g. to drive fans, washing machines, oil burners, small machine tools.

Such motors are sometimes referred to as resistance start split phase induction motor so as to distinguish them from the capacitor start and the capacitor start and run motor.

2.5.2.2 Capacitor Start Motor

The capacitor start motor is identical to a split-phase motor except that the starting windings has as many turns as the main windings. The split phase induction motor has a low starting torque. To get high starting torque, the phase difference required is 90^0.

Operation

When a capacitor of a suitable value is connected in series with the start winding it reduces inductive reactance and the two branch currents I_s and I_m now have a greater difference between them. Difference in time sets up a rotating magnetic field in stator and again, the rotor turns in the same direction. Starting torque is therefore much more than that of split phase motor.

Starting winding is opened by centrifugal switch when the motor attains 75% of synchronous speed. The motor then operates in a single phase induction motor and continues to accelerate until it reaches normal speed.

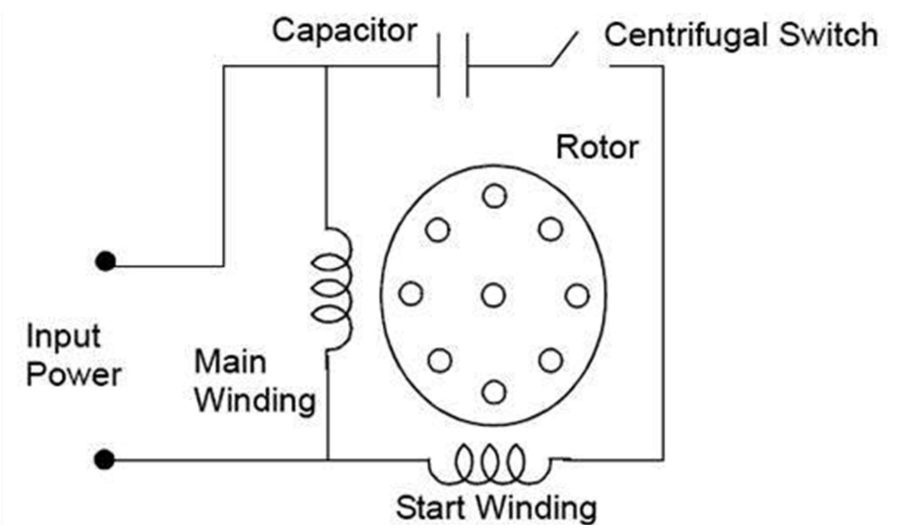

Figure 2:14 Capacitor Start Induction Motor

Characteristics

1. Although starting characteristics of a capacitor start are better than that of a split phase motor, both machines possess the same running characteristics because the main windings are identical.

2. The phase angle between the two currents is about 90 degrees compared to about 25 degrees in a split phase motor. Consequently, for the same starting torque, the current in the starting winding is only about half that in the split phase motor. Therefore the starting winding of the capacitor start motor heats up less quickly and is suited to applications involving either frequent or prolonged starting periods.

3. Capacitor start are used where high starting torque is required and where starting periods may be long e.g. to drive; compressors, large fans, pumps, high inertia loads.

   The power rating of such motors lies between 120w and 7.5kw

The capacitor used in the capacitor start motor is a large electrolytic type designed for use on AC but is short time rated. This means, capacitor must not be left on the circuit energized longer than it is specified. Depending on power rating of the motor, its value will be between 20micro Farads and 300micro Farads. It will have a working voltage of approximately 275 volts.

2.5.2.3 Capacitor-Start Capacitor Run Motor

The motor is identical to a capacitor start motor except that starting windings is not opened after starting so that both windings remain connected to the supply when the running as well as starting.

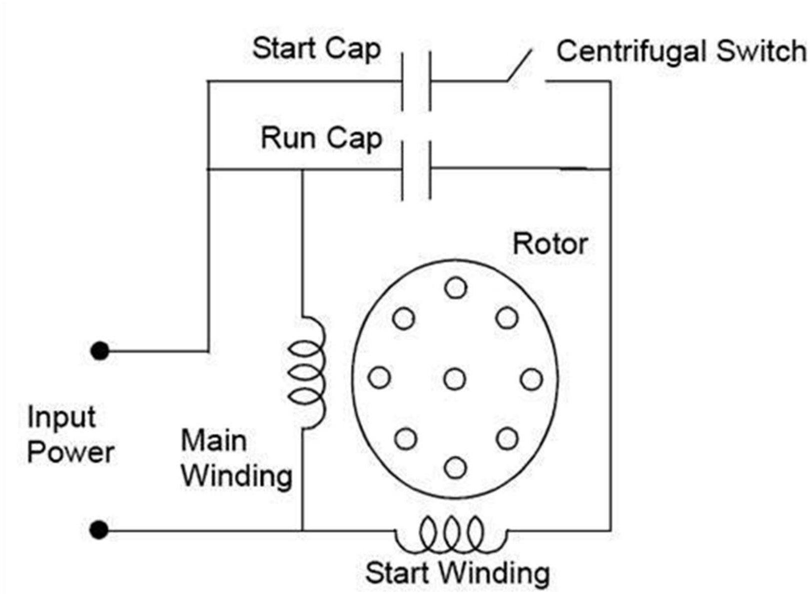

Figure 2:15 Capacitor Start Capacitor Run Induction Motor

Operation

The two capacitors are used in the starting windings as shown below.C1, the smaller capacitor required for optimum running condition is permanently connected in series with starting windings. The much larger capacitor C2, is connected in parallel with C1 for optimum starting and remains in the circuit during starting. The phase difference between the two currents $I_m + I_s$ Ó90^0 during starting while it is 90^0 during running. C1, is designed to dissipate heat associated with continuous operation of the motor. The start windings is slightly out of phase with run windings to provide start torque for the motor. Run capacitor provides the running torque once the motor is up and running.

The starting capacitor C2, is disconnected when the motor approaches about 75% of synchronous speed. The motor then runs as a single phase induction motor.

Characteristics

1. The starting winding and the capacitor can be designed for perfect 2 phase operation at any load. The motor then produces a constant torque and not a pulsating torque as in other single phase motors.
2. Because of constant torque, the motor is vibration free and can be used in; hospitals, studios and other places where silence is important.
3. Is capable of starting and driving against heavier loads than other single phase induction motors.

The start capacitor used in the capacitor start capacitor run motor is a large electrolytic type designed for use on AC but is short time rated. This means, capacitor must not be left on the circuit energized longer than it is specified. Depending on power rating of the motor, its value will be between 20micro Farads and 300micro Farads. It will have a working voltage of approximately 275 volts.

The run capacitor used in the capacitor start motor is a polypropylene type and is continuously rated. This means, capacitor must not be left on the circuit energized longer than it is specified. Depending on power rating of the motor, its value will be between 1micro Farads and 300micro Farads. It will have a working voltage of approximately 400 volts.

2.5.2.4 Permanent Capacitor Induction Motor

This motor is also called as a capacitor run motor in which a low capacitor is connected in series with the starting winding and is not removed from the circuit even in running condition. Due to this arrangement, centrifugal switch is not required. (Mehta)

The schematic circuit of this motor is shown in figure below.

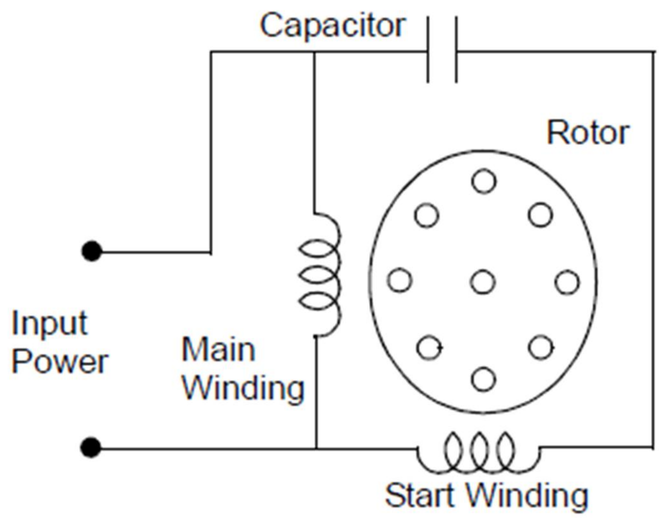

Figure 2:16 Capacitor Run Induction Motor

Operation

In this, the auxiliary winding and capacitor remains in circuit permanently and produce an approximate two phase operation at rated load point. This is the key strength of these motors.

Due to absence of the starting boost of start capacitor, starting torque is typically about 80 percent of full load torque.

Due to the continuous duty of auxiliary winding and capacitor, the rating of these components should withstand running conditions and hence permanent capacitor motor is more than equivalent split phase or capacitor start motors. These motors are used in exhaust and intake fans, unit heaters, blowers, etc.

Characteristics

1. The capacitor is capable of running continuously. The low value capacitor produces more leading phase shift but less total starting current as shown in phasor diagram.
2. Hence, the starting torque produced by these motors will be considerably lower than that of capacitor start motor.

Permanent capacitor has several advantages .They need no starting mechanism and so can be reversed and so can be reversed easily. They can be designed for optimum efficiency and high power factor at rated low.

They have a wide variety of applications depending on the design. These include fans, blowers with low starting torque needs and intermittent cycling uses such as adjusting mechanism, gate operators and garage door openers many of which need instant reversing.

2.6 Short Circuit

Normally, the insulation used to separate conductors prevents current from flowing between the conductors. When the insulation is damaged; however, a short circuit can result. A short circuit occurs when bare conductors touch and the resistance between the conductors drops to almost zero. This reduction in resistance causes current to rise rapidly, usually to many times the normal circuit current.

However, in the case of motors, at starting, voltage induced in the induction motor rotor is maximum (s=1).Since the rotor impedance is low, the rotor current is excessively high. This large rotor current is reflected in the stator. This results in high starting current in the stator at low power factor and consequently value of starting torque is low. For example, a NEMA design B motor typically has a starting current that is about six times its full-load current. For some high efficiency motors, the starting current is even higher. Motors are designed to tolerate a high starting current for a short time. As a motor accelerates to operating speed, its current drops off quickly. In the following example, the motorĝs starting current is 600% of full load current, but after eight seconds, current has dropped to the rated value. This large starting current, will produce large line voltage drop. This will adversely affect operation of other electrical equipment connected to the motor. Therefore, it is desirable and necessary to reduce the magnitude of stator current at starting and several methods are available for this purpose.

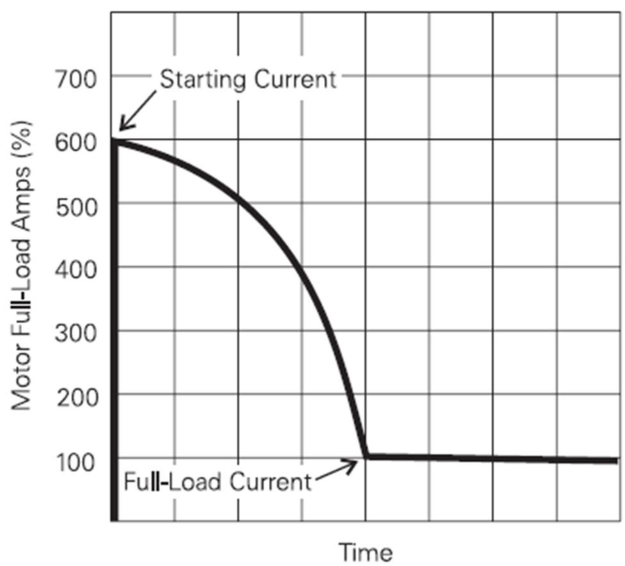

Figure 2:17 Starting Characteristics of IM

2.7 Conclusion

The motor, at the time of starting draws very high starting current for a very short duration (about 5 to 7 times the full load current) for the very short duration. The amount of current drawn by the motor depends upon its design and size. But such a high value of current does not harm the motor because of the rugged construction of the squirrel cage induction motor. Such a high value of current causes sudden undesirable voltage drop in the supply voltage. A live example of this sudden drop of voltage is the dimming of tube lights and bulbs in our homes.

Induction motors require protection from overheating due to cyclic as well as steady state overloads. Protective relays use the thermal model to continuously calculate the temperature in real time. The virtual temperature is monitored and trips to prevent overheating.

3. DESIGN

3.1 Code Requirements

The NEC or CEC requires that motor branch circuits be protected against overloads and short circuits. Overload protection may be provided by fuses, overload relays or motor thermal protectors. Short circuit protection may be provided by fuses or circuit breakers.

Short or ground fault protection is designed for:

1. Fast current rise
2. Short durations
3. Fast response time.

Overload protection is designed for:

1. Slow current rise
2. Long durations
3. Slow response time.

Short Circuit Protection is shown circled in red in the schematic below. Fractional horsepower single-phase motor overload protection may be by: the Branch Circuit Protection, a Separate Overload Device, an Integral Thermal Protector, or Impedance Protected, or a combination of these methods, depending on whether or not the motor is permanently installed, is continuous-duty, and is manually or automatically started. Overload protection for single and three-phase AC motors in the small (above 1 horsepower) and medium horsepower range is typically provided by one of two methods: Thermal Overload Relays, or Solid-state Overload Relays.

Overload protection for large three-phase motors is sometimes provided by Thermal Overload Relays which are connected to Current Transformers (CT's). These protective relays often also accept inputs from Resistance Temperature Devices (RTD's) imbedded in the motor windings (usually two per phase) and the relays are capable of displaying the winding and motor bearing temperatures, and provide both alarm and trip capability. (Motor Overload Protection)

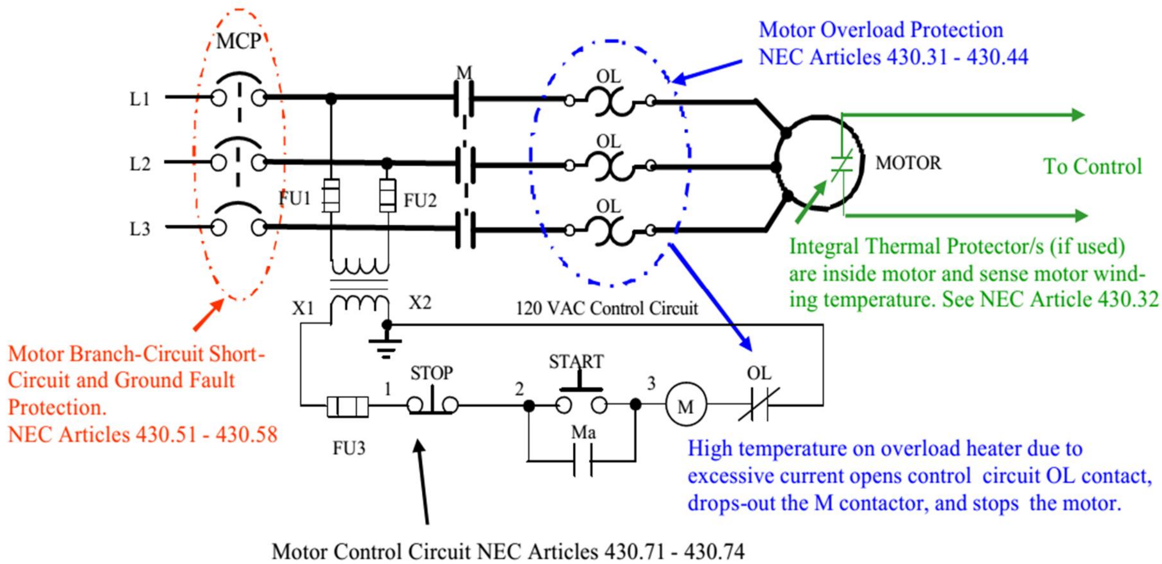

Figure 3:1 Short Circuit and Over-Load Protection

Branch-circuit and short circuit protection for a single motor is selected from Table 430.52(Appendix F) based on full load current of the motor.

Overload protection de-energizes the control circuit to the motor through the overload relays or the heaters in the motor starter. Motors get overloaded when bearings wear out or process machinery get jammed. Overload protection is completely separate from ground fault protection

The Branch circuit fuse or circuit breaker protects the motor and motor conductors from short circuit and ground faults. Table 430.52 is used to size the overcurrent device based on the percentage of the motor full load current. Motor full load current for single phase AC motors is found in Table 430.248 (Table 3-1) and for three phase AC motors in Table 430.250.

[redacted] Rules for Sizing Branch Circuit Conductors and Over Current Protection

There are many rules in the 1999 National Electrical Code for calculating loads, determining the correct size conductors, and determining the correct overcurrent protection. Simply put, conductors, shall be sized to carry the load without overheating, and the conductors and equipment from overcurrent to prevent overheating. (Unit 17 Motor Control)

[redacted] Single-Motor Branch Circuit

Sizing the motor branch circuit begins with the motor nameplate. Consider the motor nameplate of Figure below. The motor is a 1phase, 240 voltage. First, determine the type of electrical supply available. Assume, in this case, that the electrical supply is 240 V, 1 phase.

The motor full-load amperes therefore, will be 4.4 A.

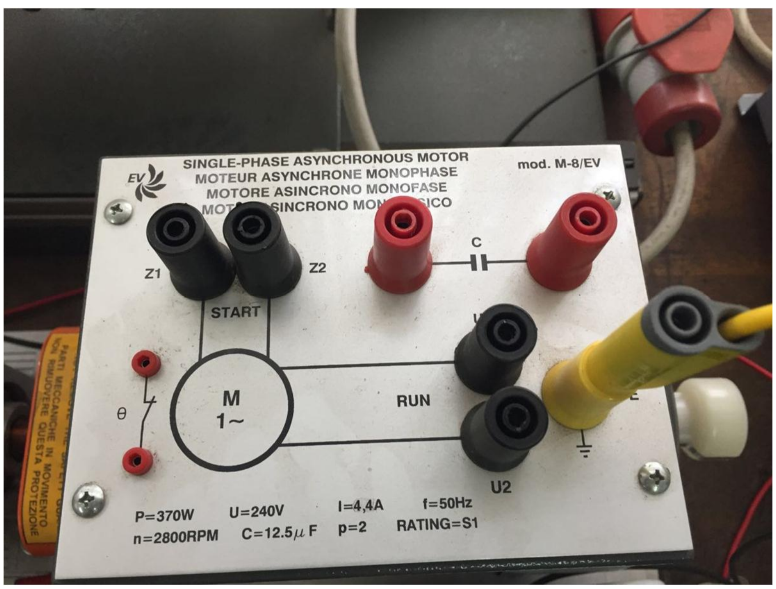

Figure 3:2 Motor Nameplate

[redacted]**Motor Full - Load Current**

The motor full-load current that is used to determine the minimum size of motor circuit components is the current listed in ***NEC Tables 430-248*** for the single phase AC MOTOR *and* ***Table 430-250*** for the three phase AC motor.

Table 3-1 Motor Full load Current

HP	115 V	230 V
1/6	4.4	2.2
1/4	5.8	2.9
1/3	7.2	3.6
1/2	9.8	4.9
3/4	13.8	6.9
1	16	8
1 1/2	20	10
2	24	12
3	34	17
5	56	28
7 1/2	80	40
10	100	50

However, this value should be checked against the motor nameplate ampere rating. Sometimes farm motor may have an ampere rating higher than the value listed in the NEC Tables. In this situation, the higher of the values should be taken for sizing component (Unit 17 Motor Control)

The nameplate current rating must be used for selecting the maximum size motor running overload protection. This is important because the overload heaters must be sized for a specific motor. If motors are changed, then the overload heaters may have to be changed.

The full-load current for a 1-phase, 240V is now 4.9A.

3.1.3.1 Disconnect for a Single Motor

Assume that the motor of Figure 21 will have a general use switch as the disconnect. However, if a circuit breaker serves as the disconnect, the rating will be in amperes. The minimum ampere rating of the circuit breaker is 1.15 times the full-load current that is 10A or more because 5A breaker would probably trip due to high starting current. (Unit 17 Motor Control)

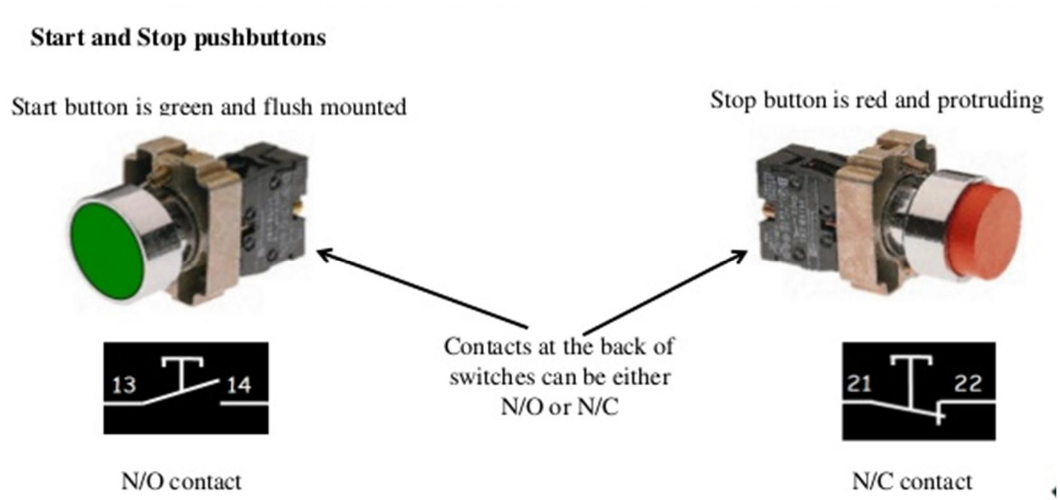

Figure 3:3 Start and Stop Pushbutton

The value of current from NEC Table 430-248 is used, rather than the nameplate current of 4.4 A.

$$2.0 \times 4.9\,A = 9.8\,A \tag{3.1}$$

3.1.3.2 Branch-Circuit Wires

The wires supplying a single motor shall have an ampere rating not less than 1.25 times the full-load current of the motor. The minimum ampere rating of the circuit wires for the motor of Figure is 6.125A.

$$1.25 \times 4.9\ A = 6.125\ A \tag{3.2}$$

Aluminum wire is seldom used for motor circuits. Most terminals in motor starters are rated only for copper wire.

3.1.3.3 Short-Circuit Protection

A branch circuit supplying a single motor is only subjected to excessive current caused by motor overloads or by ground faults and short circuits. Sometimes, a single overcurrent protective device protects against all three conditions while, in many instances, overload protection and protection from ground faults and short circuits are provided separately. First, consider them separately, and size the short- circuit and ground-fault protection for the branch circuit. The overcurrent device is either a fuse or a circuit breaker placed at the beginning of the circuit. (Unit 17 Motor Control)

Fuses are rated according to their ability to safely interrupt a given maximum value of short-circuit current flow.

Non Time Delay Fuse:

$$3.0 \times 4.9A = 14.7A \tag{3.3}$$

From the standard fuse ratings, the 15Amp Fuse was selected.

Table 3-2 Maximum setting of Ground Fault Protection

Type of Motor	Percent of Full-Load Current: Nontime Delay Fuse	Dual Element (Time-Delay) Fuse	Instantaneous Trip Breaker	*Inverse Time Breaker
Single-phase, all types				
No code letter	300	175	700	250
All ac single-phase and polyphase squirrel-cage and synchronous motors† with full-voltage, resistor or reactor starting:				
No code letter	300	175	700	250
Code letter F to V	300	175	700	250
Code letter B to E	250	175	700	200
Code letter A	150	150	700	150
All ac squirrel-cage and synchronous motors† with autotransformer starting:				
Not more than 30 amps				
No code letter	250	175	700	200
More than 30 amps				
No code letter	200	175	700	200
Code letter F to V	250	175	700	200
Code letter B to E	200	175	700	200
Code letter A	150	150	700	150
High-reactance squirrel-cage				
Not more than 30 amps				
No code letter	250	175	700	250
More than 30 amps				
No code letter	200	175	700	200
Wound-rotor—				
No code letter	150	150	700	150
Direct-current (constant voltage)				
No more than 50 hp				
No code letter	150	150	250	150
More than 50 hp				
No code letter	150	150	175	150

3.1.3.4 Overload protection

Magnetic and manual motor starters have an overload relay or trip mechanism which is activated by; heater sensitive to the motor current. The manufacturer of the motor starter provides a chart inside the motor starter listing the part number for thermal overload heaters. The heaters are sized according to the actual full-load current listed on the motor nameplate. Find the heater number from the manufacturer's list corresponding to the motor nameplate full-load current. (Unit 17 Motor Control)

A thermal protector integral with the motor and installed by the manufacturer is permitted to serve as the overload protection, *NEC Section 430-32(a) (2).* The manufacturer is required to size the thermal protector according to the multiplying factors in the *NEC.* The number of overload protective devices required for a motor is specified in the *NEC.* If fuses are used, one fuse shall be placed in each ungrounded conductor supplying the motor, *NEC Section 430-36.* The number of thermal overload heaters is specified in *NEC Table 430-37.* The minimum is one for a single-phase motor, and three for a 3-phase motor.

For our electronic starter, an overload occurs at;

$$1.15 \times 4.9\square = 4.94\square \tag{3.4}$$

Therefore when the motor draws more than 5 Amps, the relay should trip and isolate the rest of the circuit from the power supply.

3.2 Electronic starter for single phase induction motor

The main components used in the circuit comprise of a locally available step down transformer X1, two double change over relays RL2, RL3 and other discrete components shown in the figure. The main supply to the motor is routed in series with the overload relay RL1, through contacts of relay RL3.The overload relay is connected in the neutral line.

To switch on the supply to the motor, switch S1 is to be pressed momentarily, which causes the supply path to the primary of the transformer X1 to be completed via N/C contacts of relay RL1.

[redacted]Bridge Rectifier

The diode bridge is a device that changes AC to DC. The step down transformer is used to convert the higher voltage into low voltage. AC power is converted into DC using one of the electronic converters called rectifier.

During the positive half cycle of the supply, D1 and D3 conduct in series while diodes D2 and D4 are reverse biased. During the negative half cycle, D2 and D4 conduct in series but D1 and D3 switch off as they are now reverse biased. Diodes drop about 0.7volts each when operated in forward bias .So, in the bridge rectification you will drop about 1.4volts because at one instant two diodes are conducting.

[redacted]Transformer Voltage

All A.C. voltage references are R.M.S. Losses and voltage drops are also included. (Design Guide for Rectifier Use)

[illegible]. [illegible] 1.41 [illegible]. [illegible] (3.5)

[illegible]. [illegible] 0.90 [illegible]. [illegible] (3.6)

In obtaining the correct transformer to use, a drop of 1.4 volts due to the diodes means 12 volts(relay) +1.4 volts (diode)= 13.4volts. 2 or 3 volts excess than rating of the relay is required for switching since there will be slight voltage drop when the circuit works.

$$13.4\square\ \square\ 3\ \square\ 16.3\square\ \square.\square \tag{3.7}$$

$$\square\square\square\square\square\square\square\square\square\ \square\square\ \square\square\square\square\square\square\square\ \square\ \frac{\square\square.\square}{\square.\square\square\square\square\square\square}\ \square\ 11.52\square \tag{3.8}$$

$$11.52\ \square\ 0.181818\square\square\square\square\square\square\ \square\ 11.7\square \tag{3.9}$$

[redacted] Transformer Current Ratings

A transformer's A.C. current rating needs to be recalculated from the D.C. load current. The required current varies with type of rectifier chosen and filter type. The formula below is used:

$$\square\square.\square\ \square\ 0.62\ \square\ \square\square\square.\ \square\square.\square \tag{3.10}$$

$$\square\ \square\square\square\ \square\square\ \ \square\square.\ \square\ \square\ \frac{\square\square}{\square\square\square}\ \square\ 0.12\square \tag{3.11}$$

$$\square\ \square\square\square\ \square\square\ \square\square\square\square\square\square\square\square\square\ \square\square.\ \square\ \square\ \frac{\square.\square\square}{\square.\square\square}\ \square\ 0.194\square \tag{3.12}$$

Therefore a $\frac{\square\square\square}{\square\square}$volts 0.5 amps step down transformer was chosen.

The output of the diode bridge is a DC consisting of ripples also called a pulsating DC. The pulsating DC is filtered using a capacitor filter to remove the AC ripples.

[redacted] Capacitor

Capacitors are rated according to their maximum voltage and storage capacity, typically measured in micro farads. Generally, for DC power supply circuits the smoothing capacitor is an aluminum Electrolytic type that has a capacitance value of 100micro Farads or more. The larger the capacity the more the charge stored and the longer it'll take to discharge. However, a very large capacitor will take a long time to charge initially and so it will take a while before a constant voltage is output. If the current drawn from the circuit is large, then capacitor will discharge quickly and amount of ripple in output voltage will increase.

However there are two important parameters to consider when choosing suitable smoothing capacitor and this are its working voltage, which must be higher than the no load output value of the rectifier and its capacitance value which determines the amount of ripple that will be superimposed on top of the DC voltage.

[illegible] (3.14)

[illegible] (3.15)

[illegible] 0.1818V (3.16)

Where I is the DC load current, f is the frequency of the ripple or twice the input frequency and c is the capacitance in Farads.

Relay RL2 gets energized due to the DC voltage developed across capacitor C1 via the bridge rectifier. When DC current passes through the coil, magnetic field develops which attracts the moving contacts so that the contacts may break or connect. The relay coil resistance is the DC resistance of the relay. Therefore the circuit must provide sufficient current to operate the relays. Current passing through the relay can be determined using Ohmôs law.

$$\text{[illegible]} = \frac{\text{[illegible]}}{\text{[illegible]}} \qquad (3.$$

Table 3-3 Relay Coil Current

	Voltage(V)	Current(A)	Coil Resistance(Ω)
RELAY 1	240	0.570	421
RELAY 2	12	0.1	120
RELAY 3	12	0.115	104

Once the relay energizes, its N/O contacts RL2 (a) provide a short across switch S1 and supply to the primary transformer X1, becomes continuous, and hence RL2 latches even if switch S1 is subsequently opened. The other N/O contacts RL2(b) of relay RL2 ,on energization ,connect the voltage developed across capacitor C1 to relay RL3,which thus energizes and completes the supply to the motor, as long as current passing through the overload relay is within limits for the 0.5 HP motor.

RL2 acts as a latching relay. It has no default position and remains in its last position when the drive current starts flowing. This reduces energy because once actuated it requires no current flow to maintain its position. For this reason, a latching relay is useful in applications where power consumption and dissipation is limited.

When the current drawn by motor exceeds the limit (approximately 5A), RL1is energized and trips the supply to relays RL2 and RL3 which was passing via the normally closed contacts of relay RL1.As a result, the supply to the motor also trips.

Diodes D5 and D6 across relays are used for protection as freewheeling diodes. Fly back diodes are placed across the inductor so that when the relay is energized, the diode is reverse biased and does not conduct. When the relay is de energized by turning off the circuit, a large voltage spike may appear across the inductor based on the equation.

$$V = L \times \frac{di}{dt} \tag{3.16}$$

Since the current change is sudden and happens in less than microseconds, the di is finite and dt is very small, therefore voltage across coils inductance is going to be large and negative.

The danger is that the large negative voltage spikes may damage other components. However if the diode is forward biased by the spike and essentially shorts out the inductor and dissipates the spike.

Freewheeling diodes are chosen to withstand at least double the relay voltage rating.

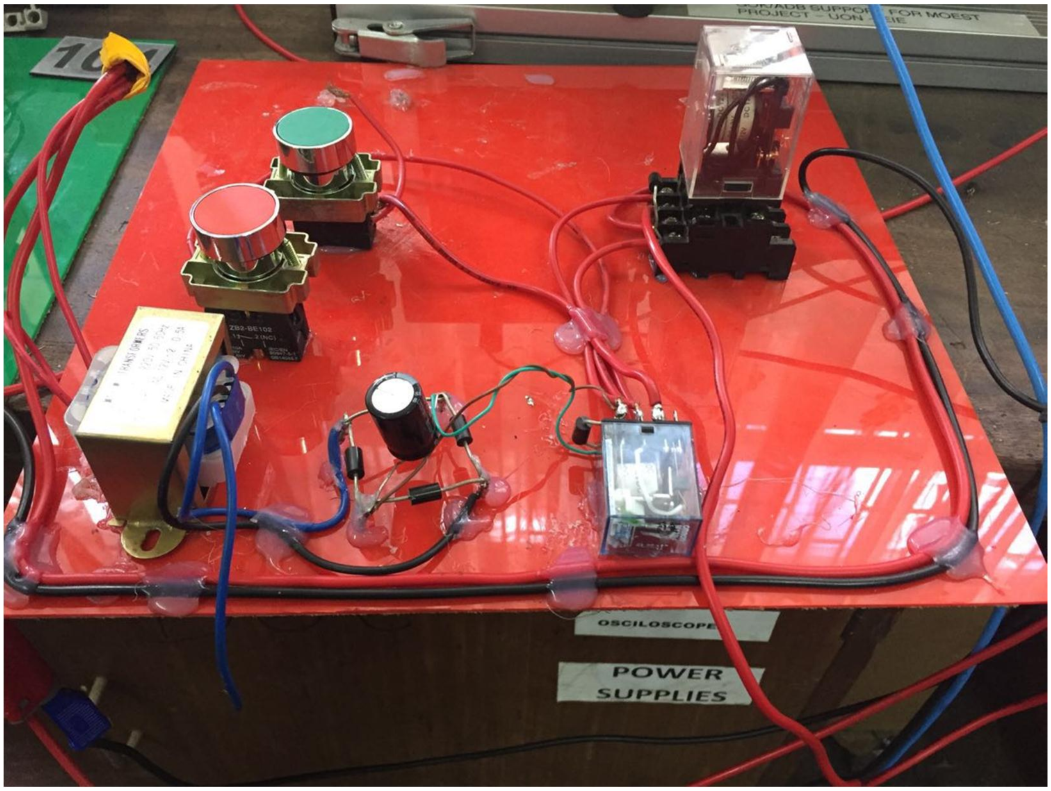

Figure 3:4 Electronic Starter for Single Phase IM

4. RESULTS

The contacts of the momentary pushbutton S1 changed state, from open to closed, when the pushbutton was pressed. It returned to its normal state as soon as the button was released. This allowed for current to pass throughout the circuit, energizing relay 2 thus providing latching and energizing relay 3 thereby using it drive a heavy current load, the motor.

The permanent split capacitor motor used only a run capacitor connected in series with the start windings to provide the phase shift required to start the motor. When a voltage was applied to the motor, current flows through the run windings to the common terminal. At the same time current flows through the run capacitor to the start windings. This produces a phase shift large enough to start the motor. Once the motor reaches running speed,start windings become auxiliary windings.

The Permanent capacitor starter was implemented. Connections made are as follows.

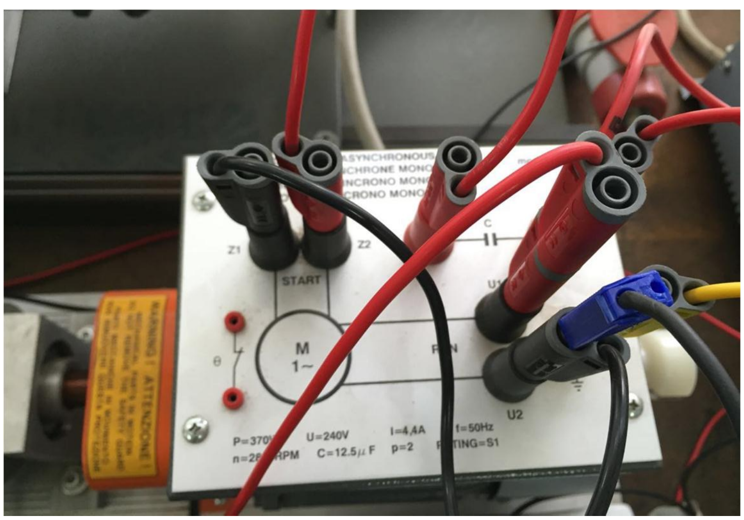

Figure 4:1 Permanent Capacitor Starter Connection Motor

As the rotors speed increases, a counter EMF is produced in the start windings which limits current to less than 1 A. This small amount of current when the motor is operating at full speed is small enough so that it will not cause start windings to overheat. This type of motor is the most preferred as there is no need for a starting mechanism.

The induction motor was loaded with a DC generator to test the overload condition.The load bank resistance was varied from maximum resistance to near minimum resistance ,that is current of 4.7A in the induction motor.

The overload relay trips thus protects my motor and generator from burning out.This is indicated by lighting of a bulb.The overload can only be reset once the bulb goes off.This is because the thermal overload relay needs to cool down before the motor can run again.

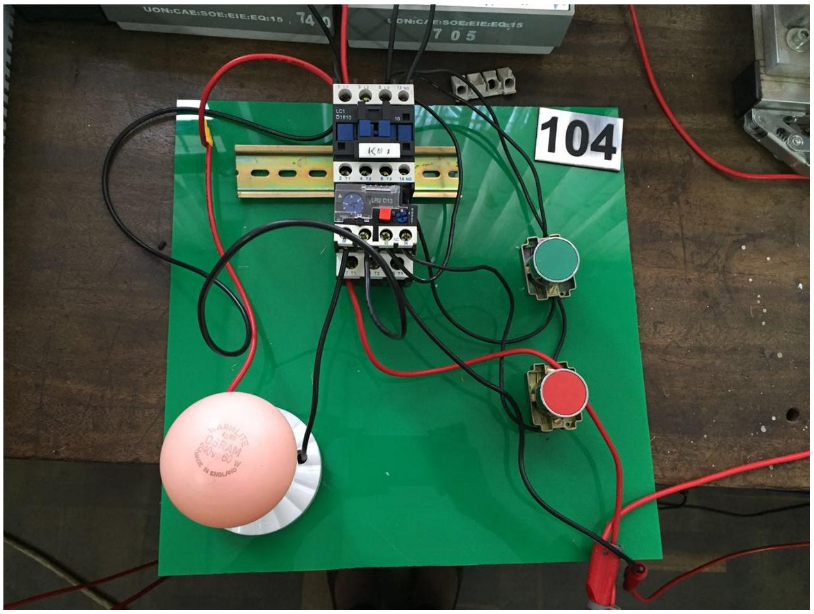

Figure 4:2 Overload Relay in Action

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The project aimed at designing an electronic starter for a single phase induction motor.

Overload relays and contactors are usually not designed to protect the motor from currents greater than about six times the normal rated current. Therefore protection from short circuit is obtained through circuit breakers and fuses placed in the power supply system.

The electronic starter features a thermal overload relay with the bi- metal strips jointly with a trip mechanism in a casing made of insulating material. Whenever an overload occurs, current heats up the bi- metal strip making them to bend and activating the trip mechanism after a particular interval based on the current setting.

The release mechanism actuates an auxiliary switch that breaks the motor contactorŝ coil. The changing position indicator signals the condition ʹtrippedʹ.

After an overload relay has operated to stop the motor, it must be reset before the motor can run again with overload protection. Magnetic overload relays can be reset immediately after tripping after tripping. Thermal overload relays must be allowed to cool a minute or longer before they can be reset.

5.2 Recommendation for future work

The areas of improvement in the project include:

1. Implementing an alternative electronic starter that is current sensitive and accurate to ensure protection of both the motor and equipment connected to it.
2. Design of a less bulky system, preferably program based that works instantly in the case of an overload.

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Appendix A - Contactor

The contactor is a latched relay. It can also be called a "momentary switch". It only requires current to be on for a "moment" for it to operate. In order to keep the contacts closed once the control current is lost, the power circuit contacts are held in position by a mechanical latch. When it is necessary to open the power circuit, the latch is released and the contacts drop open.

The contactor is operated by two coils, each with their own controlling switch. In this case, the contactor is closed or "set" by pressing the ON button and opened, or "tripped" by pressing the OFF button. Both ON and OFF buttons are sprung so that only a momentary current is used to activate the coil. (Chint)

Figure A 1 Contactor

Appendix B - Overload Relay

Relay is a sensing device which is used to sense an abnormal condition and break the circuit.

A thermal overload relay is a device to protect an electrical device like a motor/generator from catching fire/burning due to excessive heat produced during operation.The relay has a bimetallic contact that operates with temperature. When the temperature of the sysytem goes above a pre-set value, contact goes from closed operation to open and power supply to the circuit is cut and the device is saved from damages. So, it keeps the system within the safe operating temperatures. (ebay)

Figure A 2 Overload Relay

Appendix C - Overload Load Relay Wiring Terminals

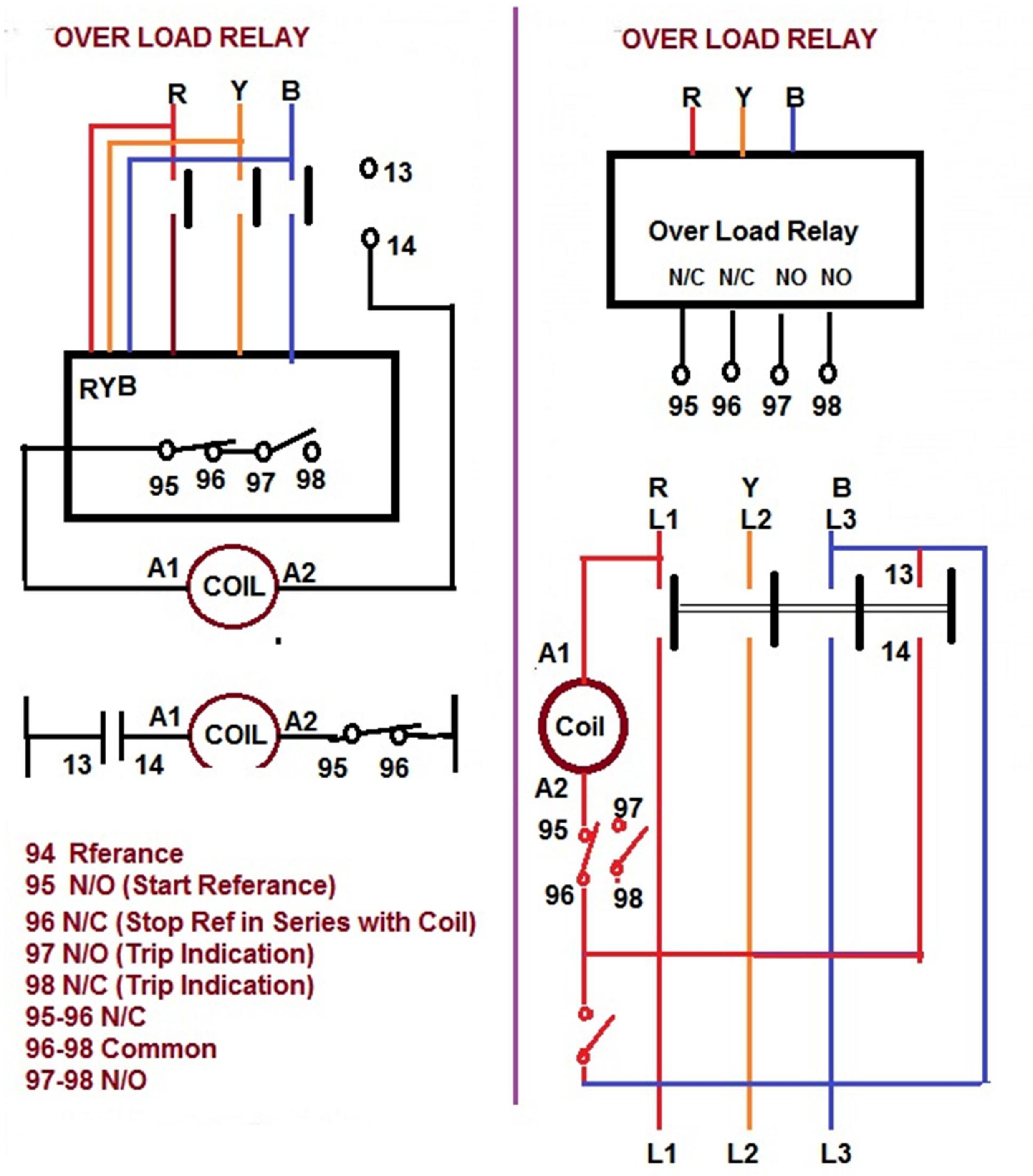

Figure A 3 Wiring Terminals of Overload Relay

Appendix D - National Electrical Code: Article 430, Part C

 (Unit 17 Motor Control)

Article 430-31. General

Part C specifies overload devices intended to protect motors, motor-control apparatus, and motor branch-circuit conductors against excessive heating due to motor overloads and failure to start.

Overload in electrical apparatus is an operating overcurrent which, when it persists for a sufficient length, would cause damage or dangerous overheating of apparatus. It does not include short circuit or ground faults.

This provisions shall not be interpreted as requiring overload protection where it might introduce additional or increased hazards, as in the case of fire pumps.

Article 430-32. Continuous Duty Motors

1. Continuous duty motor rated more than 1hp shall be protected against overload by one of the following means:

   a) A separate overload device that is responsive to motor current. This device shall be selected to trip or rated at no more than the following percent of the motor nameplate full load current rating.

      i. Motors with a marked service factor not less than 1.15 - 125%

ii. Motors with a marked temperature rise not over 40^0C - 125%

iii. All other Motors - 115%

Modification of this value shall be permitted as provided in ó430-34. Selection of Overload Relaysö.

For a Multispeed motor, each winding connection shall be considered separately. Where a separate motor overload device is so connected that it does not carry the total current designated on the motor nameplate, such as for wye delta starting, the proper percentage of the nameplate current applying to the selection or setting of the overload device shall be clearly designated on the equipment, or the manufacturerøs table shall take this into account.

2. One Horsepower or less Non-Automatically Started.

    i. Each continuous-duty motor rated at 1hp or less that is not permanently installed , is non automatically started and is within sight from the controller location shall be permitted to be protected against overload by the branch circuit, short circuit and ground fault protective device. This branch circuit protective device cannot be larger than that specified in Article 430.

    ii. Any such motor that is not in sight from the controller location shall be protected as specified in Section 430-32.Any motor rated at 1hp or less that is permanently installed shall be protected in accordance to 430-32(c)

3. One Horsepower or less, Automatically Started- Any motor of 1hp or less that is started automatically shall be protected against overload by one of the following means;

i. A separate overload device that is responsive to motor current- This device shall be selected to trip or rated at no more than the following percentage of the motor nameplate full load current rating.

ii. Motors with a marked service factor not less than 1.15 - 125%

iii. Motors with a marked temperature rise not over 40^0C - 125%

iv. All other Motors - 115%

Article 430-33. Intermittent and Similar Duty

A motor used for a condition of service that is inherently short-time, intermittent, periodic or varying duty as illustrated by Table 430-22(a), shall be permitted to be protected against overload by the branch circuit, short circuit and ground fault protective device, provided the protective device rating or setting does not exceed that specified in Table 430-152.

Any motor application shall be considered to be for continuous duty unless the nature of the apparatus it drives is such that the motor cannot operate continuously with load under any condition of use.

Where the overload relay selected in accordance with Section 430-32(a)(1) and (c) (1) is not sufficient to start the motor or carry the load, the next higher size overload relay shall be permitted to be used provided the trip current of the overload relay does not exceed the following percentage of the motor full load current rating.

- Motors with marked service factor not less than 1.15-140%
- Motors with marked temperature rise not over 40^0C-140%

- All other motors-130%

If not shunted during the start period of the motor as provided in Section 430-35, the overload device shall have sufficient time delay to permit the motor to start and accelerate its load.

Article 430-35 Shunting During Starting Periods

1. Non-automatically Started- For a non-automatically started motor the overload protection shall be permitted to be shunted or cut off of the circuit during starting period pf the motor if the device by which the overload protection is shunted or cut out cannot be left in the starting position and if fuses or inverse time circuit breakers rated or set at not over 400% of the full load current of the motor are so located in the circuit to be operative during starting period of the motor.
2. Automatically Started- The motor overload protection shall be shunted or cut out during starting period if the motor is automatically started.

Exception: The motor overload protection shall be permitted to be shunted or cut out during starting period on an automatically started motor where:

1. The motor starting period exceeds the time delay of available motor overload protective devices.
2. Listed means are provided to:
    i. Sense motor rotation and to automatically prevent the shunting or cut out in the event that the motor fails to start.
    ii. Limit the time overload protection shunting or cutout to less than the locked rotor time rating of the protected motor.

iii. Provide for shutdown and manual restart if motor running condition is not reached.

Disconnect for a single motor

A disconnect for a motor branch circuit must be capable of interrupting the locked-rotor current of the motor. This disconnecting means must disconnect both the motor and the controller from all ungrounded supply conductors, *NEC Section 430-103.* The disconnecting means must be located within sight from the motor controller, *NEC Section 430-102.* The definition of" in sight from" in *NEC Article 100* means that the controller is not more than 50 ft (15. 24 m) from the disconnect, and that the controller is actually visible when standing at the disconnect location.

A fusible switch serving as the motor circuit disconnecting means must be rated in horsepower, *NEC Section 430-109.* A circuit breaker serving as a disconnecting means is not required to be rated in horsepower but instead will be rated in amperes, *NEC Section 430-109.*

Motors with a horsepower rating not greater than 1/3 hp may use the branch-circuit overcurrent device as the disconnect, *NEC Section 430-109, Exception No. 1.*

If the motor is not larger than 2 hp, and operates at not more than 300 V, a general-use switch may serve as the disconnect, NEC Section 430-109, Exception No.2. The switch must have an ampere rating at least twice that of the full-load current of the motor.

Overload protection

Electric motors are required to be protected against overload, *NEC Section 430-32.* Overload protection is usually provided as a device responsive to motor current or as a thermal protector integral with the motor. A device responsive to motor current could be a fuse, a circuit breaker, an overload heater, or a thermal reset switch in the motor housing. An automatically resetting thermal switch placed in the windings will sense winding temperature directly.

The service factor or temperature rise must be known from the motor nameplate when selecting the proper size motor overload protection. These are indicators of the amount of overload a motor can withstand. If a motor has a service factor of 1. 15 or greater, the manufacturer has designed extra overload capacity into the motor. In this case, the overload protection may be sized as large as 125% of the nameplate full-load current. Internal heat is damaging to motor-winding insulation. A motor with a temperature rise of 40°C, or less has been designed to run relatively cool; therefore, it has greater overload capacity. The overload protection may be sized as large as 125% of the *nameplate* full-load current. A service factor of less than 1. 15 or a temperature rise of more than 40°C (104 °F) indicates little overload capacity. The overload protection under these circumstances is sized not larger than 115% of the nameplate full-load current. Size the motor overload protective device at not more than these percent of nameplate full-load current:

1. Service factor 1. 15 or greater, 125%
2. Temperature rise not greater than 40°C, 125%
3. Service factor smaller than 1.15, 115%
4. Temperature rise greater than 40°C (104°F), 115%

Appendix E - NEC Table 430.52

Table E 1 Maximum setting of Ground Fault Protection

Type of Motor	Percent of Full-Load Current: Nontime Delay Fuse	Dual Element (Time-Delay) Fuse	Instantaneous Trip Breaker	*Inverse Time Breaker
Single-phase, all types				
No code letter	300	175	700	250
All ac single-phase and polyphase squirrel-cage and synchronous motors† with full-voltage, resistor or reactor starting:				
No code letter	300	175	700	250
Code letter F to V	300	175	700	250
Code letter B to E	250	175	700	200
Code letter A	150	150	700	150
All ac squirrel-cage and synchronous motors† with autotransformer starting:				
Not more than 30 amps				
No code letter	250	175	700	200
More than 30 amps				
No code letter	200	175	700	200
Code letter F to V	250	175	700	200
Code letter B to E	200	175	700	200
Code letter A	150	150	700	150
High-reactance squirrel-cage				
Not more than 30 amps				
No code letter	250	175	700	250
More than 30 amps				
No code letter	200	175	700	200
Wound-rotor—				
No code letter	150	150	700	150
Direct-current (constant voltage)				
No more than 50 hp				
No code letter	150	150	250	150
More than 50 hp				
No code letter	150	150	175	150

Appendix F - Starter

1. **Overcurrent-**Any current in excess of the rated current of equipment or ampacity of conductor and may result in an overload condition, a short circuit condition or a ground fault condition.

2. **Overload** -Operation of equipment in excess of normal, full load rating, or of a conductor in excess of rated capacity that, when it persists for a sufficient length of time, would cause damage or dangerous overheating. A fault such as a short circuit or ground fault is not an overload.

3. **Overload protection devices-**This are devices that are intended to protect motors, motor control equipment and branch circuit conductors from excessive heating due to motor overloads. Also referred to as running protection.

4. **Branch circuit and Ground fault protection devices-**This are devices that are intended to protect the motor, the motor control apparatus and conductors against short circuits or ground faults, but not intended to protect against overload. Protection devices include fuses, circuit breaker or Motor Circuit Protector.

5. **Heater-** The amount of current drawn when the motor is first switched on. This can be 6 to 8 times the normal running current.

6. **Locked Rotor Amps-** The maximum amount of current a motor can draw when it is so overloaded that the motor cannot. This is generally enough to cause the insulation to fail and the motor to burn up.