A

REPORT ON

# "PROTECTION SYSTEM OF THREE PHASE INDUCTION MOTOR USING RELAYS"

(INFORMATIVE REPORT)

2015-16

SUBMITTED BY:

STUDENTS OF FINAL YEAR **ELECTRICAL**

UNDER THE GUIDANCE OF

Prof. VIVEK TIWARI

Anjuman-I-Islam
KALSEKAR TECHNICAL CAMPUS
School of Engineering and Technology
New Panvel

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Submitted to:

Prof. VIVEK TIWARI

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We are particularly grateful for the work done by members of my group. Before we get into this report we would like to thanks to the members of the group who are a part of this report and have given their unending contribution from start to end of this report.

We would like to our **Prof. VIVEK TIWARI** for providing as the required guidance in process of preparing the report. We would also like to express our deep regards and gratitude to the director **Dr. ABDUL RAZZAK HONNUTAGI**.

Finally, I would also like to thanks GOOGLE and WIKIPEDIA for the same.

# PREFACE

We take the opportunity to present this report "**PROTECTION SYSTEM OF THREE PHASE INDUCTION MOTOR BY USING RELAYS".** The object of this report is to focus the various methods to protect induction motor by various faults.

The report is supported by graphs and images to bring out the purpose and message. We have made sincere attempts and taken every care to present this report in precise and compact form, the language being as simple as possible.

The task of completion of the project though being difficulty was made quite simple, interesting and successful due to deep involvement and complete dedication of our group members.

# CERTIFICATE

This is to certify that the report entitled "**PROTECTION SYSTEM OF THREE PHASE INDUCTION MOTOR BY USING RELAYS**" submitted by **SHAIKH MD. AMIR, SHAIKH MOHD. ZEESHAN, SHAIKH MOHSIN, SIDDIQUI MOHAMMED SAAD** in partial fulfillment of the requirement for the award of Bachelor of engineering in "**ELECTRICAL ENGINEERING**" is an authentic word carried by them under my supervision and guidance.

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## ABSTRACT

Three-phase induction motors are accountable for 85 percent of the installed capacity of the industrial driving systems. Therefore, the protection of these motors is necessary for reliable operation of loads.

This report tends to develop for protection of three phase induction motor from single phasing, over current, phase reversal, over voltage and under voltage. Due to this electrical fault the winding of motor get heated which lead to insulation failure and thus reduce the life time of motor. This fault is generated in induction motor due to variation in induction motor parameters. When three phase induction motor runs continuously, it is necessary to protect the motor from these anticipated faults. Three phase induction motor generally directly connected through the supply, if the supply voltage has sag and swell due to fault the performance of motor is affected and in some cases winding is burned out. When phase sequence (RYB) is reversed due to wrong connection then motor start rotating in another direction, if supply system has only one phase and other phase is disconnected then it is single phasing problem. If there is problem of under or over voltage then this can harm motor severely or even it can damage it permanentaly.

# DECLARATION

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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# CHAPTER 1

## INTRODUCTION

An induction or asynchronous motor is an AC electric motor in which the electric current in the rotor needed to produce torque is obtained by electromagnetic induction from the magnetic field of the stator winding. An induction motor therefore does not require mechanical commutation, separate-excitation or self-excitation for all or part of the energy transferred from stator to rotor, as in universal, DC and large synchronous motors. An induction motor's rotor can be either wound type or squirrel-cage type.

Three-phase squirrel-cage induction motors are widely used in industrial drives because they are rugged, reliable and economical. Single-phase induction motors are used extensively for smaller loads, such as household appliances like fans. Although traditionally used in fixed-speed service, induction motors are increasingly being used with variable-frequency drives (VFDs) in variable-speed service. VFDs offer especially important energy savings opportunities for existing and prospective induction motors in variable-torque centrifugal fan, pump and compressor load applications. Squirrel cage induction motors are very widely used in both fixed-speed and variable-frequency drive (VFD) applications. Variable voltage and variable frequency drives are also used in variable-speed service.

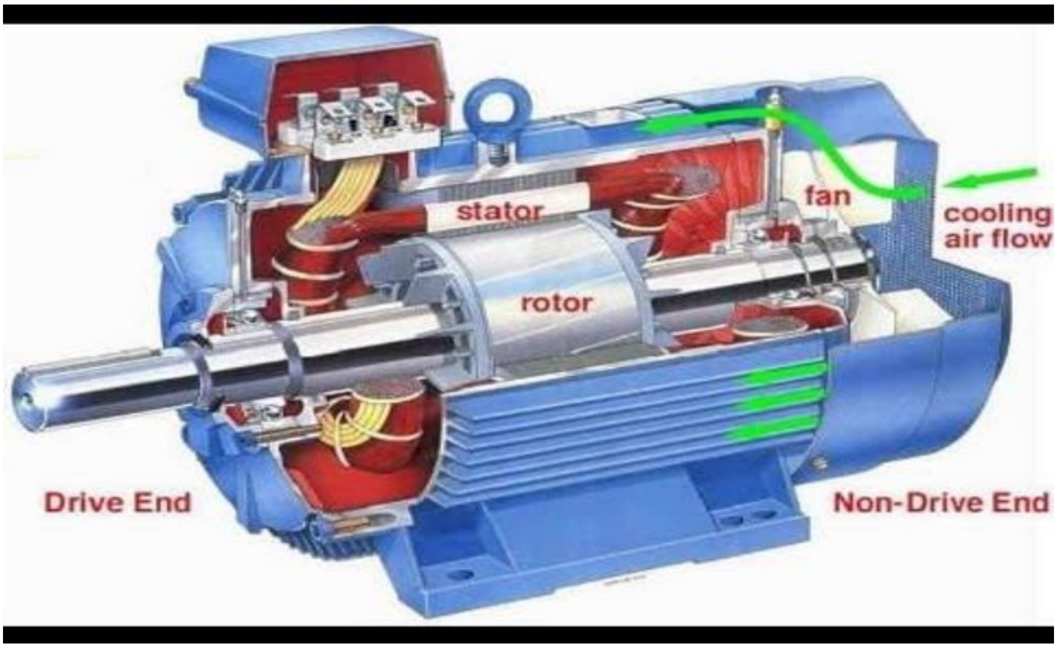


Fig 1.1 Induction motor

## 1.1 CONSTRUCTION

Just like any other motor, a 3 phase induction motor also consists of a stator and a rotor. Basically there are two types of 3 phase IM - 1. Squirrel cage induction motor and 2. Phase Wound induction motor (slip-ring induction motor). Both types have similar constructed rotor, but they differ in construction of rotor. This is explained further.

### 1.1.1 STATOR

The stator of a 3 phase IM (Induction Motor) is made up with number of stampings, and these stampings are slotted to receive the stator winding. The stator is wound with a 3 phase winding which is fed from a 3 phase supply. It is wound for a defined number of poles, and the number of poles is determined from the required speed. For greater speed, lesser number of poles is used and vice versa. When stator windings are supplied with 3 phase ac supply, they produce alternating flux which revolves with synchronous speed. The synchronous speed is inversely proportional to number of poles ($N_s = 120f / P$). This revolving or rotating magnetic flux induces current in rotor windings according to Faraday's law of mutual induction.

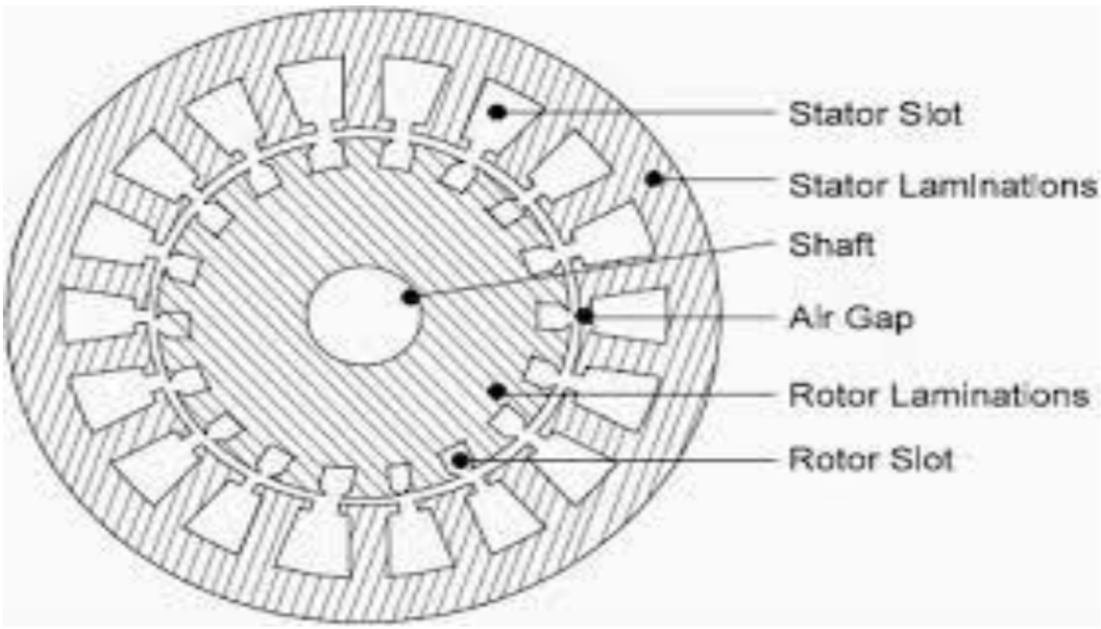


Fig 1.2 Three Phase Stator

## 1.1.2 ROTOR

Rotor of a 3 phase induction motor can be of either two types, squirrel cage rotor and phase wound rotor (or simply - wound rotor).

### SQUIRREL CAGE ROTOR

The motor rotor shape is a cylinder mounted on a shaft. Internally it contains longitudinal conductive bars (usually made of aluminum or copper) set into grooves and connected at both ends by shorting rings forming a cage-like shape. The name is derived from the similarity between this rings-and-bars winding and a squirrel cage. The field windings in the stator of an induction motor set up a rotating magnetic field through the rotor.

The relative motion between this field and the rotor induces electric current in the conductive bars. In turn these currents lengthwise in the conductors react with the magnetic field of the motor to produce force acting at a tangent orthogonal to the rotor, resulting in torque to turn the shaft. In effect the rotor is carried around with the magnetica slightly slower rate of rotation. The difference in speed is called slip and increases with load.

The conductors are often skewed slightly along the length of the rotor to reduce noise and smooth out torque fluctuations that might result at some speeds due to interactions with the pole pieces of the stator. The number of bars on the squirrel cage determines to what extent the induced currents are fed back to the stator coils and hence the current through them. The constructions that offer the least feedback employ prime numbers of bars.

The iron core serves to carry the magnetic field through the rotor conductors. Because the magnetic field in the rotor is alternating with time, the core uses construction similar to a transformer core to reduce core energy losses. It is made of thin laminations, separated by varnish insulation, to reduce eddy currents circulating in the core. The material is a low carbon but high silicon iron with several times the resistivity of pure iron, further reducing eddy-current loss, and low coercivity to reduce hysteresis loss.

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The same basic design is used for both single-phase and three-phase motors over a wide range of sizes. Rotors for three-phase will have variations in the depth and shape of bars to suit the design classification. Generally, thick bars have good torque and are efficient at low slip, since they present lower resistance to the EMF. As the slip increases, skin effect starts to reduce the effective depth and increases the resistance, resulting in reduced efficiency but still maintaining torque.

Most of the induction motors (upto 90%) are of squirrel cage type. Squirrel cage type rotor has very simple and almost indestructible construction. This type of rotor consist of a cylindrical laminated core, having parallel slots on it. These parallel slots carry rotor conductors. In this type of rotor, heavy bars of copper, aluminum or alloys are used as rotor conductors instead of wires.

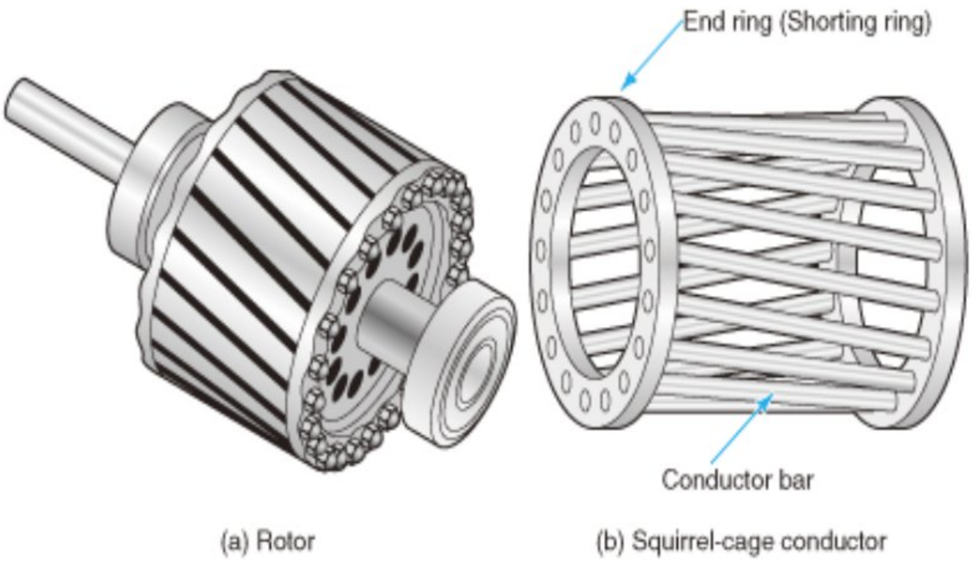


Fig 1.3 Three Phase Squirrel Cage Rotor

## PHASE WOUND ROTOR

A wound-rotor motor is a type of induction motor where the rotor windings are connected through slip rings to external resistances. Adjusting the resistance allows control of the speed/torque characteristic of the motor. Wound-rotor motors can be started with low inrush current, by inserting high resistance into the rotor circuit; as the motor accelerates, the resistance can be decreased.

Compared to a squirrel-cage rotor, the rotor of the slip ring motor has more winding turns; the induced voltage is then higher, and the current lower, than for a squirrel-cage rotor. During the start-up a typical rotor has 3 poles connected to the slip ring. Each pole is wired in series with a variable power resistor. When the motor reaches full speed the rotor poles are switched to short circuit. During start-up the resistors reduce the field strength at the stator. As a result the inrush current is reduced. Another important advantage over squirrel-cage motors is higher starting torque.

A wound-rotor motor can be used in several forms of adjustable-speed drive. Certain types of variable-speed drives recover slip-frequency power from the rotor circuit and feed it back to the supply, allowing wide speed range with high energy efficiency. Doubly fed electric machines use the slip rings to supply external power to the rotor circuit, allowing wide-range speed control. Today speed control by use of slip ring motor is mostly superseded by induction motors with variable-frequency drives.

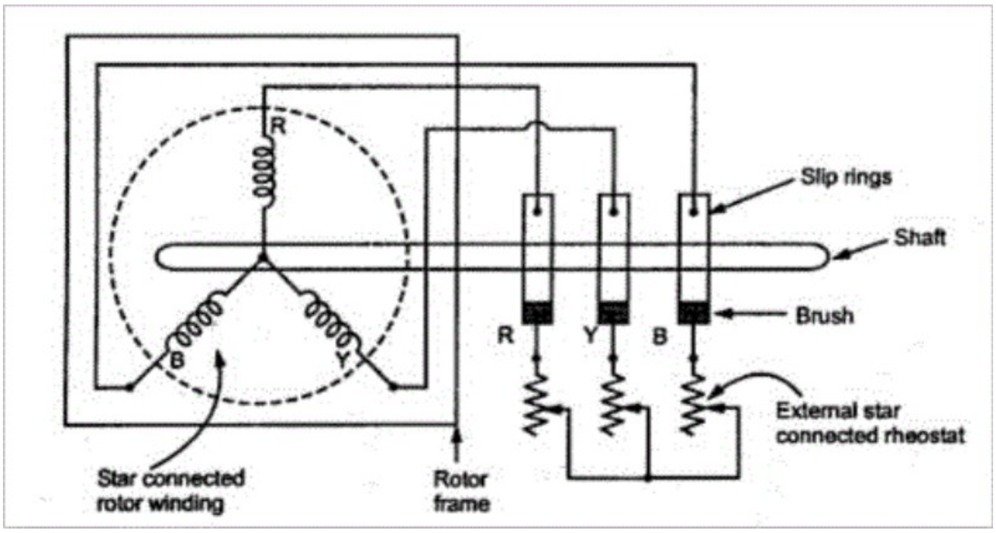


Fig 1.4 Phase Wound Rotor

## 1.3 PRINCIPLE OF OPERATION

An electrical motor is such an electromechanical device which converts electrical energy into a mechanical energy. In case of three phase AC operation, most widely used motor is Three phase induction motor as this type of motor does not require any starting device or we can say they are self starting induction motor. For better understanding the principle of three phase induction motor, the basic constructional feature of this motor must be known to us. This Motor consists of two major parts: Stator: Stator of three phase induction motor is made up of numbers of slots to construct a 3 phase winding circuit which is connected to 3 phase AC source. The three phase winding are arranged in such a manner in the slots that they produce a rotating magnetic field after AC is given to them. Rotor: Rotor of three phase induction motor consists of cylindrical laminated core with parallel slots that can carry conductors. Conductors are heavy copper or aluminum bars which fits in each slots & they are short circuited by the end rings. The slots are not exactly made parallel to the axis of the shaft but are slotted a little skewed because this arrangement reduces magnetic humming noise & can avoid stalling of motor.

The stator of the motor consists of overlapping winding offset by an electrical angle of 120°. When the primary winding or the stator is connected to a 3 phase AC source, it establishes a rotating magnetic field which rotates at the synchronous speed. Secrets behind the rotation: According to Faraday's law an emf induced in any circuit is due to the rate of change of magnetic flux linkage through the circuit. As the rotor winding in an induction motor are either closed through an external resistance or directly shorted by end ring, and cut the stator rotating magnetic field, an emf is induced in the rotor copper bar and due to this emf a current flows through the rotor conductor. Here the relative velocity between the rotating flux and static rotor conductor is the cause of current generation; hence as per Lenz's law the rotor will rotate in the same direction to reduce the cause i.e. the relative velocity.

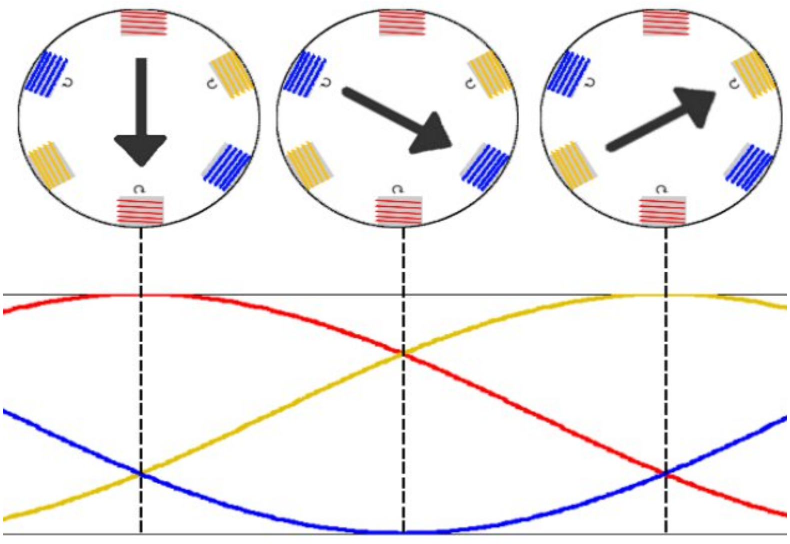

**Fig 1.5 Operating Principle Of Three Phase Induction Motor**

## 1.4 TERMS RELATED TO INDUCTION MOTOR

### SYNCHRONOUS SPEED :

An AC motor's synchronous speed, $n_s$, is the rotation rate of the stator's magnetic field,

$$n_s = \frac{120f}{p}$$

where $f$ is the motor supply's frequency, where $p$ is the number of magnetic poles and where $n_s$ and $f$ have identical units .That is, for a four-pole three-phase motor with two pole-pairs set 180° apart, $p$ equals 4,thus

$$n_s = \frac{120f}{4}$$

which equals 25 Hz (1,500 RPM) and 30 Hz (1,800 RPM) respectively for 50 Hz and 60 Hz supply systems.

### SLIP :

Slip, $s$, is defined as the difference between synchronous speed and operating speed, at the same frequency, expressed in rpm or in percent or ratio of synchronous speed. Thus

$$s = \frac{n_s - n_r}{n_s}$$

Where $n_s$ is stator electrical speed, $n_r$ is rotor mechanical speed. Slip, which varies from zero at synchronous speed and 1 when the rotor is at rest, determines the motor's torque. Since the short-circuited rotor windings have small resistance, a small slip induces a large current in the rotor and produces large torque. At full rated load, slip varies from more than 5% for small or special purpose motors to less than 1% for large motors. These speed variations can cause load-sharing problems when differently sized motors are mechanically connected. Various methods are available to reduce slip, VFDs often offering the best solution.

### EFFICIENCY :

Full load motor efficiency varies from about 85% to 97%, related motor losses being broken down roughly as follows:

- Friction and windage, 5% – 15%
- Iron or core loss, 15% – 25%
- Stator losses, 25% – 40%

- Rotor losses, 15% – 25%
- Stray load losses, 10% – 20%.

Efficiency is defined as the ratio of the output to that of input,

$$Efficiency,\ \eta = \frac{output}{input}$$

## POWER FACTOR :

The power factor of an AC electric power system is defined as the ratio of the active (true or real) power to the apparent power. Where,

- Active (Real or True) Power is measured in watts (W) and is the power drawn by the electrical resistance of a system doing useful work.
- Apparent Power is measured in volt-amperes (VA) and is the voltage on an AC system multiplied by all the current that flows in it. It is the vector sum of the active and the reactive power.
- Reactive Power is measured in volt-amperes reactive (VAR). Reactive Power is power stored in and discharged by inductive motors, transformers and solenoids.

It is common to define the Power Factor - PF - as the cosine of the phase angle between voltage and current - or the "cosφ".

PF = cos φ
Where,
PF = power factor
φ = phase angle between voltage and current

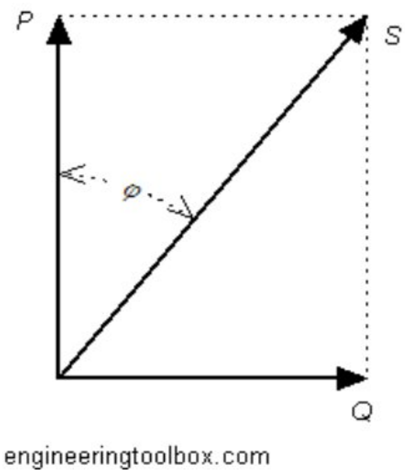


**Fig 1.6 Power Factor**

**Table 1.1 Typical Motor Power Factor**

| Power (hp) | Speed (rpm) | Power Factor | | |
|---|---|---|---|---|
| | | 1/2 load | 3/4 load | full load |
| 0 - 5 | 1800 | 0.72 | 0.82 | 0.84 |
| 5 - 20 | 1800 | 0.74 | 0.84 | 0.86 |
| 20 - 100 | 1800 | 0.79 | 0.86 | 0.89 |
| 100 - 300 | 1800 | 0.81 | 0.88 | 0.91 |

1 hp = 745.7 W

## 1.5 APPLICATIONS OF THREE PHASE INDUCTION MOTOR

Three-phase induction motors are accountable for 85 percent of the installed capacity of the industrial driving systems. These motors are used in various industries for the following purposes.

- Fans, Blowers
- Pumps, Compressors
- Grinders, Chippers
- Conveyors, Shredders
- Crushers, Mixers
- Cranes, Extruders
- Refiners, Chillers

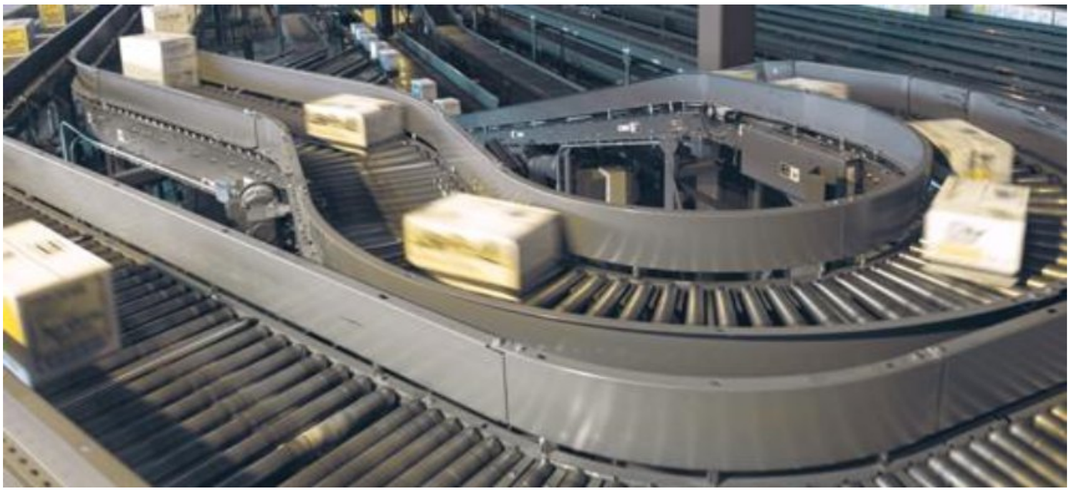

**Fig 1.7 Conveyers**

**Fig 1.8 Pumps**

# CHAPTER 2

## FAULTS IN INDUCTION MOTOR

### 2.1 TYPES OF FAULTS

- Over voltage
- Single phasing
- Under voltage
- Over current(over load)
- Over temperature
- Phase reversal

### 2.2 NECESSITY OF MOTOR PROTECTION

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

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 or chemicals.

The approximate percentages of by these individual faults are:

| | |
|---|---|
| • overload | 30% |
| • insulation damage | 20% |
| • phase failure | 14% |
| • bearing damage | 13% |
| • ageing | 10% |
| • rotor damage | 5% |
| • others | 8% |

Therefore, the following points must be observed to guarantee fault-free operation of an electrical drive:
• Correct design: a suitable motor has to be selected for each application.
• Professional operation: professional installation and regular maintenance are preconditions for fault-free operation.
• 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.

Table represents a summary of the most frequent breakdown causes for motors, their extent and the possible damage caused.

Table 2.1 Breakdown Causes For Motor

| Cause | Effect | Possible damage |
| --- | --- | --- |
| Thermal overload:<br>extreme starting conditions<br>locked rotor<br>high overload<br>under voltage<br>intermittent operation | overcurrent and<br>thus unacceptable<br>heating-up<br>of windings | soldered joint<br>damage rotor cage<br>burnt windings<br>stator windings |
| Cooling problems:<br>restricted cooling<br>ambient temperature too high | unacceptable<br>heating-up | burnt windings stator<br>windings |
| Electrical causes:<br>single phase conditions<br>unbalanced voltage<br>earth fault<br>shorted turns<br>winding short circuit | unbalanced<br>overcurrent of<br>windings heating-up<br>depending on motor<br>size and bearing<br>damage load | individual windings<br>or parts burnt |
| Mechanical causes:<br>imbalance<br>miss-alignment<br>improperly installed drive (e.g.,<br>bearing load of V-belts too high) | uneven wear of<br>bearings | bearing damage |

## 2.3 BLOCK DIAGRAM

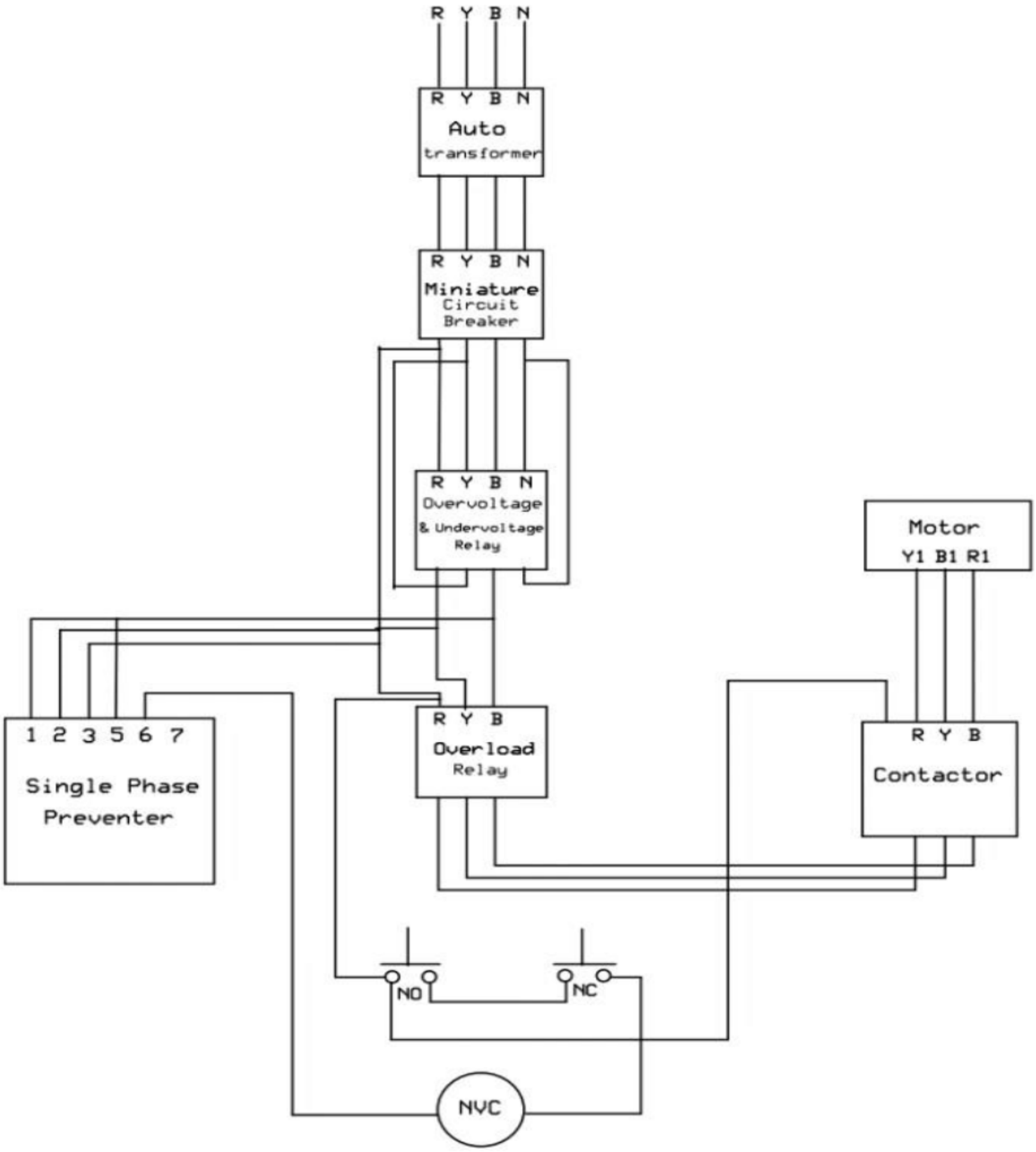


Fig 2.1 Block Diagram Of Our Protection System

# CHAPTER 3

## SINGLE PHASING OF THREE PHASE INDUCTON MOTOR

For proper working of any 3 phase induction motor it must be connected to a 3 phase alternating current (ac) power supply of rated voltage and load. Once these three phase motors are started they will continue to run even if one of the three phase supply lines gets disconnected. The loss of current through one of these phase supply is described as single phasing.

Single phasing can be identified by special protective relays which can identify and isolate the connected loads. Smaller motors rely on overcurrent and negative phase sequence relays. Motor protection relays for larger motors come readily fitted with protection against single phasing.
It has to be differentiated between:

• ***Motors in star connection:*** these motors are not put at risk by a phase failure. The currents in the motor windings, during disturbed and undisturbed operation at the failure of a single conductor, equal the currents in the other two. Due to the increasing current, a higher power loss occurs in both live windings. On the whole, the motor is running cool, since the third cold winding causes a temperature compensation. In case of an over current ,a protective current detector trips in time. Small to medium-sized (stator-critical) motors in star connection are usually not put at risk during a phase failure.

• ***Motors in delta connection***: In delta connection, the phase currents in undisturbed operation are lower by a factor $1/\sqrt{3}$ than the currents in the windings ISTR = 0.58 In. During the failure of a phase, the current increases for electromagnetic reasons by approximately 50%, In the other two windings, which are now switched in series, the current falls to approximately 67%. This phenomenon occurs because the motor keeps the power transmitted to the shaft practically constant. The absolute current increase in the windings and in both intact phases depends on the load applied.

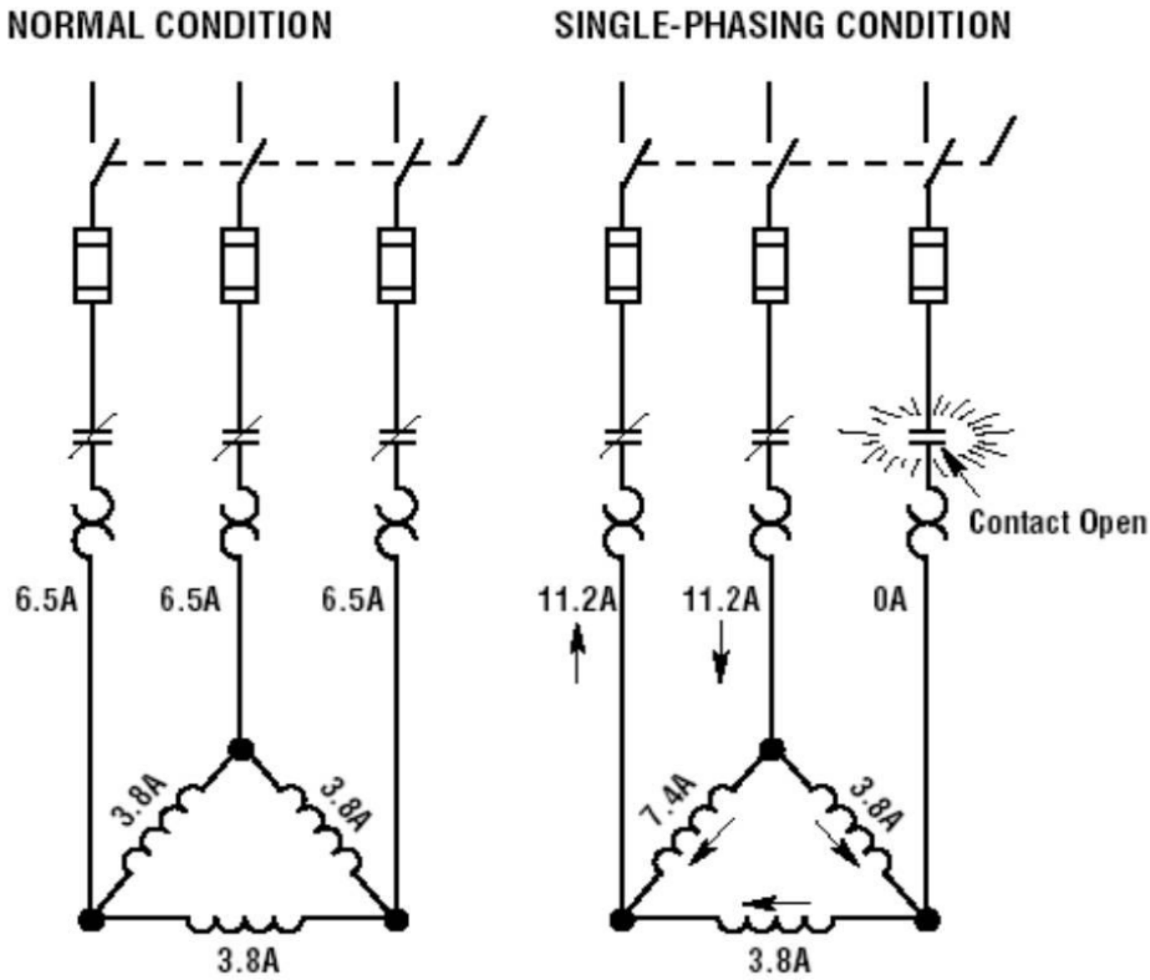


**Fig 3.1 Phase failure of a motor in star connection. Current flow in undisturbed and disturbed operation.**

$I_L$ $I_{Str}$
Currents in the phases and windings in undisturbed operation.

$I_{L1}$ $I_{Str1}$ $I_{Str2}$
Currents in the phases and windings in disturbed operation.

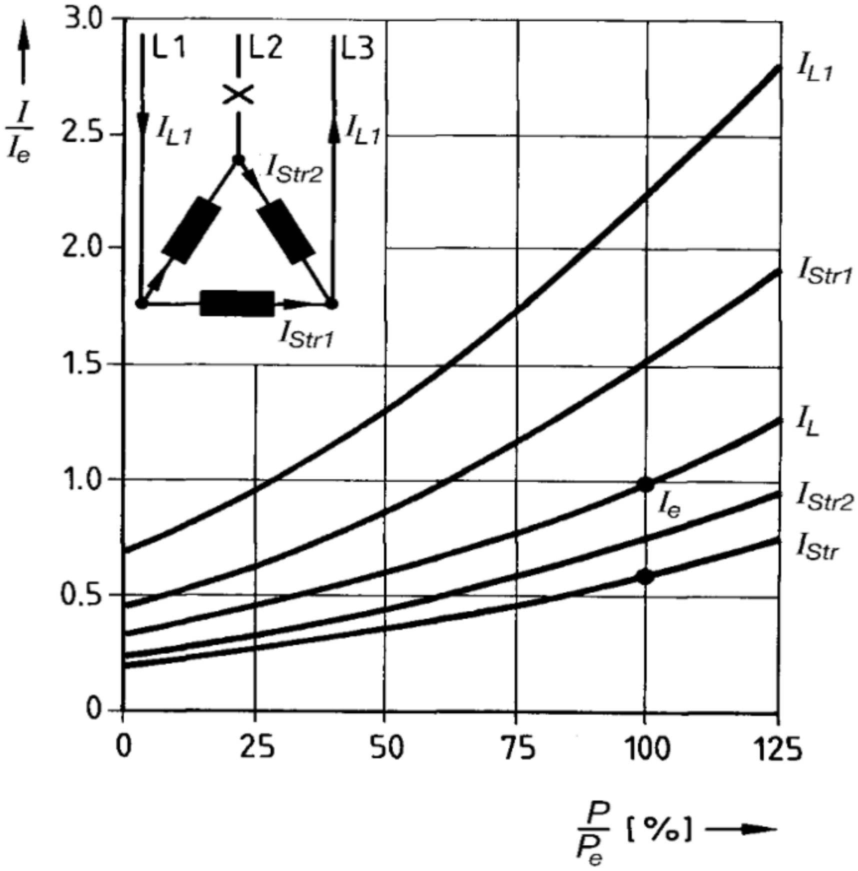


**Fig 3.2 Phase failure of a motor in delta connection. Current flow during undisturbed and disturbed operation as function of the load.**

Since the currents in the windings are not equal, they do not warm up equally either. Since heat is exchanged between individual windings and between windings and the iron body, the warming up of the stator is proportional to the sum of all losses in all windings. In general, the following applies for motors with an output of:

- Pe ≤ 10kW: they do not require a special phase failure protection, as long as the two-phase trip current is ≤ 1.25 Ie . In this case, the warming up is, at the most equal, to the warming up during a symmetrical, three-phase load.

- Pe ≥ 10 kW: for these motors, a motor protector with phase failure protection or a quick-response electronic protector is recommended. Besides electrical protection, the fast cut-out also contributes to reduced stress on the bearings. Many companies and electricity company's factory regulations demand phase-failure sensitive motor protection mainly for bigger drives, or for systems with an increased safety requirement.

For a single-phase feed of the stator, the rotor losses are considerably higher compared to a symmetrical feed. This can represent an additional danger, especially for rotor-critical motors.

## 3.1 EFFECTS OF SINGLE PHASING

**The following are the effects of single phasing:**

- Due to single phasing the current in the remaining two phases increases and it is approximately 2.4 times the normal current value.
- Single Phasing reduces the speed of the motor.
- The motor becomes noisy and starts vibrating due to uneven torque produced in the motor.
- If the motor is arranged for standby and automatic starting then the motor will not start, and if the overload relay provided fails to function then the motor may burn.
- The windings will melt due to overheating and can give a fatal shock to the personnel.
- It may cause overloading of the generator.

## 3.2 PREVENTION FROM SINGLE PHASING IN MOTOR

There are various types of protection relays which are used in the protection of three phase motor. Single phasing preventer will detect the occurrence of single phasing and it will trip the motor from circuit.

Single phasing preventer will trip the motor after some time, which is after few seconds .if the motor is used in industries where it should trip instantly, timer circuit is connected in the circuit which will trip the motor instantly.

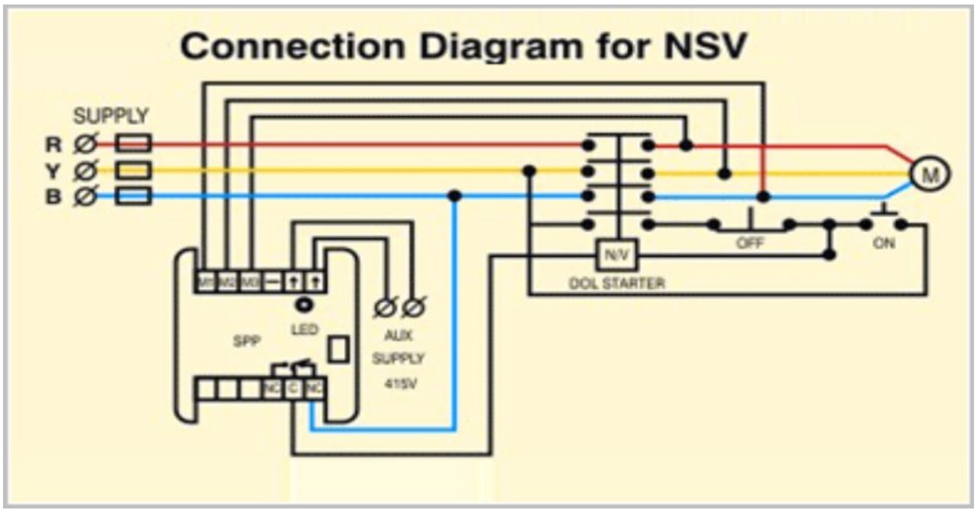


**Fig 3.3 Connection Diagram Of Single Phasing Preventer**


**Fig 3.4 Single Phasing Preventer**

# CHAPTER 4

## OVER LOADING OF THREE PHASE INDUCTION MOTOR

For understanding motor thermal overload protection in induction motor we can discuss the operating principle of three phase induction motor. There is one cylindrical stator and a three phase winding is symmetrically distributed in the inner periphery of the stator. Due to such symmetrical distribution, when three phase power supply is applied to the stator winding, a rotating magnetic field is produced. This field rotates at synchronous speed. The rotor is created in induction motor mainly by numbers solid copper bars which are shorted at both ends in such a manner that they form a cylinder cage like structure. This is why this motor is also referred as squirrel cage induction motor. Anyway let's come to the basic point of three phase induction motor - which will help us to understand clearly about motor thermal overload protection.

As the rotating magnetic flux cuts each of the bar conductor of rotor, there will be an induced circulating current flowing through the bar conductors. At starting the rotor is stand still and stator field is rotating at synchronous speed, the relative motion between rotating field and rotor is maximum. Hence the rate of cuts of flux with rotor bars is maximum, the induced current is maximum at this condition. But as the cause of induced current is, this relative speed, the rotor will try to reduce this relative speed and hence it will start rotating in the direction of rotating magnetic field to catch the synchronous speed. As soon as the rotor will come to the synchronous speed this relative speed between rotor and rotating magnetic field becomes zero, hence there will not be any further flux cutting and consequently there will not be any induced current in the rotor bars. As the induced current becomes zero, there will not be any further need of maintaining zero relative speed between rotor and rotating magnetic field hence rotor speed falls. As soon as the rotor speed falls the relative speed between rotor and rotating magnetic field again acquires a non zero value which again causes induced current in the rotor bars then rotor will again try to achieve the synchronous speed and this will continue till the motor is switch on. Due to this phenomenon the rotor will never achieve the synchronous speed as well as it will never stop running during normal operation. The difference between the synchronous speed with rotor speed in respect of synchronous speed, is termed as slip of induction motor.

The slip in a normally running induction motor typically varies from 1% to 3 % depending upon the loading condition of the motor. Now we will try to draw speed current characteristics of induction motor – let’s have an example of large boiler fan.

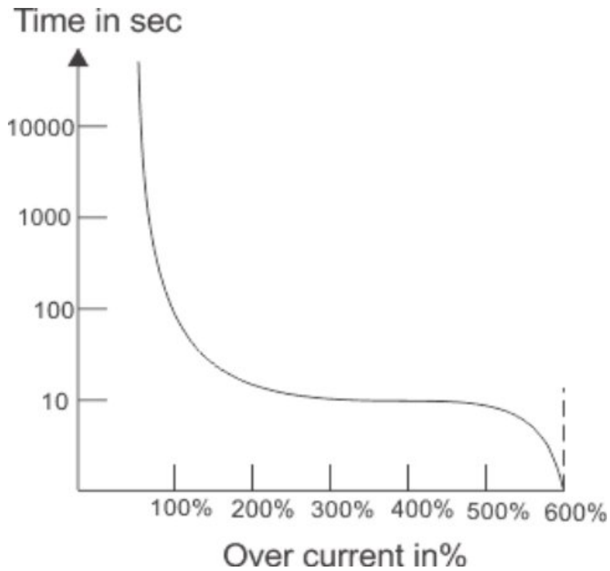


**Fig 4.1 Time v/s Over Current Graph**

In the characteristic Y axis is taken as time in second, X axis is taken as % of stator current. When rotor is stand still that is at starting condition, the slip is maximum hence the induced current in the rotor is maximum and due to transformation action, stator will also draw a heavy current from the supply and it would be around 600% of the rated full load stator current. As the rotor is being accelerated the slip is reduced, consequently the rotor current hence stator current falls to around 500% of the full load rated current within 12 seconds when the rotor speed attains 80% of synchronous speed. After that the stator current falls rapidly to the rated value as the rotor reaches its normal speed.

Now we will discuss about thermal over loading of electrical motor or over heating problem of electric motor and the necessity of motor thermal overload protection. Whenever we think about the overheating of a motor, the first thing strikes in our mind is over loading. Due to mechanical over loading of the motor draws higher current from the supply which leads to excessive over heating of the motor. The motor can also be excessively over heated if the rotor is mechanically locked i.e. becomes stationary by any external mechanical force. In this situation the motor will draw excessively high current from the supply which also leads to thermal over loading of electrical motor or excessive over heating problem. Another cause of overheating is low supply voltage. As the power id drawn by the motor from the supply depends upon the loading condition of the motor, for lower supply voltage, motor will draw higher current from mains to maintain required torque. Single phasing also causes thermal over loading of motor. When one phase of the supply is out of service, the remaining two phases draw higher current to maintain required load torque and this leads to overheating of the motor. Unbalance condition between three phases of supply also causes over heating of the motor winding, as because unbalance system results to negative sequence current in the stator winding. Again, due to sudden loss and reestablish of supply voltage may cause excessive heating of the motor. Since due to sudden loss of supply voltage, the motor is de-accelerated and due to sudden reestablishment of voltage the motor is accelerated to achieve its rated speed and hence for that motor draws higher current form the supply.

As the thermal over loading or over heating of the motor may lead to insulation failure and damage of winding, hence for proper motor thermal overload protection, the motor should be protected against the following conditions.

1. Mechanical over loading,
2. Stalling of motor shaft,
3. Low supply voltage,
4. Single phasing of supply mains,
5. Unbalancing of supply mains,
6. Sudden Loss and rebuilding of supply voltage.

## 4.1 EFFECTS OF OVER CURRENT (OVER LOADING)

- Over heating of motor wind
- Loss of power
- Efficiency of motor decreases
- Temperature of motor increases
- Copper loss increases
- Current in winding increases rapidly
- Working time of motor gets affected

## 4.2 PREVENTION FROM THERMAL OVER LOADING

The most basic protection scheme of the motor is thermal over load protection which primarily covers the protection of all the above mentioned condition. To understand the basic principle of thermal over load protection let's examine the schematic diagram of basic motor control scheme.

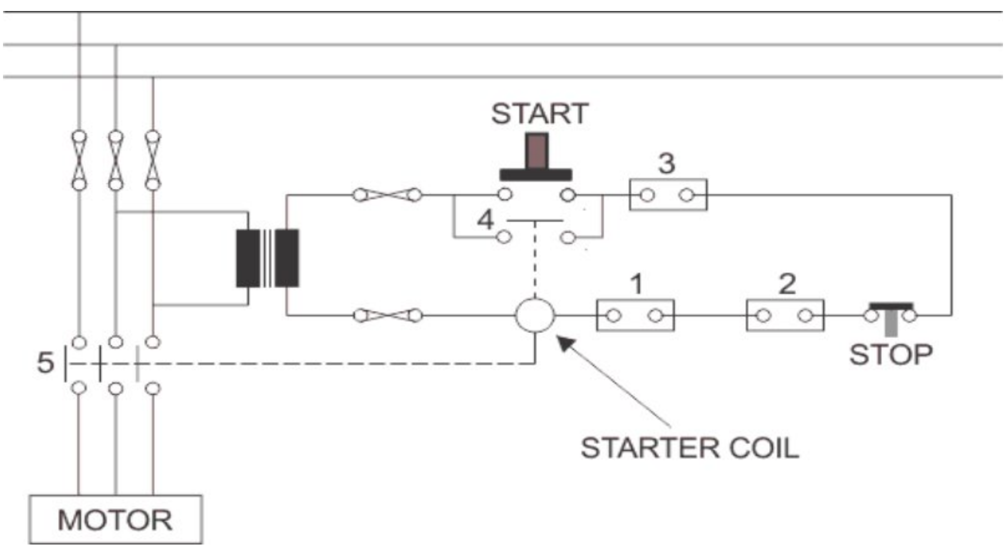


**Fig 4.2 Schematic Diagram Of Basic Motor Control Scheme**

In the figure above, when START push is closed, the starter coil is energized through the transformer. As the starter coil is energized, normally open (NO) contacts 5 are closed hence motor gets supply voltage at its terminal and it starts rotating. This start coil also closes contact 4 which makes the starter coil energized even the START push button contact is released from its close position. To stop the motor there are several normally closed (NC) contacts in series with the starter coil as shown in the figure. One of them is STOP push button contact. If the STOP push button is pressed, this button contact opens and breaks the continuity of the starter coil circuit consequently makes the starter coil de-energized. Hence the contact 5 and 4 come back to their normally open position. Then, in absence of voltage at motor terminals it will ultimately stop running. Similarly any of the other NC contacts (1, 2 & 3) connected in series with starter coil if open; it will also stop the motor. These NC contacts are electrically coupled with various protection relays to stop operation of the motor in different abnormal conditions.

Let’s look at the thermal over load relay and its function in motor thermal overload protection. The secondary of the CTs in series with motor supply circuit, are connected with a bimetallic strip of the thermal over load relay (49). As shown in the figure below, when current through the secondary of any of the CTs, crosses it’s predetermined values for a predetermined time, the bi-metallic strip is over heated and it deforms which ultimately causes to operate the relay 49. As soon as the relay 49 is operated, the NC contacts 1 and 2 are opened which de-energizes the starter coil and hence stop the motor.

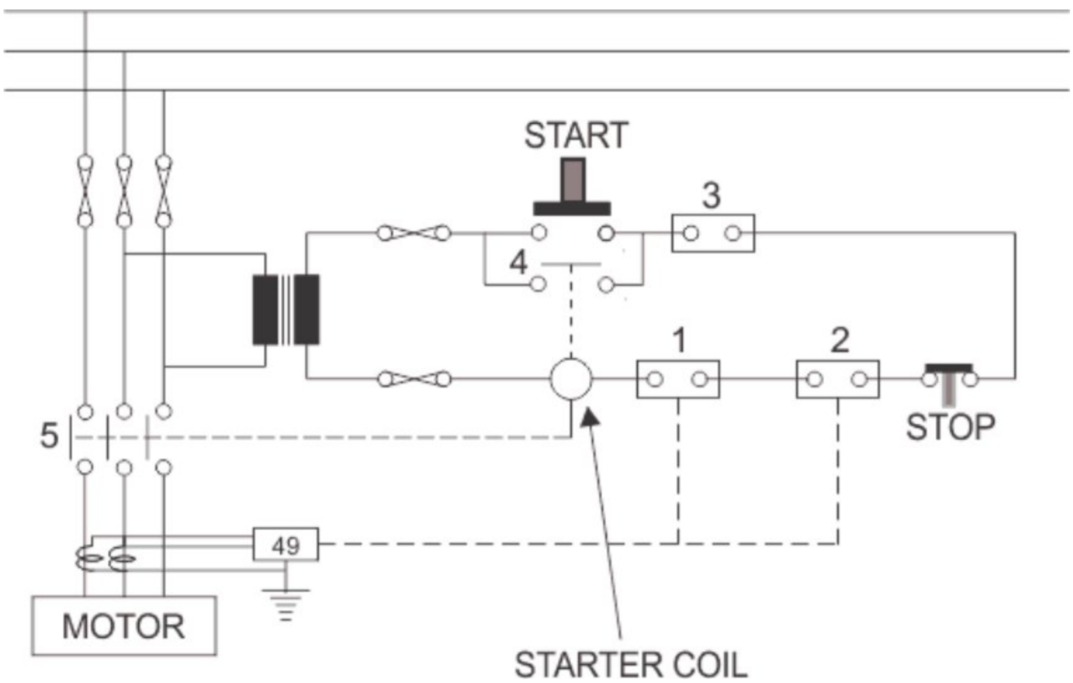


**Fig 4.3 Thermal Over Load Relay (49)**

Another thing we have to remember during providing motor thermal overload protection. Actually every motor does have some predetermined overload tolerance value. That means every motor may run beyond its rated load for a specific allowable period depending on its loading condition. How long a motor can run safely for a particular load is specified by the manufacturer. The relation between different loads on motor and corresponding allowable periods for running the same in safe condition is referred as thermal limit curve of the motor. Let’s look at the curve of a particular motor, given below.

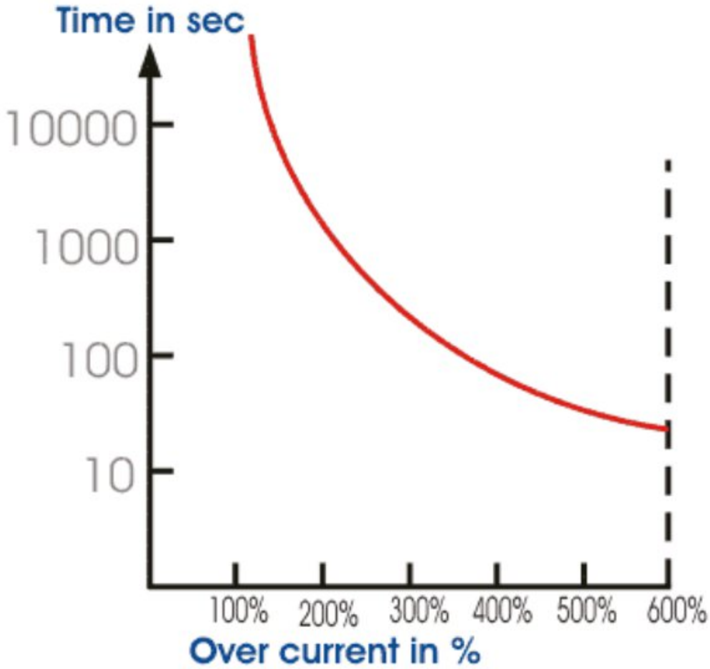


**Fig 4.4 Time v/s Over Current Graph**

Here Y axis or vertical axis represents the allowable time in seconds and X axis or horizontal axis represents percentage of overload. Here it is clear from the curve that, motor can run safely without any damage due to overheating for prolonged period at 100% of the rated load. It can run safely 1000 seconds at 200% of normal rated load. It can run safely 100 seconds at 300% of normal rated load. It can run safely 15 seconds at 600% of normal rated load. The upper portion of the curve represents the normal running condition of the rotor and the lower most portion represents the mechanical locked Now the operating time Vs actuating current curve of the chosen thermal over load relay should be situated below the thermal limit curve of the motor for satisfactory and safe operation. Let’s have a discussion on more details- condition of the rotor.

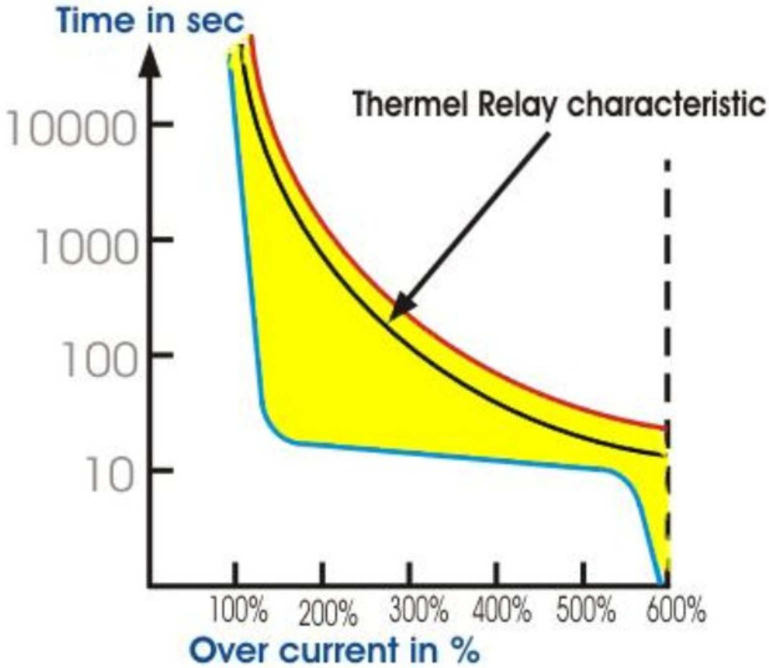


**Fig 4.5 Thermal Relay Characteristics**

Remember the characteristics of starting current of the motor – During start up of the induction motor, the stator current goes beyond 600% of normal rated current but it stays up to 10 to 12 seconds after that stator current suddenly falls to normal rated value. So if the thermal overload relay is operated before that 10 to 12 seconds for the current 600% of normal rated then the motor cannot be started. Hence it can be concluded that the operating time v/sg actuating current curve of the chosen thermal over load relay should be situated below the thermal limit curve of the motor but above the starting current characteristics curve of the motor. Probable position of the thermal current relay characteristics is bounded by these two said curves as shown in the graph by highlighted area.

Another thing has to be remembered during choosing of thermal overload relay. This relay is not an instantaneous relay. It has a minimum delay in operation as the bimetallic strip required a minimum time to be heated up and deformed for maximum value of operating current. From the graph it is found that the thermal relay will be operated after 25 to 30 seconds if either the rotor is suddenly mechanically blocked or motor is fail to start. At this situation the motor will draw a huge current from the supply. If the motor is not isolated sooner, severer damage may occur.

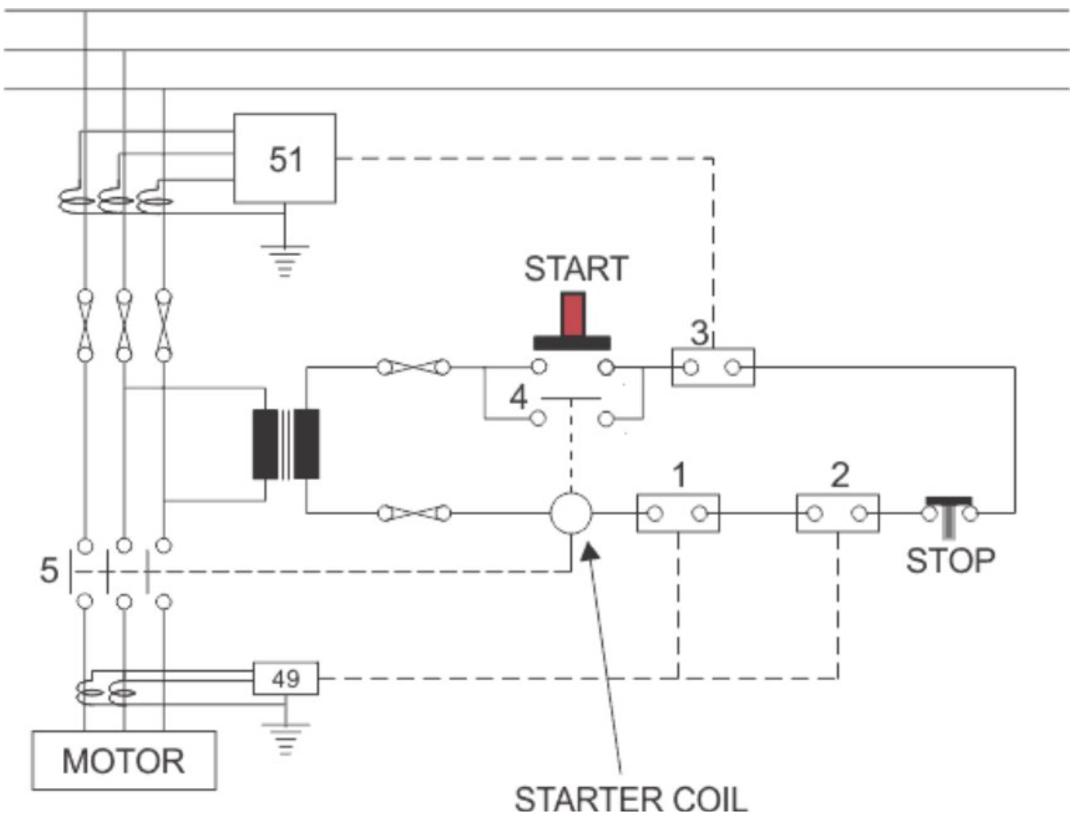


**Fig 4.6  Resistance Temperature Detector**

This problem is overcome by providing time over current relay with high pickup. The time current characteristics of these over current relays are so chosen that for lower value of over load, the relay will not operate since thermal overload relay will be actuated before it. But for higher value of overload and for blocked rotor condition time over load relay will be operated instead of thermal relay because former will actuate much before the latter. Hence both the bimetallic over load relay and time over current relay are provided for complete motor thermal overload protection.

There is one main disadvantage of bimetallic thermal over load relay, as the rate of heating and cooling of bi-metal is affected by ambient temperature, the performance of the relay may differ for different ambient temperatures. This problem can be overcome by using RTD or resistance temperature detector. The bigger and more sophisticated motors are protected against thermal over load more accurately by using RTD. In stator slots, RTDs are placed along with stator winding.

# CHAPTER 5

## OVER VOLTAGE IN INDUCTION MOTOR

Motors are designed to operate within ± 10% of their nameplate rated voltages. When motors operate at conditions of over and under voltage, motor efficiency and other performance parameters are degraded.

There are certain standard utilization voltages for motors. These correspond to (but are about 4% lower than) standard service voltages. The voltage difference is established to allow for a reasonable line voltage drop between the transformer secondary and the point of use.

Motors sometimes come in multi voltage ratings. The different voltages are accommodated by making different connections in the motor terminal box. For 1:2 ratios like 230/460, the connections change coil groups from parallel to series. For 1:1.73 ratios like 2,300/4,000, the connections change coil groups from delta (for the lower voltage) to wye (for the higher voltage). There is no difference in performance at the different voltage ratings because the different connection compensates to put the same total current through each winding turn. Tri-voltage motors (e.g., 208-230/460 volt [V]), are designed to produce rated torque at each voltage, but will slip more and operate hotter at 208 V than at 230 or 460 V. Additionally, some 230/460-V motors are marked "Usable on 208 Volts." Note that the motor nameplate efficiency is measured at rated voltage and may be reduced when operating at a reduced voltage.

**Table 5.1 Service and Utilization Voltage**

| | | | | | | |
|---|---|---|---|---|---|---|
| Service Voltage | 208 | 240 | 480 | 600 | 2,400 | 4,160 |
| Utilization Voltage | 200 | 230 | 460 | 575 | 2,300 | 4,000 |

Over voltages are caused on power systems due to external and internal influencing factors. The voltage stress caused by over voltage can damage the lines and equipment's connected to the system. Over voltages arising on a system can be generally classified into two main categories as below:

## 1. EXTERNAL OVER VOLTAGES

This type of over voltages originates from atmospheric disturbances, mainly due to lightning. This takes the form of a surge and has no direct relationship with the operating voltage of the line. It may be due to any of the following causes:

a) Direct lightning stroke

b) Electromagnetically induced over voltages due to lightning discharge taking place near the line, called 'side stroke'.
c) Voltages induced due to atmospheric changes along the length of the line.
d) Electrostatically induced voltages due to presence of charged clouds nearby.
e) Electrostatically induced over voltages due to the frictional effects of small particles like dust or dry snow in the atmosphere or due to change in the altitude of the line.

## 2. INTERNAL OVER VOLTAGES

These over voltages are caused by changes in the operating conditions of the power system. These can be divided into two groups as below:

## 1. SWITCHING OVER VOLTAGES OR TRANSIENT OVER OPERATION VOLTAGES OF HIGH FREQUENCY

This is caused when switching operation is carried out under normal conditions or when fault occurs in the network. When an unloaded long line is charged, due to Ferranti Effect the receiving end voltage is increased considerably resulting in over voltage in the system. Similarly when the primary side of the transformers or reactors is switched on, over voltage of transient nature occurs.

## 2. TEMPORARY OVER VOLTAGES

These are caused when some major load gets disconnected from the long line under normal or steady state condition

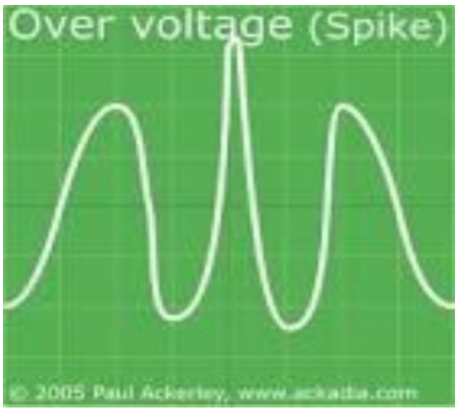


**Fig 5.1 Graphical Representation of Over Voltage**

## 5.1 EFFECTS OF OVER VOLTAGE

Supplying voltage over the design voltage of a motor will not increase motor torque or performance. The various problems associated with over voltage are as follows

- Over voltage tends to stress the insulation of the electrical equipment's and likely to cause damage to them when it frequently occurs.
- Over voltage caused by surges can result in spark over and flash over between phase and ground at the weakest point in the network, breakdown of gaseous/solid/ liquid insulation, failure of transformers and rotating machines.
- Iron losses will always be higher in motors that are experiencing over voltage.
- In some cases, the motor draws excessive current and attempts to magnetize the iron core above its design capacity.
- This can lead to saturation of the iron core, above which additional losses are incurred due to eddy currents.
- These losses increase disproportionately with the rise in voltage over the design voltage.
- As a motor is put under additional stress, its lifetime will decrease.
- Small motors are more sensitive to over-voltage than large motors. The effects of over-voltage are felt particularly on motors which are lightly loaded.

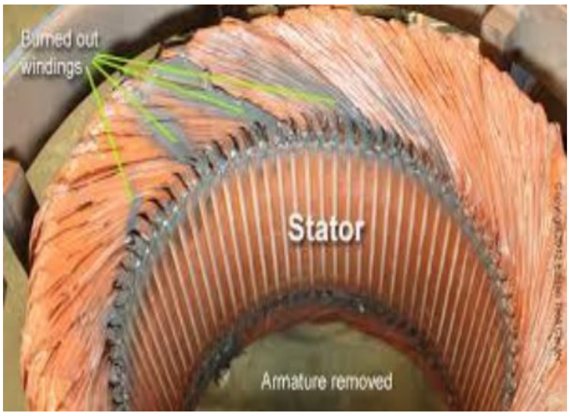


**Fig 5.2 Effect Of Over Voltage in Stator Winding**

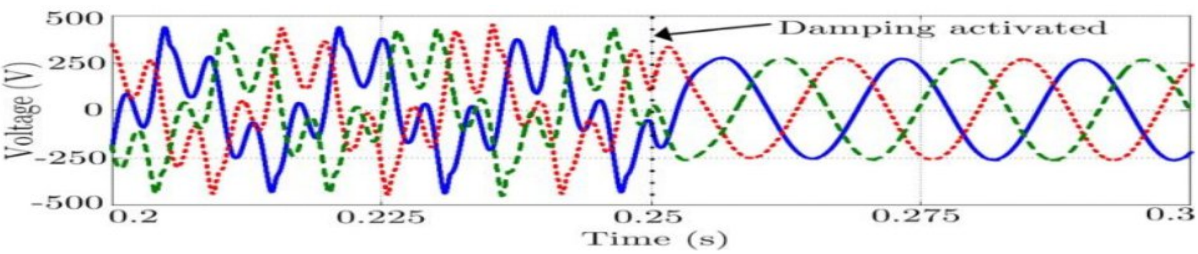


**Fig 5.3 Damping Curve**

## 5.2 PREVENTION OF MOTOR FROM OVER VOLTAGE

- Generally, in variable speed motor systems adopting an inductor as a power generation motor, an accidental over-voltage or over-current may be induced to a secondary-winding side, due to a problem on the electric power system, and a power converter which supplies an excitation current having a variable frequency may be damaged as a result of the induced over-current.
- Over-current and over-voltage prevention methods applying a short-circuit device are generally used to prevent the above problems.
- The over-current and over-voltage prevention methods applying a short-circuit device of the variable speed motor systems generally utilize an over-voltage prevention device ,i.e our OVER VOLTAGE PROTECTION RELAY.

**Fig 5.4 Over/Under Voltage Relay**

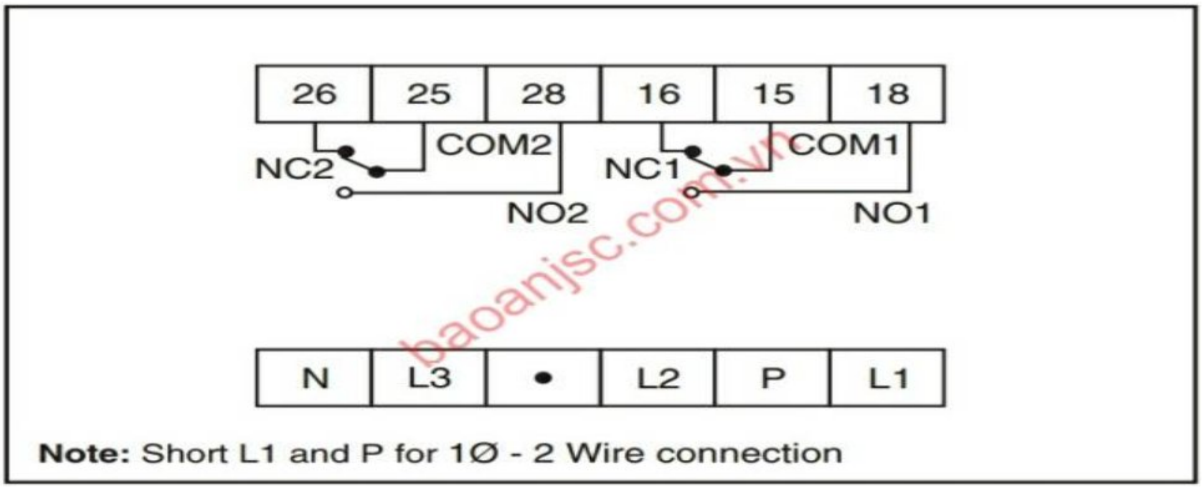


Fig 5.5 Connection Diagram Of Relay

# CHAPTER 6

## UNDER VOLTAGE IN INDUCTION MOTOR

- Voltage depressions caused by faults on the system affect the performance of induction motors, in terms of the production of both transient currents and transient torques.
- It is often desirable to minimize the effect of the voltage dip on both the induction motor and more importantly on the process where the motor is used.
- In order for the user to achieve optimum protection, he must prioritize the importance of the different processes, and then choose the appropriate method to minimize the effects of voltage dips, within the constraints of the supply and budget.
- The worst case scenario is that of a three phase fault which occurs electrically close to the motor.
- When a voltage dip lasts longer than a cycle, many AC contactors will fall out, disconnecting the motor from the supply (and the fault). that the voltage dip is caused by a three phase fault which is electrically close to the motor which is normally valid for most plant.
- If this assumption is not valid, i.e. the impedance of the fault as seen by the motor, is of the same order as the leakage inductance of the motor, then the fault impedance can be added to the stator series impedance in the following analysis in order to obtain meaningful results.
- When a three phase fault occurs close to the motor no electrical energy can enter or leave the motor.
- It is obvious that current can still flow in both the stator and the rotor windings, thus torque can be produced.
- The energy stored in the magnetic field can therefore be dissipated either as mechanical energy or as heat due to copper losses in the motor.
- A motor has experienced a fault and the contactors are allowed to drop out, effectively open circuiting the motor. At a time later, once the fault has been cleared, the motor is reconnected to the supply.
- This section explores what the effects are of the last two operations especially if the motor needs to be operated as soon as possible. When the motor terminals are disconnected from the supply, once again no energy can enter or leave the magnetic field via the electrical terminals.

Further as there is no current in the stator, torque cannot be produced, thus energy cannot be transferred to the mechanical load.
(1) Load switched on and power factor correction capacitors switched off.
(2) Poor system voltage regulation.
**VOLTAGE SAG CAUSES**
(1) Local and remote faults that happen in transmission and distribution especially faults in parallel feeders and customers installation.
(2) Connection of heavy loads and starts up of large

## 6.1 EFFECTS OF UNDER VOLTAGE

- In the case of an under voltage, the low voltage causes the torque developed to reduce. This results in an increase of slip and a reduction in speed.
- The motor tries to reduce the slip by drawing more current. This overloads the motor and can cause overheating.
- Under voltage causes many problems with the equipment that required steady state voltage especially modern load so it causes malfunction, miss operation and in some times full operation stoppage.
- Tripping of contactors and electromagnetic relays.
- Disconnection and less efficiency in rotating machines.
- The torque of an induction motor varies as the square of the voltage, so any small variation in voltage will significantly affect the starting and maximum torque.
- The speed of a motor is going to change slightly with high or low voltage. At 110 percent voltage the speed will increase about 1 percent
- The torque of an induction motor varies as the square of the voltage, so any small variation in voltage will significantly affect the starting and maximum torque. At 110 percent voltage, torque will increase by 21 percent.
- At 110 percent voltage, the efficiency of a motor may actually increase up to 1 percent. However, at 90 percent voltage, the efficiency is going to decrease about 2 percent. This will especially be a factor to consider for larger motors because of the cost of a lower efficiency.
- The starting and full load current will also be affected by changes in voltage.

## 6.2 PREVENTION OF UNDER VOLTAGE

- Generally, in variable speed motor systems adopting an inductor as a power generation motor, an accidental over-voltage or over-current may be induced to a secondary-winding side, due to a problem on the electric power system, and a power converter which supplies an excitation current having a variable frequency may be damaged as a result of the induced over-current.
- Over-current and over-voltage prevention methods applying a short-circuit device are generally used to prevent the above problems.
- The over-current and over-voltage prevention methods applying a short-circuit device of the variable speed motor systems generally utilize an over-voltage prevention device ,i.e our UNDER VOLTAGE PROTECTION RELAY.

## CONCLUSION:

Protection of three phase induction motor from over voltage, under voltage, single phasing, and overheating and phase reversal provide the smooth running of motor improves its lifetime and efficiency. Generally these faults generated when supply system is violating its rating. In three phase induction motor when running at rated voltage, current and load these faults are not generated. For smooth running of motor generally concentration on supply voltage under the prescribe limit and load which is driven by the motor should also be under the specified limit. Induction & synchronous motors are valuable assets to today's industrial facilities.

The temperature rise of motor dictates its life. When applied, thermal protection can prevent loss of motor life. Additional protection elements such as overvoltage, under voltage, unbalance, ground fault, differential, short circuit and stator RTD supplement the thermal model protection and provide complete motor protection. Harsh conformal coating of motor protection relays should be considered to avoid the environmental effects of harsh gaseous sulphide (H2S, etc.)

REFERENCES :


- www.edgefxkits.com
- www.electrical4u.com
- ieeexplore.ieee.org
- https://en.wikipedia.org/wiki/In
- www.electricaleasy.com
- https://www.youtube.com
- Nptel lectures of Induction motor Modelling.
- Vas P. ," Vector Control of AC Machines ", Oxford University Press, Oxford,1990.
- Abb (2010).LV drives ,model ACS800
  www.Abb.com/drives
- P.S.Bimbhra,electrical machinery.New delhi,india:khanna publishers
- www.standards.ieee.org/finds tds/ standard/ 252-1995.html
- electrical – engineering portal. com/ basics cp 3 phase – induction – motor –4
- .I.J Nagrath & D. P Kothari. The McGraw-Hill.
- www.marineinsight.com/ tech/ marine electrical
- Slemon, GR and A Stravghen, electrical machine,
- Addition Wesley Reading, Mass 1980.
- Babbage, C.; Herschel, J. F. W. (Jan 1825). "Account of the Repetition of M. Arago's Experiments on the Magnetism Manifested by Various Substances during the Act of Rotation". Philosophical Transactions of the Royal Society 115 (0): 467–496.
- Thompson, Silvanus Phillips (1895). Polyphase Electric Currents and Alternate-Current Motors (1st ed.). London: E. & F.N. Spon. p. 261. Retrieved 2 December 2012.
- Tesla, Nikola; AIEE Trans. (1888). "A New System for Alternating Current Motors and Transformers". AIEE 5: 308–324. Retrieved17 December 2012.
- Baily, Walter (June 28, 1879). "A Mode of producing Arago's Rotation". Philosophical magazine: A journal of theoretical, experimental and applied physics (Taylor & Francis).
- EEE 112 (2004). *IEEE Standard Test Procedure for Polyphase Induction Motors and Generators*. New York, N.Y.: IEEE. ISBN 0-7381-3978-5.
- Bailey, Benjamin Franklin (1911). The Induction Motor. McGraw-Hill
- Behrend, Bernhard Arthur (1901). The Induction Motor: A Short Treatise on its Theory and Design, With Numerous Experimental Data and Diagrams. McGraw Publishing Company / Electrical World and Engineer.S