Ethiopian TVET-System

Basic Biomedical Equipment Servicing Level II

Based on May 2011 Occupational Standards

October, 2019

Module Title: Maintaining and Repairing Basic Electrical Machines and Drives

TTLM Code: EEL BES2 M07 TTLM 1019v1

This module includes the following Learning Guides

LG26: Troubleshooting Electrical System or equipment

LG Code: EEL BES2 M07 LO1-LG- 26

LG27: Troubleshooting Electrical System or equipment

LG Code: EEL BES2 M07 LO2-LG- 27

LG28: Troubleshooting Electrical System or equipment

LG Code: EEL BES2 M07 LO3-LG- 28

LG29. Troubleshooting Electrical System or equipment

LG Code: EEL BES2 M07 LO3-LG- 29

LG30: Troubleshooting Electrical System or equipment

LG Code: EEL BES2 M07 LO3-LG- 30

Instruction Sheet	**LG26: Troubleshooting Electrical System or equipment**

This learning guide is developed to provide you the necessary information regarding the following content coverage and topics –

- Types of electrical machine and drives

1.1 DC machines

1.2 AC machine

1.3 Drives System

- Explaining and constructing the principles of machine operation
- Verifying the correct size and degree of protection
- Identifying and interpreting name plate data

This guide will also assist you to attain the learning outcome stated in the cover page. Specifically, upon completion of this Learning Guide, you will be able to –

- **Types of electrical machine and drives**

1.4 DC machines

1.5 AC machine

1.6 Drives System

- **Explain and construct the principles of machine operation**
- **Verify the correct size and degree of protection**
- **Identify and interpret name plate data**

Appropriate personal protective equipment is used in line with standard procedures.

Learning Instructions:

1. Read the specific objectives of this Learning Guide.
2. Follow the instructions described below 3 to 114.
3. Read the information written in the information "Sheet 1, Sheet 2, Sheet 3 and Sheet 4"
4. Accomplish the "Self-checks"

Information Sheet-1	**Types of electrical machine and drives**

1.1 **Types of electrical machine and drives**

1.1.1 DC machines

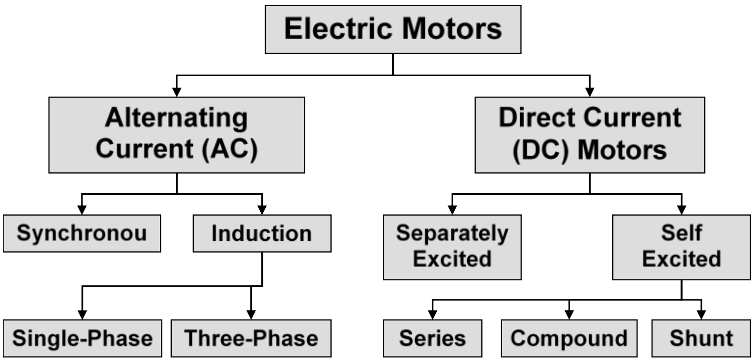
1.1.2 AC machine

1.1.3 Drives System

Electrical motors can be classified in to Ac motors and DC motors. Run to

Introduction

Although a far greater percentage of the electrical machines in service are AC machines, the DC machines are of considerable industrial importance. The principal advantage of the DC machine, particularly the DC motor, is that it provides a fine control of speed. Such an advantage is not claimed by any AC motor. However, DC generators are not as common as they used to be, because direct current, when required, is mainly obtained from an AC supply by the use of rectifiers. Nevertheless, an understanding of DC generator is important because it represents a logical introduction to the behavior of DC motors. Indeed many DC motors in industry actually operate as d DC generators for a brief period. In this chapter, we shall deal with various aspects of DC generators



1.1.1 DC machines

Types of DC machines

DC Generator - Basics

- Means of converting mechanical energy into electrical energy.
- Internally produces only A.C.
- **Commutators and brush assemblies used as a crude but effective way to rectify the AC produced internally to give a DC output to the external load,**

Essentials for production of EMF in a DC Generator

- Main magnetic field created by field windings, carrying a current and wound round the poles.
- Windings (conductors) placed around a rotating armature in which an alternating EMF is produced.
- A prime mover to drive the armature windings in the main field to cause a relative motion required for inducing an EMF in the conductors.
- A Commutator and brush assembly to collect and rectify the EMF induced to get a DC output.

Types of Generators

- An electric generator is a machine that converts mechanical energy into electrical energy. An electric generator is based on the principle that whenever flux is cut by a conductor, an e.m.f. is induced which will cause a current to flow if the conductor circuit is closed. The direction of induced e.m.f. (and hence current) is given by Fleming's right hand rule. Therefore, the essential components of a generator are:

a. A magnetic field

b. Conductor or a group of conductors

c. Motion of conductor w.r.t. magnetic field.

- The magnetic field in a DC generator is normally produced by electromagnets rather than permanent magnets. Generators are generally classified according to their methods of field excitation. The behavior of a DC generator on load depends upon the method of field excitation adopted.

On this basis, DC generators are divided into the following two classes:

(i) Separately excited DC generators

(ii) Self-excited DC generators which may be

a. Series Generators

b. Shunt Generators

c. Compound Generator (Long Shunt & Short shunt)

"Over" Compounded, "Level" Compounded, "Under" Compounded, " Cumulatively" compounded", Differentially" compounded.

Types of D.C. Motors

- Like generators, there are three types of d.c. motors characterized by the connections of field winding in relation to the armature viz.:

a. **Shunt-wound motor**

b. **Series-wound motor**

c. **Compound-wound motor**

A. <u>Shunt-wound motor</u>

Shunt-wound motor in which the field winding is connected in parallel with the armature figure A. The current through the shunt field winding is not the same as the armature current. Shunt field windings are designed to produce the necessary m.m.f. by means of a relatively large number of turns of wire having high resistance. Therefore, shunt field current is relatively small compared with the armature current.

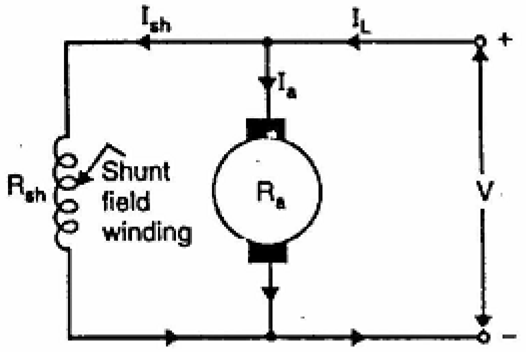


Figure A) shunt wound motor

B. <u>Series-wound motor</u>

- Series wound motor in which the field winding is connected in series with the armature shown in figure B. Therefore, series field winding carries the armature current. Since the current passing through a series field winding is the same as the armature current, series field windings must be designed with much fewer turns than shunt field windings for the same m.m.f.

Therefore, a series field winding has a relatively small number of turns of thick wire and, therefore, will possess a low resistance.

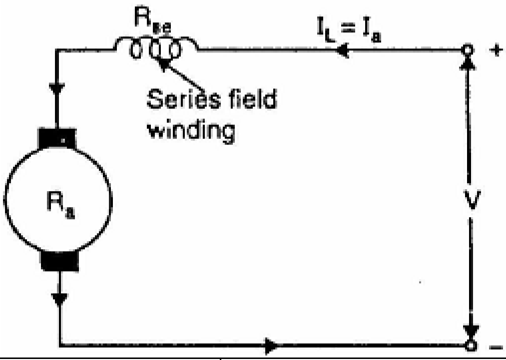


Figure B) series wound motor

C. <u>Compound-wound motor</u>

- Compound wound motor which has two field windings; one connected in parallel with the armature and the other in series with it. There are two types of compound motor connections (like generators). When the shunt field winding is directly connected across the armature terminals shown in figure C (i), it is called **short-shunt connection**. When the shunt winding is so connected that it shunts the series combination of armature and series field shown in figure C (ii), it is called **long-shunt connection**.

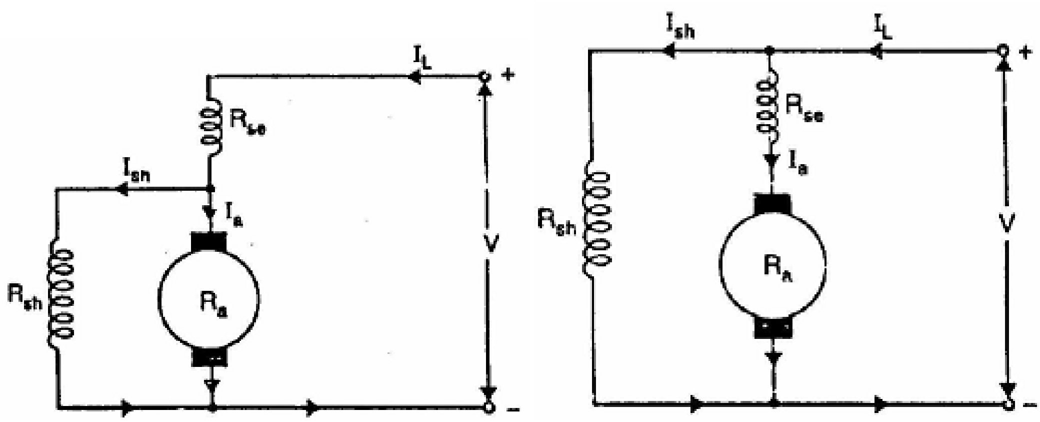


Figure C (i) short shunt connection   C (ii) long shunt connection

- The compound machines (generators or motors) are always designed so that the flux produced by shunt field winding is considerably larger than the flux produced by the series field winding. Therefore, shunt field in compound machines is the basic dominant factor in the production of the magnetic field in the machine.

❖ Reference Principle of electric machines (mehta) pdf.

1.1.2 AC machine

1.1.2.1 <u>Types of AC Motors</u>

It Has To Be Distinguished Between **Single-Phase** and **Three Phase Motors**

- Single-Phase Motors
- Three-Phase Induction Motors which may be
    - ✓ Squirrel cage Motors or
    - ✓ Slip-ring Motors

✓ Three-Phase Synchronous Motors

1.1.2.2 **Types of Single-Phase Motors**

Single-phase motors are generally built in the fractional-horsepower range and may be classified into the following four basic types:

Single-phase induction motors

(i) split-phase type

(iii) shaded-pole type

A.C. series motor or universal motor

Repulsion motors

(i) Repulsion-start induction-run motor

(ii) Repulsion-induction motor

Synchronous motors

(i) Reluctance motor

(ii) Hysteresis motor

(ii) Capacitor type

Single-Phase Induction Motors

Introduction:

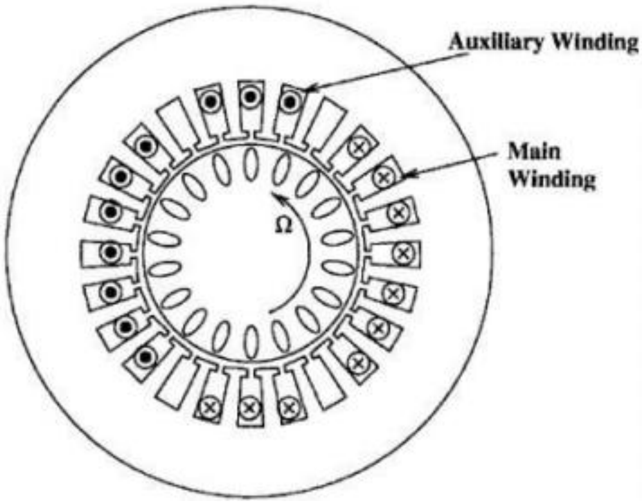
The single-phase induction motor is the most frequently used motor for refrigerators, washing machines, clocks, drills, compressors, pumps, and so forth. In addition to this, single phase motors are reliable, cheap in cost, simple in construction and easy to repair.

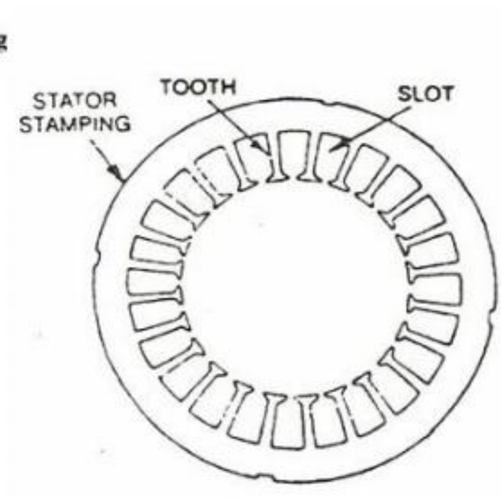
Construction:

The construction parts on of single phase induction motor consist of main two parts: Stationary stator and revolving rotor. The stator separate from rotor by small air gap have ranges from 0.4 mm to 4 mm depends to size of motor.

- ✓ **Stator:**

The single-phase motor stator has a laminated iron core with slots as shown in following figure.





- ✓ Two windings arranged vertically inside the slots of stator:
    1. One is the main (or running winding).
    2. Auxiliary winding (or starting winding) as showing in the figure below.

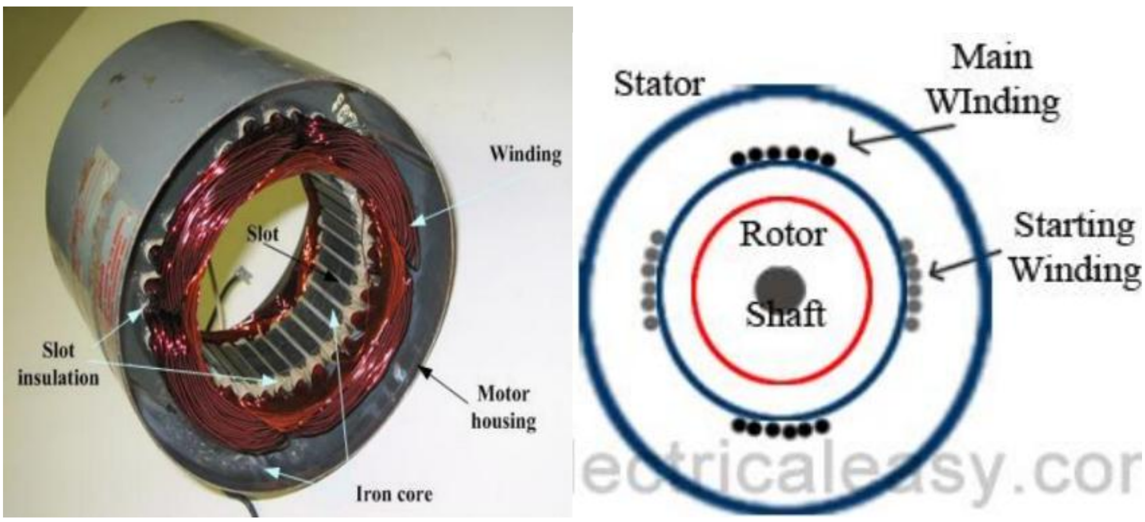


Figure Stator of 1- phase induction motor

- ✓ **Rotor:**

The rotor, mounted on a shaft, It consists of a laminated cylindrical core with slots; aluminum bars are molded on the slots and short-circuited at both ends with a ring as shown in figure below. This type of rotor is called "Squirrel cage rotor ".

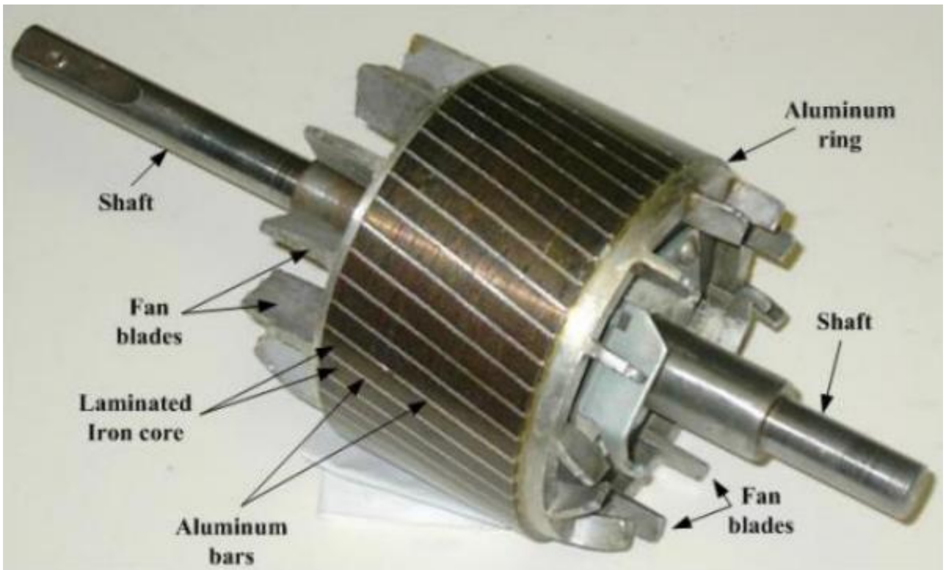


Figure Squirrel cage rotor

I. **<u>Split Phase Induction Motor:</u>**

A type if single phase motor which consist of main winding, auxiliary winding and a centrifugal switch. The auxiliary winding is usually opened by the centrifugal switch when the motor attained a predetermined speed.

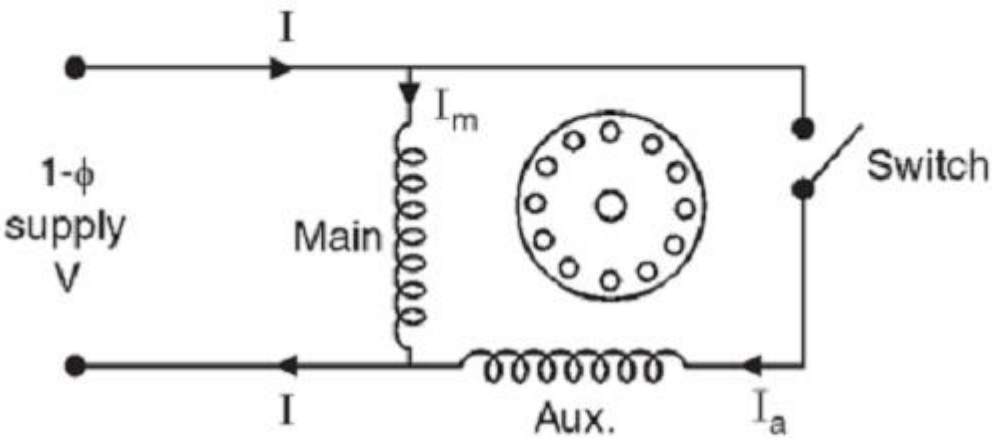


Figure Split phase induction motor

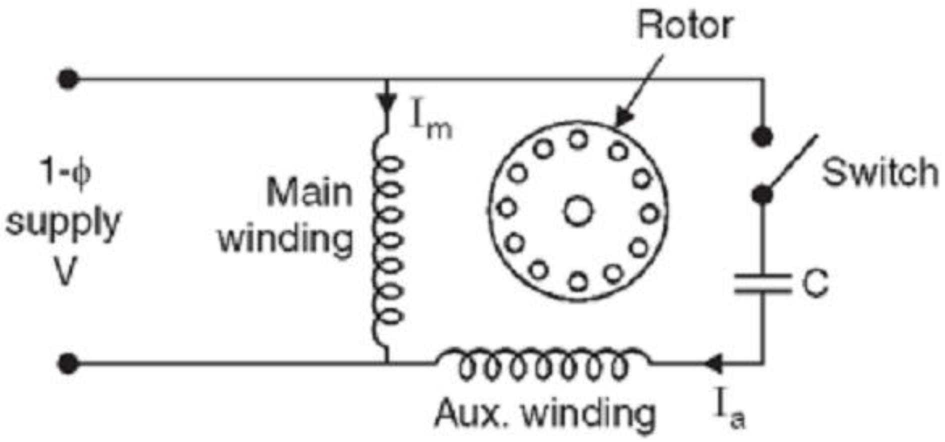
Capacitor Motor- is a kind of a single phase motor having a capacitor connected in series with the auxiliary winding. The start coil is connected all times in the circuit as well as the running winding. It is commonly used in electric fan and washing machine motors.

The capacitor motor also comprises a main and an auxiliary winding with different turn ratios. On a capacitor motor with running capacitor, the capacitor remains all the time connected. Capacitor motors with run capacitor CB are suitable for application with low starting torque. The reactive power of the capacitor should be app., 1.3 kvar per KW nominal power of the motor.

II. Capacitor Start Induction Motor:

Capacitor Start Motor- is a kind of a single phase motor having a capacitor connected in series with the auxiliary winding. The starting coil is disconnected from the circuit when the motor comes up to near normal speed. It is used in water pump, machine drives, stationary grinder, etc.

The capacitor-start motor is identical to a split-phase motor except that a capacitor C (3-20 μF) is connected in series with the starting winding as shown in figure below.



The auxiliary winding and the capacitor are disconnected at about 75% of the synchronous speed. Therefore, at the rated speed the capacitor start motor operates only on the main winding like a split-phase motor.

III. Single phase motors with start and running capacitor

are used for application where a very high starting torque is required i.e. air compressor. During starting condition both capacitors are connected in parallel. The starting capacitor is about two or three times bigger (in capacity) then the running capacitor. After the motor reached its nominal speed the starting capacitor is cut off. The running capacitor and the auxiliary winding in series to it remain connected during the operation of the motor. Single phase motor with start and running capacitor

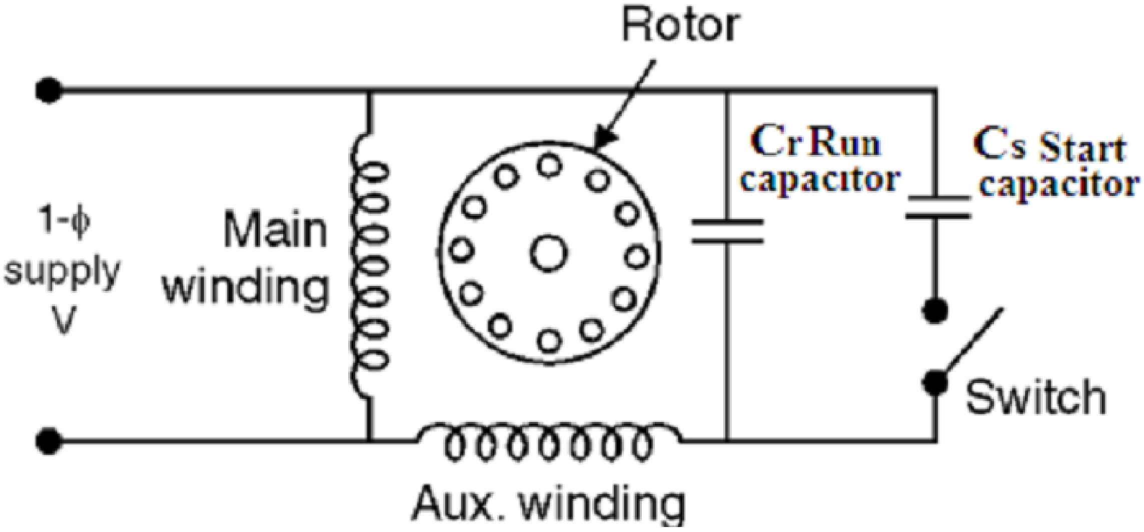


Figure Capacitor-start capacitor-run motor

IV. **Repulsion Motor**-

This motor is like that of any single phase motor but its rotor is like the armature of a DC motor, and the opposite brushes on its commutator are short circuited. The armature produces field poles with the same polarity to the adjacent stator field and are repelled by them, so this repulsion causes the armature to rotate. From this action the motor derives its name.

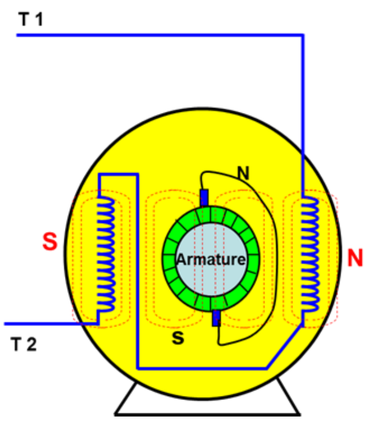


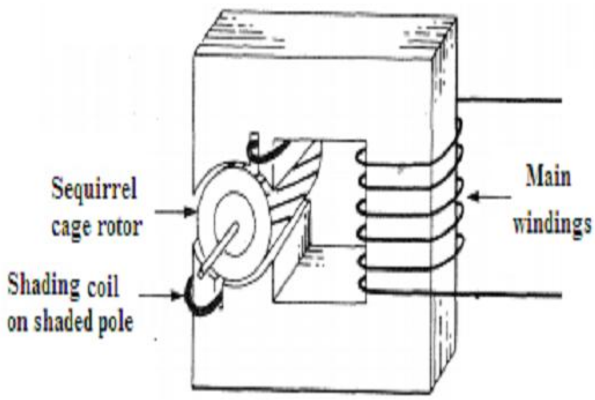
Figure Repulsion motor

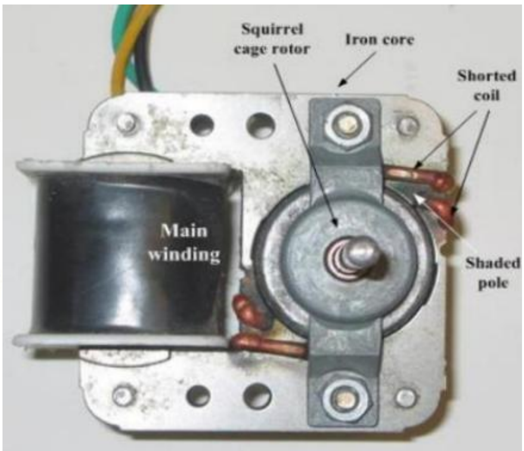
V. **Universal Motor**

This kind of single phase motor is very similar to the characteristic of a DC motor. It could be activated by both **AC** and **DC** power supply, thus its name was termed universal motor. It has a commutator and brushes on its armature which are connected in series to its field windings. It has a varying speed with low speed to large load and high speed to small loads. Thus, it is best suited for light duty household appliances.

VI. **SHADED-POLE-MOTOR or SPLIT – POLE – MOTOR**.

It is made for low power only, up to app. 200W. It can operate on single-phase AC without any additional components. It is used in record players, tape recorders, fans, etc. The rotor is a kind of squirrel-cage type. The poles of the Split-Pole-Motor are split. One half of each pole has a short circuit ring made of copper. The two short circuit rings produce a shift of the magnetic flux in the pole shanks. First the pole shank with no short circuit ring is producing its maximum field strength and sometime later the one with the short circuit ring is producing its maximum field strength. Thus, creating an artificial rotating field.





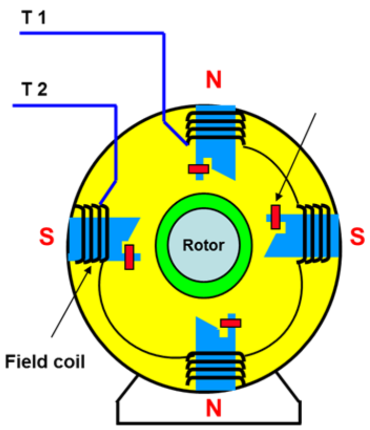


Figure Shaded pole motor

1.1.2.2 Three-phase motors

It is a commonly used motor in the industry to drive machineries. It has 3-main windings which is powered by a three-phase line.

Three-phase AC motors can only operate if all three phases of the supply voltage are available at the same time. If one phase is missing, the motor stops and the remaining two phases have to be switched off immediately to avoid destruction of the motor.

The most commonly used motor for the three-phase system is the **ASYNCHRONOUS MOTOR**. Asynchronous means, the rotor does not follow in its rotation speed the applied frequency. The rotation lags the frequency by app. 5%. In its simplest construction, the rotor is a cage of metal bars, also named as **SQUIRREL-CAGE**. The stator consists of a frame of laminated iron-sheets. Inside the slots are the windings, comprising a number of independent coils. For rotation at least three independent coils are required. The three coils are connected to the three phases of the supply voltage. The connections are made in a junction box attached to the motor.

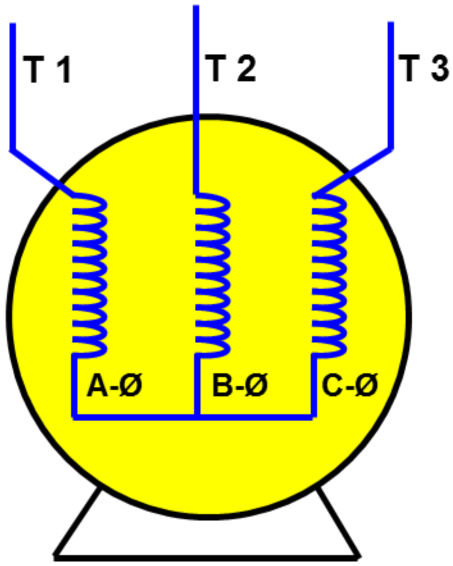


Figure Construction of a 3-phase Motor

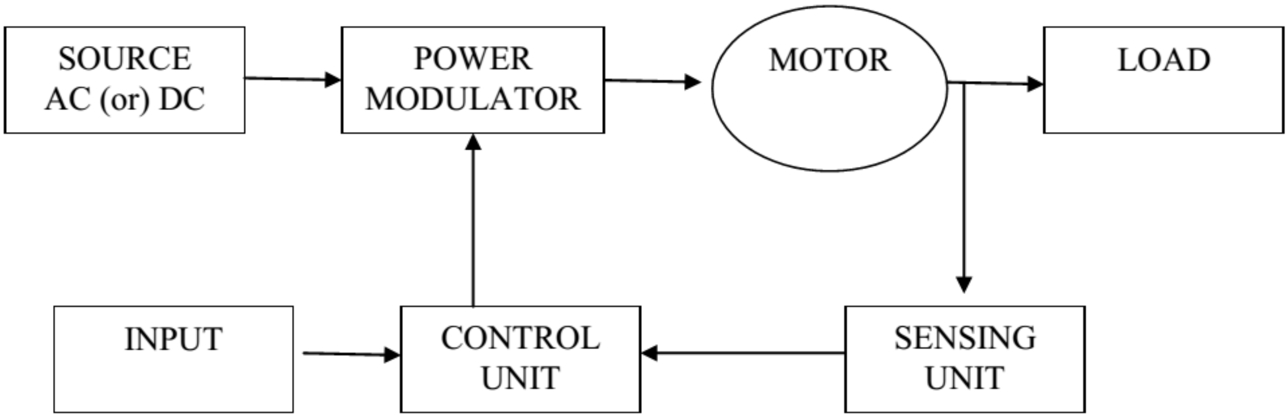
- Reference https://www.researchgate.net/publication/332835297
- Ahmed M. T. Ibraheem Alnaib on 03 May 2019

1.1.3 Drives System

- **Drive:** A combination of prime mover, transmission equipment and mechanical Working load is called a drive
- **Electric drive:** An Electric Drive can be defined as an electromechanical device for converting electrical energy to mechanical energy to impart motion to different machines and mechanisms for various kinds of process control.

BLOCK DIAGRAM OF AN ELECTRICAL DRIVES

The basic block diagram for electrical drives used for the motion control is shown in the following figure1.1



- The aggregate of the electric motor, the energy transmitting shaft and the control equipment by which the motor characteristics are adjusted and their operating conditions with respect to mechanical load varied to suit practical requirements is called as **electric drive**.

Drive system=Drive + load

BASIC COMPONENT (or) ELEMENTS OF ELETCRIC DRIVES

Block diagram of electric drive:

1. Load: usually a machinery to accomplish a given task. Eg-fans, pumps, washing machine etc.

2. Power modulator: modulators (adjust or converter) power flow from the source to the motion

3. Motor: actual energy converting machine (electrical to mechanical)

4. Source: energy requirement for the operation the system.

5. Control: adjust motor and load characteristics for the optimal mode.

Power modulators:

Power modulators regulate the power flow from source to the motor to enable the motor to develop the torque speed characteristics required by the load.

The common function of the power modulator is,

- ✓ They contain and control the source and motor currents with in permissible limits during the transient operations such as starting, braking, speed reversal etc.
- ✓ They converts the input electrical energy into the form as required by the motors.
- ✓ Adjusts the mode of operation of the motor that is motoring, braking are regenerative.

Power modulators may be classified as,

- ✓ Converters uses power devices to convert uncontrolled valued to controllable output.
- ✓ Switching circuits switch mode of operation
- ✓ Variable impedance
- ✓ Converters

They provide adjustable voltage/current/frequency to control speed, torque output power of the motor.

The various type of converters are,

- ✓ AC to DC rectifiers
- ✓ DC to DC choppers
- ✓ AC to AC choppers
- ✓ AC to AC –AC voltage controllers (voltage level is controlled)
- ✓ Cyclo converter (Frequency is controlled)
- ✓ DC to AC inverters

Switching circuits

Switching circuits are needed to achieve any one of the following.

- ✓ Changing motor connection to change its quadrant of operation.
- ✓ Changing motor circuits parameters in discrete steps for automatic starting and braking control.

- ✓ For operating motors and drives according to a predetermine sequence
- ✓ To provide inter locking their by preventing maloperation
- ✓ Disconnect under up normal condition

Eg: electromagnetic contactors, PLC in sequencing and inter locking operation, solid state relays etc.

Variable impedance

- ✓ Variable resisters are commonly used for AC and DC drives and also needed for dynamic braking of drives
- ✓ Semiconductors switch in parallel with a fixed resistance is used where stepless variation is needed. Inductors employed to limit starting current of ac motors.

The following points must be given utmost important for the selection of motor. The factors are:

- ✓ Nature of the mechanical load driven
- ✓ Matching of the speed torque characteristics of the motor with that of the load
- ✓ Starting conditions of the load.

Self-Check -1	Written Test

Direction: From the given alternatives write the correct answer on the space provided for each of the following questions.

Brush, Electric Machine Field winding, Stator, Generator, Inter-pole, Commutator, Motor, Armature, Rotor

1. ___________________ used to convert alternating current in to direct current in case of generator.
2. ___________________ used to prevent a dc machine from spark.
3. __________________ is to provide a connection between the armature coils and the external load.
4. __________________ are converters that are used to continuously translate electrical input to mechanical output or vice versa.
5. ___________________ an electromagnet that produces the magnetic flux cut by the armature.

Answer Sheet

Score = ____________

Rating: _____________

1.2 Explaining and constructing the principles of machine operation

Generator Principle

An electric generator is a machine that converts mechanical energy into electrical energy. An electric generator is based on the principle that whenever flux is cut by a conductor, an e.m.f. is induced which will cause a current to flow if the conductor circuit is closed. The direction of induced e.m.f. (and hence current) is given by Fleming's right hand rule.

Therefore, the essential components of a generator are:

(a) A magnetic field

(b) Conductor or a group of conductors

(c) Motion of conductor w.r.t. magnetic field.

Simple Loop Generator

Consider a single turn loop ABCD rotating clockwise in a uniform magnetic field with a constant speed as shown in Fig. (1.2). as the loop rotates, the flux linking the coil sides AB and CD changes continuously. Hence the e.m.f. induced in these coil sides also changes but the e.m.f. induced in one coil side adds to that induced in the other.

1. When the loop is in position no. 1 [See Fig. 1.1], the generated e.m.f. is zero because the coil sides (AB and CD) are cutting no flux but are moving parallel to it.

2. When the loop is in position no. 2, the coil sides are moving at an angle to the flux and, therefore, a low e.m.f. is generated as indicated by point 2 in Fig. (1.2).

3. When the loop is in position no. 3, the coil sides (AB and CD) are at right angle to the flux and are, therefore, cutting the flux at a maximum rate. Hence at this instant, the generated e.m.f. is maximum as indicated by point 3 in Fig. (1.2).

4. At position 4, the generated e.m.f. is less because the coil sides are cutting the flux at an angle.

5. At position 5, no magnetic lines are cut and hence induced e.m.f. is zero as indicated by point 5 in Fig. (1.2).

6. At position 6, the coil sides move under a pole of opposite polarity and hence the direction of generated e.m.f. is reversed. The maximum e.m.f. in this direction (i.e., reverse direction, See Fig. 1.2) will be when the loop is at position 7 and zero when at position 1. This cycle repeats with each revolution of the coil.

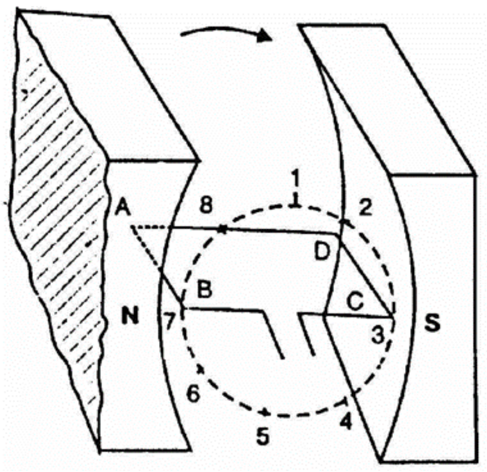


Fig. (1.1)

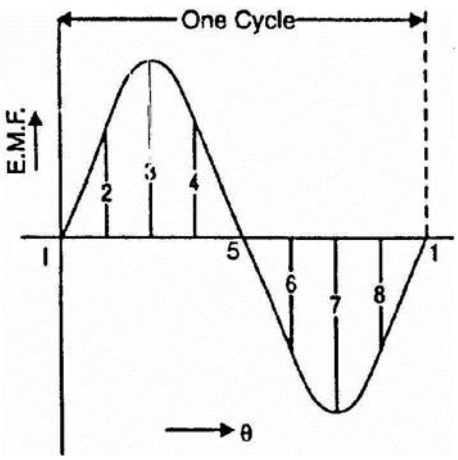


Fig. (1.2)

Note that e.m.f. generated in the loop is alternating one. It is because any coil side, say AB has e.m.f. in one direction when under the influence of N-pole and in the other direction when under the influence of S-pole. If a load is connected across the ends of the loop, then alternating current will flow through the load.

The alternating voltage generated in the loop can be converted into direct voltage by a device called commutator. We then have the d.c. generator. In fact, a commutator is a mechanical rectifier.

Construction of d.c. Generator

The d.c. generators and d.c. motors have the same general construction. In fact when the machine is being assembled, the workmen usually do not know whether it is a d.c. generator or motor. Any d.c. generator can be run as a d.c. motor and vice-versa. All d.c. machines have five principal components viz.,

i. field system
ii. armature core
iii. armature winding
iv. commutator (v)

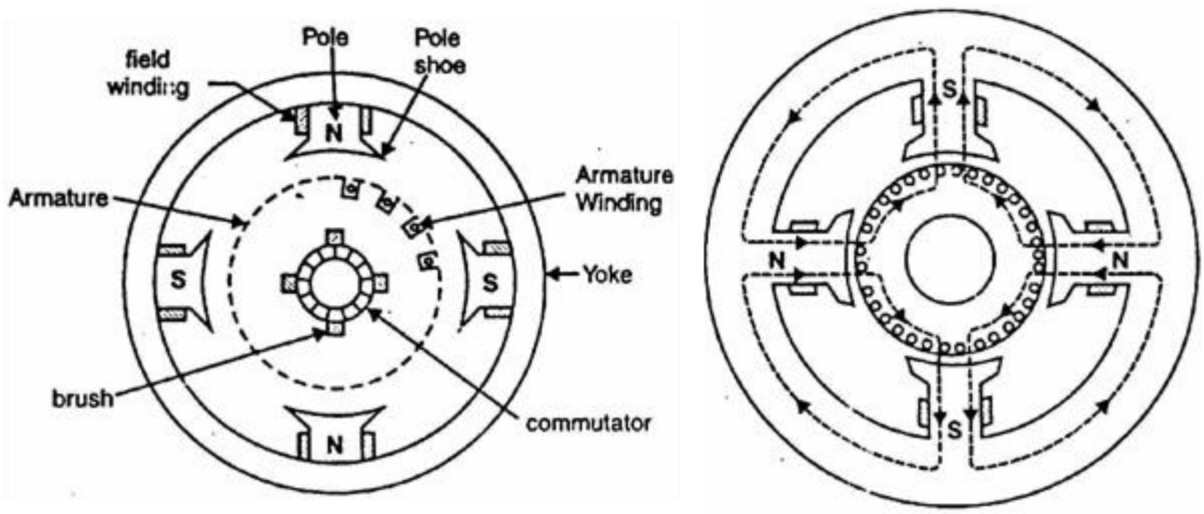


Figure brushes

i. **Field system**

The function of the field system is to produce uniform magnetic field within which the armature rotates. It consists of a number of salient poles (of course, even number) bolted to the inside of circular frame (generally called yoke). The yoke is usually made of solid cast steel whereas the pole pieces are composed of stacked laminations. Field coils are mounted on the poles and carry the d.c. exciting current. The field coils are connected in such a way that adjacent poles have opposite polarity.

The m.m.f. developed by the field coils produces a magnetic flux that passes through the pole pieces, the air gap, the armature and the frame. Practical d.c. machines have air gaps ranging from 0.5 mm to 1.5 mm. Since armature and field systems are composed of materials that have high permeability, most of the m.m.f. of field coils is required to set up flux in the air gap. By reducing the length of air gap, we can reduce the size of field coils (i.e. number of turns).

ii. **Armature core**

The armature core is keyed to the machine shaft and rotates between the field poles. It consists of slotted soft-iron laminations (about 0.4 to 0.6 mm thick) that are stacked to form a cylindrical core. The laminations are individually coated with a thin insulating film so that they do not come in electrical contact with each other. The purpose of laminating the core is to reduce the eddy current loss. The laminations are slotted to accommodate and provide mechanical security to the armature winding and to give shorter air gap for the flux to cross between the pole face and the armature "teeth".

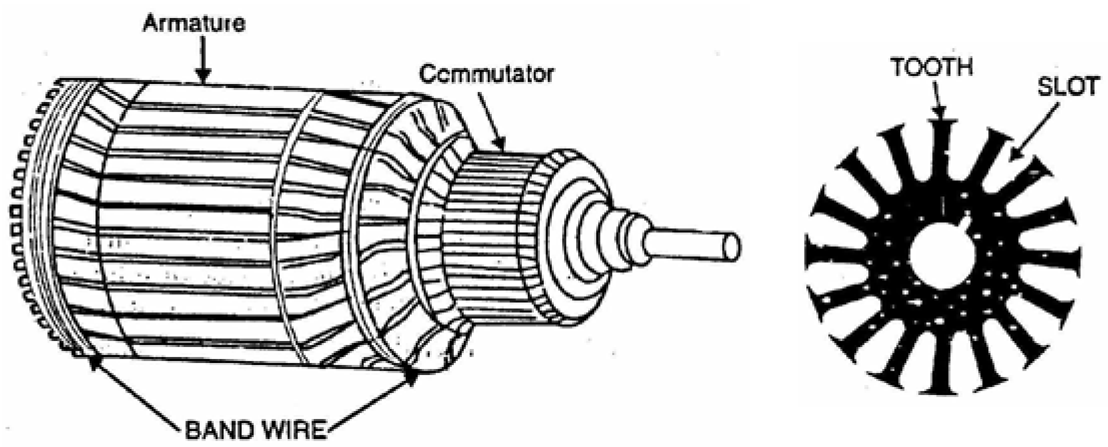


Figure armature core and tooth

iii. **Armature winding**

The slots of the armature core hold insulated conductors that are connected in a suitable manner. This is known as armature winding. This is the winding in which “working” e.m.f. is induced. The armature conductors are connected in series-parallel; the conductors being connected in series so as to increase the voltage and in parallel paths so as to increase the current. The armature winding of a d.c. machine is a closed-circuit winding; the conductors being connected in a symmetrical manner forming a closed loop or series of closed loops.

iv. **Commutator**

A commutator is a mechanical rectifier which converts the alternating voltage generated in the armature winding into direct voltage across the brushes. The commutator is made of copper segments insulated from each other by mica sheets and mounted on the shaft of the machine. The armature conductors are soldered to the commutator segments in a suitable manner to give rise to the armature winding. Depending upon the manner in which the armature conductors are connected to the commutator segments, there are two types of armature winding in a d.c. machine viz., (a) lap winding (b) wave winding.

Great care is taken in building the commutator because any eccentricity will cause the brushes to bounce, producing unacceptable sparking. The sparks may bum the brushes and overheat and carbonise the commutator.

v. **Brushes**

The purpose of brushes is to ensure electrical connections between the rotating commutator and stationary external load circuit. The brushes are made of carbon and rest on the commutator. The brush pressure is adjusted by means of adjustable springs. If the brush pressure is very large, the friction produces heating of the commutator and the brushes. On the other hand, if it is too weak, the imperfect contact with the commutator may produce sparking.

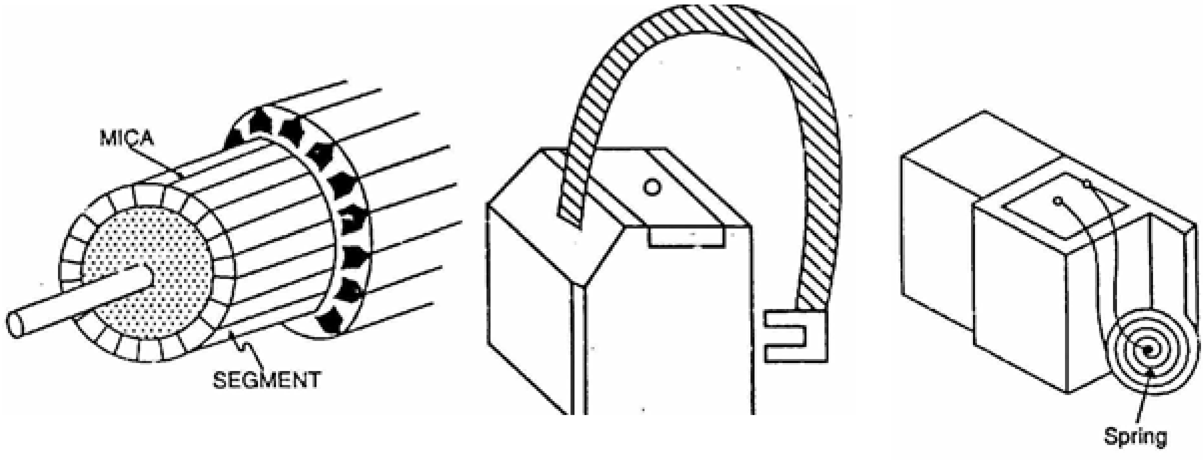


Figure commutator segment and brush holder

Multipole machines have as many brushes as they have poles. For example, a 4-pole machine has 4 brushes. As we go round the commutator, the successive brushes have positive and negative polarities. Brushes having the same polarity are connected together so that we have two terminals viz., the +ve terminal and the −ve terminal

Note that e.m.f. generated in the loop is alternating one. It is because any coil side, say AB has e.m.f. in one direction when under the influence of N-pole and in the other direction when under the influence of S-pole. If a load is connected across the ends of the loop, then alternating current will flow through the load.

The alternating voltage generated in the loop can be converted into direct voltage by a device called commutator. We then have the d.c. generator. In fact, a commutator is a mechanical rectifier.

D.C. Motor Principle

A machine that converts d.c. power into mechanical power is known as a d.c. motor. Its operation is based on the principle that when a current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force. The direction of this force is given by Fleming’s left hand rule and magnitude is given by;

$$F = BI\} \quad \text{newtons}$$

Basically, there is no constructional difference between a d.c. motor and a d.c. generator. The same d.c. machine can be run as a generator or motor.

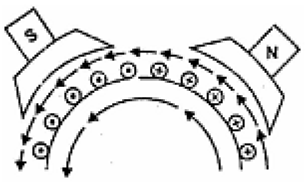
Working of D.C. Motor

Consider a part of a multipolar d.c. motor as shown in Fig below. When the terminals of the motor are connected to an external source of d.c. supply:

i. The field magnets are excited developing alternate N and S poles;

ii. The armature conductors carry ^currents. All conductors under N-pole carry currents in one direction while all the conductors under S-pole carry currents in the opposite direction.

Suppose the conductors under N-pole carry currents into the plane of the paper and those under S-pole carry currents out of the plane of the paper. Since each armature conductor is carrying current and is placed in the magnetic field, mechanical force acts on it. Applying Fleming's left hand rule, it is clear that force on each conductor is tending to rotate the armature in anticlockwise direction. All these forces add together to produce a driving torque which sets the armature rotating. When the conductor moves from one side of a brush to the other, the current in that conductor is reversed and at the same time it comes under the influence of next pole which is of opposite polarity. Consequently, the direction of force on the conductor remains the same



Back or Counter E.M.F.

When the armature of a d.c. motor rotates under the influence of the driving torque, the armature conductors move through the magnetic field and hence e.m.f. is induced in them as in a generator The induced e.m.f. acts in opposite direction to the applied voltage V(Lenz's law) and in known as back or counter e.m.f. E_b. The back e.m.f. $E_b (= P \phi ZN/60\ A)$ is always less than the applied voltage V, although this difference is small when the motor is running under normal conditions.

Applications of D. C. Motors

Instead of just stating the applications, the behaviour of the various characteristics like speed, starting torque etc., which makes the motor more suitable for the applications, is also stated in the Table 6.1.

Type of motor	Characteristics	Applications
Shunt	Speed is fairly constant and medium starting torque.	1) Blowers and fans 2) Centrifugal and reciprocating pumps 3) Lathe machines 4) Machine tools 5) Milling machines 6) Drilling machines
Series	High starting torque. No load condition is dangerous. Variable speed.	1) Cranes 2) Hoists, Elevators 3) Trolleys 4) Conveyors 5) Electric locomotives
Cumulative compound	High starting torque. No load condition is allowed.	1) Rolling mills 2) Punches 3) Shears 4) Heavy planers 5) Elevators
Differential compound	Speed increases as load increases.	Not suitable for any practical application.

Table

1. Shunt motors

The characteristics of a shunt motor reveal that it is an approximately constant speed motor. It is, therefore, used

(i) where the speed is required to remain almost constant from no-load to Full-load

(ii) Where the load has 10 be driven at a number of speeds and any one of which is Required to remain nearly constant

Industrial use: Lathes, drills, boring mills, shapers, spinning and weaving machines etc.

2. Series motors

It is a variable speed motor i.e., speed is low at high torque and vice-versa.

However, at light or no-load, the motor tends to attain dangerously high speed.

The motor has a high starting torque. It is, therefore, used

(i) Where large starting torque is required e.g., in elevators and electric traction

(ii) (ii) where the load is subjected to heavy fluctuations and the speed is

Automatically required to reduce at high torques and vice-versa

Industrial use: Electric traction, cranes, elevators, air compressors, vacuum cleaners, hair drier, sewing machines etc.

3. **Compound motors**

Differential-compound motors are rarely used because of their poor torque characteristics. However, cumulative-compound motors are used where a fairly constant speed is required with irregular loads or suddenly applied heavy loads.

Industrial use: Presses, shears, reciprocating machines etc.

Operation principle of single phase motors

As the name suggests, these motors are used on single-phase supply. Single-phase motors are the most familiar of all electric motors because they are extensively used in home appliances, shops, offices etc. It is true that single-phase motors are less efficient substitute for 3-phase motors but 3-phase power is normally not available except in large commercial and industrial establishments. Since electric power was originally generated and distributed for lighting only, millions of homes were given single-phase supply. This led to the development of single-phase motors. Even where 3-phase mains are present, the single-phase supply may be obtained by using one of the three lines and the neutral. In this chapter, we shall focus our attention on the construction, working and characteristics of commonly used single-phase motors.

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 or running winding M. The starting winding is located 90° electrical from the main winding [See Fig. (9.13 (i))] And operates only during the brief period when the motor starts up. The two windings are so resigned that the starting winding S has a high resistance and relatively small reactance while the main winding M has relatively low resistance and large reactance as shown in the schematic connections in Fig. (9.13 (ii)). Consequently, the currents flowing in the two windings have reasonable phase difference c (25° to 30°) as shown in the phasor diagram in

Fig. (9.13 (iii)).

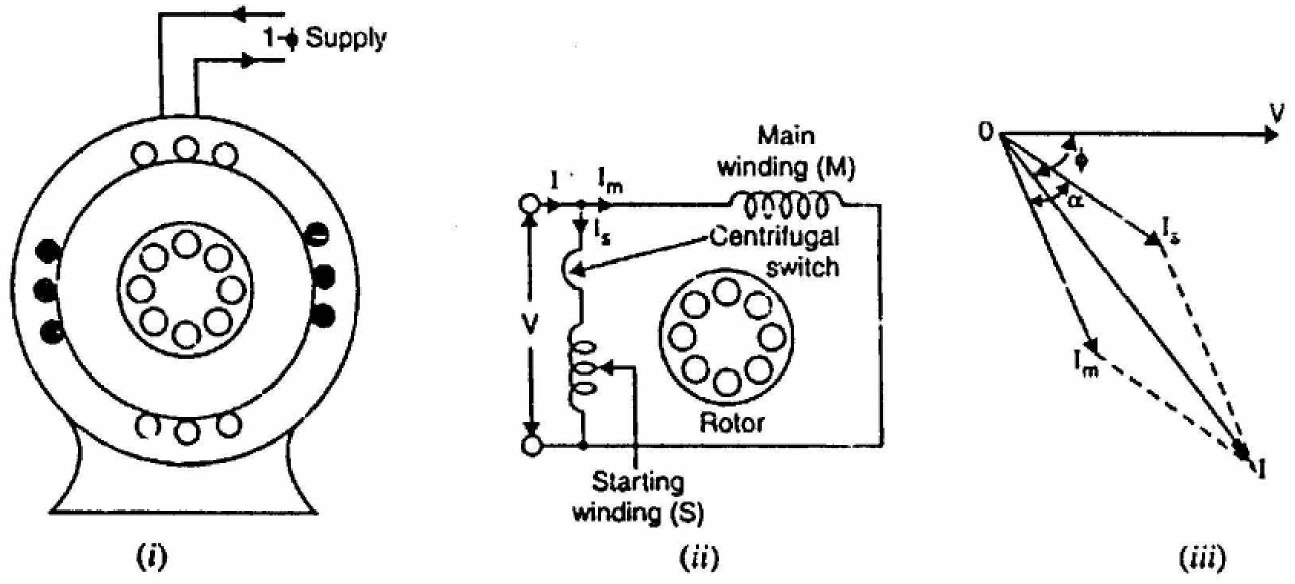


Fig.(9.13)

Operation

When the two stator windings are energized from a single-phase supply, the main winding carries current Im while the starting winding carries current Is.

(ii) Since main winding is made highly inductive while the starting winding highly resistive, the currents Im and Is have a reasonable phase angle a (25° to 30°) between them as shown in Fig. (9.13 (iii)). 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;

$$T_s = kI_m\, I_s \sin\alpha$$

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

(iii) When the motor reaches about 75% of synchronous speed, the centrifugal switch opens the circuit of the starting winding. The motor then operates as a single-phase induction motor and continues to accelerate till it reaches the normal speed. The normal speed of the motor is below the synchronous speed and depends upon the load on the motor.

Characteristics

(i) The sinning torque is 15 to 2 times the full-loud torque mid (lie starting current is 6 to 8 times the full-load current.

(ii) Due to their low cost, split-phase induction motors are most popular single-phase motors in the market.

(i) Since the starting winding is made of fine wire, the current density is high and the winding heats up quickly. If the starting period exceeds 5 seconds, the winding may burn out unless the motor is protected by built-in-thermal relay. This motor is, therefore, suitable where starting periods are not frequent.

(ii) An important characteristic of these motors is that they are essentially constant-speed motors. The speed variation is 2-5% from no-load to full-load.

(iii) These motors are suitable where a moderate starting torque is required and where starting periods are infrequent e.g., to drive:

(a) Fans (b) washing machines (c) oil burners (d) small machine tools etc.

The power rating of such motors generally lies between 60 W and 250 W.

Capacitor-Start Motor

The capacitor-start motor is identical to a split-phase motor except that the starting winding has as many turns as the main winding. Moreover, a capacitor C is connected in series with the starting winding as shown in Fig. (9.14 (i)). The value of capacitor is so chosen that Is leads Im by about 80°

$$(\text{i.e., } \alpha \simeq 80°)$$

which is considerably greater than 25° found in split-phase motor [See Fig. (9.14(ii))]. Consequently, starting torque $(T_s = k\, I_m\, I_s \sin \alpha)$ is much more than that of a split-phase motor Again, the starting winding is opened by the centrifugal switch when the motor attains about 75% of synchronous speed. The motor then operates as a single-phase induction motor and continues to accelerate till it reaches the normal speed.

Characteristics

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

II. The phase angle between the two currents is about 80° compared to about 25° in a split-phase motor. Consequently, for the same starting torque, the current in the starting winding is only about half that in a split-phase motor.

Therefore, the starting winding of a capacitor start motor heats up less quickly and is well suited to applications involving either frequent or prolonged starting periods.

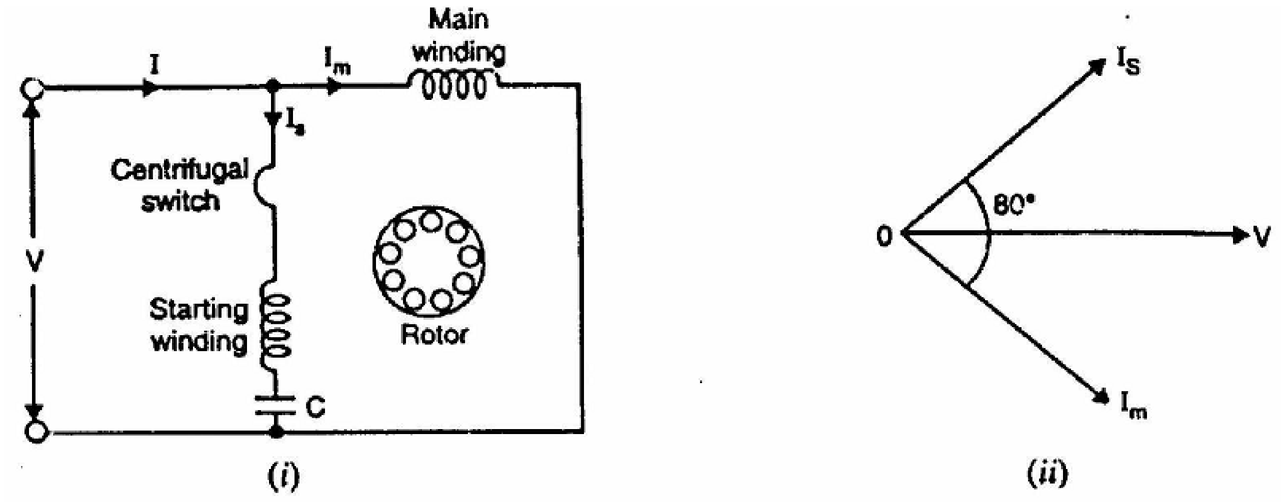


Fig.(9.14)

III. Capacitor-start motors are used where high starting torque is required and where the starting period may be long e.g., to drive:

(a) compressors (b) large fans (c) pumps (d) high inertia loads

The power rating of such motors lies between 120 W and 7-5 kW.

Capacitor-Start Capacitor-Run Motor

This motor is identical to a capacitor-start motor except that starting winding is not opened after starting so that both the windings remain connected to the supply when running as well as at starting. Two designs are generally used.

I) In one design, a single capacitor C is used for both starting and running as shown in Fig. (9.15 (i)). This design eliminates the need of a centrifugal switch and at the same time improves the power factor and efficiency of the motor.

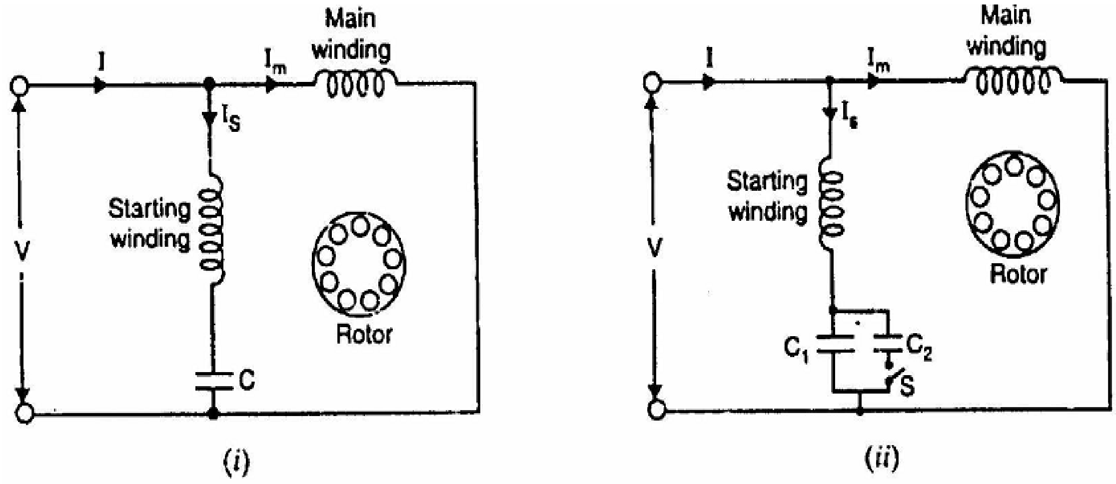


Fig.(9.15)

II) In the other design, two capacitors C1 and C2 are used in the starting winding as shown in Fig. (9.15 (ii)). The smaller capacitor C1 required for optimum running conditions is permanently connected in series with the starting winding. The much larger capacitor C2 is connected in parallel with C1 for optimum starting and remains in the circuit during starting. The starting capacitor C1 is disconnected when the motor approaches about 75% of synchronous speed. The motor then runs as a single-phase induction motor.

Characteristics

I) 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.

II) (ii) Because of constant torque, the motor is vibration free and can be used in: (a) hospitals (b) studios and (c) other places where silence is important.

Shaded-Pole Motor

The shaded-pole motor is very popular for ratings below 0.05 H.P. (~ 40 W) because of its extremely simple construction. It has salient poles on the stator excited by single-phase supply and a squirrel- cage rotor as shown in Fig. (9.16). A portion of each pole is surrounded by a short-circuited turn of copper strip called shading coil.

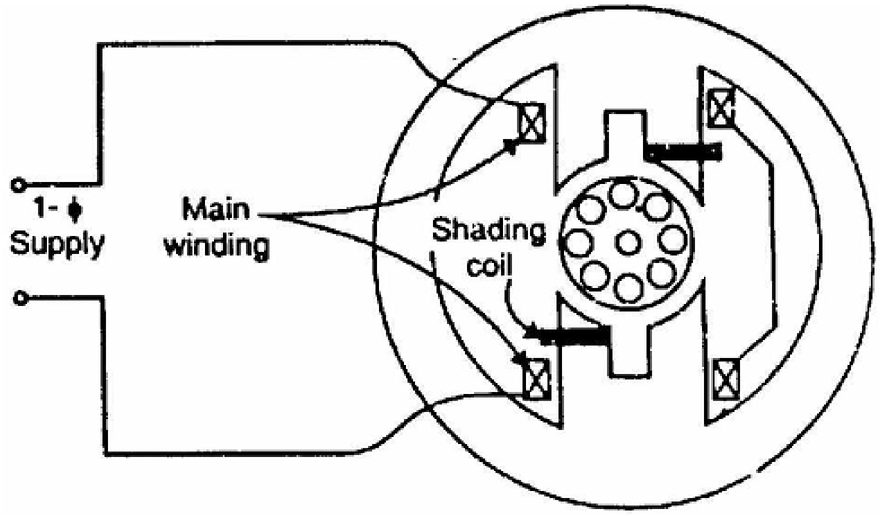


Fig.(9.16)

Operation

The operation of the motor can be understood by referring to Fig. (9.17) which shows one pole of the motor with a shading coil.

I) During the portion OA of the alternating-current cycle [See Fig. (9.17)], the flux begins to increase and an e.m.f. is induced in the shading coil. The resulting current in the shading coil will be in such a direction (Lenz's law) so as to oppose the change in flux. Thus the flux in the shaded portion of the pole is weakened while that in the unshaded portion is strengthened as shown in Fig. (9.17 (ii)).

II) During the portion AB of the alternating-current cycle, the flux has reached almost maximum value and is not changing. Consequently, the flux distribution across the pole is uniform [See Fig. (9.17 (iii))] Since no current is flowing in the shading coil. As the flux decreases (portion BC of the alternating current cycle), current is induced in the shading coil so as to oppose the decrease in current. Thus the flux in the shaded portion of the pole is strengthened while that in the unshaded portion is weakened as shown in Fig. (9.17 (iv)).

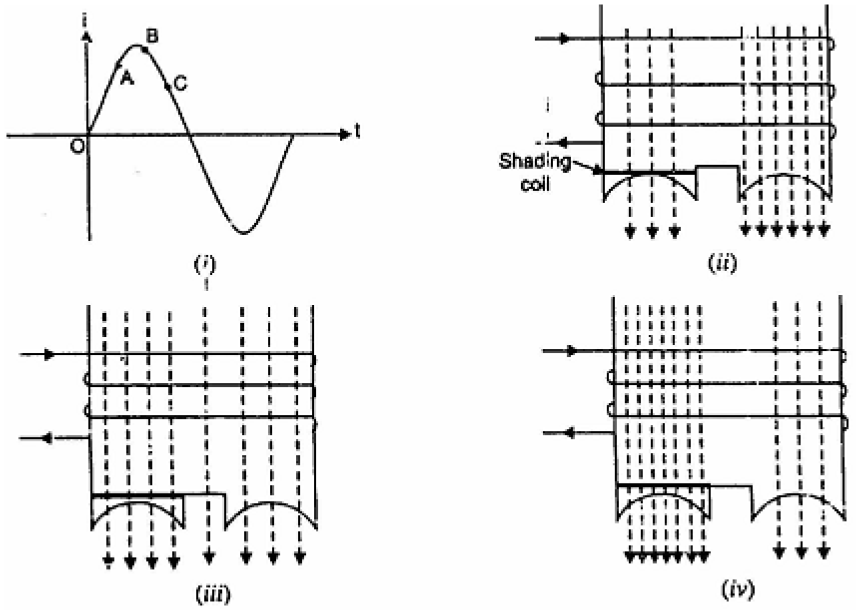


Fig.(9.17)

III) The effect of the shading coil is to cause the field flux to shift across the pole face from the unshaded to the shaded portion. This shifting flux is like a rotating weak field moving in the direction from unshaded portion to the shaded portion of the pole.

IV) The rotor is of the squirrel-cage type and is under the influence of this moving field. Consequently, a small starting torque is developed. As soon as this torque starts to revolve the rotor, additional torque is produced by single-phase induction-motor action. The motor accelerates to a speed slightly below the synchronous speed and runs as a single-phase induction motor.

Characteristics

(i) The salient features of this motor are extremely simple construction and absence of centrifugal switch.

(ii) Since starting torque, efficiency and power factor are very low, these motors are only suitable for low power applications e.g., to drive: (a) small fans (6) toys (c) hair driers (d) desk fans etc.

The power rating of such motors is upto about 30 W.

A.C. Series Motor or Universal Motor

A d.c. series motor will rotate in the same direction regardless of the polarity of the supply. One can expect that a d.c. series motor would also operate on a single-phase supply. It is then called an a.c. series motor. However, some changes must be made in a d.c. motor that is to operate satisfactorily on a.c. supply. The changes effected are:

(i) The entire magnetic circuit is laminated in order to reduce the eddy current loss. Hence an a.c. series motor requires a more expensive construction than a d.c. series motor.

(ii) The series field winding uses as few turns as possible to reduce the reactance of the field winding to a minimum. This reduces the voltage drop across the field winding.

(iii) A high field flux is obtained by using a low-reluctance magnetic circuit.

(iv) There is considerable sparking between the brushes and the commutator when the motor is used on a.c. supply. It is because the alternating flux establishes high currents in the coils short-circuited by the brushes. When the short-circuited coils break contact from the commutator, excessive sparking is produced. This can be eliminated by using high-resistance leads to connect the coils to the commutator segments.

Construction

The construction of en a.c. series motor is very similar to a d.c. series motor except that above modifications are incorporated [See Fig. (9.20)]. such a motor can be operated either on a.c. or d.c. supply and the resulting torque-speed curve is about the same in each case. For this reason, it is sometimes called a universal motor.

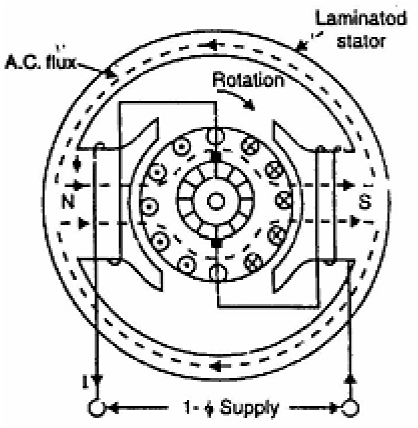


Fig.(9.20)

Operation

When the motor is connected to an a.c. supply, the same alternating current flows through the field and armature windings. The field winding produces an alternating flux φ that reacts with the current flowing in the armature to produce a torque. Since both armature current and flux reverse simultaneously, the torque always acts in the same direction. It may be noted that no rotating flux is produced in this type of machines; the principle of operation is the same as that of a d.c. series motor.

Characteristics

The operating characteristics of an a.c. series motor are similar to those of a d.c. series motor.

(i) The speed increases to a high value with a decrease in load. In very small series motors, the losses are usually large enough at no load that limit the speed to a definite value (1500 - 15,000 r.p.m.).

(ii) The motor torque is high for large armature currents, thus giving a high starting torque.

(iii) At full-load, the power factor is about 90%. However, at starting or when carrying an overload, the power factor is lower.

Applications

The fractional horsepower a.c. series motors have high-speed (and corresponding small size) and large starting torque. They can, therefore, be used to drive:

(a) High-speed vacuum cleaners

(b) Sewing machines

(c) Electric shavers

(d) Drills

(e) Machine tools etc.

Single-Phase Repulsion Motor

A repulsion motor is similar to an a.c. series motor except that:

(i) Brushes are not connected to supply but are short-circuited [See Fig. (9.21)]. consequently, currents are induced in the armature conductors by transformer action.

(ii) The field structure has non-salient pole construction.

By adjusting the position of short-circuited brushes on the commutator, the starting torque can be developed in the motor.

Construction

The field of stator winding is wound like the main winding of a split-phase motor and is connected directly to a single-phase source. The armature or rotor is similar to a d.c. motor armature with drum type winding connected to a commutator (not shown in the figure). However, the brushes are not connected to supply but are connected to each other or short-circuited. Short-circuiting the brushes effectively makes the rotor into a type of squirrel cage. The major difficulty with an ordinary single-phase induction motor is the low starting torque. By using a commutator motor with brushes short-circuited, it is possible to vary the starting torque by changing the brush axis. It has also better power factor than the conventional single-phase motor.

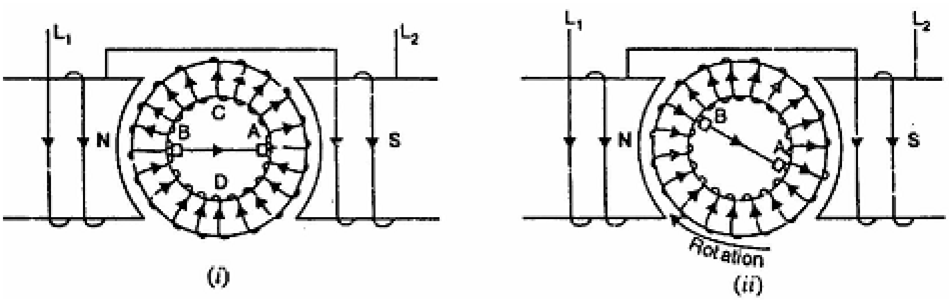


Fig.(9.21)

Principle of operation

The principle of operation is illustrated in Fig. (9.21) which shows a two-pole repulsion motor with its two short-circuited brushes. The two drawings of Fig. (9.21) represent a time at which the field current is increasing in the direction shown so that the left-hand pole is N-pole and the right-hand pole is S-pole at the instant shown.

(i) In Fig. (9.21 (i)), the brush axis is parallel to the stator field. When the stator winding is energized from single-phase supply, e.m.f. is induced in the armature conductors (rotor) by induction. By Lenz's law, the direction of the e.m.f. is such that the magnetic effect of the resulting armature currents will oppose the increase in flux. The direction of current in armature conductors will be as shown in Fig. (9.21 (i)). With the brush axis in the position shown in Fig. (9.21 (i)), current will flow from brush B to rush A where it enters the armature and flows back to brush B through the two paths ACB and ADB. With brushes set in this position, half of the armature conductors under the N-pole carry current inward and half carry current outward. The same is true under S-pole. Therefore, as much torque is developed in one direction as in the other and the armature remains stationary. The armature will also remain stationary if the brush axis is perpendicular to the stator field axis. It is because even then net torque is zero.

(ii) If the brush axis is at some angle other than 0° or 90° to the axis of the stator field, a net torque is developed on the rotor and the rotor accelerates to its final speed. Fig. (9.21 (ii)) represents the motor at the same instant as that in Fig. (9.21 (i)) but the brushes have been shifted clockwise through some angle from the stator field axis. Now e.m.f. is still induced in the direction indicated in Fig. (9.21 (i)) and current flows through the two paths of the armature winding from brush A to brush B. However, because of the new brush positions, the greater part of the conductors under the N- pole carry current in one direction while the greater part of conductors under S-pole carry current in the opposite direction. With brushes in the position shown in Fig. (9.21 (ii), torque is developed in the clockwise direction and the rotor quickly attains the final speed.

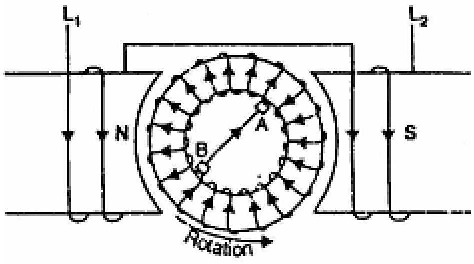


Fig.(9.22)

(iii) The direction of rotation of the rotor depends upon the direction in which the brushes are shifted. If the brushes are shifted in clockwise direction from the stator field axis, the net torque acts in the clockwise direction and the rotor accelerates in the clockwise direction. If the brushes are shifted in anti-clockwise direction as in Fig. (9.22). the armature current under the pole faces is reversed and the net torque is developed in the anti-clockwise direction. Thus a repulsion motor may be made to rotate in either direction depending upon the direction in which the brushes are shifted.

(iv) The total armature torque in a repulsion motor can be shown to be

$$T_a \propto \sin 2\alpha$$

Where

α = angle between brush axis and stator field axis

For maximum torque, $2\alpha = 90°$ or $\alpha = 45°$

Thus adjusting α to 45° at starting, maximum torque can be obtained during the starting period. However, α has to be adjusted to give a suitable running speed.

Characteristics

(i) The repulsion motor has characteristics very similar to those of an a.c. series motor i.e., it has a high starting torque and a high speed at no load.

(ii) The speed which the repulsion motor develops for any given load will depend upon the position of the brushes.

(iii) In comparison with other single-phase motors, the repulsion motor has a high starring torque and relatively low starting current.

Repulsion-Start Induction-Run Motor

Sometimes the action of a repulsion motor is combined with that of a single-phase induction motor to produce repulsion-start induction-run motor (also called repulsion-start motor). The machine is started as a repulsion motor with a corresponding high starting torque. At some predetermined speed, a centrifugal device short-circuits the commutator so that the machine then operates as a single-phase induction motor. The repulsion-start induction-run motor has the same general construction of a repulsion motor. The only difference is that in addition to the basic repulsion- motor construction, it is equipped with a centrifugal device fitted on the armature shaft. When the motor reaches 75% of its full pinning speed, the centrifugal device forces a short-circuiting ring to come in contact with the inner surface of the commutator. This snort-circuits all the commutator bars. The rotor then resembles squirrel-cage type and the motor runs as a single-phase induction motor. At the same time, the centrifugal device raises the brushes from the commutator which reduces the wear of the brushes and commutator as well as makes the operation quiet.

Characteristics

(i) The starting torque is 2.5 to 4.5 times the full-load torque and the starting current is 3.75 times the full-load value.

(ii) Due to their high starting torque, repulsion-motors were used to operate devices such as refrigerators, pumps, compressors etc. However, they posed a serious problem of maintenance of brushes, commutator arid the centrifugal device. Consequently, manufacturers have stopped making them in view of the development of capacitor motors which are small in size, reliable and low-priced.

Repulsion-Induction Motor

The repulsion-induction motor produces a high starting torque entirely due to repulsion motor action. When running, it functions through a combination of induction-motor and repulsion motor action.

Construction

Fig. (9.23) shows the connections of a 4-pole repulsion-induction motor for 230 V operation. It consists of a stator and a rotor (or armature)

(i) The stator carries a single distributed winding fed from single-phase supply.

(ii) The rotor is provided with two independent windings placed one inside the other. The inner winding is a squirrel-cage winding with rotor bars permanently short-circuited. Placed over the squirrel cage winding is a repulsion commutator armature winding. The repulsion winding is connected to a commutator on which ride short-circuited brushes. There is no centrifugal device and the repulsion winding functions at all times.

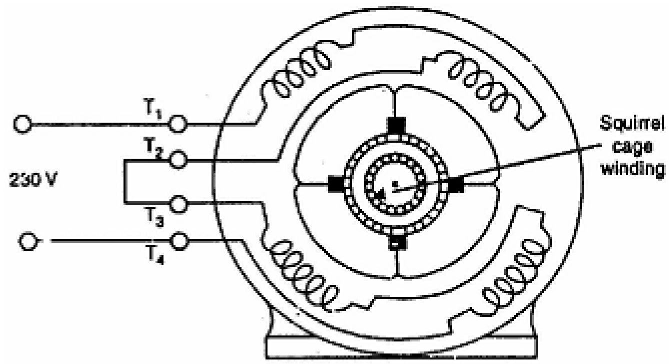


Fig.(9.23)

Operation

(i) When single-phase supply is given to the stator winding, the repulsion winding (i.e., outer winding) is active. Consequently, the motor starts as a repulsion motor with a corresponding high starting torque.

(ii) As the motor speed increases, the current shifts from the outer to inner winding due to the decreasing impedance of the inner winding with increasing speed. Consequently, at running speed, the squirrel cage winding carries the greater part of rotor current. This shifting of repulsion- motor action to induction-motor action is thus achieved without any switching arrangement.

(iii) It may be seen that the motor starts as a repulsion motor. When running, it functions through a combination of principle of induction and repulsion; the former being predominant.

Characteristics

(i) The no-load speed of a repulsion-induction motor is somewhat above the synchronous speed because of the effect of repulsion winding. However,

The speed at full-load is slightly less than the synchronous speed as in an induction motor.

(ii) The speed regulation of the motor is about 6%.

(iii) The starting torque is 2.25 to 3 times the full-load torque; the lower value being for large motors. The starting current is 3 to 4 times the full-load current.

This type of motor is used for applications requiring a high starting torque with essentially a constant running speed. The common sizes are 0.25 to 5 H.P.

Single-Phase Synchronous Motors

Very small single-phase motors have been developed which run at true synchronous speed. They do not require d.c. excitation for the rotor. Because of these characteristics, they are called unexcited single-phase synchronous motors.

The most commonly used types are:

(i) Reluctance motors

(ii) Hysteresis motors

The efficiency and torque-developing ability of these motors is low; The output of most of the commercial motors is only a few watts.

Reluctance Motor

It is a single-phase synchronous motor which does not require d.c. excitation to the rotor. Its operation is based upon the following principle: Whenever a piece of ferromagnetic material is located in a magnetic field; a force is exerted on the material, tending to align the material so that reluctance of the magnetic path that passes through the material is minimum.

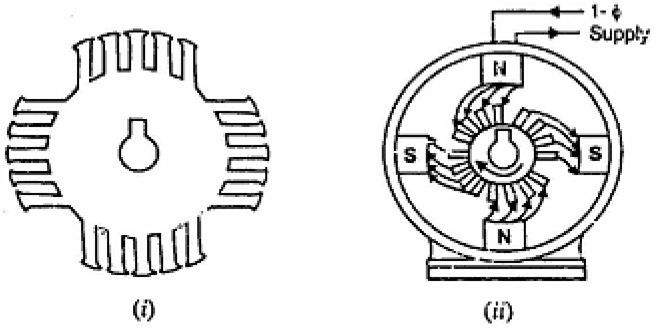


Fig.(9.24)

Construction

A reluctance motor (also called synchronous reluctance motor) consists of:

a stator carrying a single-phase winding along with an auxiliary winding to

(i) Produce a synchronous-revolving magnetic field.

(ii) A squirrel-cage rotor having unsymmetrical magnetic construction. This is achieved by symmetrically removing some of the teeth from the squirrel- cage rotor to produce salient poles on the rotor. As shown in Fig. (9.24 (i)), 4 sailent poles have been produced on me rotor. The salient poles created on the rotor must be equal to the poles on the stator.

Note that rotor salient poles offer low reductance to the stator flux and, therefore, become strongly magnetized.

Operation

(i) When single-phase stator having an auxiliary winding is energized, a synchronously-revolving field is produced. The motor starts as a standard squirrel-cage induction motor and will accelerate to near its synchronous speed.

(ii) As the rotor approaches synchronous speed, the rotating stator flux will exert reluctance torque on the rotor poles tending to align the salient-pole axis with the axis of the rotating field. The rotor assumes a position where its salient poles lock with the poles of the revolving field [See Fig. (9.24 (ii))]. Consequently, the motor will continue to run at the speed of revolving flux i.e., at the synchronous speed.

(iii) When we apply a mechanical load, the rotor poles fall slightly behind the stator poles, while continuing to turn at synchronous speed. As the load on the motor is increased, the mechanical angle between the poles increases progressively. Nevertheless, magnetic attraction keeps the rotor locked to the rotating flux. If the load is increased beyond the amount under which the reluctance torque can maintain synchronous speed, the rotor drops out of step with the revolving field. The speed, then, drops to some value at which the slip is sufficient to develop the necessary torque to drive the load by induction-motor action.

Characteristics

(i) These motors have poor torque, power factor and efficiency.

(ii) These motors cannot accelerate high-inertia loads to synchronous speed.

(iii) The pull-in and pull-out torques of such motors are weak.

Despite the above drawbacks, the reluctance motor is cheaper than any other type of synchronous motor. They are widely used for constant-speed applications such as timing devices, signaling devices etc.

Hysteresis Motor

It is a single-phase motor whose operation depends upon the hysteresis effect

i.e., magnetization produced in a ferromagnetic material lags behind the magnetizing force.

Construction It consists of:

(i) A stator designed to produce a synchronously-revolving field from a single-phase supply. This is accomplished by using permanent-split capacitor type construction. Consequently, both the windings (i.e., starting as well as main winding) remain connected in the circuit during running operation as well as at starting. The value of capacitance is so adjusted as to result in a flux revolving at synchronous speed.

(ii) A rotor consisting of a smooth cylinder of magnetically hard steel, without winding or teeth.

Operation

(i) When the stator is energized from a single-phase supply, a synchronously- revolving field (assumed in anti-clockwise direction) is produced due to split-phase operation.

(ii) The revolving stator flux magnetizes the rotor. Due to hysteresis effect, the axis of magnetization of rotor will lag behind the axis of stator field by hysteresis lag angle a as shown in Fig. (9.25). Thus the rotor and stator poles are locked. If the rotor is stationary, the starting torque produced is

given by:

$$T_s \propto \phi_s \phi_r \sin\alpha$$

where ϕ_s = stator flux.

ϕ_r = rotor flux.

From now onwards, the rotor accelerates to synchronous speed with a uniform torque.

III) After reaching synchronism, the motor continues to run at synchronous speed and adjusts its torque angle so as to develop the torque required by the load.

Characteristics

I) A hysteresis motor can synchronize any load which it can accelerate, no matter how great the inertia. It is because the torque is uniform from standstill to synchronous speed.

II) Since the rotor has no teeth or salient poles or winding, a hysteresis motor is inherently quiet and produces smooth rotation of the load.

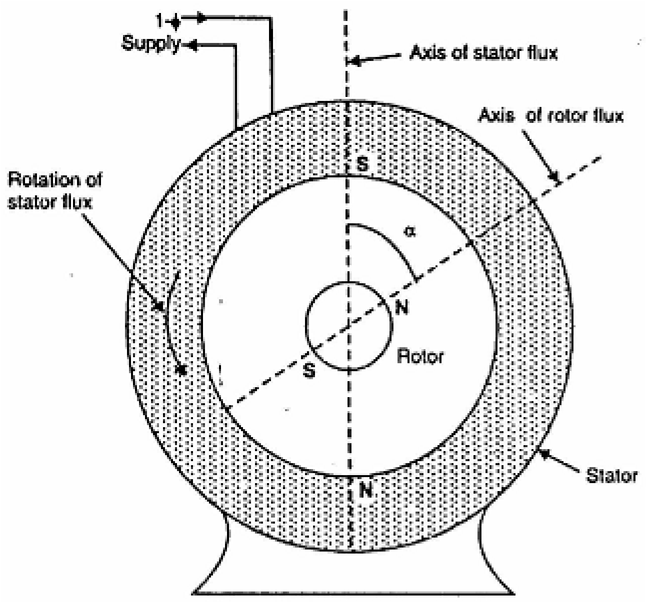


Fig.(9.25)

III) The rotor takes on the same number of poles as the stator field. Thus by changing the number of stator poles through pole-changing connections, we can get a set of synchronous speeds for the motor.

Applications

Due to their quiet operation and ability to drive high-inertia toads, hysteresis motors are particularly well suited for driving (i) electric clocks (ii) timing devices (iii) tape-decks (iv) from-tables and other precision audio-equipment.

Self-Check 2	multiple choice

Part II: Enumeration

Direction: multiple choice

1) The starting winding of a single phase motor is placed in the
   - A. Rotor
   - B. stator
   - C. armature
   - D. field
2) DC motor with constant speed
   - A. DC series motor
   - B. DC shunt motor
   - C. DC compound motor
   - D. All

1) Which DC motors has approximately constant speed
   - B) DC series motor
   - C) DC shunt motor
   - D) DC compound motor
   - E) All

Answer Sheet

Score = ___________

Rating: ____________

Name: ________________________ Date: ______________

Information Sheet-3	1.3. Verifying the correct size and degree of protection

Types of Cables

- Armoured Cables
- Unarmoured Cables
- Braided Cables
- Screened Cables
- Power Cables
- Control Cables
- Single core cables
- Multi-core cables
- Fire resistant cables
- Flame retardant cables
- Data Cables
- Thermocouple cables
- Twisted Pair
- Co-axial cables

Cable Conductors

- Cable conductors may be either solid or stranded.
- Stranding makes cables more flexible and allows higher current carrying capacities, easy to handle and easy to solder.
- The factors that determine the choice of the conductors are the weight, the cost, and the environment where the conductors are used.

- Although SILVER is the best conductor it is used only in special circuits as it is costly
- Resistivity :silver 1.64 X 10^{-8} ohm meters at 20^{o} C copper : 1.72X 10^{-8} ohm meters at 20^{o} C
- Copper is the choice of good conductors cables for the following reasons.

1. It possess low resistivity (for annealed copper it is 1.72X 10^{-8} ohm meters at 20^{o} C)
2. It is more ductile (can be drawn into fine strands)
3. It has relatively more tensile strength. (The greatest stress a substance can bear along its length without tearing apart.)
4. It can also be easily soldered.

Current rating of cables

The current rating of a cable is that current the cable is able to carry continuously without the conductor temperature exceeding 80^{o}C with an ambient air temperature of 45^{o}C. (35^{o}C rise).

If the ambient temperature exceeds 45^{o}C the cable must be de-rated (rating must be reduced).

The cables are also de-rated if the cables are bunched together or enclosed in a pipe or trunking, which reduces the effective cooling.

STANDARD SIZE POWER CABLES AND THEIR CURRENT RATINGS

Conductor cross sectional area	Single core current rating. A	Voltage drop per Ampere per metre in mV	Three core current rating A	Voltage drop per ampere per meter in mV.
1.0	13	54	11	47
1.5	17	35	14	30
2.5	24	18	20	16
4	32	12	27	10
6	41	7.8	34	6.7
10	57	4.6	47	4.0

16	**76**	**2.7**	**63**	**3.8**
25	**100**	**1.7**	**84**	**1.5**
50	**155**	**0.98**	**125**	**0.89**
70	**190**	**0.68**	**160**	**0.64**
95	**235**	**0.49**	**195**	**0.5**

Standard sizes of Power Cables

3x1.5 Sq.mm	3x50 Sq.mm
3x2.5 Sq.mm	3x70 Sq.mm
3x4.0 Sq.mm	3x95 Sq.mm
3x6.0 Sq.mm	3x120 Sq.mm
3x10 Sq.mm	3x150 Sq.mm
3x16 Sq.mm	3x240 Sq.mm
3x25 Sq.mm	3x300 Sq.mm
3x35 Sq.mm	3x400 Sq.mm

Standard sizes of Control cables

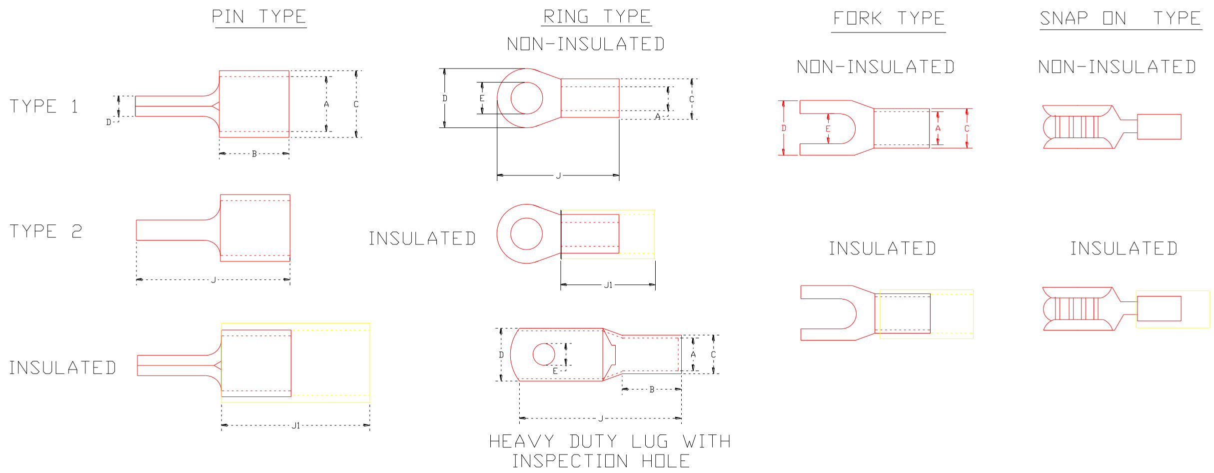
1x1.5/2.5/4/6 sq.mm	19x1.5 sq.mm
5x1.5 sq.mm	27x1.5 sq.mm
7x1.5 sq.mm	33x1.5 sq.mm
9x1.5 sq.mm	DC Cables
12x1.5 sq.mm	2x1.5/2.5/4/6
16x1.5 sq.mm	

Cable Termination

Cable sockets (lugs) are either soldered or more often crimped onto each wire by a compression tool (Hand or hydraulic)

Cable sockets must be securely attached to the appliance by well-chosen screws/bolts/spring washers etc. A loose terminal will become a source of localized overheating.

Types of Lugs



Degrees of Protection

Although some characteristic numerals to indicate the degree of protection can be combined in different ways, only a few degrees of protection are usually employed. They are: IP21,

IP22, IP23, IP44 and IP55.

The first three numerals apply to open motors and the other two refer to enclosed motors. For special and more dangerous areas there are other commonly used degrees of protection such as IPW 55 (weather protection) IP56 (protections against water jets), IP65 (totally protected against dust) and IP66 (totally protected against dust and water jets).

Bearing sealing

Frame sizes 225S/M to 355A/B can be supplied with sealing system WSeal®, as serial item this sealing system consists of a V'Ring ring with double lips and metal cap mounted on this ring.

Among the other available sealing systems for the line W22, is the revolutionary sealing system W3 Seal®, formed by three seals: V'Ring, O'Ring and Taconite Labyrinth. This sealing system has been developed by WEG to protect the motor against accumulation of solid and liquid impurities present in environment, which provides to the motor the protection degree IP66.

Other degrees of protection for motors are not so common. Any of the above mentioned degree of protection fully meets the lower requirements of the lower (smaller figures). Thus, for example, an motor with degree of protection IP55 replaces with advantages the motors with degree of protection IP12, IP22 or IP23, ensuring higher protection against accidental exposure to dust and water. This allows the production standardization with a single type of motor that meets all the cases, with an additional advantage for user in the case of less demanding environments.

Weather Protected Motors

According to IEC 60034-5, the motor will be weather protected when due to its design (technical discussion between customer and WEG), the defined protections provide a correct operation of the motor against rain, dust and snow.

WEG also uses the letter W to indicate the degree of protection of the motor to indicate that the motor has a special paint plan (weather protected). The painting plans may vary according to the environmental severity, which should be informed by the customer during motor specification/order.

Aggressive environments require that equipment be perfectly suitable to support such conditions ensuring high reliability in service without showing any problems.

WEG manufactures a wide range of electric motors with special characteristics, suitable for use in shipyards, ports, fishing plants and several naval applications, as well as in chemical and petrochemical industries and other aggressive environments. So WEG motors are suitable to operate under the most severe operational conditions.

Care of Cables

- Cables fitted in main decks, machinery spaces and other exposed areas must be properly protected from injury and mechanical stresses.
- When hot repair work such as arc welding, gas cutting etc are carried out near the cables or on the bulkheads nearby, cables must be adequately protected from damage due to spark or molten metals , by covering with fire proof covers, sheets etc.
- Securing of cables in cable trays must be proper. Cables must be protected from loose or vibrating metals to prevent chaffing or damage to the

Drying out cables

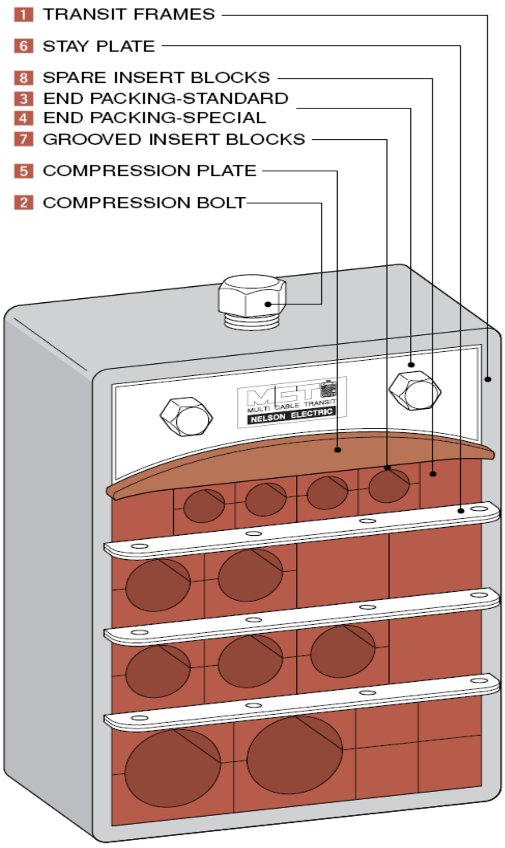
- Cables in exposed and damp situations may develop low insulation resistance.
- Cables can be dried out by injecting a heating current from a current injection test or a welding transformer.

- The voltage should be 30 – 50V and the current should not exceed the rating of the cable.
- Temperature rise to be below 30^0C
- Temperature and insulation resistance should be measured and recorded every hour
- Final readings of at least 20Megohms to earth and 100Meghoms between cores should be expected.

Cable Penetrations

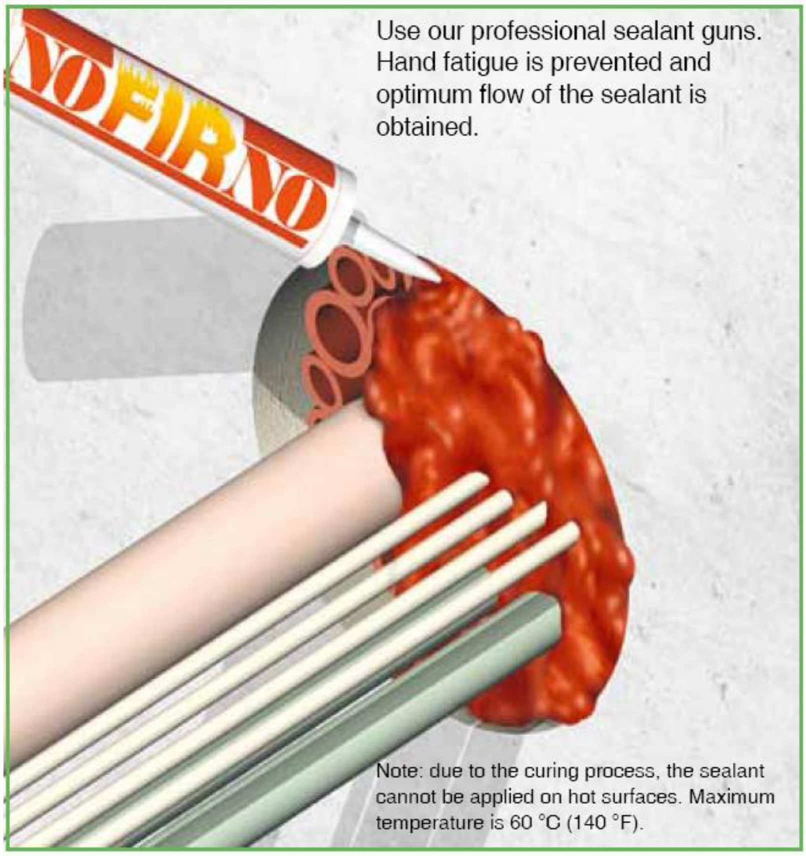
- When a single cable is passing through a deck or bulkhead, it can pass through a pipe gland which may be a single compression, double compression or explosion proof type depending upon the area of penetration (watertight, non-watertight or hazardous area)
- When a bunch of cables of the same type (power, control, instrument, high voltage) pass through coaming, the coamings should be compound filled (water-proof or fire-proof) and sealed after cable laying.
- MCTs (Multiple Cable Transits) can be used for better aesthetics and sealing provided proper planning precedes cable laying. Use of MCTs involve a high capital expenditure.

Multiple Cable Transit – Block Type



All cable penetrations through firewalls, blast walls, through switchgear room walls and between safe and hazardous area shall be sealed using multi cable transits to maintain the integrity of system and prevent gas migration. The sealed transit shall ensure that the fire integrity of the wall is maintained.

Multiple Cable Transit – Sleeve Type



Self-Check 2	Written test

Part II: Enumeration

Direction: write the following equation

1. List types of cable
    a) _______
    b) _______
    c) _______
    d) _______
2. Explain way of cable degree protection
    ____
    ____
    ____

Answer Sheet

Score = ___________

Rating: ____________

Name: __________________________ Date: ________________

Information Sheet-4	4. Identifying and interpreting name plate data

Name Plate Details

- Ingress Protection
- Duty
- Type of Enclosure
- Connection
- Makers Name/Type
- S.No.
- Bearings
- KW/HP
- Voltage
- Frequency
- Full load Current
- Frame Size
- RPM
- Class of insulation

Voltage, frequency and phase of power supply should be consistent with the **motor nameplate** rating. A motor will operate satisfactorily on voltage within 10% of nameplate value, or frequency within 5%, or combined voltage and frequency variation not to exceed 10%.

<u>Voltage</u>

Common 60 hz voltages for single-phase motors are 115 volt, 230 volt, and 115/230 volt.

Common 60 hz voltage for three-phase motors are 230 volt, 460 volt and 230/460 volt. Two hundred volt and 575 volt motors are sometimes encountered. In prior NEMA standards these voltages were listed as 208 or 220/440 or 550 volts. Motors with these voltages on the **nameplate** can safely be replaced by motors having the current standard markings of 200 or 208, 230/460 or 575 volts, respectively. Motors rated 115/208-230 volt and 208-230/460 volt, in most cases, will operate satisfactorily at 208 volts, but the torque will be 20% - 25% lower.

Operating below 208 volts may require a 208 volt (or 200 volt) motor or the use of the next higher horsepower, standard voltage motor.

Phase

Single-phase motors account for up to 80% of the motors used in the United States but are used mostly in homes and in auxiliary low-horse power industrial applications such as fans and on farms.

Three-phase motors are generally used on larger commercial and industrial equipment.

Current (amps)

In comparing motor types, the full load amps and/or service factor amps are key parameters for determining the proper loading on the motor. For example, never replace a PSC type motor with a shaded pole type as the latter's amps will normally be 50% - 60% higher. Compare PSC with PSC, capacitor start with capacitor start, and so forth.

Hertz / Frequency

In North America **60 hz** (cycles) is the common power source. However, most of the rest of the world is supplied with **50 hz** power.

Horsepower

Exactly 746 watts of electrical power will produce 1 HP if a motor could operate at 100% efficiency, but of course no motor is 100% efficient. A 1 HP motor operating at 84% efficiency will have a total watt consumption of 888 watts. This amounts to 746 watts of usable power and 142 watts loss due to heat, friction, etc. (888 x .84 = 746 = 1 HP).

Horsepower can also be calculated if torque is known, using one of these formulas:

$$HP = \frac{\text{Torque (lb-ft)} \times \text{RPM}}{5{,}250}$$

$$HP = \frac{\text{Torque (oz-ft)} \times \text{RPM}}{84{,}000}$$

$$HP = \frac{\text{Torque (lb-in)} \times \text{RPM}}{63{,}000}$$

Speed

The approximate RPM at rated load for small and medium motors operating at 60 hz and 50 hz at rated volts are as follows:

	60 hz	50 hz	Synch. Speed
2 Pole	3450	2850	3600
4 Pole	1725	1425	1800
6 Pole	1140	950	1200
8 Pole	850	700	900

Synchronous speed (no-load) can be determined by this formula:

$$\frac{\text{Frequency (Hertz) x 120}}{\text{Number of Poles}}$$

Insulation Class

Insulation systems are rated by standard NEMA classifications according to maximum allowable operating temperatures. They are as follows:

Class	Maximum Allowed Temperature*	
A	105°C	(221°F)
B	130°C	(266°F)
F	155°C	(311°F)
H	180°C	(356°F)

Motor temperature rise plus maximum ambient

Generally, replace a motor with one having an equal or higher insulation class. Replacement with one of lower temperature rating could result in premature failure of the motor. Each 10°C rise above these ratings can reduce the motor's service life by one half.

Service Factor

The service factor (SF) is a measure of continuous overload capacity at which a motor can operate without overload or damage, provided the other design parameters such as rated voltage, frequency and ambient temperature are within norms. Example: a 3/4 HP motor with a 1.15 SF can operate at .86 HP, (.75 HP x 1.15 = .862 HP) without overheating or otherwise damaging the motor if rated voltage and frequency are supplied at the motor's leads. Some motors, including most LEESON motors, have higher service factors than the NEMA standard.

It is not uncommon for the original equipment manufacturer (OEM) to load the motor to its maximum load capability (service factor). For this reason, do not replace a motor with one of the same nameplate horsepower but with a lower service factor. Always make certain that the replacement motor has a maximum HP rating (rated HP x SF) equal to or higher than that which it replaces. Multiply the horsepower by the service factor for maximum potential loading.

For easy reference, standard NEMA service factors for various horsepower motors and motor speeds are shown in this table.

	FOR DRIP PROOF MOTORS Service Factor Synchronous Speed (RPM)			
HP	3600	1800	1200	900
$^1/_6$, $^1/_4$, $^1/_3$	1.35	1.35	1.35	1.35
$^1/_2$	1.25	1.25	1.25	1.25
$^3/_4$	1.25	1.25	1.15	1.15
1	1.25	1.15	1.15	1.15
$1^1/_2$ up	1.15	1.15	1.15	1.15

The NEMA service factor for totally enclosed motors is 1.0. However, many manufacturers build TEFC with a 1.15 service factor.

Capacitors

Capacitors are used on all fractional HP induction motors except shaded pole, split-phase and polyphase. Start capacitors are designed to stay in circuit a very short time (3-5 seconds), while run capacitors are permanently in circuit. Capacitors are rated by capacity and voltage. Never use a capacitor with a voltage less than that recommended with the replacement motor. A higher voltage is acceptable.

Efficiency

A motor’s efficiency is a measurement of useful work produced by the motor versus the energy it consumes (heat and friction). An 84% efficient motor with a total watt draw of 400W produces 336 watts of useful energy (400 x .84 = 336W). The 64 watts lost (400 - 336 = 64W) becomes heat.

Thermal Protection (Overload)

A thermal protector, automatic or manual, mounted in the end frame or on a winding, is designed to prevent a motor from getting too hot, causing possible fire or damage to the motor. Protectors are generally current and temperature-sensitive. Some motors have no inherent protector, but they should have protection provided in the overall system’s design for safety.

Never bypass a protector because of nuisance tripping. This is generally an indication of some other problem, such as overloading or lack of proper ventilation.

Never replace nor choose an automatic-reset thermal overload protected motor for an application where the driven load could cause personal injury if the motor should restart unexpectedly. Only manual-reset thermal overloads should be used in such applications.

Basic types of overload protectors include:

Automatic Reset: After the motor cools, this line-interrupting protector automatically restores power. It should not be used where unexpected restarting would be hazardous.

Manual Reset: This line-interrupting protector has an external button that must be pushed to restore power to the motor. Use where unexpected restarting would be hazardous, as on saws, conveyors, compressors and other machinery.

Resistance Temperature Detectors: Precision-calibrated resistors are mounted in the motor and are used in conjunction with an instrument supplied by the customer to detect high temperatures.

Individual Branch Circuit Wiring

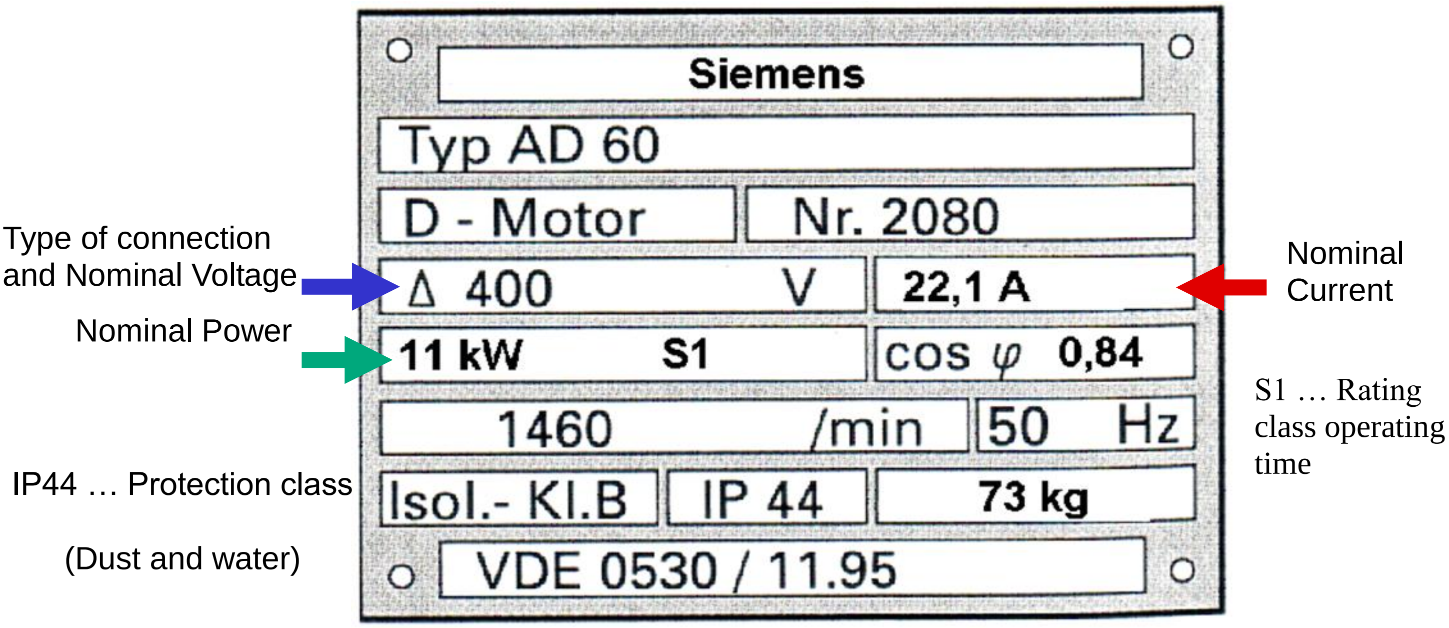
All wiring and electrical connections should comply with the National Electrical Code (NEC) and with local codes and practices. Undersized wire between the motor and the power source will limit the starting and load carrying abilities of the motor. The recommended copper wire and transformer sizes are shown in the following charts.

Single Phase Motors - 230 Volts

Transformer		Distance – Motor to Transformer (Feet)				
HP	kVA	100	150	200	300	500
1.5	3	10	8	8	6	4
2	3	10	8	8	6	4
3	5	8	8	6	4	2
5	7.5	6	4	4	2	0
7.5	10	6	4	3	1	0

WIRE GAGE

Data from the rating Name plate



Self-check 4	Written- test

Instructions: Answer all the questions listed below. Illustrations may be necessary to aid some explanations/answers. Write your answers in the sheet provided in the next page.

1. List out basic information n name plate data
   a) ______________
   b) ______________
   c) ______________
   d) ______________
   e) ______________
   f) ______________

Answer Sheet

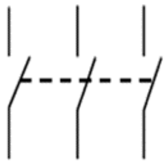
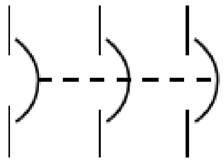
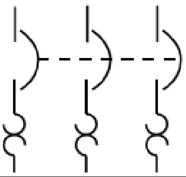
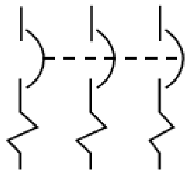
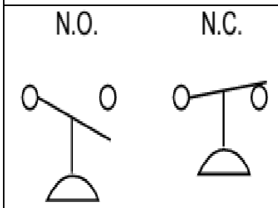
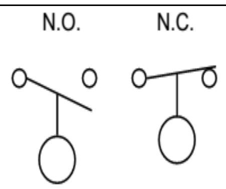
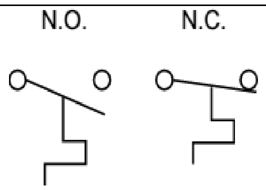
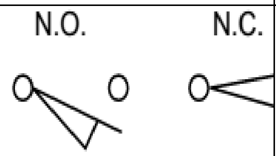
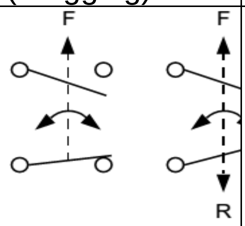
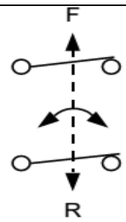
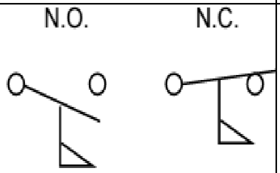
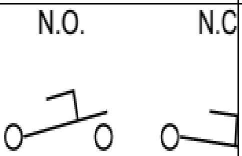
Score = ____________

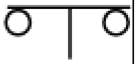
Rating: _____________

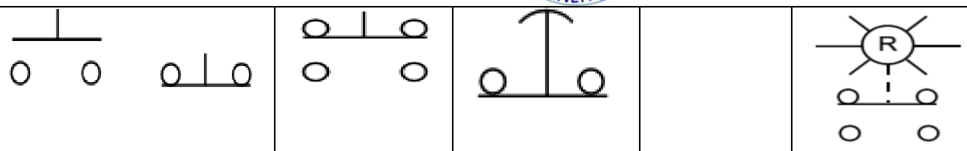
Name: ___________________________ Date: ________________

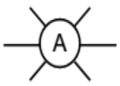
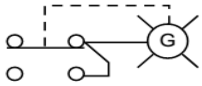
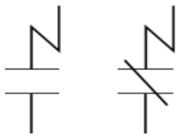
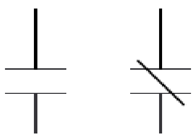
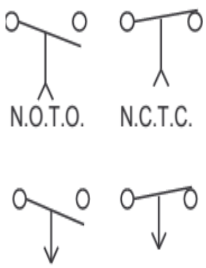
Information sheet 5	Installing machines and drives according to the specifications.

Standard Elementary Diagram Symbols

SWITCHES			
Disconnect	Circuit Interrupter	Circuit Breakers w/ Thermal OL	Circuit Breakers w/ Magnetic OL
			
Pressure &Vacuum Switches	Liquid Level Switches	Temperature Actuated Switches	
			
Limit Switches	Speed (Plugging)	Anti-Plug	
			
Flow Switches	Foot Switches		
			

PUSH BUTTONS – MOMENTARY CONTACT				
NO NC	N.O. & N.C. (double circuit)	Mushroom Head	Wobble Stick 	Illuminated



PILOT LIGHTS		INSTANT OPERATING CONTACTS		TIMED CONTACTS
Non Push-to-Test 	Push-to-Test 	w/ Blowout 	w/o Blowout 	Contact action retarded after coil is: Energized Deenergized 

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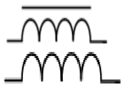
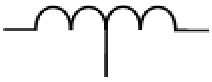
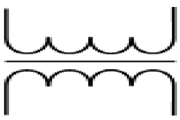
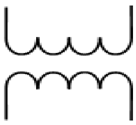
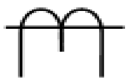
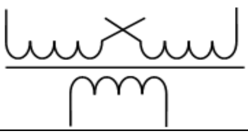
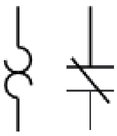
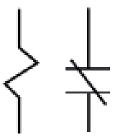
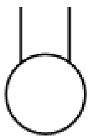
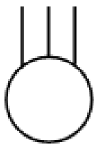
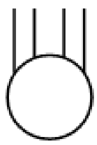
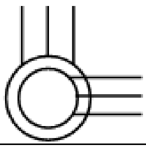
Iron Core Air Core 	Auto  Iron Core  Air Core  Current  Dual Voltage 

OVERLOAD RELAYS	AC MOTORS
Thermal  Magnetic 	Single Phase  3-Phase Squirrel Cage  2-Phase, 4-Wire  Wound Rotor 

DC MOTORS

Installing control and drives system

Electric motors present some special problems from the stand point of control. An electric motor will try to provide the power required by a load, even if it results in self-destruction. Therefore, a motor must be protected from overloads. A motor draws up to six times as much current when the rotor is not turning as it does when operating at full speed. Control contacts, and wires must be capable of carrying this high current during starting without causing damage or excessive voltage drop. If a motor should stall, the disconnect switch and control device must be capable of handling the high locked-rotor current. For example, a 100-hp, 460-V, 3-phase electric motor powering an irrigation pump draws 124 A when operating at full load. The locked-rotor current of the motor, however, is nearly 750 A, NEC Table 430-151.

The motor starter and disconnect switch must be capable of interrupting 750 A in the event the motor stalls. If the disconnect or controller is not rated for this high level of current, it could explode the instant it is opened.

Motor circuits will' be safe and motors will be protected provided the wiring procedures of NEC Article 430 are applied. Proper sizing of motor overload protection will ensure many years of dependable service.

TYPES OF MOTOR CONTROLLERS

A controller is simply a means of closing the circuit supplying power to an electrical motor,

- According to NEC 430-81 (a). Controlling may be accomplished **manually** or **automatically**. The simplest motor controller is an attachment plug and receptacle. This method is permitted only for portable motors rated at 1/3 hp and less,
- NEC Section/1 430-81(c). Motors larger than 1/3 hp are permitted to be cord connected, but the starting and stopping of the motor must be accomplished by one of the means discussed next.

The branch-circuit protective device, such as a circuit breaker, may serve as the controller for stationary motors, not larger than 1/8 hp, that are normally allowed to operate continuously.

- An example is a clock motor, NEC Section 430-8l (b). These motors are designed with a high impedance, and they cannot be overloaded even if the rotor stalls.

A time-delay circuit breaker is permitted to serve as a motor controller, NEC Section 430-83, Exception No.2. This is frequently the case with farm machinery. Circuit breakers are subject to failure after repeated on and off cycling and, therefore, they are not the best choice for a controller. It is also difficult to size a circuit breaker small enough to provide overload protection for the motor, and still not trip due to the high inrush starting current of the motor.

A fusible knife switch, Figure 1, can serve as a motor controller, provided the switch has a horsepower rating sufficient for the motor supplied, NEC Section430-90.

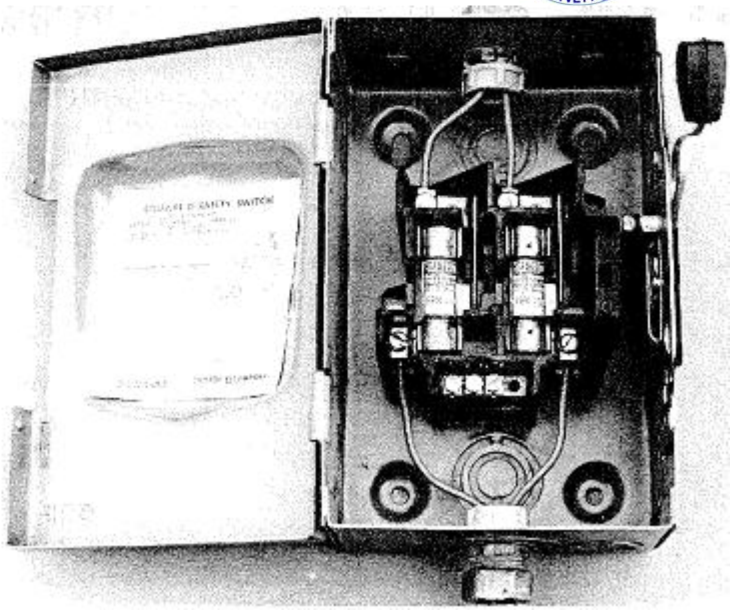


Figure 1 A fusible knife switch may be used as a motor controller.

Time-delay fuses can usually be sized small enough to provide overload protection, and still not blow during starting. The knife switch must be rated in horsepower, NEC Section 430-83. The switch must also have a voltage rating sufficient for the circuit. A 250-V switch is required for motors operating at 120 V, 208 V, and 240 V. A 600-V switch is required for motors operating at 277 V or 480 V.

An ordinary snap switch rated in amperes or horse-power is permitted to be used as a controller for motors rated at not more than 2 hp, and for circuits operating at not more than 300 V, NEC Section 430-83, and ExceptionNo.1.

The general-use snap switch must have an ampere rating twice that of the full-load current of the motor. A 1/3-hp motor, for example, draws 7.2 A full-load current at 115 V. A general-use snap switch with a 15-A rating would be required for this motor.

7.2 A X 2 = 14.4 A

Switches rated for use only on alternating-current circuits are permitted to control motors with a full-load current of 80% of the current rating of the switch. Therefore, a 30-A ac switch is permitted to supply a moto which draws 24 A.

30 A X 0.8 = 24 A

A 2-hp electric motor operating at 115 V draws 24 A

Snap switches for motors are available which do provide overload protection, Figure 2. This type switch, rather than an ordinary switch, is preferred for controlling motors up to 2 hp.

A manual motor starter rated in horsepower provide reliable control and overload protection for motors up to about 5 hp single phase, and 10 hp 3 phase, Figure 3 A thermally activated trip mechanism opens the mote circuit automatically if an overload occurs. The overload heaters are sized based upon the full-load current rating of the motor. Manual motor starters are available for both single- and 3-phase motors.

Magnetic motor starters use an electric solenoid co to close the contacts and start the motor, Figure 4. These motor starters may be operated by a person actually activating a starting control, or they may be operate automatically. Only the magnetic motor starter can be controlled automatically. Magnetic motor starters can operate motors of up to several hundred horsepower

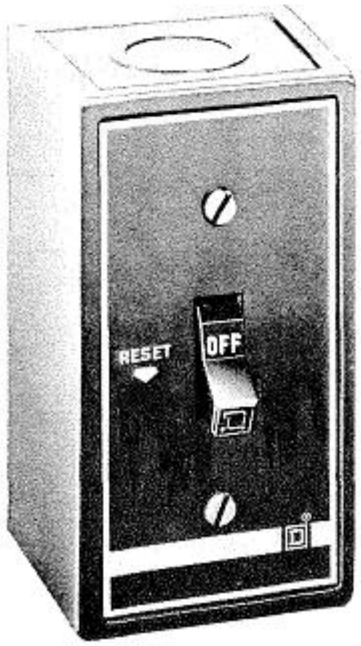


Figure 2 A motor controller with a maximum rating of 2 hp

Thermally activated overload relays break the circuit to the coil of the starter if a motor overload occurs. The overload heaters are sized for the nameplate full-load current of the motor.

Figure 3 Manual motor starter

MAGNETIC MOTOR STARTER CONSTRUCTION AND OPERATION

Understanding the operation and components of a magnetic motor starter is important when wiring a motor circuit, as well as when performing repairs when there is a malfunction. Only one manufacturer's motor starter is shown in the text, but all have essentially the same features. The main contacts replaced if they become pitted and burned.

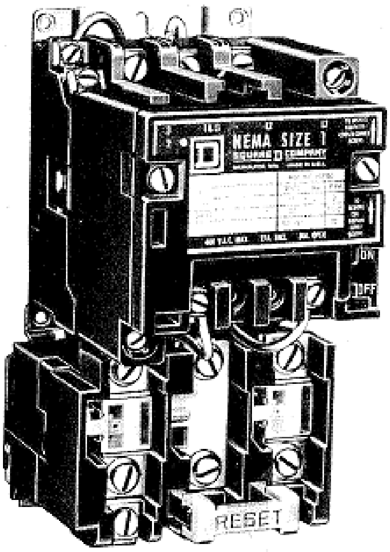


Figure 4 Magnetic motor starter

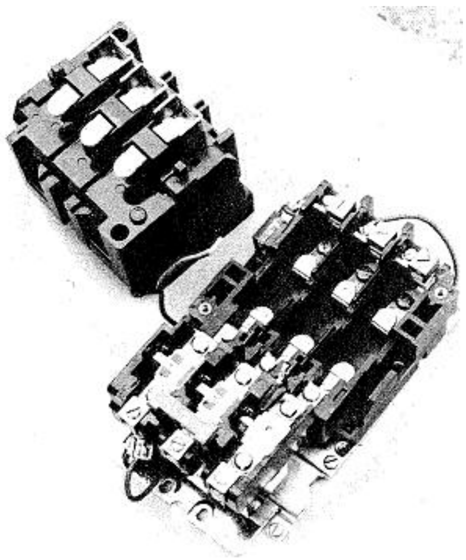


Figure 5 inside the main part of the starter

After many years of service, these contacts may become pitted and burned from the arcing as they open the circuit. Replacement kits for the main contacts are available.

Electrical power supplied to the coil of the solenoid closes the motor-starter contacts. The coil must be rated for the voltage of the control circuit electrical supply.

- ✓ Typical voltages are 24, 120, 208, 240, 277, and 480 volts.
- ✓ A coil is replaceable. If the coil becomes damaged, only the coil need be replaced.
- ✓ The steel solenoid core fits all coils made for the particular size and model of motor starter.
- ✓ The magnetic coil of a motor starter must be rated for the particular control voltage. The coil can be replaced.

- An auxiliary holding contact is supplied with the motor starter. It is required when a start-stop station is used as the control device.
- The holding contact is replaceable should a short circuit occur in the control wiring, causing damage to the holding contact.
- An overload relay section is added to the motor starter to sense motor current. This entire unit can be removed from the motor starter, Figure 6.

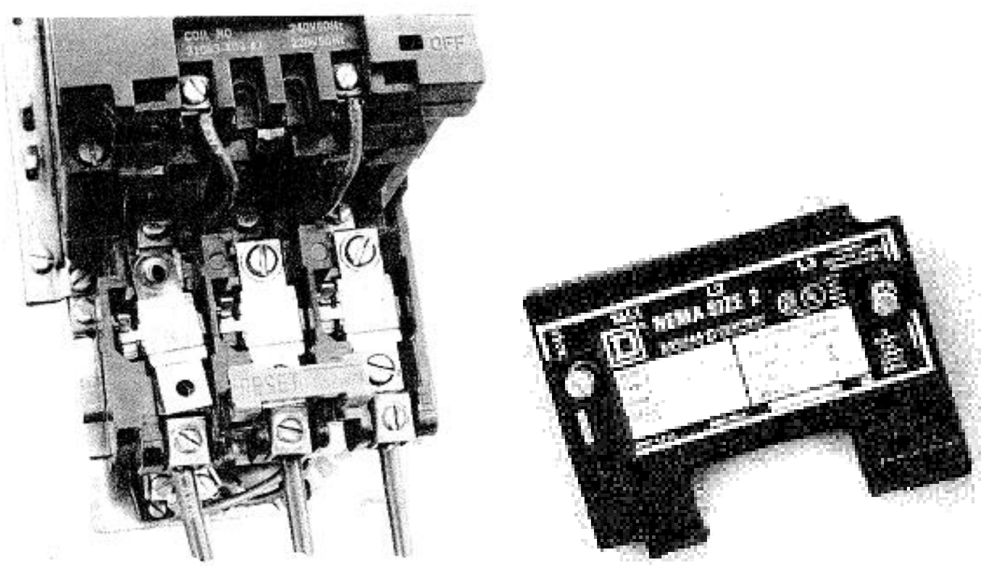


Figure 6 Overload thermal units or heaters must be sized for the full-load current of the motor.

- A normally closed contact is usually sealed inside the overload section. Some models have one normally closed contact, while others have two or three. If this section becomes damaged, the entire section usually must be replaced.
- Heating elements are added to this section sized for the nameplate full-load current of the motor. These overload heaters are replaceable.
    - ✓ The holding contact or interlock may become damaged if a short circuit occurs in the control circuit. The holding contact can be replaced.

NEMA SIZES STANDARD

The National Electrical Manufacturers Association (NEMA) has developed a standard numbering system for motor starter sizes. The same numbering system is used by all manufacturers.

- The sizes range from 00 to 8. The larger the number, the greater is the horsepower rating of the starter.

Figure 6, Overload thermal units or heaters must be sized for the full-load current of the motor.

- The starters are rated according to the current they will be expected to carry continuously, and interrupt if the motor should stall.
- The motor current depends upon the supply voltage. Naturally then, a given size of motor starter could handle a higher horsepower motor at 460 V than at 230 V.

NEMA sizes and horsepower ratings are given in Table 1.

Table 1 Motor horsepower and voltage ratings for NEMA size motor starters

NEMA Size	Single phase 115 V	Single phase 230 V	Three phase 200 V	Three phase 230 V	Three phase 460 V
00	⅓	1	1 ½	1 ½	2
0	1	2	3	3	5
1	2	3	7 ½	7 ½	10
1P	3	5	—	—	—
2	3	7 ½	10	15	25
3	7 ½	15	25	30	50
4	—	25	40	50	100
5	—	50	75	100	200
6	—	—	150	200	400
7	—	—	—	300	600
8	—	—	—	450	900

Motor starters are available with two poles or three poles.

- The 2-pole motor starter is used for single-phase motors. Two-pole motor starters are usually available up to NEMA size 3.
- A 3-pole motor starter may be used for either a 3-phase motor or a single-phase motor. If a 3-pole starter is used for a single-phase motor, only two of the three poles are used. The third pole is simply ignored. Since 3-pole motor starters are more readily available than 2-pole starters, this is a common practice.

Single-phase and 3-phase horsepower ratings on a motor starter are not equivalent. NEMA sizes are equivalent, however, insofar as the current they will handle.

Some 3-pole motor starters list both the single-phase and poly phase horsepower ratings, others do not. There is a simple rule that should be followed:

A 3-pole motor starter will handle a single-phase motor with a horse-power rating only half as large as a 3-phase motor.

For example, a NEMA size 2 3-pole motor starter will handle a 15-hp, 230-V, 3-phase motor. The same size motor starter is capable of handling only a 7l/2-hp, single-phase, 230-V motor. The reason is clear when the full-load current for each motor is compared from NEC Tables 430-148 and 430-150. This rule does not hold true exactly, however, for the NEMA small sizes 00 and 0, as shown in Table 1. For sizes 1 and larger, the horse power essentially doubles as the size number is increased by 1.

NEMA ENCLOSURE TYPES

The enclosure for housing the motor starter is selected for the type of environment in the area. NEMA has developed a standard numbering system for types of electrical equipment enclosures.

The enclosure type, except NEMA 1, is required to be marked on motor starter enclosures,

- NEC Section 430-91. This is a recent Code requirement; therefore, most motor starters presently in use are not so marked.
- NEC Table 430-91 gives NEMA enclosure types for motor starters, listing the outdoor and indoor conditions for which they are suitable. Common enclosures used for agricultural, commercial, and industrial locations are as follows.
  - ✓ NEMA 1: General-purpose enclosure used in any location that is dry and free from dust and flying flammable materials,
  - ✓ NEMA 3: Weather-resistant enclosure which is suitable for use outdoors. Not suitable for use in dusty locations.
  - ✓ NEMA 4: Watertight and dust tight enclosure suitable for outdoor locations as well as inside wet locations. Water can be sprayed directly on the enclosure without it leaking inside. Suitable for most agricultural locations provided corrosion is not a problem.
  - ✓ NEMA 4X: Watertight, dust tight, and corrosion-resistant enclosure suitable for outside and inside wet, dusty, and corrosive areas. Suitable for agricultural buildings.

Available with stainless steel and nonmetallic enclosures, NEMA 1, enclosure for dry and dust-free environments

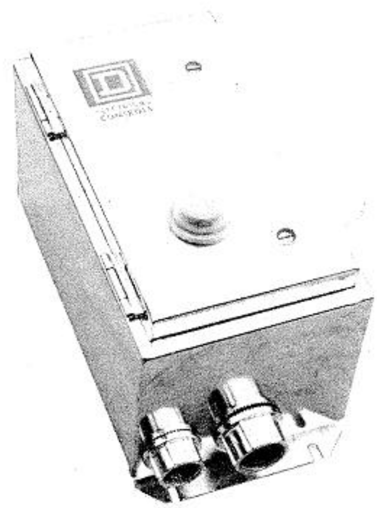


Figure 7 N EMA 4X, corrosion-resistant enclosure for wet or dusty areas

- ✓ NEMA 7: Explosion proof enclosure suitable for installation in Class I areas containing hazardous vapors. Must also be rated for the type of hazardous vapor, such as gasoline vapor, Group D,

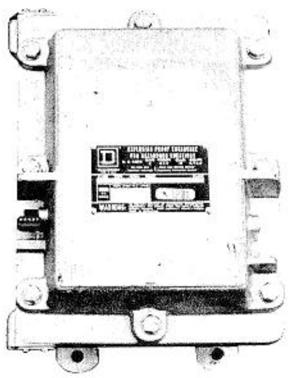


Figure 8 NEMA 9, dust-ignition-proof enclosure for areas where dust is suspended in the air and may cause a fire or explosion, such as a commercial grain elevator

- ✓ NEMA 9: Dust-Ignition-Proof enclosure suitable for installation in Class II hazardous areas, such as grain elevators. Must be rated for the type of dust, such as grain
- ✓ NEMA 7, expansion proof enclosure for areas where hazardous vapors, such as gasoline vapor, are present

Figure 9 EMA 4X, corrosion-resistant enclosure for wet or dusty areas

- ✓ NEMA 9, dust-ignition-proof enclosure for areas where dust is suspended in the air and may cause a fire or explosion, such as a commercial grain elevator
- ✓ NEMA 7: Explosion proof enclosure suitable for installation in Class I areas containing hazardous vapors. Must also be rated for the type of hazardous vapor, such as gasoline vapor, Group D,
- ✓ NEMA 9: Dust-Ignition-Proof enclosure suitable for installation in Class II hazardous areas, such as grain elevators. Must be rated for the type of dust, such as grain dust, Group G. Some manufacturers build one enclosure rated as NEMA 7 and 9.
- ✓ NEMA 12: Dust tight, drip tight, and oil-retardant enclosure suitable for machine tools and areas where there are flammable flying particles, such as in cotton gins and textile processing and handling operations.

SINGLE-MOTOR BRANCH CIRCUIT

A motor branch circuit consists of several different parts that must be sized properly. The motor is unique because it draws a very high starting current in comparison to the full-load running current. The motor also may be break down while in operation. Means must be provided to

- Disconnect power, usually automatically, if' failure occurs. The components of most motor circuit are shown in a diagram at the beginning of NEC Article 430. Information supplied on the motor nameplate necessary for sizing the circuit components.
  - ✓ Branch-circuit disconnect
  - ✓ Branch-circuit short-circuit and ground-fault protection
  - ✓ Branch-circuit wires
  - ✓ Motor controlled
  - ✓ Motor running overload protection

- ✓ Motor control circuit where a magnetic motor starter used.

Sizing the motor branch circuit begins with the motor nameplate. Consider the motor nameplate of Figure 10 the motor is 3 phase, dual voltage. First, determine

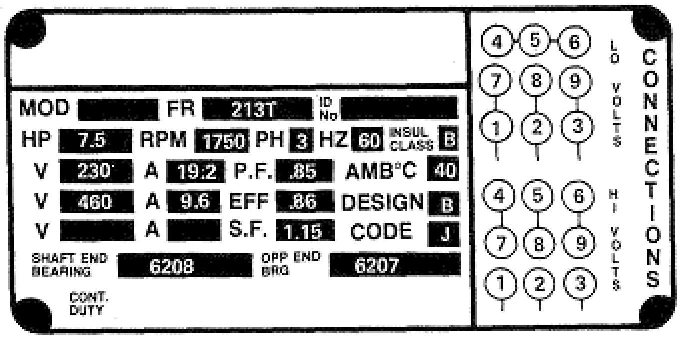


Figure 10 Information required for wiring a motor branch circuit is contained on the motor nameplate.

The type of electrical supply available. Assume, in this case, that the electrical supply is 240 V, 3 phase. The motor full-load current therefore, will be 19.2 A.

The type of electrical equipment from which the motor circuit will originate must be determined. Common sources of electrical power for electric motors are:

1. Circuit-breaker panelboards
2. Fusible panelboards
3. Fusible disconnects tapped from a feeder, Figure 11
4. Fusible disconnects tapped from a bus duct

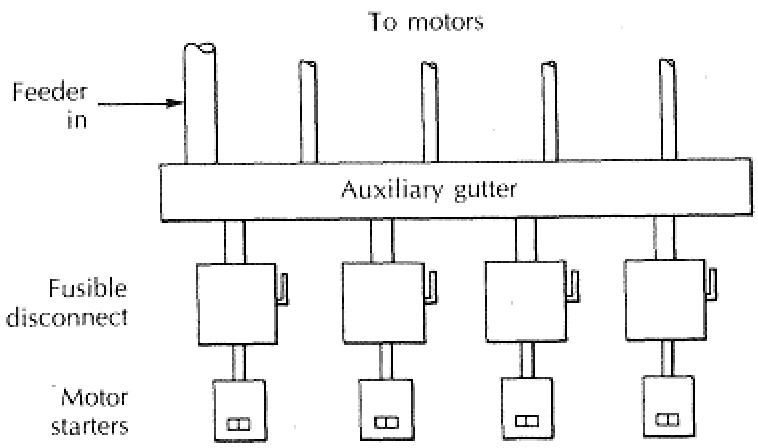


Figure 11A group of motors tapped from a single feeder, using fusible switches as disconnects

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 430-148 and 430-150 (Tables 2 and 3 in this text), NEC Section 430-6(a).

However, this value should be checked against the motor nameplate ampere rating. Sometimes a 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 components, (See notes to Tables 2 and 3).

- 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 3-phase, 208-V electric motor is not listed in NEC Table 430-150. The footnote at the bottom of the table tells how to obtain the correct value. Actually, a 208-V motor usually operates at about 200 V. The correct value is determined by multiplying the full-load current for a 230-V motor by 1.15.

✓ For example, a 200-V, 10-hp motor would draw 32 A.

HP	115 V	230 V
⅙	4.4	2.2
¼	5.8	2.9
⅓	7.2	3.6
½	9.8	4.9
¾	13.8	6.9
1	16	8
1 ½	20	10
2	24	12
3	34	17
5	56	28
7 ½	80	40
10	100	50

Table 2 (NEC Table 430-148) Full-load currents in amperes; single-phase alternating-current motors

The following values of full-load currents are for motors running at usual speeds and motors with normal torque characteristics. Motors built for especially low speeds or high torques may have higher full-load currents, and multi-speed motors will have full-load current varying with speed, in which case the name-plate current ratings shall be used.

To obtain full-load currents of 208- and 200-volt motors, increase corresponding 230-volt motor full-load currents by 10 and 15 percent, respectively.

The voltages listed are rated motor voltages. The currents Listed shall be permitted for system voltage ranges of 110 to 120 and 220 to 240. Reprinted with permission from NFPA 70-1984, National Electrical Code®, and National Fire Protection Association. This reprinted material is not the complete and official position of the NFPA on the referenced subject which is represented only by the standard in its entirety.

	Induction Type Squirrel-Cage and Wound-Rotor Amperes					Synchronous Type †Unity Power Factor Amperes			
HP	115 V	230 V	460 V	575 V	2300 V	230 V	460 V	575 V	2300 V
½	4	2	1	.8					
¾	5.6	2.8	1.4	1.1					
1	7.2	3.6	1.8	1.4					
1 ½	10.4	5.2	2.6	2.1					
2	13.6	6.8	3.4	2.7					
3		9.6	4.8	3.9					
5		15.2	7.6	6.1					
7 ½		22	11	9					
10		28	14	11					
15		42	21	17					
20		54	27	22					
25		68	34	27		53	26	21	
30		80	40	32		63	32	26	
40		104	52	41		83	41	33	
50		130	65	52		104	52	42	
60		154	77	62	16	123	61	49	12
75		192	96	77	20	155	78	62	15
100		248	124	99	26	202	101	81	20
125		312	156	125	31	253	126	101	25
150		360	180	144	37	302	151	121	30
200		480	240	192	49	400	201	161	40

Table 17-3 (NEC Table 430-150) Full-load current* 3-phase alternating-current motors

Induction Type Squirrel-Cage and Wound-Rotor

Amperes

For full-load currents of 208- and 200-volt motors, increase the corresponding 230-volt motor full-load current by 10 and 15 percent, respectively.

*These values of full-load current are for motors running at speeds usual for belted motors and motors with normal torque characteristics. Motors built for especially low speeds or high torques may require more running current, and multispeed motors will have full-load current varying with speed, in which case the nameplate current rating shall be used.

For 90 and 80 percent power factor the above figures shall be multiplied by 1 .1 and 1 .25 respectively.

The voltages listed are rated motor voltages. The currents listed shall be permitted for system voltage ranges of 110 to 120, 220 to 240, 440 to 480, and 550 to 600 volts.

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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 sigh 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.

This circuit breaker must have an ampere rating not less than 115% of the motor full-load current, NEC Section 430-110(a).

There are exceptions to these rules for motor disconnects. Motors with a horsepower rating not greater than 1/8 hp may use the branch-circuit overcurrent device as 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 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. An ac switch used on an ac circuit need only be rated at 1. 25 times the full- load current of the motor.

Cord and plug connected motors may use an attachment plug and receptacle as the motor disconnect. This type of disconnect would be used for motors on portable or movable equipment used on the farm. The plug and receptacle should have a horsepower rating not smaller than the rating of the motor if it is intended to break power while operating, NEC Section 430-109, Exception

No. 5. The current rating of the attachment plug and receptacle must be not less than 115% of the full-load current of the motor.

A fusible switch or a circuit breaker is permitted to serve as both the controller and disconnect, NEC Section 430-111. However, the requirements for motor controllers discussed previously must be met.

Assume that the motor of Figure 10 will have a fusible switch as disconnect. The disconnect switch must have a rating marked on the switch of at least 71/2 hp. However, if a circuit breaker serves as disconnect, the rating will be in amperes. The minimum ampere rating of the circuit breaker is 1. 15 times the full-load current, or 25 A. A 25-A or 30-A circuit breaker would be chosen. A circuit breaker rated at 30 A or more would most likely be chosen, because a 25-A breaker would probably trip due to the high starting current. The value of current from NEC Table 430-150 is used, rather than the nameplate current of 19.2 A.

1. 15 X 22 A= 25 A

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. For a multispeed motor, the highest normal full-load current shall be used, NEC Section 430-22(a).

The minimum ampere rating of the circuit wires for the motor of Figure 17-13 is 28 A.

1. 25 X 22 A = 28 A

The minimum size copper branch-circuit wire is found in NEC Table 310-16. If the wire is THWN copper, the minimum size is No. 10 AWG. The footnote at the bottom of NEC Table 310-16 which specifies the maximum rating overcurrent device for wire sizes No. 14, 12, and 10 AWG does not apply in the case of electric motor circuits, NEC Section 210-19(a). Aluminum wire is seldom used for motor circuits.

Most terminals in motor starters are rate only for copper wire.

Problem 1

A single-phase, 5-hp, 230-V electric motor has a nameplate current rating of 26 A. Determine the minimum size copper THWN branch-circuit wire.

Solution

Look up the full-load current of a 5-hp single-phase, 230- V motor in NEC Table 430-148. The current value is 28 A. The minimum ampere rating of the wire is 35 A.

1.25 X 28 A = 35 A

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,

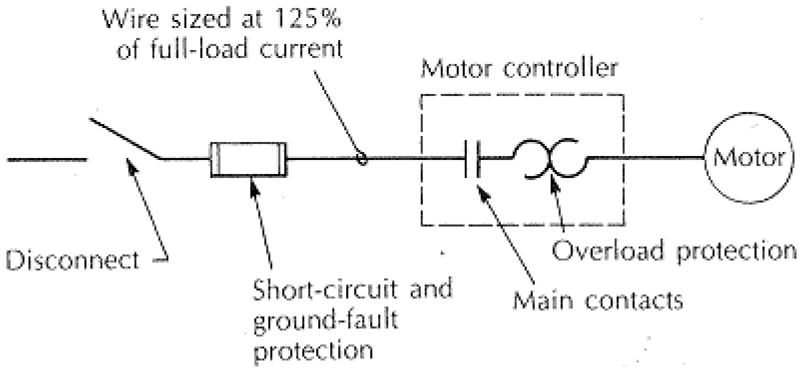


Figure 12 Parts of a motor branch circuit

The short circuit and ground-fault protection must be capable of carrying the starting current of the motor, NEC Section 430-52. The maximum rating of a time delay fuse or an inverse time circuit breaker is determined using NEC Table 430-152

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

Table 4 (NfC Table 430-152) Maximum rating or setting of motor branch-circuit short circuit and ground-fault protective devices

An inverse time circuit breaker is an ordinary circuit breaker which provides short -circuit protection, but it will carry an overload for a limited period of time. The code letter given on the nameplate of the motor is needed to determine the maximum size short-circuit and ground fault protection. The motor of Figure 10 has a code letter J. This is an ac 3-phase squirrel-cage motor; there- fore from NEC Table 430-152, the maximum size time-delay fuse is 175% of the motor full-load current, or 39 A. The motor full-load current must be taken from NEC Table 430-150. The maximum size inverse time circuit breaker would be 250% of the motor full-load current, or 55 A.

The motor short-circuit and ground-fault protective device should be sized as small as possible without causing nuisance tripping. Remember that the minimum size in the case of a circuit breaker is 1.15 times the full-load current of the motor, NEC Section 430-58. The motor of Figure 10 is shown in Figure 17-16 with all components sized within the limits of the National Electrical Code. A suggested procedure is to determine the over-current protection size, using the value determined in NEC Table 430-152. If the motor is not driving a hard starting load, then choose the next smaller protective device than the value determined. If this is too small, then choose the next size larger. In no case is the fuse permitted to be sized larger than 225% of the full-load current, NEC Section 430-52, Exception No. 2(b). For a circuit breaker, the maximum size is not permitted to exceed 400% for a motor drawing 100 A or less, and 300% for motors drawing more than 100 A, NEC Section 430-52, Exception No. 2(c).

Fuse: 1.75 X 22 A= 38 A (Use a 35-A or 40-A fuse.)

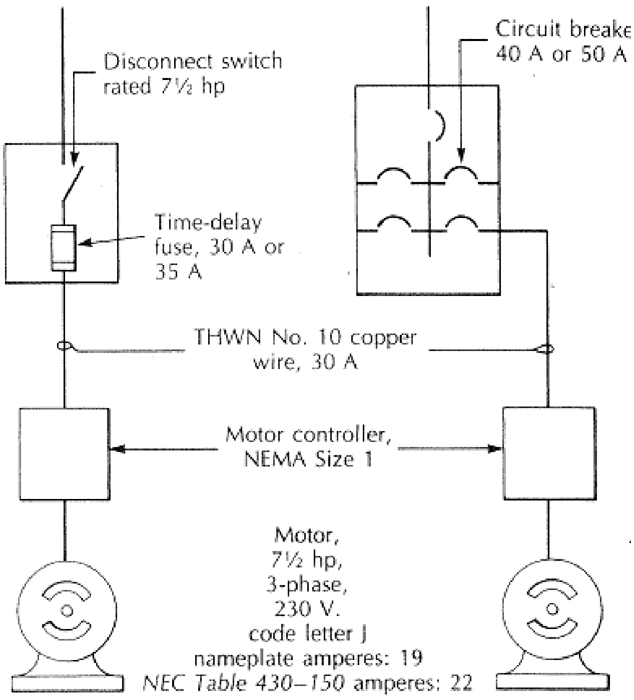


Figure 13 properly sized components of a motor circuit

Circuit breaker:

2.5 X 22 A = 55 A

(Use a 50-A or 60-A breaker.)

Problem 2

A single-phase, 5-hp 230-V electric motor with nameplate full-load current of 26 A drives a normal starting load and has a code letter G. Determine th proper size motor short-circuit protective time-delay fuse.

Solution

Determine the full-load current from NEC Table 430 148 and the fuse multiplier from NEC Table 430-152

Full-load current: 28 A

Fuse multiplier: 175% 1. 75 X 28 A = 49 A

Use a 50-A fuse. The minimum wire size is No. 11 AWG copper THWN with a rating of 35 A.

FEEDER SUPPLY SEVERAL MOTORS

Groups of motors may be supplied by a single feeder. An example would be a feeder from the main service in a barn to the motor control center in a feed room. The feeder wires are required to have a minimum rating equal to the sum of the full-load current of all motors supplied, plus 25% of the full-load current of the largest motor, NEC Section 430-24. Consider the following example with single-phase, 230-V motors:

Silo unloader-5 hp, 28 A

Silo unloader-3 hp, 17 A

Conveyer-! hp, 8 A

Bunk Feeder-2 hp, 12 A

The minimum size wire must have an ampere rating of 72

28+ 17 + 8 + 12 + (0.25 X 28) = 72 A

Using copper THWN, the minimum size is No.4 AWG

Next, disconnect must be selected for the motor feeder. The disconnect for a feeder serving a group of motors shall have a horsepower rating not less than the sum of the horsepower ratings of the motors served,

NEC Section 430-112. For the example, a fusible disconnect switch must have a horsepower rating not less than 5 + 3 + 1 + 2 = 11 hp. The disconnect to be chosen would probably be rated at 15 hp.

If a circuit breaker serves as the disconnect, it must have a current rating not less than 115% of the sum of the full-load currents of all the motors served, NEC Section 430-JJO(c)(2).

For the example, this would be 75 A.

1.15 X (28 + 17 + 8 + 12) = 1.15 X 65 = 75 A

The minimum size standard circuit breaker would be 80 A.

Typically, feeders serving groups of motors will be sized large enough to provide for future expansion. Therefore, the previous calculations serve only as a guide. To make sure that the feeder is adequate for present and future needs, th~ feeder in the example would not be sized for the minimum, but rather for at least 100 A. The wire size could possibly be either No. 3 AWG copper THW or No. 1 AWG THW aluminum. The overcurrent protection would then be sized according to the ampere rating of the feeder, NEC Section 430-62(b).

The short-circuit protection for a feeder supplying a specific fixed motor load can be sized according to the rules of NEC Section 430-62(a). This only applies to a fixed motor load that will not be changed in the future.

Consider the previous example, assuming that circuit breakers serve as disconnect and short-circuit protection for each motor. A fusible disconnect switch will serve as the short-circuit protection for the feeder.

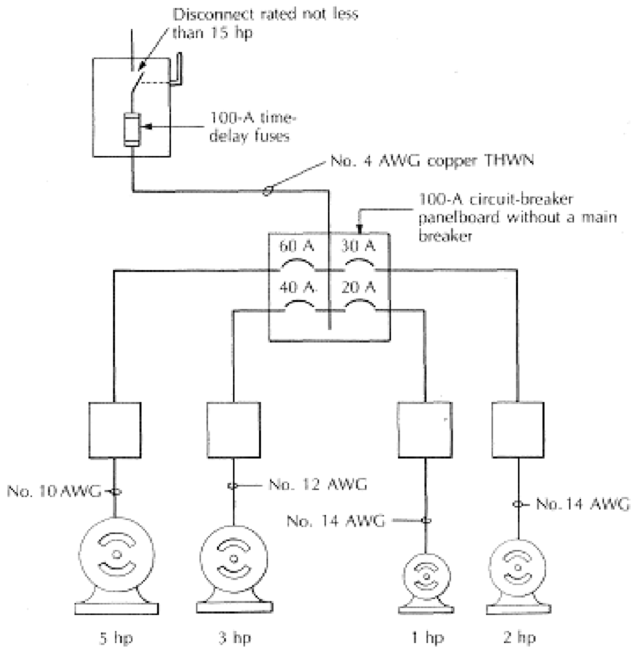


Figure 14 Feeder wire serving a specific group of single-phase, 230-V motors shows the sizes of wire

and overcurrent protection for each circuit.

The maximum rating of short -circuit protection for the feeder is determined by taking the maximum size motor branch-circuit short-circuit device and adding to it the full-load current of all other motors served.

The largest branch-circuit protection for the example is a 60-A circuit breaker for the 5-hp motor. Add to this 60 A the full-load currents for the 3-hp, 2-hp and 1-hp motors.

The fuse size is 100 A maximum.

60+ 17 + 12 + 8 = 97 A

It must be remembered that the feeder overcurrent device is permitted to exceed the ampere rating of the feeder only when the feeder is supplying a specific motor load. The panelboard is often used to serve other loads; therefore, the feeder then must be protected at its ampacity.

For the example, a No. 3 AWG copper wire instead of a No. 4 should be chosen.

For group motor installations, dual-element, time delay fuses for each motor may be sized at 125% of the motor full-load current rating. This provides motor branch-circuit protection, as well as running overload protection.

The main feeder dual-element, time-delay fuse may generally be sized at llf2 times the ampere rating of the largest motor of the group, plus the full-load current rating of the other motors of the group.

(1. 5 X 28) + 17 + 8 +12 = 79 A (Use 80-A fuses.) This fuse size would be a minimum.

FEEDER TAPS

A common practice is to tap motor branch circuits directly from a motor feeder. This is permitted as long as the branch-circuit wire is terminated at an overcurrent device sized properly for the circuit, NEC Section 430-28. The branch-circuit wire size may be smaller than the feeder wire size. If the tap wire from the feeder to the overcurrent device is not more than 10 ft (3.05 m), and is enclosed in raceway, the branch-circuit wire may be as small as necessary to serve the motor load. However, if the tap is more than 10 ft (3. 05 m) but not more than 25 ft (7 .62 m) in length, the branch-circuit wire must have an ampere rating at least one-third the rating of the feeder conductors.

Consider the example of a No. 4 AWG copper THW feeder wire supplying the three motors of

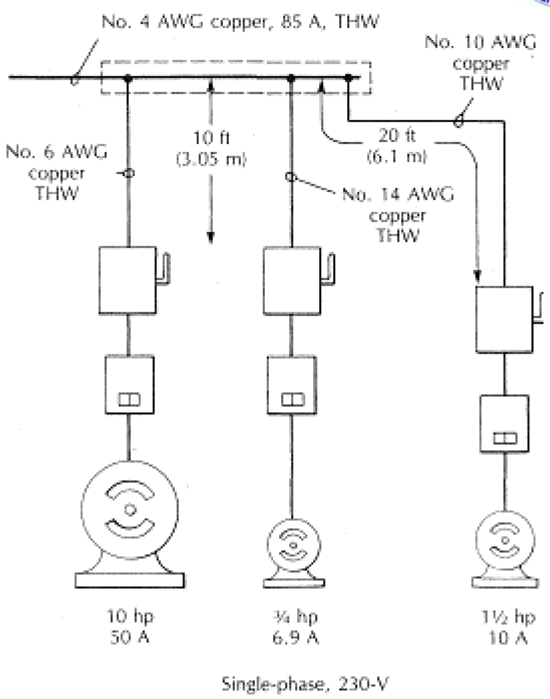


Figure 15 Motor branch-circuit taps from a feeder. The motors are single phase.

The tap wire from the feeder to the fusible disconnect for the %-hp and 10-hp, 230-V, single-phase motors is not required to be a minimum size because the tap is not more than 10ft (3.05 m) long. However, the ll/2-hp motor tap is more than 10ft (3.05 m) long; therefore, it must have an ampere rating not less than one-third that of the feeder wire, or a minimum rating of 28 A. If the wires are copper THW, then the minimum size is No. 10 AWG. If the tap had not been more than 10 ft (3 .05 m) long, then the ll/2-hp motor circuit. Could have been wired with No. 14 AWG THW copper wire.

MOTOR CONTROL CIRCUIT

A magnetic motor starter is operated with an electric solenoid coil. A diagram of the power flow to the motor and the control circuit is included with each magnetic motor starter.

A typical diagram is shown in Figure 16. The heavy lines show the power flow to the motor. The narrow lines belong to the control circuit which is prewired by the manufacturer. The holding contact or interlock is the set of contacts between terminals 2 and 3. These contacts close at the same time the main contacts close.

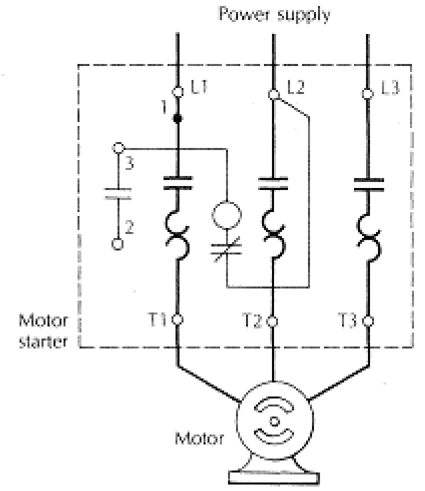
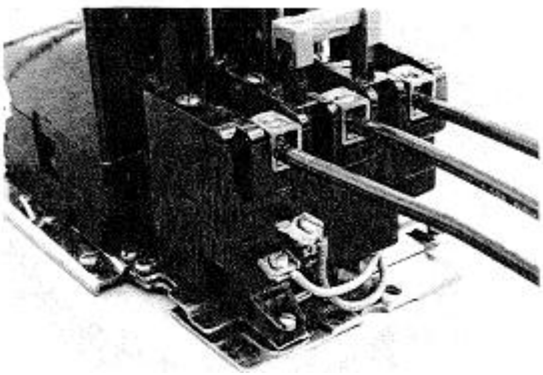


Figure 16 starter Schematic diagram of a magnetic motor

The control wire goes from terminal 3 to the coil which closes the contacts, then from the coil through a normally closed overload relay contact. Some motor starters have as many as three of these contacts in series. If the motor overloads, the thermal units will heat up and trip open this overload relay contact, breaking the control circuit and reenergizing the coil. This opens the motor circuit. From the normally closed overload relay contact, the control circuit wire goes to terminal L2. The terminals of the overload relay are shown in Figure 17.



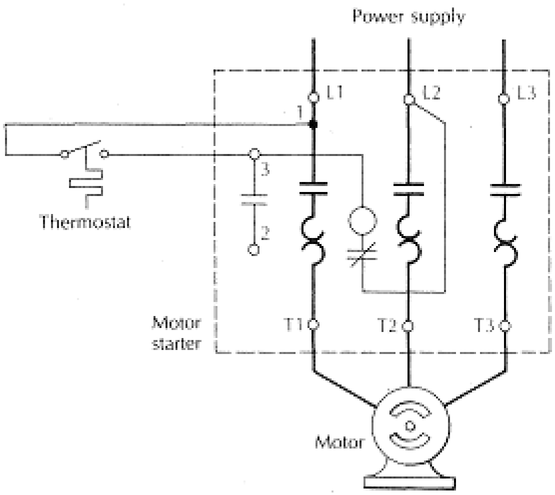


Figure 17 Overload relay terminals of a magnetic   Figure 18 Simple switch device,   such as a thermostat, controlling a magnetic motor starter

Consider the situation where a simple switching device, such as a thermostat, is used to control the motor, Figure 18. When the thermostat closes, it must complete the circuit to energize the motor starter coil. Power is obtained from terminal 1, which is located next to terminal Ll. The other side of the thermostat is connected to terminal 3. When the thermostat closes, electrical current flows from terminal 1 through the thermostat to the coil. From the coil, current flows through the overload relay contact to terminal L2. When the thermostat opens, the circuit is broken and the main contacts open. Only two wires are required when a simple switch device is used to control the motor starter; terminal 2 is not used.

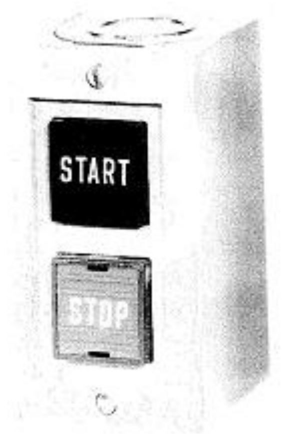


Figure 19 Start-stop station for a magnetic motor starter

A start-stop station (also called a push-button station) is another common device used to control a motor. The start and stop push buttons are momentary contacts. They immediately return to their original position after they have been pressed.

A start-stop motor control circuit is requires a 3-wire control circuit. Current can flow from terminal 1 through the normally closed stop button. As soon as the start button is depressed, current flows to terminal 3 and then through the coil to complete the circuit. The main contacts and the holding contact between terminals 2 and 3 are now closed. When the start button is released the start contact opens, but current now flows from terminal 2 to terminal 3 through the

Figure 18 Simple switch device, such as a thermostat, controlling a magnetic motor starter

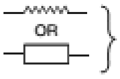
Figure 19 Start-stop station for a magnetic motor starter holding contact, keeping the coil energized and the contacts closed. Now the only way to stop the motor is to press the stop button or open the overload relay. Diagrams for wiring common motor control circuits are contained inside the motor starter. It is a good idea to put numbers on the control circuit wires to help keep them identified.

1) **DEVICES, SYMBOLS, AND CIRCUITS**

<u>Devices and symbols</u>

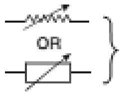
Any electrical drawing representing an electrical installation or a circuit takes the help of specific symbols to represent various electrical devices in shorthand. This provides a quick idea to the reader about a circuit or installation, and is particularly useful while troubleshooting.

Therefore, it is important to familiarize oneself with various symbols. Some of the commonly used device symbols are detailed in the following section and in Figure.



Resistance


Capacitor

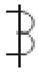


Variable resistor

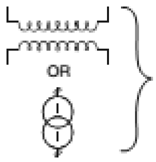
Fuse

Impedance

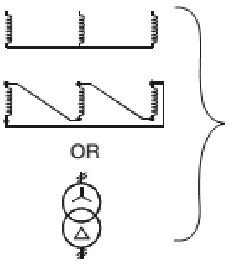

Battery


Current transformer

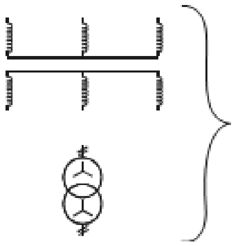

Winding, coil or choke



Single-phase transformer



Three-phase star–delta transformer


Three-phase star–star transformer

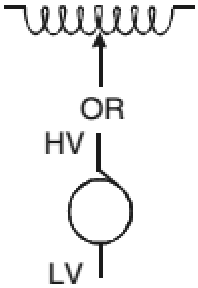
Ammeter

Voltmeter

Wattmeter

Frequency meter

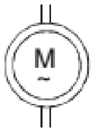
Power factor meter

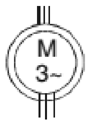


Auto transformer

Motor

Generator





Single-phase induction motor cage rotor

Three-phase induction motor wound-

Electrical circuits

Electrical circuits are circuits used to interconnect different electrical equipments together to enable the working of an electrical device.

- Electrical schematics are commonly classified into **power circuit** and **control circuit**.
    - ✓ A power circuit consists of the main power device (a motor, a generator, or other power devices) along with heavy power conductors, contactors, protection devices.
    - ✓ A control circuit consists of switches, field device contacts, timers, relay coils, relay, contacts, protection devices, and light power conductors.

Power circuits

Power circuits are required for carrying power to or from heavy electrical equipment like motors, alternators, or any electrical installation.

They carry out the following functions:

- ✓ Solation using devices such as isolators, linked switches and circuit breaks.
- ✓ Circuit control using devices such as contactors, motor circuit breakers, etc.
- ✓ Protection against overload and short-circuits using thermal overload relays, electro-magnetic relays, circuit breakers, with releases, fuses, etc.

Power circuits have to carry heavy power and therefore, they consist of heavy conductors along with contactors used for switching the power on and off. Protection devices are also included in the same power circuit for resolving an overload condition or any other concerned faults.

Control circuit

A control circuit is for the automatic control of equipment, for safety interlocking, and sequencing the operations of the plant equipment and machines. Control circuits hardware consists of relay contacts, wires, hardware timers, and counters, relay coils, etc. These consist of input contacts representing various conditions; the output coils are energized or de-energized depending on the input conditions represented by the control circuit.

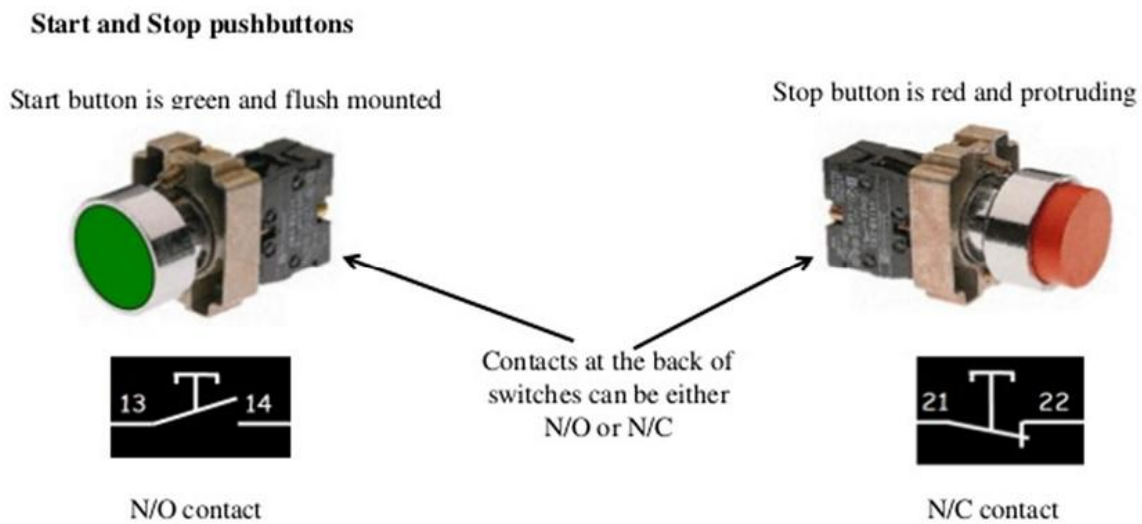
Input contacts represent the binary state of the condition:

- ✓ True or false
- ✓ On or off.

There are two types of contacts

- ✓ NO (normally open) and
- ✓ NC (normally closed).

- Input contact: These are contacts of relays, contactors, timers, counter, field instrument switches, pressure switches, limit switches, etc.
- Output coil: These have two states – On or off. Output coil can be auxiliary contactor or Main contactor coil.



A few simple control circuits are shown in Figure 2.3 to represent logical AND, OR, and such conditions.

1. ‘AND’ operation circuit

Figure (a) shows a simple control circuit (AND operation) with two input contacts (NO) representing two conditions that must be true to complete the circuit to switch on the output relay coil and change the state of output from ‘Off’ to ‘On’.

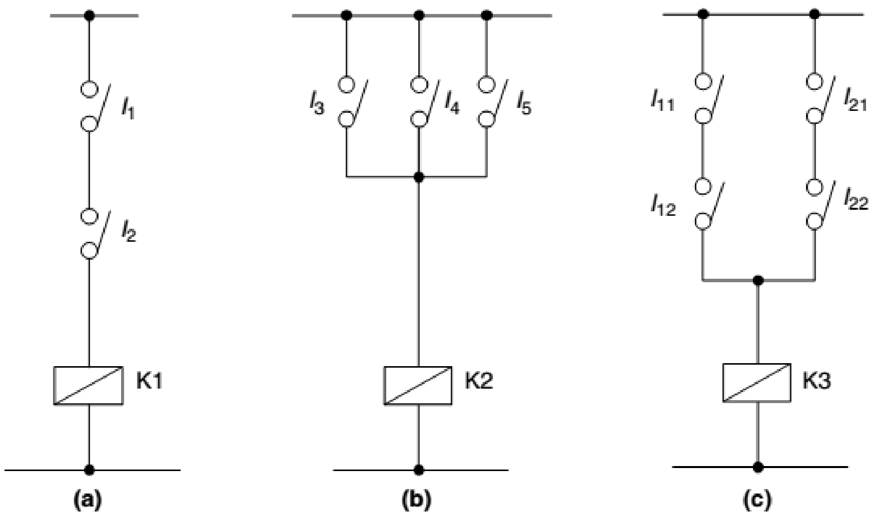
2. ‘OR’ operation circuit

Figure (b) shows a circuit with three input contacts (NO) representing that at least one of the three conditions should be true to complete the circuit to switch On the relay coil and change output state from ‘Off’ to ‘On’.

3. ‘AND with OR’ operation circuit

Figure (c) shows a control circuit, consisting of a combination of AND and OR operations.

There are two parallel (OR condition) paths with two input contacts (NO) connected in series in each path representing AND conditions. The path for coil K3 will be completed when one of the path conditions comes true. The circuit then will switch ‘On’ the relay coil and change the output state from ‘Off’ to ‘On’.



CONTROL DEVICES

Common control ladder diagrams and schematic wiring diagrams use some basic symbols and terminology. Switches and contacts are the basic control components, and they take several different forms.

Switches and contacts may be operated mechanically by a timer or by some change in condition, such as temperature, pressure, flow, liquid level, or humidity. Switches and contacts are described by the number of poles and the number of throws. The number of poles is the number of paths into a switch or contact. The number of throws is the number of paths leaving each pole.

It must also be known if the switch or contact is I the open or closed position when it is in the activate state. If the switch or contact is open when in the activated state, it is considered to be normally open (NO: when it is in the opposite position, it is said to be normally closed (NC). Common single-pole, single-thrm

- ✓ **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.

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 it's rated current.

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.

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

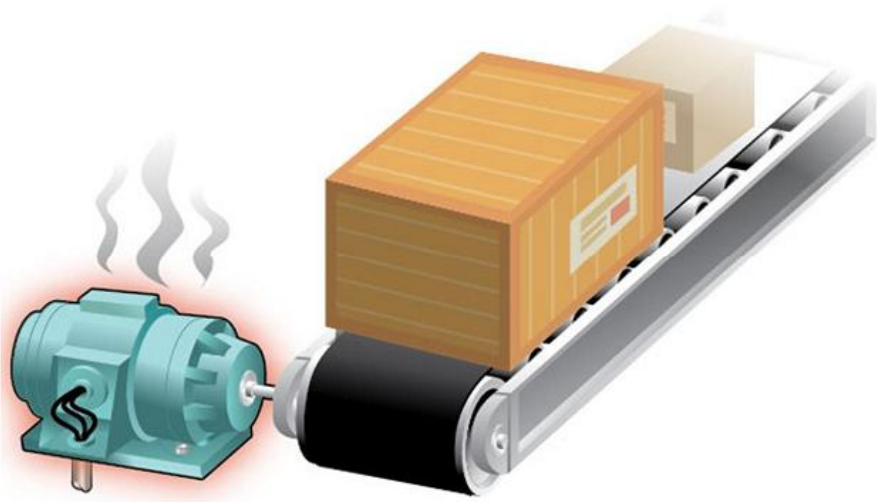


Figure 2:6 Overload of Motor

Overload Protection

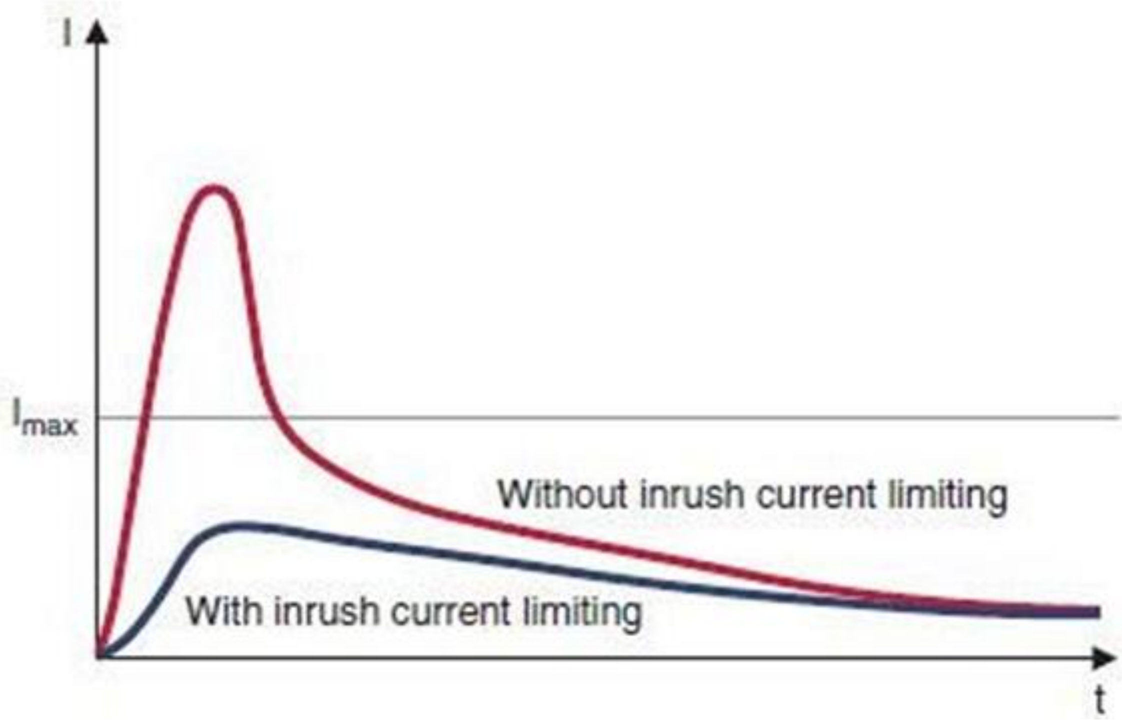
As mentioned earlier overload protection prevents an electric motor from drawing too much current, overheating and literally ‘burning out’

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

1. Resting

2. Starting

3. Operating under load



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 it’s 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 ‘burn out’. (Cutler-Hammer)

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

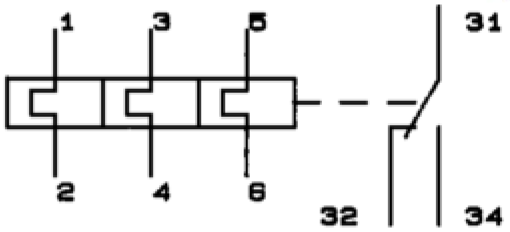
Thermal relays as the name implies, rely on the rising temperatures caused by the overload current to trip the overload mechanism

THERMAL OVER LOAD RELAY

Objectives: Study the thermal relay as protection device for motors.

Overload Protection protects the motor from drawing too much **curren**t and **overheating**, from literally ‘burning out’.

Graphical symbol and description



The thermal relay is composed of a bimetallic lamel which is heated when the circuit current flows through it.

Under overload conditions (current greater than the rated calibration value) the bimetallic lamel gets deformed after a given time, driving the auxiliary contacts (exchange contact).

These are therefore used in the control circuit for operating the protection devices of main circuit. After the relay is operated it is necessary to wait some minutes for allowing the lamel to cool down, therefore resetting the operating conditions after the fault causing the opening has been removed. The relay can be either manually rearmed by pressing the special push-button, or it can be automatically rearmed. In the latter case, following a given time, the relay contacts are automatically closed, and they remain closed.

Contactor with motor - protector relay

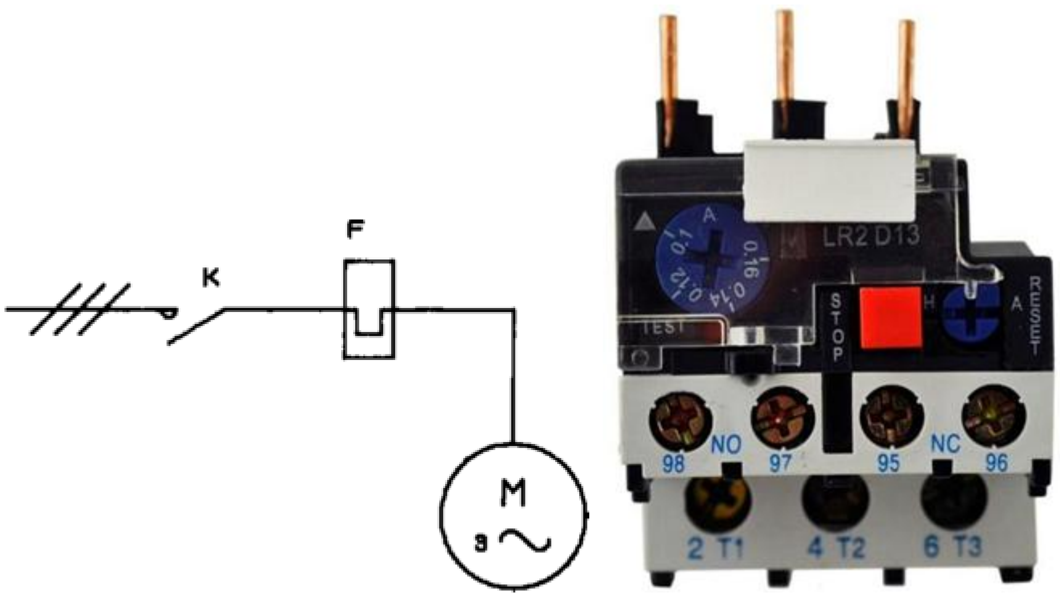


Figure overload relay

The thermal relay F (motor-protector) must be connected immediately upstream the motor

M. Under overload conditions its auxiliary contacts have to switch the main contactor K off and to operate a possible signalling.

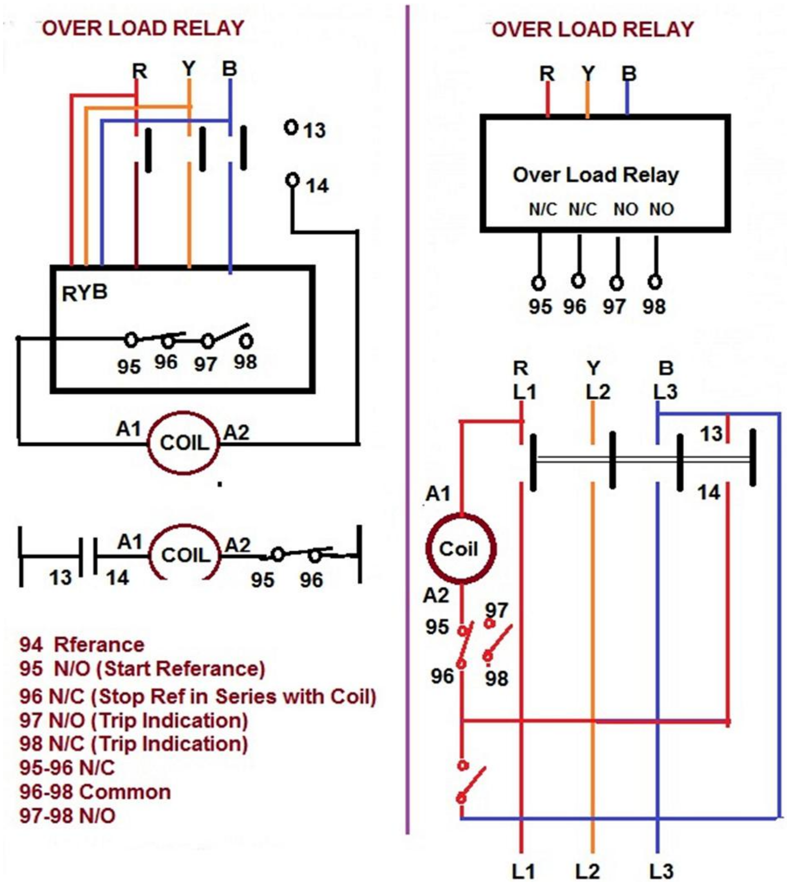


Figure Wiring Terminals of Overload Relay

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.

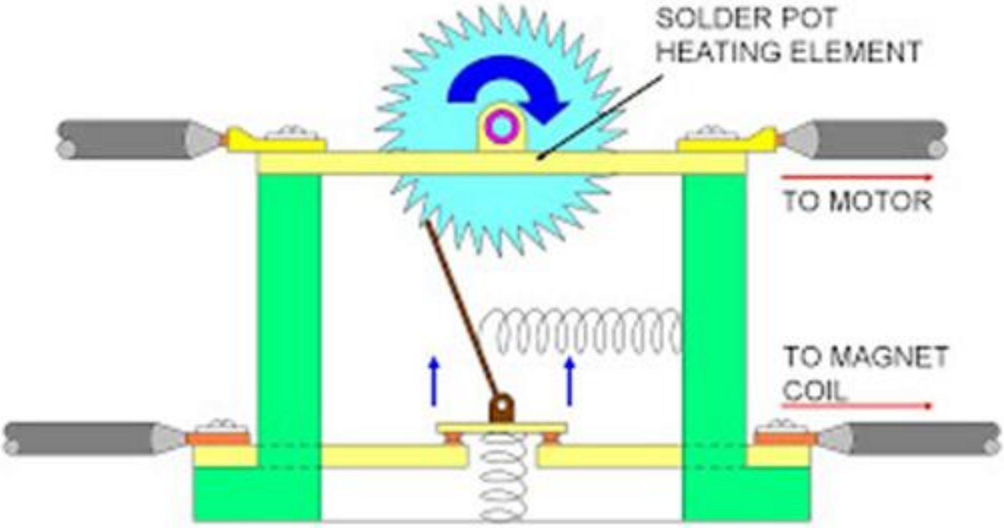


Figure 2:8 Eutectic Overload Relay

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)

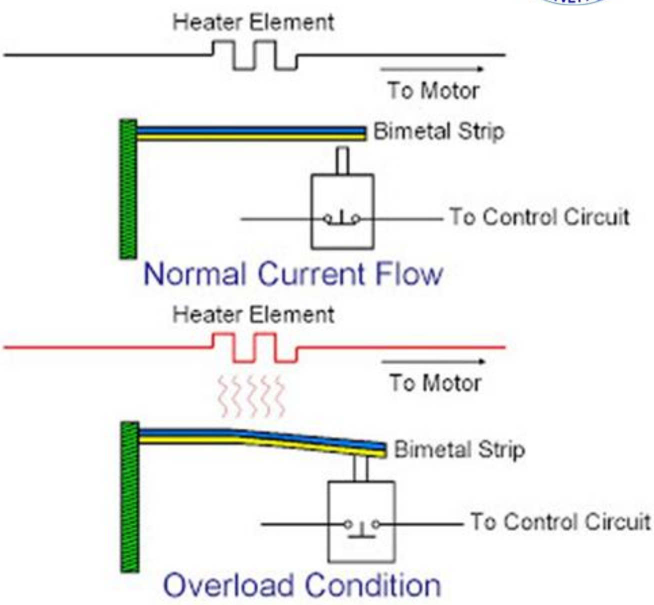


Figure 2:9 Bimetallic Overload Relay

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.

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 device's 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.

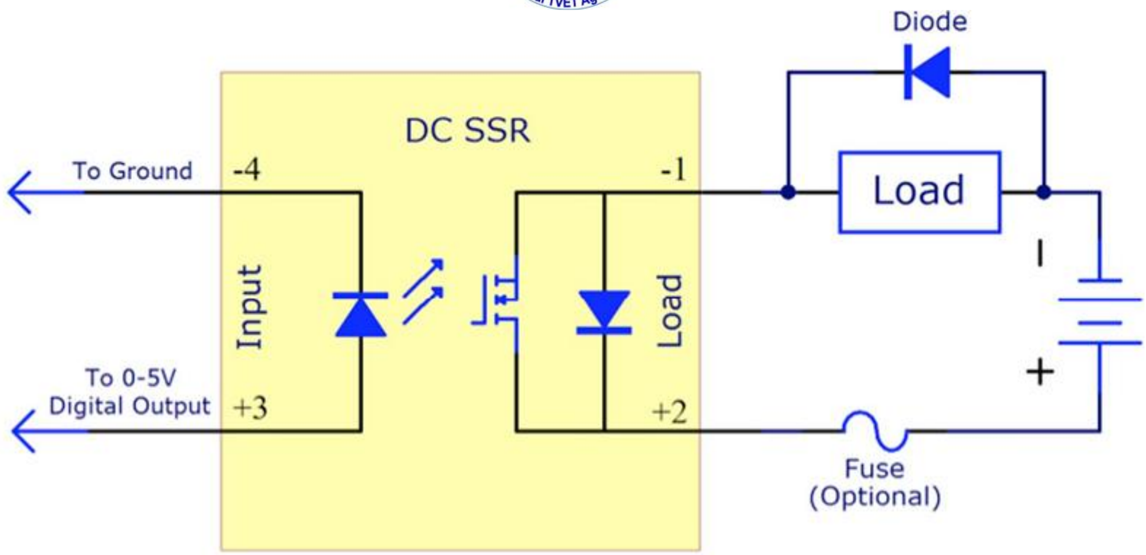


Figure 2:10 Solid State Overload Relay

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.

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 'cooling off' 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.

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'.

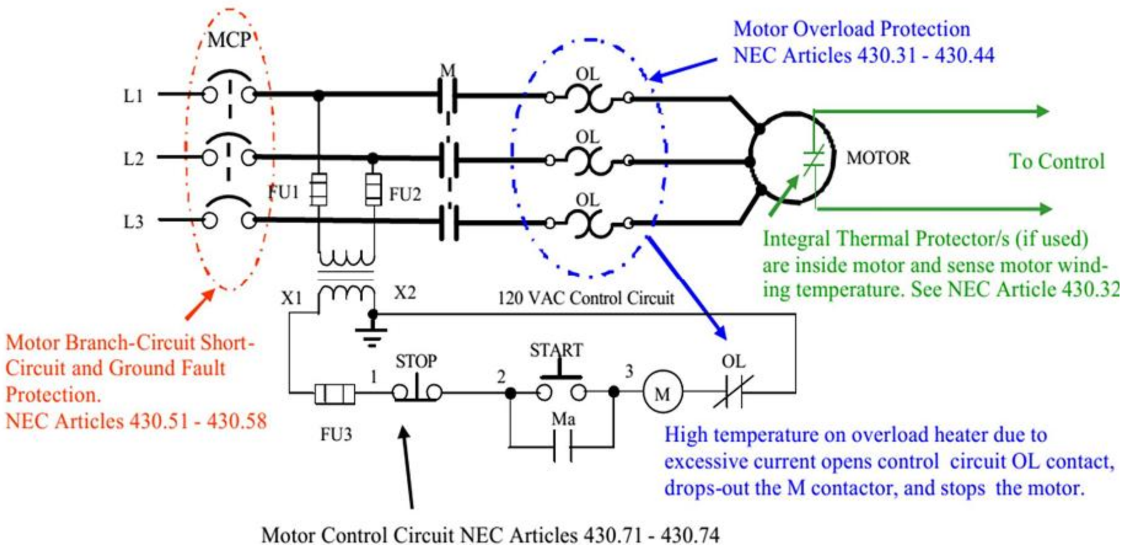


Figure Short Circuit and Over-Load Protection

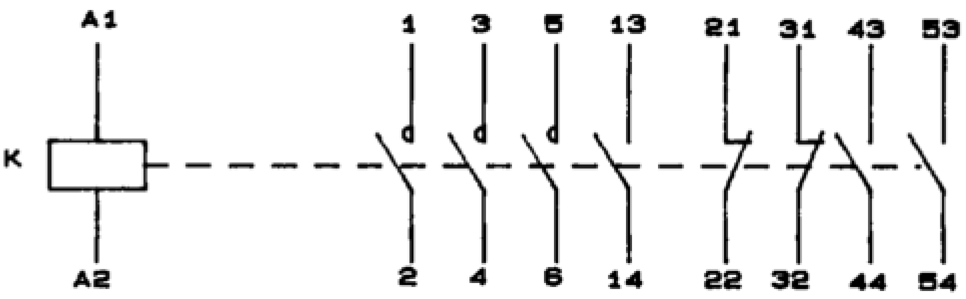
- **CONTACTOR**

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.

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

Graphical symbol and description



The electromagnet is composed of a magnetic core and of the associated excitation coil A1-A2. When a current flows through the coil, the coil attracts an anchor to which the moving contacts are connected. They can therefore perform their function.

Figure Contactor

The moving contacts are of two kinds: main or power contacts, coded with a single digit and able to withstand the high current through the plant, and auxiliary contacts, coded with two digits and able to withstand only the currents through the control circuits.

Manual Contactor

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

- ✓ Unit is encased and not exposed.
- ✓ Ø Double break contacts are used instead of single break
- ✓ Ø Unit is physically smaller
- ✓ Ø 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

- **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.

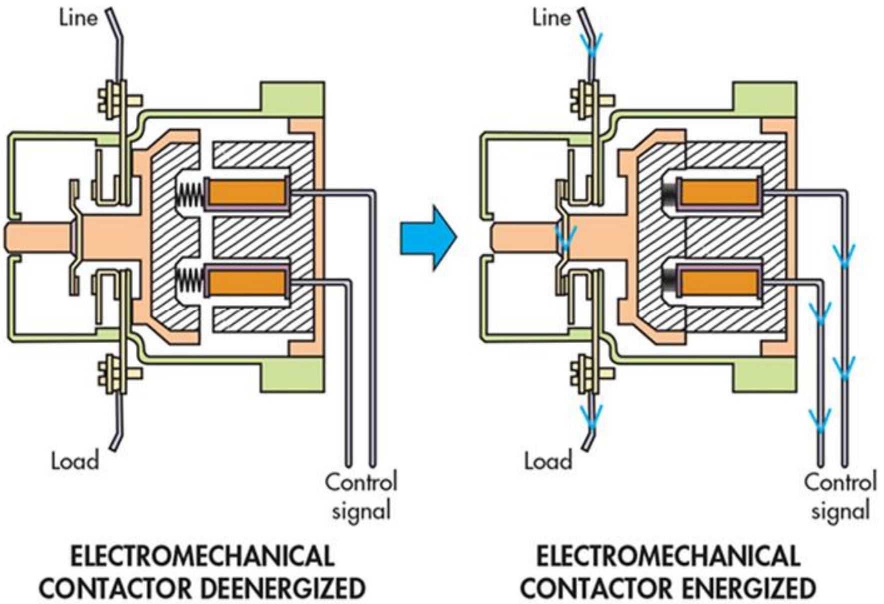
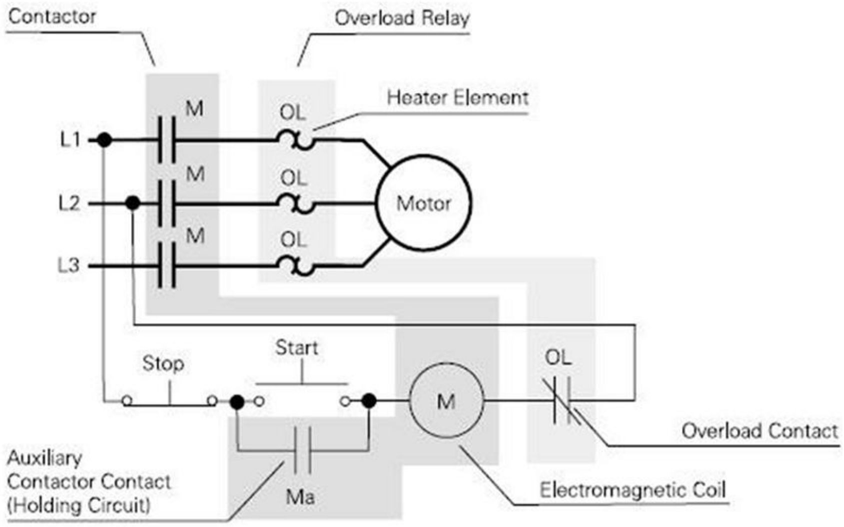


Figure 2:5 Magnetic Contactors

Main components of contactor are

1. Electromagnetic E frame
2. Armature
3. Coil
4. Spring
5. Two sets of contacts.



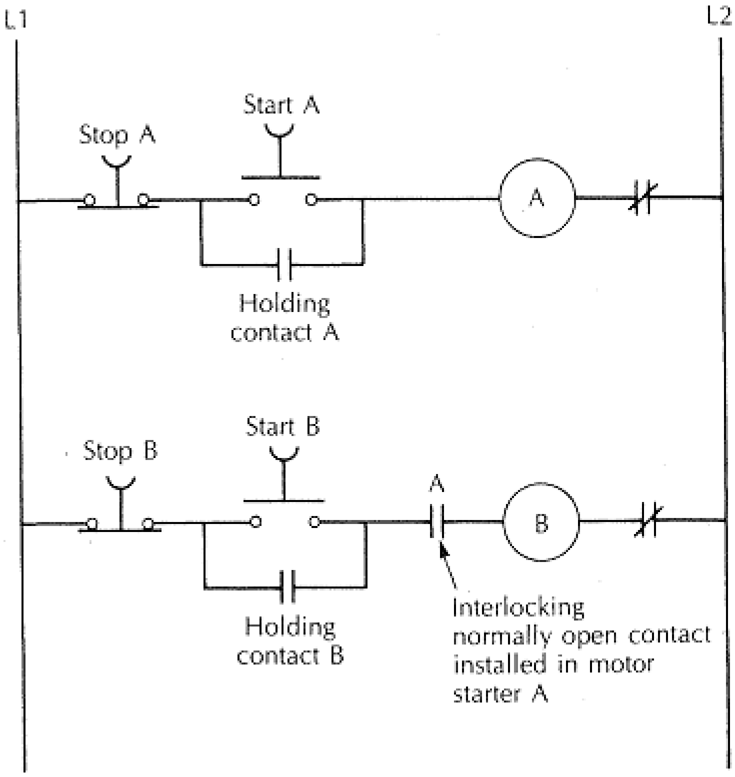


Figure Motor B is interlocked with motor A so that motor B cannot start unless motor A is running.

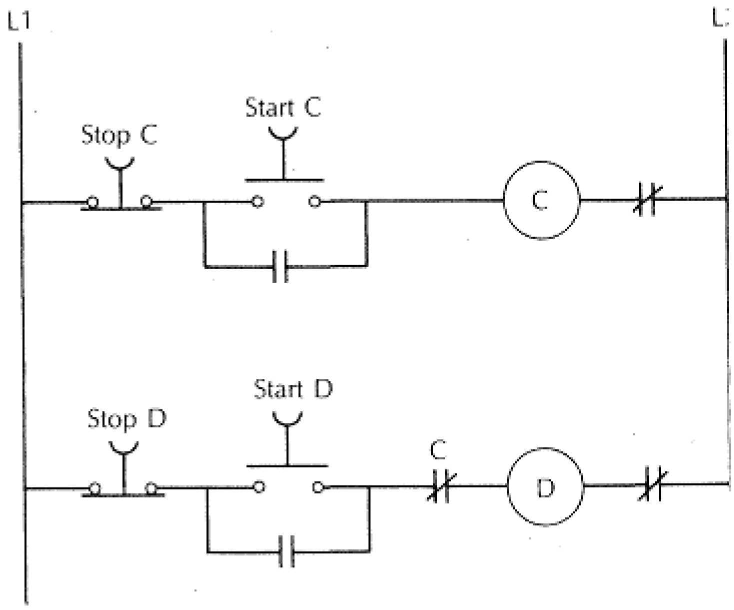


Figure Motor D is interlocked with motor C so the motor D cannot start if motor C is running.

A single-pole, double-throw (SPDT) switch or contact has one input wire and two output wires. One is normally open, and the other is normally closed. Many control devices use this type of contact so that one device can be used for many different purposes. Both output wires may be used, but often only one is used. Common single-pole, double-throw contacts are shown in Figure

Example

Design control circuit for ‘Tank water level control’. Operation sequence should be such that

- When the water level goes below the low-level limit, open the inlet valve of water tank.
- When water level goes above high limit is detected, close the inlet valve.

Build a control circuit for the same.

As shown in Figure below, when the level is initially low, coil K will pick up (since both level switch NC contacts will remain as it is), thus energizing the inlet valve to open.

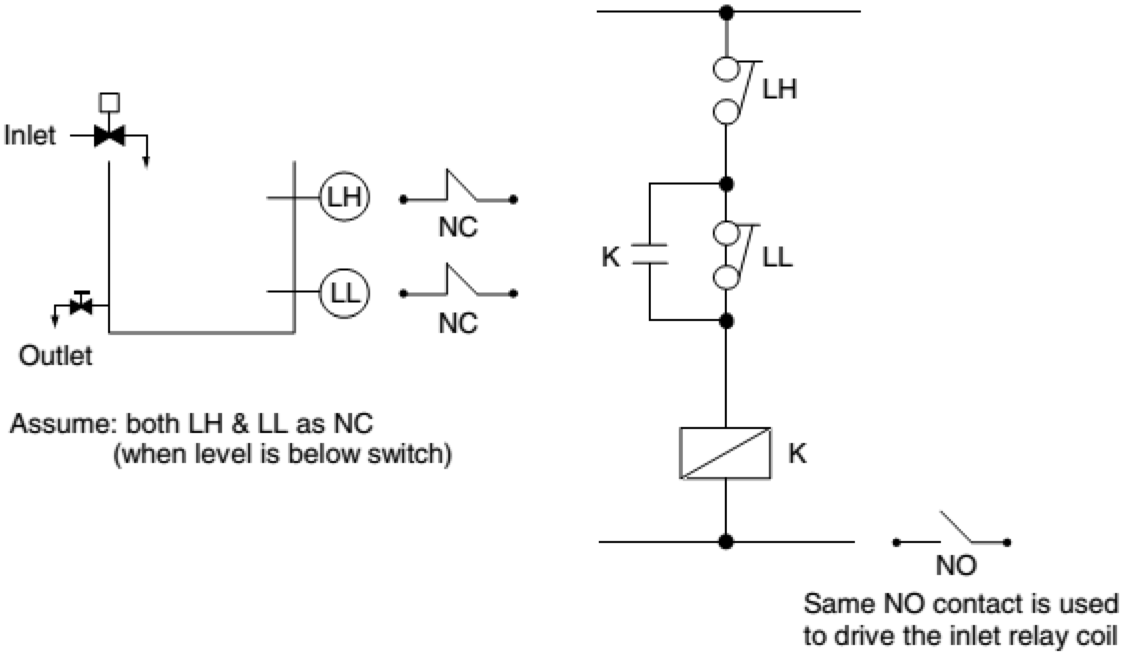
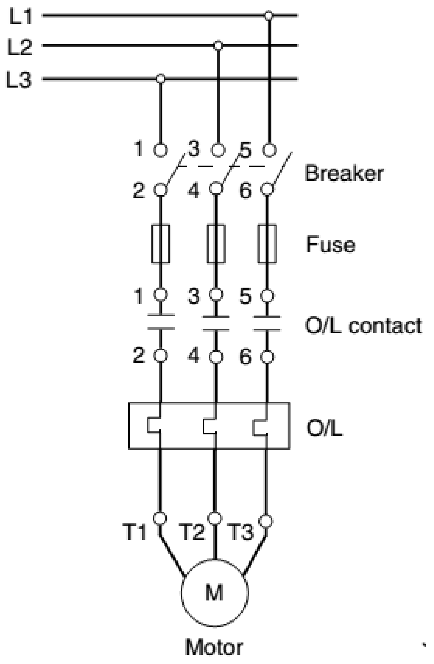


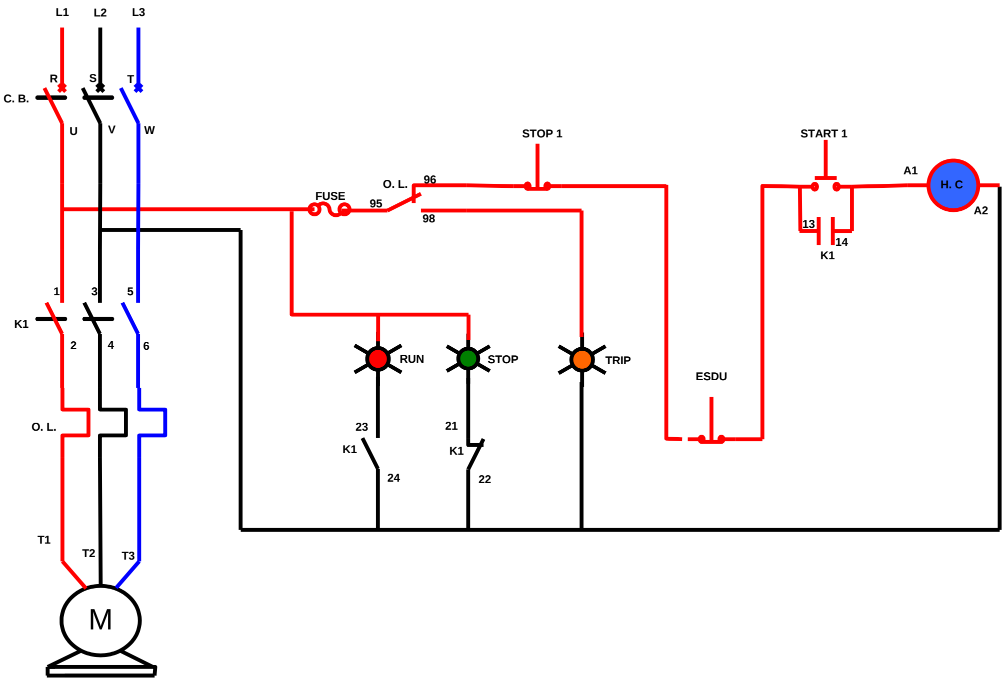
Figure simple control circuit for water tank inlet valve operation

As the level rises above switch LL, its NC contact will open but still coil K will remain latched through latching contact K. Once the level rises above switch LH, its NC contact will open causing coil K to de-latch or de-energize and the inlet valve will close. Now, coil K will not pick up or inlet valve will not open unless the water level drops below low-level switch LL.

For example, Figure below depicts a Direct-on-line (DOL) starter power circuit used for a three-phase induction motor. As shown, the three-phase power input is connected to the motor through a contactor.



Emergency Shut down Unit (ESDU) Full Voltage Across the Line (FVAL) motor starter with indicating lights.



Power is passed to the motor when the contacts (of the contactor) are in closed condition. Protection devices such as **fuses**, and **overload relays** are provided in series with power conductors to detect unhealthy conditions during operation.

The power circuit consists of a three-phase main supply with a fuse unit for protection

purposes. The other side of the fuse unit is connected to a power contactor. The output

terminals of the contactor are connected to an overload relay. Finally, the overload relay

output terminals are connected to motor terminals.

Operation principles of DOL

The control circuit for the motor works on a 110 V AC single-phase supply. The phase of the control supply is connected to a NC contact of the overload relay (O/L). The wire from the O/L relay contact is connected to an auto/manual mode selector switch.

In the auto mode, the motor gets a start/run command through a potential-free contact of a relay, which in turn is energized with a Programmable Logic Controller (PLC) output.

In the manual mode, the motor can be started with the help of a start pushbutton. When the start pushbutton is pressed, the control circuit is completed and the auxiliary control contactor (K1) coil is energized. A potential-free NO contact of the contactor (K1) is closed and keeps the contactor K1 latched when the start pushbutton is released. When the auxiliary contactor (K1) is on, the motor power circuit is completed and the motor starts and remains on until the contactor K1 is de-energized and the power circuit to the motor terminals is broken. The motor can be stopped with a stop pushbutton. The NC contact of a stop pushbutton breaks the control supply to the auxiliary control contactor

K1 and the motor is stopped. The neutral for the control circuit is connected with a neutral link (N/L).

To indicate that the motor is ON or running, an indication lamp is connected in parallel to the contactor, which goes ON whenever the auxiliary contactor is turned on.

Another indication lamp to indicate a motor trip is connected to a NO contact of the overload relay. When the motor is overloaded, the NO contact is closed and the TRIP indication lamp is turned ON, until the overload relay is reset.

Example Three-phase motor with star–delta starter

The electrical drawing in Figure below depicts this power circuit.

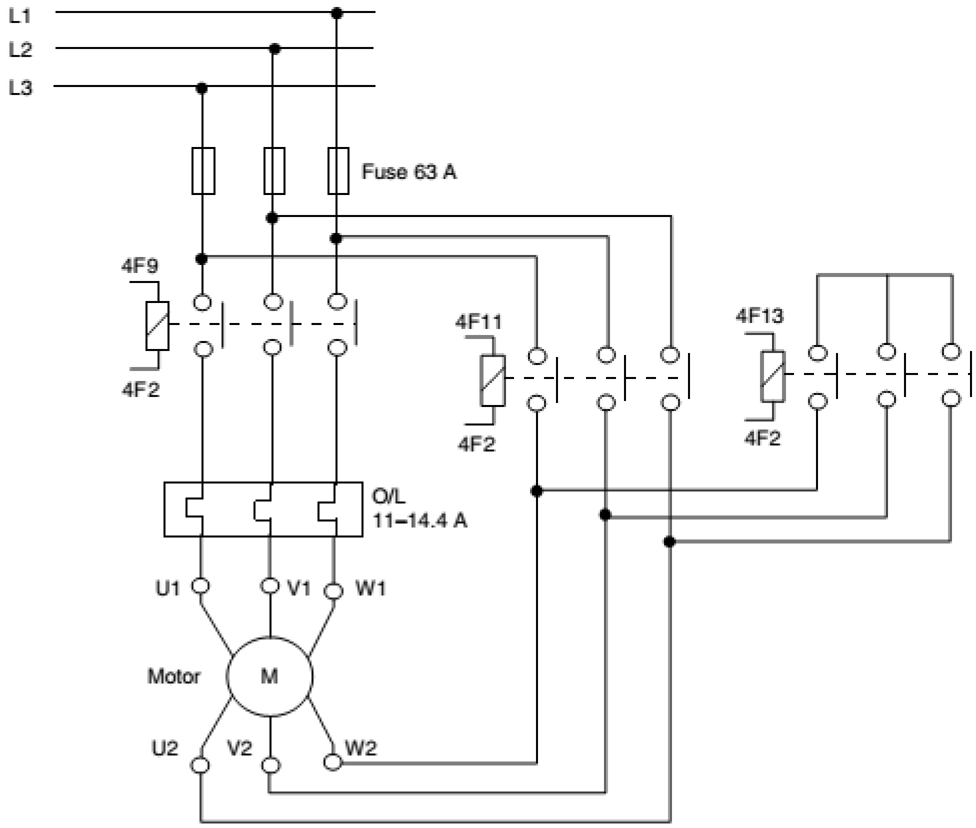
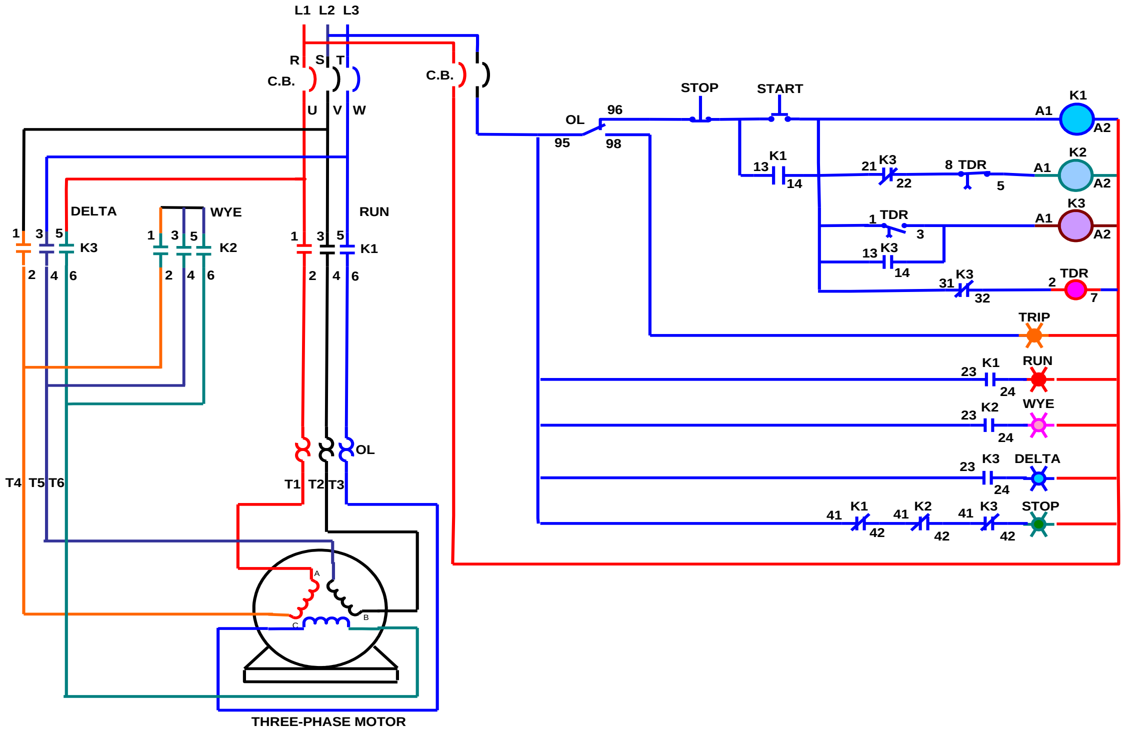


Figure Typical electrical drawing of power circuit for a three-phase motor with star–delta starter

Wye-Delta Reduced voltage motor starter, (Momentarily on Timer) with indicating lights



Operation principle of star delta starting of three phase motor

The power circuit consists of a three-phase mains supply with a fuse unit, three contactors – line contactor, star contactor, and delta contactor. The line contactor gets its three-phase power supply from the fuse unit and the output terminals of the line contactor are connected to the overload relay.

Overload relay output terminals are connected to the motor terminals – U1, V1, W1. Motor terminals U2, V2, W2 are connected through either star or delta contactors.

The star contactor and delta contactor are mutually interlocked in the control circuit to ensure only one contactor is on at a time. When the delta timer is on, the motor-winding terminals – U2, V2, W2 – get a three-phase supply and the motor is delta-connected.

When the star contactor is on, the motor terminals – U1, V1, W1 – are shorted and the motor is star-connected.

The control circuit as shown in Figure above, for the motor, works on a 110 V AC single phase supply. The phase of the control supply is connected to a NC contact of the overload relay (O/L). The wire from the O/L relay contact is connected to an auto/manual mode selector switch.

In an auto mode, the motor gets a start/run command through a potential-free contact of a relay, which in turn is energized with a PLC output.

In the manual mode, the motor can be started with the help of a start pushbutton. When the start pushbutton is pressed momentarily, the control circuit is completed and the line contactor is energized. A potential-free NO contact of the line contactor is closed and keeps the control complete when the start pushbutton is released. When the motor is started, the star contactor is closed and the motor is started with a star connection. As the motor runs for a few seconds, the delta timer picks up, which energizes the delta contactor and de-energizes the star contactor. The motor continues to run, connected in the delta configuration, until it is stopped with the stop pushbutton or trips due to an overload or an external interlock.

As can be viewed in Figure above each contactor used contacts that are given at the end of the drawing.

Note: The overload relay in this circuit is actually connected in series with the phase winding of the motor in the normal running mode (i.e., delta connection). The motor rated current is normally indicated in terms of the line current which is greater than the phase current by a factor of 3 . Selection and setting of the overload relay must take this into consideration.

THERMAL PROTECTION IN MOTOR WINDINGS

A motor may have a thermal protector in the windings to sense motor overheating. This thermal protector may be required to be wired-in as a part of the control circuit wiring. In this case, the thermal protector is simply wired in series with the control circuit. If the thermal protector opens, the control circuit is broken and the motor stops. A ladder diagram of a thermal protector in a control circuit is shown in Figure 17-34.

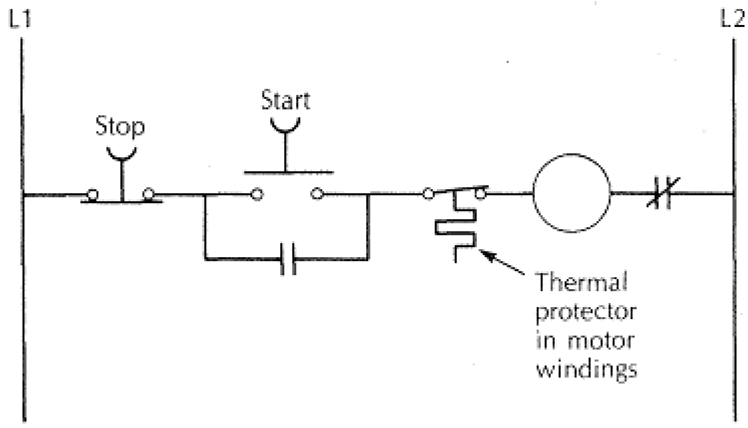


Figure A thermal protector in the motor windings may be wired in series with the control circuit.

LOW-VOLTAGE CONTROL

A magnetic motor starter may be operated from a control transformer-supplied 24-V or 120-V system.

This is of importance particularly for a large 460- V motor. A control transformer may step down the 460-V line voltage to 120 V. If the transformer is an integral part of the motor controller, it is permitted to be protected by fuses installed on the primary of the transformer, NEC Section 430-72 (c). Fuse holders are usually supplied as an integral part of the transformer.

The control electrical supply may be completely external to the motor branch circuit. A typical example would be a programmable controller operating a group of motors. The programmable controller output would most

PROTECTING THE CONTROL CIRCUIT

The motor control circuit is considered a Class 1remote-control circuit, and it falls within the scope of NEC Article 725, as well as Part F of Article 430. The motor control circuit wire may be tapped directly from the motor circuit wires, usually L1 and L2. Further, the control circuit wire carries only the current required by the coil in the motor starter; therefore, it is permitted to be a smaller wire size than is required for the motor circuit. The sizes of the motor control circuit wires are usually Nos. 14 or 12 AWG copper.

A start-stop station is often mounted in the cover of the motor controller. In this installation, the control circuit wires are completely within the motor controller. This wire need not be protected by a fuse, provided the motor circuit short-circuit and ground-fault protective device has a rating not more than the value in Column B of Consider the example of a 3-phase, 230-V, 15-hp motor which has a full-load current of 42 A, Figure 17-

Maximum Ampere Rating of Motor

Circuit Short-Circuit and Ground-Fault

Protective Device

The motor circuit wire is No. 6 AWG THWN cop- per, and the motor circuit short -circuit protection is a 70-A time-delay fuse. The control circuit wire inside the controller enclosure is permitted to be No. 14 AWG, according to .

The motor circuit in the example has a second control station remote from the controller. The control wires are considered protected by the motor circuit short-circuit and ground-fault protective device provided it does not exceed the value of Column C of Table 17-5 for the size of control circuit wire in use. The minimum size wire to the remote station for the motor of Figure 17-49 is No. 10 AWG, unless separate overcurrent protection is provided for the control circuit. Fuse holders are available to add to the motor starter to protect the control circuit wires.

Consider an example where a remote start-stop station controls a 7 lJ2-hp, single-phase, 230-V electric motor with a full-load current of 40 A. The motor circuit wire is No. 8 AWG copper THW, and the short-circuit protection is an 80-A circuit breaker.

Motor control circuit conductors are required to be provided with suitable mechanical protection where there are subject to physical abuse, NEC Section 430-73. Disconnect for the motor circuit and control circuit must be adjacent, NE (Section 430-74). If they are not adjacent, a warning labe must be placed at the motor controller indicating that twl separate disconnects are required to shut off power in th controller. The location of the control circuit disconnect must be specified at the motor controllers so that maintenance personnel will know where to find it.

REVERSING MOTOR STARTERS

Electric motors may be called upon to drive a rnachine which must be reversible. An example is a fee· conveyer that operates in either direction to deliver fee to two batches of animals. A reversible motor starter I required to select the desired direction. For a 3-phas motor, only two lead wires to the motor must be versed. However, for a single-phase motor, the starting winding leads must be reversed with respect to the rurning windings.

The ieast expensive means of reversing electric ffi{tors of small horsepower sizes is with a manually operated drum switch.

3-phase electric motor forward, a reverse, and an off position. The wiring of one type of drum switch to reverse a 3-phase motor. Note the phase rotation at the motor for the forward and the reverse positions. A single-phase motor is more difficult to reverse.

Electric motors of large-horsepower sizes can only be reversed with a reversing magnetic motor starter. This type has two magnetic contactors, forward-stop-reverse, push-button station is required. The wiring of a reversing magnetic starter for a 3-phase electric motor. The two magnetic contactors must be electrically or mechanically interlock.

The normally closed interlocking contacts prevent both contactors from being closed at the same time, causing a short circuit.

- **Interlocked to prevent both from being closed at one time. Closing both at one time will cause a short circuit.**

Self-Check -5	Written Test

Directions: Answer all the questions listed below. Use the Answer sheet provided in the next page:

1. Write types of motor control device
2. Explain power circuit and control circuit
3. Write the function of overload relay
4. Explain operation principle of contacted

Answer Sheet

Name: _________________________ Date: _______________

Instruction Sheet	LG27: Troubleshooting Electrical System or equipment

This learning guide is developed to provide you the necessary information regarding the following content coverage and topics –

- Prepare maintenance and repair works
- Types of maintenance
- Preparing maintenance work instructions and schedule
- Identifying and testing Materials, tools, equipment, and PPE
- Identifying Potential hazards for prevention and control measures

This guide will also assist you to attain the learning outcome stated in the cover page. Specifically, upon completion of this Learning Guide, you will be able to –

- Prepare maintenance and repair works
- Types of maintenance
- Prepare maintenance work instructions and schedule
- Identify and teste Materials, tools, equipment, and PPE
- Identify Potential hazards for prevention and control measures

Appropriate personal protective equipment is used in line with standard procedures.

Learning Instructions:

5. Read the specific objectives of this Learning Guide.
6. Follow the instructions described below 3 to 54.
7. Read the information written in the information “Sheet 1, Sheet 2, Sheet 3 and Sheet 4”
8. Accomplish the “Self-checks”

Information Sheet-1	2.1 Types of maintenance

2.1.1 Types of Maintenance

1. Run to Failure Maintenance (RTF)
2. Preventive Maintenance (PM)
3. Corrective Maintenance (CM)
4. Improvement Maintenance (IM)
5. Predictive Maintenance (PDM)

1. **Run to Failure Maintenance (RTF):** The required repair, replacement, or restore action performed on a machine or a facility after the occurrence of a failure in order to bring this machine or facility to at least its minimum acceptable condition. It is the oldest type of maintenance. It is subdivided into two types:
    - *Emergency maintenance:* it is carried out as fast as possible in order to bring a failed machine or facility to a safe and operationally efficient condition.
    - *Breakdown maintenance:* it is performed after the occurrence of an advanced considered failure for which advanced provision has been made in the form of repair method, spares, materials, labour and equipment.

- *Disadvantages:*

1. Its activities are expensive in terms of both direct and indirect cost.
2. Using this type of maintenance, the occurrence of a failure in a component can cause failures in other components in the same equipment, which leads to low production availability.
3. Its activities are very difficult to plan and schedule in advance.

2. **Preventive Maintenance (PM):** It is a set of activities that are performed on plant equipment, machinery, and systems before the occurrence of a failure in order to protect them and to prevent or eliminate any degradation in their operating conditions. The maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning and the effects limited. It is good for those machines and facilities which their failure would cause serious production losses. Its aim is to maintain machines and facilities in such a condition that breakdowns and emergency repairs are minimised. Its activities include replacements, adjustments, major overhauls, inspections and lubrications.

Preventive maintenance subdivided into different kinds according to the nature of its activities:

- *Routine maintenance* which includes those maintenance activities those are repetitive and periodic in nature such as lubrication, cleaning, and small adjustment.
- *Running maintenance* which includes those maintenance activities that are carried out while the machine or equipment is running and they represent those activities that are performed before the actual preventive maintenance activities take place.

- *Opportunity maintenance* which is a set of maintenance activities that are performed on a machine or a facility when an unplanned opportunity exists during the period of performing planned maintenance activities to other machines or facilities.
- *Window maintenance* which is a set of activities that are carried out when a machine or equipment is not required for a definite period of time.
- *Shutdown preventive maintenance*, which is a set of preventive maintenance activities that are carried out when the production line is in total stoppage situation.

3. **Corrective Maintenance (CM):** Corrective maintenance can be defined as the maintenance which is required when an item has failed or worn out, to bring it back to working order. Corrective maintenance is carried out on all items where the consequences of failure or wearing out are not significant and the cost of this maintenance is not greater than preventive maintenance. In this type, actions such as repair, replacement, or restore will be carried out after the occurrence of a failure in order to eliminate the source of this failure or reduce the frequency of its occurrence. This type of maintenance is subdivided into three types:

- *Remedial maintenance*, which is a set of activities that are performed to eliminate the source of failure without interrupting the continuity **of the** production process. The way to carry out this type of corrective maintenance is by taking the item to be corrected out of the production line and replacing it with reconditioned item or transferring its workload to its redundancy.
- *Deferred maintenance*, which is a set of corrective maintenance activities that are not immediately initiated after the occurrence of a failure but are delayed in such a way that will not affect the production process.
- *Shutdown corrective maintenance*, which is a set of corrective maintenance activities that are performed when the production line is in total stoppage situation.

1. *The main objectives of corrective maintenance* are the maximisation of the effectiveness of all critical plant systems, the elimination of breakdowns, the elimination of unnecessary repair, and the reduction of the deviations from optimum operating conditions. *The difference between corrective*

maintenance and preventive maintenance is that for the corrective maintenance, the failure should occur before any corrective action is taken. *Corrective maintenance is different from run to failure maintenance* in that its activities are planned and regularly taken out to keep plant's machines and equipment in optimum operating condition. The way to perform corrective maintenance activities is by conducting four important steps:

1. Fault detection.
2. Fault isolation.
3. Fault elimination.
4. Verification of fault elimination.

In the fault elimination step several actions could be taken such as adjusting, aligning, calibrating, reworking, removing, replacing or renovation.

- Corrective maintenance has several prerequisites in order to be carried out effectively:

1. Accurate identification of incipient problems.
2. Effective planning which depends on the skills of the planners, the availability of well-developed maintenance database about standard time to repair, some procedures, and the required labour skills, specific tools, parts and equipment.
3. Proper repair procedures.
4. Adequate time to repair.
5. Verification of repair.

4. **Improvement Maintenance (IM)**: It aims at reducing or eliminating entirely the need for maintenance. This type of maintenance is subdivided into three types as follows:

    - *Design-out maintenance* which is a set of activities that are used to eliminate the cause of maintenance, simplify maintenance tasks, or raise machine performance from the maintenance point of view by redesigning those machines and facilities which are vulnerable to frequent occurrence of failure and their long-term repair or replacement cost is very expensive.
    - *Engineering services* which include construction and construction modification, removal and installation, and rearrangement of facilities.
    - *Shutdown improvement maintenance*, which is a set of improvement maintenance activities that are performed while the production line is in a complete stoppage situation.

5. **Predictive Maintenance (PDM):** is a set of activities that detect changes in the physical condition of equipment (signs of failure) in order to carry out the appropriate maintenance work for maximising the service life of equipment without

increasing the risk of failure. It is classified into two kinds according to the methods of detecting the signs of failure:

A. *Condition-based predictive maintenance*

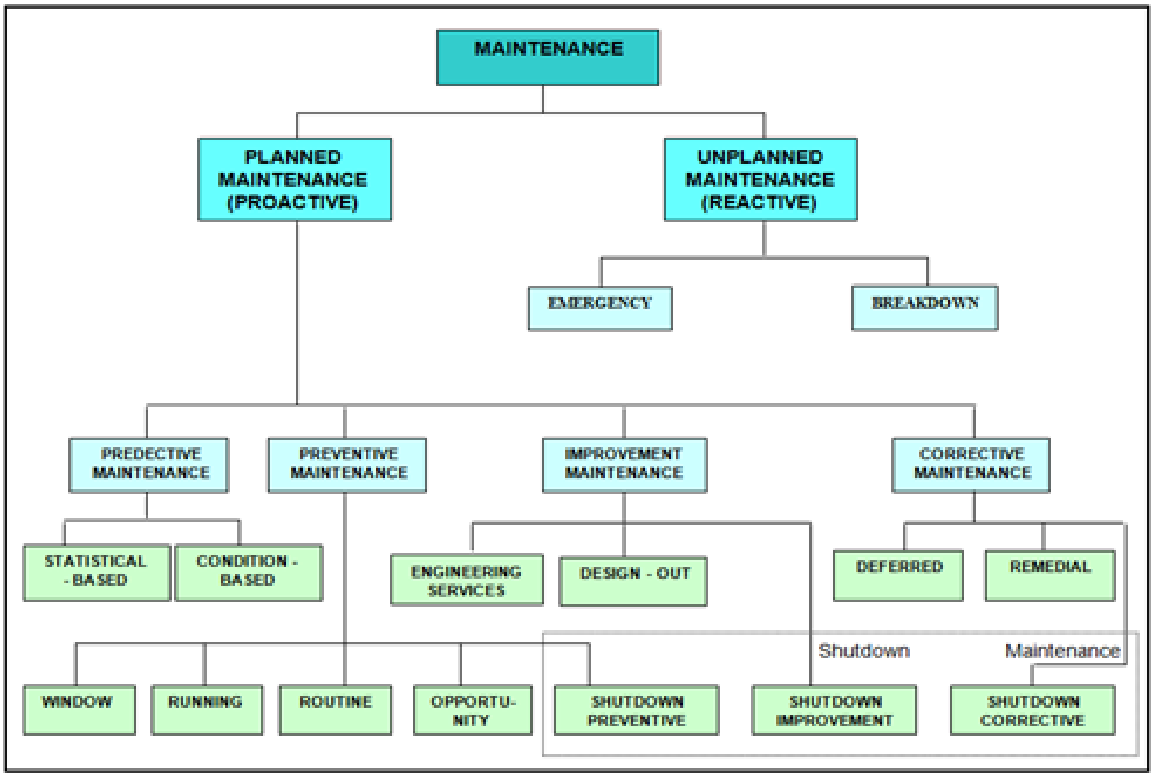
B. *Statistical-based predictive maintenance*

A. Condition-based predictive maintenance depends on continuous or periodic condition monitoring equipment to detect the signs of failure.

B. Statistical-based predictive maintenance depends on statistical data from the meticulous recording of the stoppages of the in-plant items and components in order to develop models for predicting failures.

2. The drawback of predictive maintenance is that it depends heavily on information and the correct interpretation of the information. Some researchers classified predictive maintenance as a type of preventive maintenance. The main difference between preventive maintenance and predictive maintenance is that *predictive maintenance uses monitoring the condition of machines or equipment to determine the actual mean time to failure* whereas *preventive maintenance depends on industrial average life statistics.*

Types of Maintenance



Self-Check 1	Written Test

1. Some common types of maintenance
   a. ____________
   b. ____________
   c. ____________
   d. ____________
2. Important steps of corrective maintenance activities:
   a. ____________
   b. ____________
   c. ____________
   d. ____________

Score = ___________

Rating: ____________

Answer Sheet

Information Sheet-2	2.2 Preparing maintenance work instructions and schedule

2.2.1 Standards and References

Reclamation Standards

Electrical maintenance recommended practices for some equipment are contained in other Facilities, Instructions, Standards, and Techniques volumes that will be referenced in this volume. Manufacturer's maintenance requirements, as defined in instruction books, also must be incorporated into a complete maintenance program. Other recommended maintenance practices are defined in Power Equipment Bulletins (PEB). Recommended practices, including recommended intervals defined in FIST volumes, are based on power industry best practices, published standards, and Reclamation's experience maintaining equipment in hydroelectric power plants. This FIST volume includes references to published standards produced by the Institute of Electrical and Electronics Engineers (IEEE™), National Fire Protection Association (NFPA), and other professional organizations, where they exist.

Maintenance and Test Procedures

Electrical maintenance activities fall into three general categories:

- **Routine Maintenance – Activities** that are conducted while equipment and systems are in service. These activities are predictable and can be scheduled, staffed, and budgeted. Generally, these are the activities scheduled on a time-based, run-time-meter-based, or a number of operations schedule. Some examples are visual inspections, infrared scans, and cleaning, functional tests, measurement of operating quantities, lubrication, oil tests, governor, and excitation system alignments.
- **Maintenance Testing – Activities** that involve the use of test equipment to assess condition in an offline state. These activities are predictable and can be scheduled, staffed, and budgeted. They may be scheduled on a time, meter, or number of operations basis but may be planned to coincide with scheduled equipment outages. Since these activities are predictable, some offices consider them "routine maintenance" or "preventive maintenance."
  - ✓ Some examples are Doble testing, meggering, relay testing, circuit breaker trip testing, alternating current (AC) high-potential (Hipot) tests, high voltage direct current (HVDC) ramp tests, battery load tests.
- **Diagnostic Testing – Activities** that involve use of test equipment to assess condition of equipment after unusual events such as faults, fires, or equipment failure/repair/replacement or when equipment deterioration is suspected. These activities are not predictable and cannot be scheduled because they are required

after a forced outage. Each office must budget contingency funds for these events.

- ✓ Some examples are Doble testing, AC Hipot tests, HVDC ramp tests, partial discharge measurement, wedge tightness, core magnetization tests, pole drop tests, turns ratio, and core ground tests

This FIST volume addresses scheduling of maintenance activities in the first two categories. It does not address follow up work generated by routine maintenance or maintenance testing, nor does it address diagnostic testing (with a few exceptions). Also, maintenance staff may be used for other activities such as improvements and construction, but this guide does not address these activities.

2.2.2 Maintenance Schedules and Documentation

Complete, accurate, and current documentation is essential to an effective maintenance program. Whether performing preventive, predictive, or reliability centered maintenance, keeping track of equipment condition and maintenance—performed and planned—is critical.

Maintenance recommendations contained in this volume should be used as the basis for establishing or refining a maintenance schedule. Recommendations can be converted into Job Plans or Work Orders in another maintenance management system. Once these job plans and work orders are established, implementation of well-executed maintenance is possible.

The maintenance recordkeeping system must be kept current so that a complete maintenance history of each piece of equipment is available at all times. This is important for planning and conducting an ongoing maintenance program and provides documentation needed for the Power O&M.

Regular maintenance and emergency maintenance must be well documented as should special work done during overhauls and replacement.

The availability of up-to-date drawings to management and maintenance staff is extremely important. Accurate drawings are very important to ongoing maintenance, testing, and new construction; but they are essential during emergencies for troubleshooting. In addition, accurate drawings are important to the continued safety of the staff working on the equipment.

2.2.3 Job Plan Templates

Job plan templates have been created to assist in the development of site-specific Job Plans for electrical and mechanical PM. The electrical job plan templates include all PM activities prescribed in this volume and may be augmented to include manufacturer's maintenance requirements and other site-specific considerations. Local development of complete job plans that match FIST volume requirements can be expedited by adopting these templates.

2.2.4 Power O&M Reviews

Electrical maintenance is one area covered in the Power Review of O&M (PRO&M). PRO&M utilizes regularly scheduled Annual (self-assessment), Periodic (regionally conducted), and Comprehensive (Denver conducted) reviews.

Each level of review is intended to assess compliance with accepted practices in operation, maintenance, and management. The accepted practices for electrical equipment maintenance are defined in this and other FIST volumes, Power Equipment Bulletins, and in the references cited in this document.

2.2.5 Safety during Maintenance

Performing maintenance on electrical equipment can be hazardous. Electrical and mechanical energy can cause injury and death if not managed properly. All maintenance activity must be conducted in accordance with FIST Volume 1-1, Hazardous Energy Control Program (HECP), and Reclamation Safety and Health Standards (RSHS). A job hazard analysis (JHA) must be conducted as well. Visitors, contractors, and others working under clearances must be trained in HECP and must follow all JHA and clearance procedures.

2.2.6 LECTRICAL EQUIPMENT MAINTENANCE SCHEDULES

- **Control Circuits**

Control circuits (usually 125 Vdc, 250 Vdc, or 120 Vac) provide the path for all control functions for major equipment in the powerplant. Reliability of thesecircuits is paramount. Although tested during commissioning, these circuits can become compromised over time through various means:

- ✓ Modifications and construction work which unintentionally break circuit integrity or introduce wiring errors.
- ✓ Age and deterioration of wiring rendering the system nonfunctional.
- ✓ Connections that become loose.
- ✓ Failure of individual control and protection devices due to misuse, old age, or inadvertent damage.

Verifying the integrity of the control devices and interconnecting wiring requires a “functional test” of these circuits. Functional testing of control circuits may be considered completed in the course of normal plant operation. However, control circuits that rarely are used should be functionally tested on a periodic basis.

<u>Maintenance Schedule for Control Circuits</u>

Maintenance or Test	Recommended Interval	Reference
Functional test control circuits	3-6 years	NFPA 70B under specific equipment and Appendix H

- **Fuses**

Fuses provide power and control circuit protection by interrupting current under certain overload and fault conditions.

<u>Maintenance Schedule for Fuses</u>

Some fuse failures are self-evident. Loss of meter indication or control circuit operation may indicate a blown (open) fuse. Other fuses that are critical to equipment operation may be monitored and their opening alarmed. However, some fuse operation cannot be detected remotely and should be assessed by regular maintenance. It may be as simple as looking for the "fuse operated" indicator on the fuse, or it may require checking with an ohmmeter. Failure to do so may result in more significant failure leading to an outage.

Maintenance or Test	Recommended Interval	Reference
Review equipment ratings	5 years	NERC Planning Standard FAC-009-1
Remove, inspect, and check Check fuse mounting clips, etc.	3-6 years	NFPA 70B, 15.2.3 Annex H.2j Annex I.1
Visual inspection and infrared scan, while loaded or immediately thereafter.	Annually	NFPA 70B, 15 NFPA 70B, 20.17 Annex H

- **Generators and Large Motors**

Generators produce electrical energy from mechanical power transmitted from the turbine. Large motors drive pumps to move water. Generators and large motors included in this section are synchronous machines performing the primary function of the power or pumping plant.

References and Standards

Maintenance references and standards from which the recommendations are drawn are numerous:

- ✓ Manufacturers instruction books
- ✓ FIST Volume 3-1, Testing Solid Insulation of Electrical Equipment

- ✓ Power O&M Bulletin No. 19 - Maintenance Schedules and Records
- ✓ IEEE Standard (Std.) 432-1992, Guide for Insulation Maintenance for Rotating Electric Machinery (5 horsepower [hp] to 10,000 hp)
- ✓ IEEE Std. 95-1997, Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Direct Voltage
- ✓ IEEE Std. 43-2000, Recommended Practice for Testing Insulation Resistance of Rotating Machinery …e.t.c

Maintenance Schedule for Generators and Large Motors

Maintenance or Test	Recommended Interval
Preventive maintenance and inspections	No standard recommended interval. Machine specific PM according to site operating conditions. Also, see Appendix B.
Stator winding - physical inspection	During 1-, 2½-, and 5-year warranty inspections; thereafter, during major maintenance outages but not to exceed 5 years.
Stator winding - high voltage DC ramp test	3 to 5 years and after prolonged maintenance outage.
Stator winding - insulation resistance polarization index (Megger®)	Performed in lieu of HVDC ramp test
Stator winding - AC Hipot test	At factory and as an acceptance test. Non-routine thereafter but may be used to verify insulation integrity before and/or after stator winding repair.
Stator winding - partial discharge measurements (on line monitoring with partial discharge equipment)	Nonroutine. Performed if problems are suspected.

Continued

Stator winding - black out test	Nonroutine. Performed when deterioration is suspected.
Stator winding - ozone measurement	Nonroutine. Performed when deterioration detected.
Stator winding - wedge tightness measurements	During 1-, 2½-, and 5-year warranty inspections; thereafter, performed after rotor is removed (particularly if unit in operation for 20-25 years without rewedging).
Stator winding - power factor measurements (Doble)	Nonroutine. May be performed in conjunction with other generator condition tests.
Stator core - physical inspection	During 1-, 2½-, and 5-year warranty inspections; thereafter, during major maintenance outages but not to exceed 5 years.
Stator core - core magnetizing test	Nonroutine. Should be performed prior to rewind or if core has been damaged.
Rotor - physical inspection	During major maintenance outages but not to exceed 5 years.
Rotor - insulation resistance polarization (Megger®)	Nonroutine. Performed when deterioration is suspected.
Rotor - AC pole drop test	Nonroutine. Performed when deterioration is suspected.
Thrust and upper guide bearing insulation test	Annually per FIST Volume 5-11.

- **Ground Connections**

Equipment grounding is an essential part of protecting staff and equipment from high potential caused by electrical faults. Equipment grounding conductors are subject to failure due to

- ✓ corrosion,
- ✓ loose connections, and
- ✓ Mechanical damage.

Grounding may also be compromised during equipment addition and removal or other construction-type activities. Periodically verifying grounding system integrity is an important maintenance activity.

Maintenance Schedule for Ground Connections in Substations/Switchyards

Maintenance or Test	Recommended Interval
Visual inspection, tighten connectors	Annually

- **Motors (< 500 hp**)

Motors of this type drive pumps, valves, gates, and fans. They are usually induction motors and are generally less than 500 hp but may be somewhat larger. Critical motors should routinely be tested.

Maintenance Schedule for Motors

Maintenance or Test	Recommended Interval	Reference
Insulation resistance (Megger®)	Annually	FIST Volume 3-4, 2.2
Infrared scan	Annually	NFPA 70B, 20-17.5

- **Relays and Protection Circuits**

Western Electricity Coordinating Council (WECC) Minimum Operating Reliability Criteria requires that: "Each system shall provide for periodic testing of protective systems and remedial action schemes which impact the reliability and security of the interconnected system operation."

Protective relays monitor critical electrical and mechanical quantities and initiate emergency shutdown whenever they detect out-of-limits conditions.

Protective relays must operate correctly when abnormal conditions require and must not operate at any other time.

Electrical protective relays are calibrated with settings derived from system fault and load studies. Initial settings are provided when relays are installed or replaced. However, electrical power systems change as new generation and transmission lines are added or modified. This may mean that relay settings are no longer appropriate. Outdated relay settings can be hazardous to personnel, to the integrity of the power plant and power system, and to the equipment itself.

Therefore, it is necessary to periodically conduct a fault and load study and review protective relay settings to ensure safe and reliable operation.

Fault and load studies and relay settings are provided by the Electrical Design

Group (D-8440) at 303-445-2850. Field-initiated changes to relay settings should be verified by this group.

Protective relays currently in use in Reclamation include electro-mechanical, solid-state, and microprocessor-based packages. Calibration and maintenance recommendations differ from type to type because of their different design and operating features.

Calibration: This process usually includes removal of the relay from service to a test environment. Injecting current and/or voltage into the relay and observing the response according to the manufacturer's test procedure verifies the recommended settings. Calibration of electro-mechanical relays is recommended frequently since operating mechanisms can wear and get out of adjustment.

Calibration of solid-state and microprocessor-based relays is recommended less frequently since there are fewer ways for them to get out of calibration.

Relay Functional Test: This process verifies that the protective outputs of the relay (e.g., contact closures) actually operate as intended. This can be accomplished as part of the calibration procedure in most cases, but relay functional testing should be verified according to the maintenance schedule.

Protective relays operate into protection circuits to accomplish the desired protective action. Similar to control circuits, protection circuit integrity may be compromised by construction, modifications, deterioration, or inadvertent damage. A compromised protection circuit may not provide the system and plant protection desired. Periodic functional testing is recommended to ensure the integrity of protection circuits.

Protection Circuit Functional Testing: This process verifies that the entire protective "trip path" from protective relay through circuit breakers (or other protective equipment) is intact and functional. This requires actually operating the entire circuit to verify correct operation of all components.

Protective circuit functional testing is accomplished as follows:

- ✓ Conduct a Job Hazard Analysis.
- ✓ Verify that testing will not disrupt normal operation or endanger staff or equipment.
- ✓ With lockout relays reset, initiate lockout relay trip with the protective device contact.3
- ✓ Verify the lockout relay actually tripped from the protective relay action.

Verify that circuit breakers actually tripped (or other protective action occurred) from the lockout relay action.

- ✓ Activate the lockout relay from each protective device. After the first full test of lockout relay and breakers, it may be desirable to lift the trip bus from the lockout relay so as not to repeatedly trigger the lockout—a meter may be substituted to verify contact initiation.

Caution: Do not forget to reconnect the trip bus to the lockout relay when testing is complete.

Where functional testing of ALL protection circuits is unfeasible, testing of the most critical protection circuits and devices is still recommended.

Reclamation standard design for lockout relay and circuit breaker control circuits includes the use of the red position/coil status indicator light to monitor the continuity of the circuit through the trip coil. These lights should be lit when the lockout relay is in the "Reset" position or when the breaker is closed. If the light is not lit, this may indicate a problem with the coil integrity which should be addressed immediately.

Maintenance Schedule for Relays and Protection Circuits

Maintenance or Test	Recommended Interval	Reference
Fault/load study and recalculate settings	5 years	Reclamation Recommended Practice NERC FAC-009-1
Electro-mechanical relays Calibration and functional testing	Upon commissioning and every 2 years	NFPA 70B, 8.9.7 and 20.10.3 Annex Table I.1 Per manufacturer's instructions Fist 3-8 WECC Std. 11.4
Solid-state relays Calibration and functional testing	Upon commissioning 1 year after commissioning and every 3 years	NFPA 70B, 8.9.7 and 20.10.3 Annex Table I.1 Per manufacturer's instructions Fist 3-8 WECC Std. 11.4
Microprocessor relays Calibration and functional testing	Upon commissioning 1 year after commissioning and every 8-10 years	Reclamation Recommended Practice Per manufacturer's instructions Fist 3-8 WECC Std. 11.4
Protection circuit functional test, including lockout relays	Immediately upon installation and/or upon any changes in wiring and every 3-6 years	FIST Volume 3-8 NFPA 70B Annex Table H.4(c) Manufacturer's instruction manuals PEB No. 6
Check red light lit for lockout relay and circuit breaker coil continuity	Daily[1]	Reclamation Recommended Practice
Lockout relays Cleaning and lubrication	5 years	Power Equipment Bulletin No. 6 and Manufacturer's instructions

References and Standards

Maintenance references and standards from which the recommendations are drawn are numerous:

• Manufacturers' instruction books

• Doble Transformer Maintenance and Test Guide

• IEEE Std. 62-1995

• FIST Volume 3-30, Transformer Maintenance

• FIST Volume 3-31, Transformer Diagnostics

• NFPA 70B - Recommended Practices for Electrical Equipment Maintenance

• Transformers: Basics, Maintenance, and Diagnostics (Reclamation manual)

Self-Check -2	Written Test

Directions: Answer all the questions listed below. Use the Answer sheet provided in the next page:

1. Explain Activities of Routine Maintenance
2. Explain Activities of Maintenance Testing with example
3. Explain Activities of Diagnostic Testing with example

Information Sheet	2.3 Identifying and testing Materials, tools, equipment, and PPE

2.3.1 Select tools and testing devices

A tool is any instrument used in doing work. A hand tool is any tool operated by hand to do work. A power tool is operated by some source of power other than human power.

2.3.2 Tool Habits

There are good tool habits which will help you perform your work more efficiently as well as safely. A place for everything and everything in its place" is just common sense.

You cannot do an efficient, fast repair job if you have to stop and look around for each tool that you need. The following rules, if applied, will make your job easier. Keep each tool in its proper storage place. A tool is useless if you cannot find it. If you return each tool to its proper place, you will know where it is when you need it. ***Keep your tools in good condition.*** Keep them free of rust, nicks, burrs, and breaks. ***Keep your tool setcomplete.*** If you are issued a tool box, each tool should be placed in it when not in use. ***use each tool only on the job for which it was designed.*** If you use the wrong tool to make an adjustment, the result will probably be unsatisfactory. ***Keep your tools where you easy reach and where they cannot fall on the floor or on machine.*** Avoid placing tools anywhere above machinery or electrical apparatus. Serious damage will result if the tool falls into the machinery after the equipment is turned on or running

Screw driver

Is a tool designed to loosen or tighten screws. Screwdrivers are available in many different shapes, sizes, and materials. Screwdrivers are used for driving or removing screws or with slotted or special heads.

Slot-Head or standard Screw driver

Is designed for use on screws with slotted heads. This type of screw is often used on the terminals of switches, receptacles, and lamp holders.

Phillips screwdriver

Is designed for use on screws with an X-shaped insert in their heads.

PLIERS

Pliers are used to cut and shape electric conductors and to grip a variety of objects.

This has caused many types of pliers to be developed.

<u>Needle-nose pliers</u> Forming loops on small conductors Cutting and stripping small conductors

Cutting small conductors

Crimping wire lugs

<u>Diagonal pliers (dykes)</u> Cutting small conductors

Cutting conductors in limited space

Wire strippers

Wrench

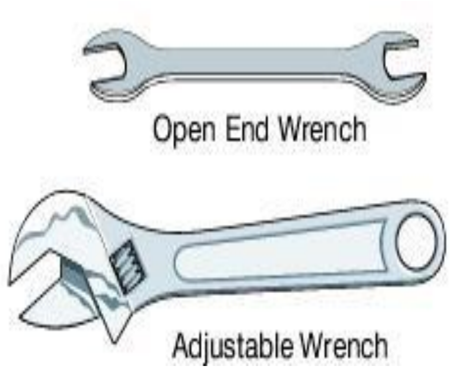
(side cutters)

Cutting large conductors Forming loops on large conductors

Pulling and holding large conductors

Stripping insulation from conductors

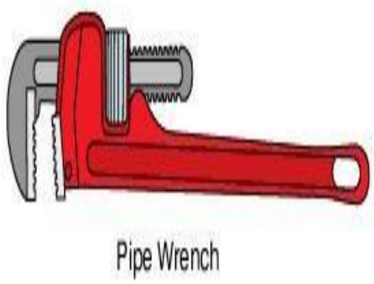
A wrench is a tool specially designed to tighten or loosen nuts, bolts, studs, and pipes.



Wrenches are made from steel alloy to prevent breakage.

There are many different types of wrenches. Each type has its own use. By using the proper wrench for the task to be done, you will not break the wrench, damage the equipment, or cause personal injury.

HEX KEY WRENCH (or ALLEN KEY)



A. Double open end wrench

B. Double boxed end wrench

C. Combination wrench

2.3.3 Testing devices

There are many kinds of instrument used for the measurement of electrical/electronic quantities.

For experimental work in the lab, individual voltmeters to measure voltage, ammeters to measure current, and ohmmeters to measure resistance are sometimes used. More often, a single multimeter is usually used to accurately measure voltage, current, or resistance

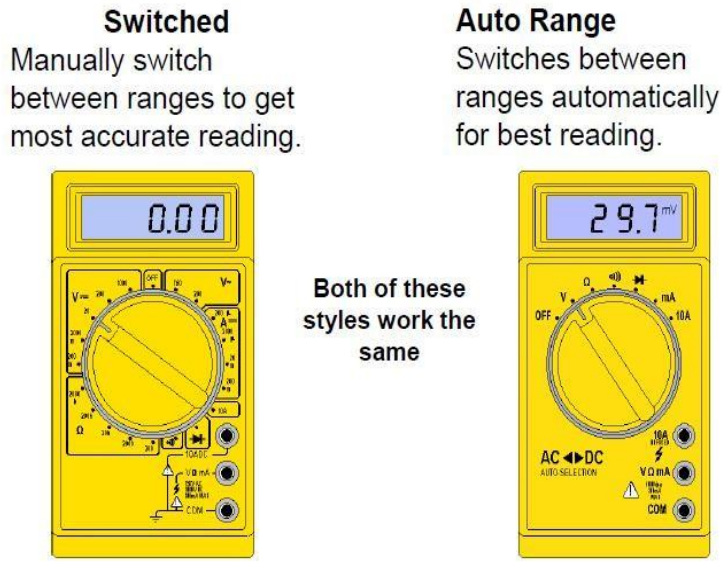
What is a Multimeter?

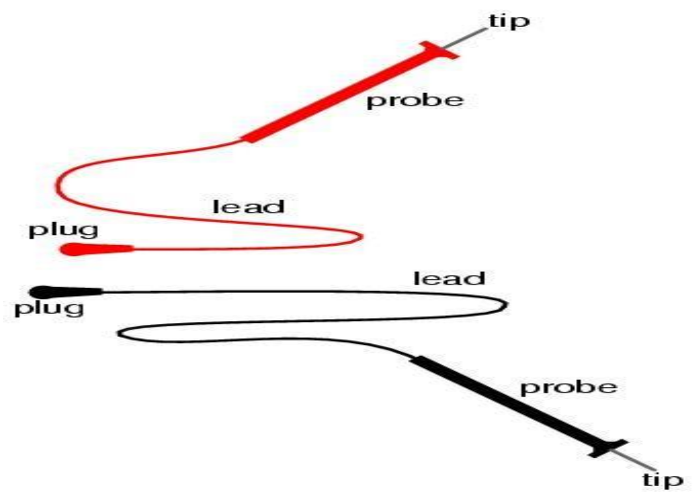
Multimeter is a devise used to measure voltage, resistance and current in electronics & electrical equipment. It is also used to test continuity between2 points to verify if there is any breaks in circuit or line.

There are two types of multimeter Analog & Digital

- Analog has a needle style gauge
- Digital has a LCD display

There are two styles of multimeters



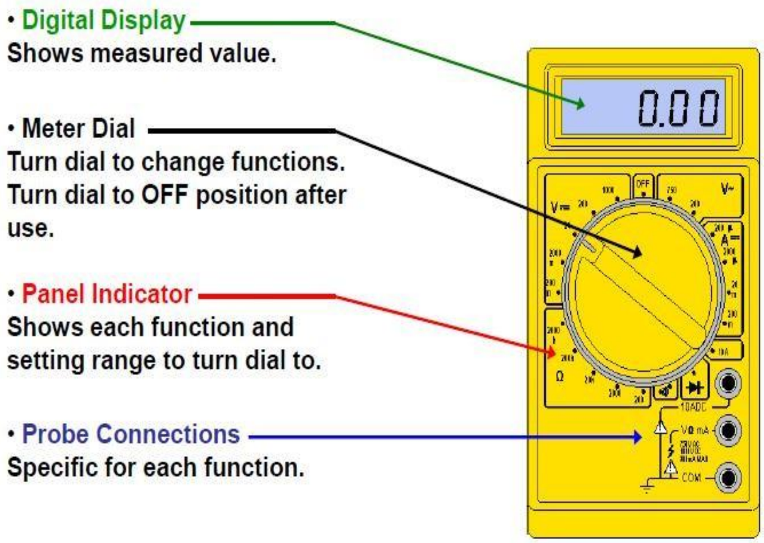


Red meter lead is connected to Voltage/Resistance or amperage port Is considered the positive connection.

Black meter lead is always connected to the common port. Is considered the negative connection

Probes are the handles used to hold tip on the tested connection. Tips Are at the end of the probe and provides a connection point.

Display & Dial Settings

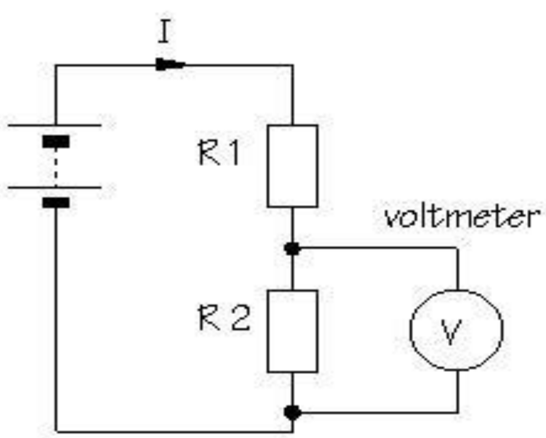


Measuring Voltage using multimeter

Voltage (V) is the unit of electrical pressure; one volt is the potential difference needed to cause one amp of current to pass through one ohm of resistance. Voltage is broke up into 2 sections AC & DC Alternating Current (AC) is house voltage (110vac) Direct Current (DC) is battery voltage (12vdc) On switched meters use one value higher than your expected value

To measure voltage connects the leads in parallel between the two points where the measurement is to be made.

The multimeter provides a parallel pathway so it needs to be of a high resistance to allow as little current flow through it as possible.



Measuring Resistance and Continuity

Resistance (R) is the opposition to current flow. Resistance is measured in Ohm's Disconnect power source before testing Remove component or part from system before testing Measure using lowest value, if OL move to next level Testing for continuity is used to test to verify if a circuit, wire or fuse is complete with no open Audible continuity allows an alarm if circuit is complete If there is no audible alarm resistance of 1ohm to .1ohm should be present.

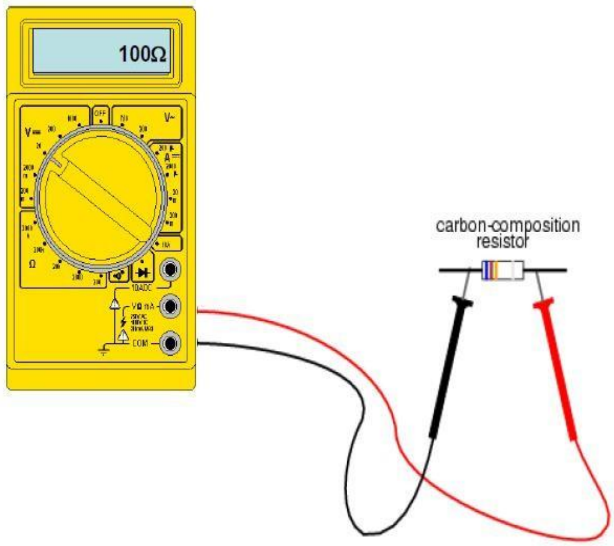


Figure: Measuring Resistance

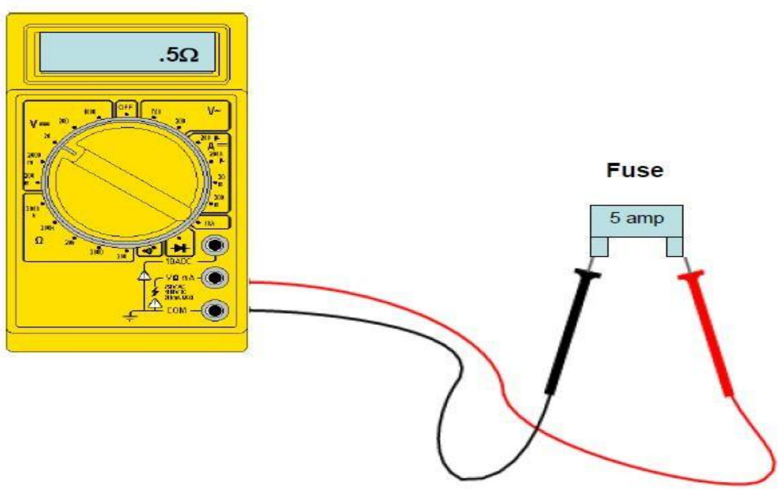


Figure: Measuring or Testing Continuity

Measuring Current

Current (amps) is the flow of electrical charge though a component or conductor Current is measured in amps or amperes Disconnect power source before testing Disconnect completed circuit at end of circuit Place multimeter in series with circuit Reconnect power source and turn ON Select highest current setting and work your way down.

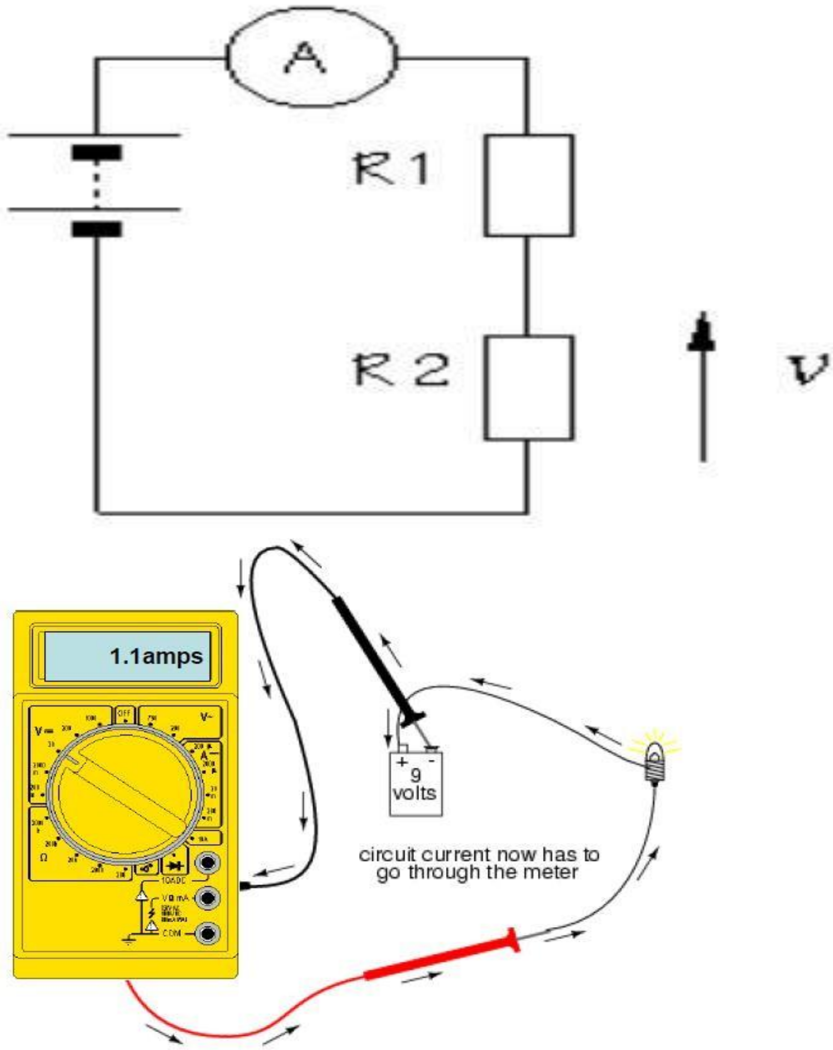


Figure: Measuring Current

Oscilloscope

An oscilloscope, or scope for short, is an electronic test instrument that is used to observe an electronic signal, typically voltage, as a function of time. In other words it is a voltage versus time plotter. Oscilloscopes come in two basic types, analogue or digital, and support various features and functions useful for measuring and testing electronic circuits. An oscilloscope is a key piece of test equipment for any electronics designer.

Parts of an Oscilloscope

Internally, an oscilloscope is a fairly complex piece of electronic equipment. Fortunately, its operation is simplified through the use of various features and knowing its internal workings is not key to its use.

Despite this, as a good designer, it is important to understand the correct operation of test equipment and any affect it may have on the circuit under test

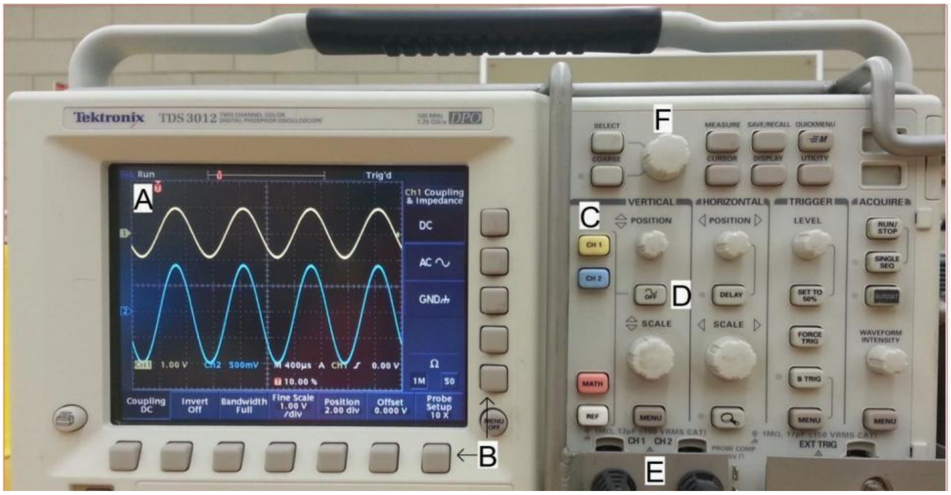


Figure . Oscilloscope features.

a. **Display:** The main feature of an oscilloscope is its display (Figure 1 A). Analogue versions of oscilloscopes use Cathode Ray Tube (CRT) displays, while digital scopes use LCD (or similar) screens.

b. **Probes**: The voltage signals that are to be measured must be transferred to the oscilloscope. This is done using oscilloscope probes. Probes are specially designed to minimize noise and interference, while also creating a known load effect on the circuit (so it can be accounted for). Some probes also have protective features to prevent any damage a signal may cause to the oscilloscope (such as overvoltage)

Figure 2. Oscilloscope probe.

Probes, through a cable, are attached to the channel inputs (Figure 1 E) on the oscilloscope using a connector (usually a BNC). The probing end can consist of either a sharp point (Figure 2 Probe Tip), which can be held against a pin, pad, or other conductor, or a small clip (Figure 2 Attachable Probe Clip), convenient for attaching the probe to a wire or other small circuit feature. In addition, a grounding clip (Figure 2 Probe Ground Clip) is located at the end of a small wire on the probe. The grounding clip is connected, through the oscilloscope, to chassis (hydro) ground (in other words, the clip is always at the reference voltage and cannot be used to measure signals), and should be attached to the ground or common signal of the circuit to be measured. Note the probe is relatively heavy and can generally NOT be supported by the circuit features it may be attached to. Take care when attaching clips.

a. **Channels; an** oscilloscope channel generally refers to the input (Figure 1 E) of a signal (kind of like tuning in a TV channel, except that you can see more than one channel at a time on a scope). It can also refer to the path of the signal through the oscilloscope. An oscilloscope can have 1 or more channels, and it is common to have 2 or 4. Having multiple channels allows for the simultaneous measurement of multiple signals, making comparisons and other functions easier. Each channel typically has its own set of controls or a common set that is toggled. Channel waveforms can be removed from the display using the Off button (Figure 1 D).

b. **Controls:** The controls of an oscilloscope can be used to adjust almost any aspect of the scope from display parameters to advanced mathematical functions. The controls themselves consist of dials, toggles, buttons, and switches as seen in Figure 1.

Horizontal and Vertical Scaling and Positioning

The vertical (y) axis of the graticule represents the voltage being measured. The horizontal (x) axis represents time. Each axis is measured in a grid, whose physical spacing is typically 1cm squares, but represents units of voltage and time. These units can be scaled using the dials labeled ‘Scale’ as seen in Figure 1. In addition, the horizontal and vertical position of a signal can be adjusted using the ‘Position’ dials as seen in Figure 1.

The current grid scale and position is displayed over the graticule (or beneath it if the context menu is off). In addition, the zero position of each channel is indicated by the numbered marker on the left of the graticule. Note that each channel can have a different vertical scale and position, but all channels share the same horizontal scale and position. To adjust a waveform, it is first selected using the channel select buttons (Figure 1C), and then changed via the appropriate dial (note, some context menu items also require the correct channel to be selected).

Signal Generator

The signal generator is exactly what its name implies: a generator of signals used as a stimulus for electronic measurements. Most circuits require some type of input signal whose amplitude varies over time. The signal may be a true bipolar AC1 signal(with peaks oscillating above and below a ground reference point) or it may vary over a range of DC offset voltages, either positive or negative. It may be a sine wave or other analog function, a digital pulse, a binary pattern or a purely arbitrary wave shape.

The signal generator can provide “ideal” waveforms or it may add known, repeatable amounts and types of distortion (or errors) to the signal it delivers. See Figure 2. This characteristic is one of the signal generator’s greatest virtues, since it is often impossible to create predictable distortion exactly when and where it’s needed using only the circuit itself. The response of the DUT in the presence of these distorted signals reveals its ability to handle stresses that fall outside the normal performance envelope

Waveform Characteristics

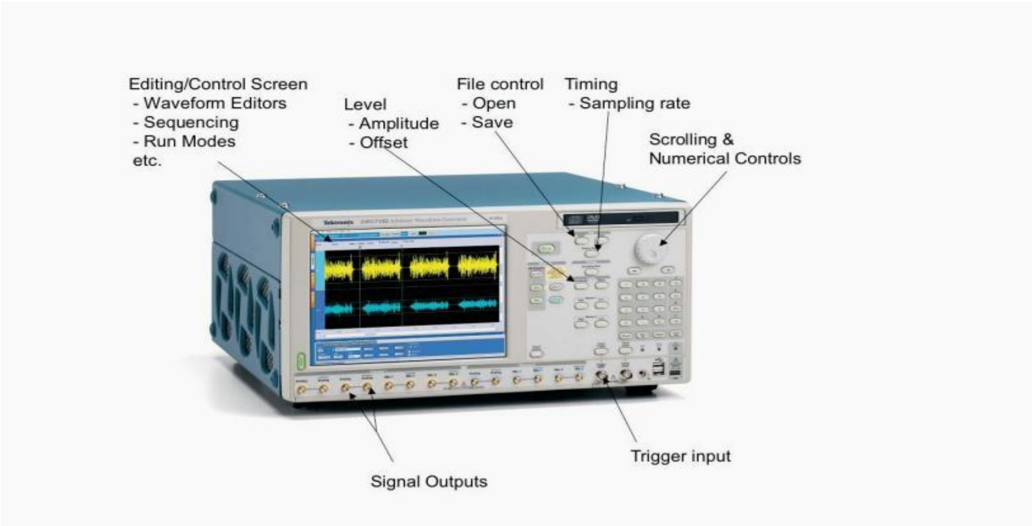
Wave forms have many characteristics but their key properties pertain to amplitude, frequency, and phase:

Amplitude: A measure of the voltage "strength" of the waveform. Amplitude is constantly changing in an AC signal. Signal generators allow you to set a voltage range, for example, —3 to +3 volts. This will produce a signal that fluctuates between the two voltage values, with the rate of change dependent upon both the wave shape and the frequency.

Frequency: The rate at which full waveform cycles occur. Frequency is measured in

Hertz (Hz), formerly known as cycles per second. Frequency is inversely related to the period (or wavelength) of the waveform, which is a measure of the distance between two similar peaks on adjacent waves. Higher frequencies have shorter periods.

Phase: In theory, the placement of a waveform cycle relative to a 0 degree point. In practice, phase is the time placement of a cycle relative to a reference waveform or point in time



Calibrators: A calibrator is equipment used to adjust instrument accuracy, often associated with a specific application.

Tachometer: A tachometer is optical measurement equipment. It needs to 'see' the rotating object.

Oxygen analyzer: Analyzing the oxygen content in breathing machine, anesthesia machine, infant incubator and concentrator machine.

Self-Check -3	Written Test

Directions: Answer all the questions listed below. Use the Answer sheet provided in the next page:

Part1 Chose the correct answer for the following Questions

1. …………. Is an electronic test instrument that is used to observe an electronic signal?
   A. Multimeter C. Oscilloscope
   B. Signal generator D. Tachometer
2. Which one of the following are used for the measurement of electrical/electronic quantities?
   A. Oscilloscope C. Tachometer
   B. Signal generator D. Multimeter
3. A single Multimeter is usually used to accurately measure……...
   A. Voltage C. Current
   B. Resistance D. All
4. …………… Is designed for use on screws with an X-shaped insert in their heads.
   A. Phillips screwdriver C. Plier
   B. Slot-head screwdriver D. None
5. The key properties of Waveform Characteristics are………
   A. Amplitude C. Phase
   B. Frequency D. All

Answer Sheet

Score = ____________

Rating: _____________

Name: __________________________ Date: _______________

Information Sheet	2.4. Identifying Potential hazards for prevention and control measures

2.4.1 Potential hazards

There's a wide range of factors to consider when trying to ensure the health, safety and welfare of clients, employees and the environment in care-service businesses such as crèches, playgroups and residential care homes. Make sure you:

- ✓ check the suitability of all potential staff before employing them
- ✓ train staff in all health and safety procedures
- ✓ keep the design and layout of your premises simple and obstacle-free
- ✓ maximize accessibility - by providing lifts, for example
- ✓ keep electrical, mechanical and other equipment in good order
- ✓ keep up repairs to your premises
- ✓ install user-friendly fixtures and fittings in your premises
- ✓ keep your premises secure
- ✓ Communicate your health and safety policy to everybody in your group.
- ✓ arrange health and safety training for those who need it
- ✓ provide suitable equipment - from protective gloves to lifting equipment
- ✓ keep wash facilities clean and well stocked
- ✓ provide sufficient rest rooms and ensure rest breaks are taken
- ✓ train staff in managing waste on site
- ✓ store wastes properly before disposal
- ✓ segregate incompatible wastes - especially hazardous wastes
- ✓ store liquid wastes away from watercourses and drains
- ✓ fit stair and bath rails
- ✓ use non-slip flooring
- ✓ keep hazardous substances such as chemicals and medicines locked away with restricted access
- ✓ provide adequate lighting

2.4.2 OHS guidelines

Occupational Health and Safety procedures for a given work area

Occupational health and safety (OH&S) is the term used to describe the laws and processes that help to protect employees from death, disease and injury while at work.

What is hazard?

The Occupational Health and Safety Regulation 2001 define a hazard as ‘anything (including work practices or procedures) that has the potential to harm the health or safety of a person’.

Hazard: is also a situation or thing that has the potential to harm a person. Hazards at work may include: noisy machinery, a moving forklift, chemicals, electricity, working at heights, a repetitive job, violence at the workplace etc.

Risk: is the possibility that harm (death, injury or illness) might occur when exposed to a hazard.

Hazards can be grouped into five broad areas:

- Physical k hazard e.g. noise, radiation, light, vibration
- Chemical hazard e.g. poisons, dusts
- Psychological hazard e.g. fatigue, violence
- Biological e.g. viruses, bacterial infection , parasites
- Mechanical/electrical hazard e.g. trips and falls, tools, electrical equipment (micro or macro shock).

Hazards can arise from: work environment use of machinery and substances poor work design inappropriate systems and procedures.

Risk management

Risk management is a proactive process that helps you responds to change and facilitate continuous improvement in your business. It should be planned, systematic and cover all reasonably foreseeable hazards and associated risks. It involves four steps to set out hazards;

Identify hazards – find out what could cause harm.

Assess risks if necessary – understand the nature of the harm that could be caused by the hazard, how serious the harm could be and the likelihood of it happening.

Control risks – implement the most effective control measure that is reasonably practicable in the circumstances.

Review control measures-to ensure they are working as planned.

Step 1 – How to identify hazard

Identifying hazards in the workplace involves finding things and situations that could potentially cause harm to people. Hazards generally arise from the following aspects of work and their interaction: physical work environment equipment, materials and substances used work tasks and how they are performed work design.

How to find hazards

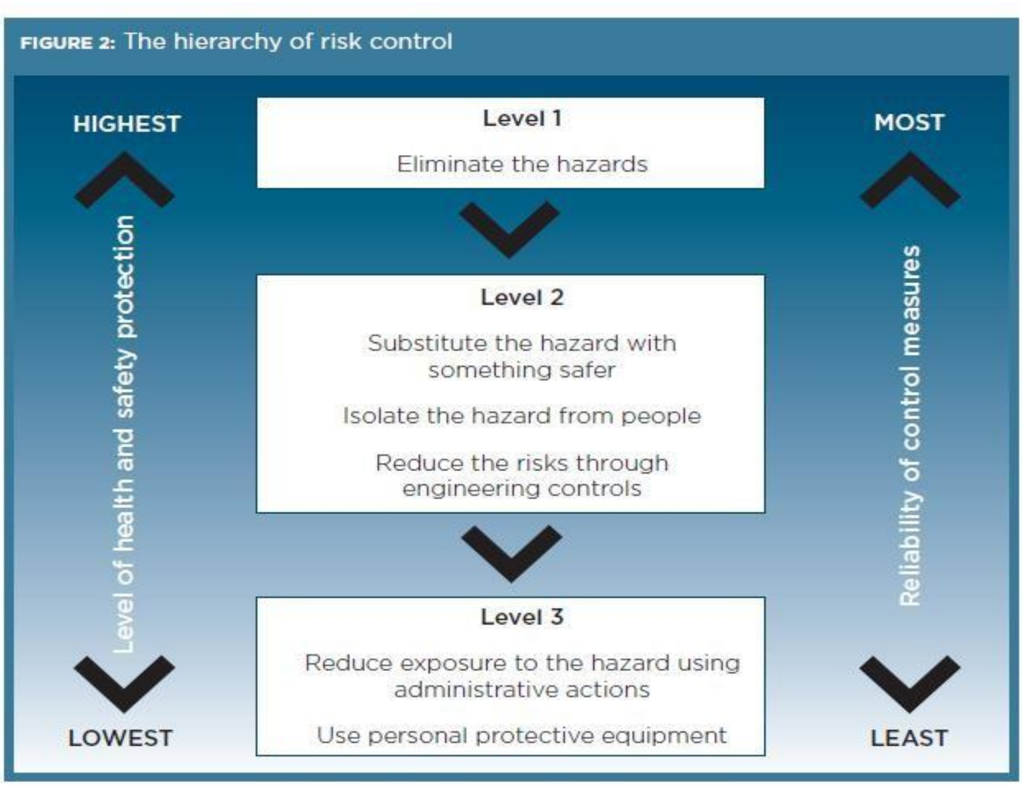
- Inspect the work place
- Consult your workers
- Review available information's

Step 2 – How to assess risk

A risk assessment involves considering what could happen if someone is exposed to a hazard and the likelihood of it happening. A risk assessment can help you determine: how severe a risk is whether any existing control measures are effective what action you should take to control the risk how urgently the action needs to be taken.

STEP 3 – How to control risks

The most important step in managing risks involves eliminating them so far as is reasonably practicable, or if that is not possible, minimizing the risks so far as is reasonably practicable. The hierarchy of risk control. The ways of controlling risks are ranked from the highest level of protection and reliability to the lowest as shown in Figure below.



CODE OF PRACTICE | HOW TO MANAGE WORK HEALTH AND SAFETY RISKS

LEVEL- 1 Control measures

You must always aim to eliminate a hazard, which is the most effective control.

If this is not reasonably practicable, you must minimize the risk by working through the other alternatives in the hierarchy. The best way to do this is by, firstly, not introducing the hazard into the workplace. For example, you can eliminate the risk of a fall from height by doing the work at ground level.

LEVEL- 2 control measures

If it is not reasonably practicable to eliminate the hazards and associated risks, you should minimize the risks using one or more of the following approaches:

Substitute the hazard with something safer

For instance, replace solvent-based paints with water-based ones.

Isolate the hazard from people

This involves physically separating the source of harm from people by distance or using barriers. For instance, use remote control systems to operate machinery; store chemicals in a fume cabinet. Use engineering controls

An engineering control is a control measure that is physical in nature, including a mechanical device or process. For instance, use mechanical devices such as trolleys to move heavy loads; place guards around moving parts of machinery; install residual current devices (electrical safety switches); set work rates on a production line to reduce fatigue.

LEVEL- 3 control measures

These control measures do not control the hazard at the source. They rely on human behavior and supervision, and used on their own, tend to be least effective in minimizing risks. Two approaches to reduce risk in this way are:

Use administrative controls

Administrative controls are work methods or procedures that are designed to minimize exposure to a hazard.

For instance, develop procedures on how to operate machinery safely, limit exposure time to a hazardous task, and use signs to warn people of a hazard.

2.2.2 Ethiopia Electrical Code

Color identification of bare conductors and cable cores (EELP's Regulation)

Function	Colour identification of core of rubber of PVC insulted
Earthling	White

Live of .c single - phase circuit	Green
Neutral of a.c single - phase or three - phase circuit	Black
Phase R of three - phase a.c circuit	Green
Phase S of three - phase a.c circuit	Yellow
Phase T of three - phase a.c circuit	Red

2.2.3 Follow environmental protection legislation and regulations

MEDICAL CENTRES SAFETY PROGRAM

- ❖ Safety includes a range of hazards including mishaps (an unlucky accident), injuries on the job, and patient care hazards.
- ❖ The most common safety mishaps are “needle sticks” (staff accidentally stick themselves with a needle) or patient injury during care.
- ❖ As a manager, ensure all staff and patients are safe within the facility.
- ❖ Note: it’s everyone’s responsibility!

Laboratory safety

Laboratory Safety Comes First!

- ❖ Hand washing
- ❖ Standard (Universal) precautions
- ❖ Electrical Safety
- ❖ Fire Safety

Basic Laboratory Safety Issues

- ❖ Hand washing
- ❖ Smoking
- ❖ Food & Drink
- ❖ Eye & Face Protection
- ❖ Cosmetics
- ❖ Shoes
- ❖ Hair & Jewelry
- ❖ Eye Wash/Safety Showers
- ❖ Do Not Mouth Pipette

❖ Good Housekeeping

❖ Sharp Objects

Basic Rules of Bio Safety

The basic rules of Bio safety are essential to avoid occupational hazards when working in the laboratory.

1. Washing hands following all laboratory activities, following the removal of gloves and immediately after contact with infectious agents.
2. Do not mouth pipette.
3. Use protective laboratory coats and gloves.
4. Do not eat, drink, smoke or store food in the laboratory.
5. Manipulate infectious agent carefully to avoid spills and the production of aerosols and droplets.
6. Decontaminate work surface before and after use, and immediately after spills.
7. Use needles, syringes and other sharps only absolutely necessary.

Rules of Environmental and Safety Compliance

- All personnel working in laboratories must be trained in safe work practices and hazardous waste disposal.
- Maintain an accurate hazardous materials inventory.
- Properly label all hazardous materials.
- Segregate incompatible materials and place in safe storage locations.
- Use fume hood and other appropriate controls when using flammables, toxic or odorous vapors.
- Wear the appropriate protective equipment, such as a laboratory coat, gloves, safety glasses.
- Use non-hazardous material instead of hazardous materials whenever possible.

There are several meeting that are medical equipment managers are required to attend as the organizations technical representative. The following are:

- Patient safety
- Environmental of Care
- Space Utilization Committee
- Equipment Review Board
- Infection Control (optional)

- Safety of our patient/staff is paramount to the success of our organizations mission.
- The Joint Commission on the Accreditation of Healthcare Organization publishes annual lists detailing “National Patient Safety Goals” to be implemented by healthcare organization.
- Goals are developed by experts in patient safety nurses, physicians, pharmacists, risk managers, and other professionals with patient-safety experience in a variety of settings.
- Patient safety is among the most important goals of every healthcare provider, and processes concerned with patient safety provides way for biomedical managers and clinical engineering departments to gain visibility and positively affect their workplace.

Electrical Safety

- Electrical safety is the containment of limitation of hazardous such as, electrical shock, explosion, fire or damage to equipment and buildings.
- Preventive maintenance programs reduce electrical hazards such as:
  - The physiological effects of electricity.
  - Leakage current
  - Ground fault
  - Electrical short hazard.
  - The use of proper power wiring distribution, and ground system in reducing electrical shock hazards.
  - Specialized electrical safety test equipment

Chemical Safety

- Laboratories use a lot of chemicals that caustic and corrosives
  - Concentrated acids or bases, organic solvents that are noxious and flammable, eye irritants, mutagens, teratogens, etc.
- Spills are possible
  - Wear gloves
  - Clean the outside of the instrument
  - Look for spill marks inside and clean these as well
- Ask lab personnel to help clean up the equipment, especially if you are taking to the shop
- Address any concerns to the Chemical Safety Officer

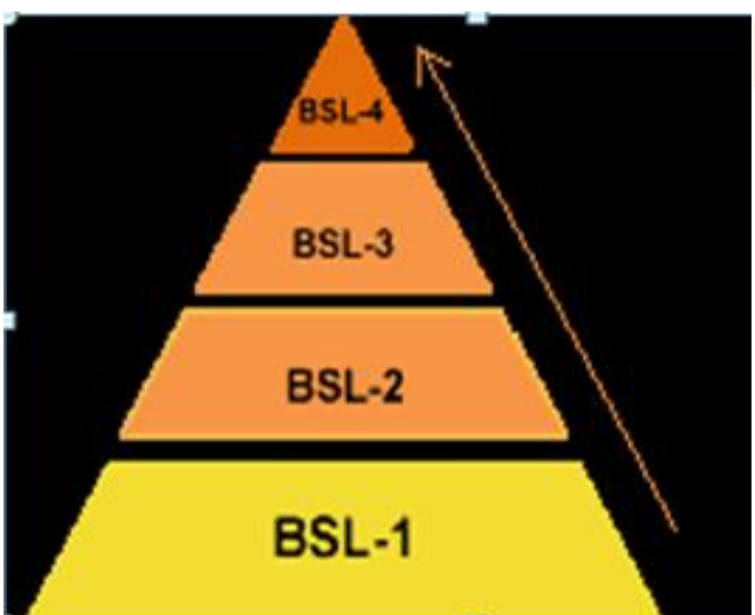
Biological Safety

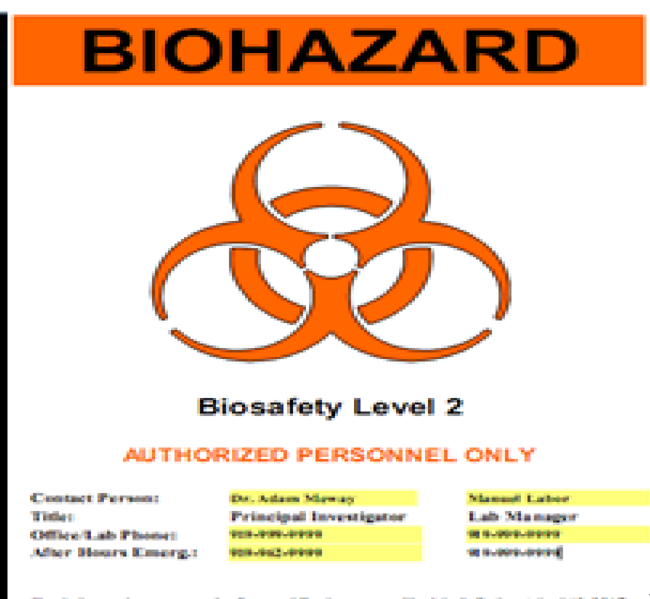
- A biomedical technician will be working with instruments that come in contact with infectious organisms or patient samples, both of which could be hazardous to one's health. All such samples, whether from healthy or sick, are to be considered hazardous
- Wearing proper protection such as lab coats, eye protection and gloves should be made a habit
- Instruments must be decontaminated by the lab personnel before repair is attempted, especially if moving the equipment to the shop
- Some of the instruments may be located within labs and unmovable
- Work with the biological safety officer to ensure your safety

Levels of Biological Safety

- Depending on the hazard posed by the organism being cultured, different biological safety levels are mandated.
- These safety levels, BSL 1 – BSL 4 specify containment and precautions, with level 1 being least restrained and 4 being highly contained.
- Hazards are generally higher in research lab than in routine clinical labs
- Know the biosafety officer and address questions

Biohazard Signs and Biosafety Levels





Self-Check -1	Written Test

Directions: Answer all the questions listed below. Use the Answer sheet provided in the next page:

1. What is OH&S Policy &Procedure?
1. Write at list three Basic Rules of Bio Safety?
1. What are the advantages of OH&S for an organization?
1. Write at list three Basic Laboratory Safety Issues?
1. Write Ethiopia Electrical Code colour identification of bare conductors and cable cores (EELP's Regulation)?

Answer Sheet

Instruction Sheet	LG28: Troubleshooting Electrical System or equipment

This learning guide is developed to provide you the necessary information regarding the following content coverage and topics –

- Instruments are checked/ inspected to ensure safe operation
- Conduct appropriate functional test(s) and inspection to ensure that the testing conducted on the device conforms with the manufacturer's instruction/manual
- Work site is cleaned and cleared of all debris and left in safe condition in accordance with company procedures
- Test results are recorded in Instrument/ control devices history cards
- Report is prepared and completed according to company requirements.

This guide will also assist you to attain the learning outcome stated in the cover page. Specifically, upon completion of this Learning Guide, you will be able to –

- Instruments are checked/ inspected to ensure safe operation
- Conduct appropriate functional test(s) and inspection to ensure that the testing conducted on the device conforms with the manufacturer's instruction/manual

- Work site is cleaned and cleared of all debris and left in safe condition in accordance with company procedures
- Test results are recorded in Instrument/ control devices history cards
- Report is prepared and completed according to company requirements.

Appropriate personal protective equipment is used in line with standard procedures.

Learning Instructions:

9. Read the specific objectives of this Learning Guide.
10. Follow the instructions described below 3 to 54.
11. Read the information written in the information “Sheet 1, Sheet 2, Sheet 3 and Sheet 4”
12. Accomplish the “Self-checks”

Information Sheet-1	3.1. Following safety policies and procedures

3.1.1 Follow safety policies and procedures

OHS guidelines

Occupational Health and Safety procedures for a given work area

Occupational health and safety (OH&S) is the term used to describe the laws and processes that help to protect employees from death, disease and injury while at work.

ELECTRICAL SAFETY POLICY

Purpose

Safety-related work practices shall be employed at the University of Denver (DU) to prevent electric shock or other injuries resulting from either direct or indirect electrical contacts, when work is performed near or on equipment or circuits which are or may become energized. The specific safety-related work practices shall be consistent with the nature and extent of the associated electrical hazards.

Definitions

De-energized: Free from any electrical connection to a source of potential difference and from electrical charge; not having a potential different from that of the earth Disconnecting means: A device, or group of devices, or other means by which the conductors of a circuit can be disconnected from their source of supply.

Energized: Electrically connected to a source of potential difference. Equipment: A general term including material, fittings, devices, appliances, fixtures, apparatus, and the like, used as a part of, or in connection with, an electrical installation.

Exposed: Capable of being inadvertently touched or approached nearer than a safe distance by a person.

It is applied to parts not suitably guarded, isolated, or insulated.

Ground-fault circuit-interrupter (GFCI): A device intended for the protection of personnel that functions to deenergize a circuit or a portion of a circuit within an established period of time when a current to ground exceeds some predetermined value that is less than that required to operate the overcurrent protective device of the supply circuit.

Guarded: Covered, shielded, fenced, enclosed, or otherwise protected by means of suitable covers, casings, barriers, rails, screens, mats, or platforms to remove the likelihood of approach to a point of danger or contact by persons or objects.

Insulated: Separated from other conducting surfaces by a dielectric (including air space) offering a high resistance to the passage of current.

Overcurrent: Any current in excess of the rated current of equipment or the ampacity of a conductor. It may result from overload, short circuit, or ground fault.

Qualified person: One who has received training in and has demonstrated skills and knowledge in the construction and operation of electric equipment and installations and the hazards involved.

Note 1 to the definition of "qualified person": Whether an employee is considered to be a "qualified person" will depend upon various circumstances in the workplace. For example, it is possible and, in fact, likely for an individual to be considered "qualified" with regard to certain equipment in the workplace, but "unqualified" as to other equipment.

Note 2 to the definition of "qualified person": An employee who is undergoing on-the-job training and who, in the course of such training, has demonstrated an ability to perform duties safely at his or her level of training and who is under the direct supervision of a qualified person is considered to be a qualified person for the performance of those duties.

4. Responsibilities

Supervisors

- Anticipate all work hazards and utilize all safeguards as necessary.
- Ensure that all employees are properly trained, instructed in the safe operation of electrical equipment and are aware of all hazards associated with the use of these electrical devices.
- Initiate any necessary administrative action required to enforce safety practices.
- Request assistance from Facilities Management on equipment and devices, which require unique safety practice instruction.

Employees

- Follow DU's electrical safety policies/procedures and instructions of the responsible supervisor.
- Bring to the attention of the supervisor and/or the Environmental Health and Safety Department (EHS) potentially hazardous situations such as discrepancies between instruction, procedures, and policies, faulty equipment, misapplication of device, etc.
- Recognize that malfunctioning electrical equipment must be repaired or replaced before use. The repair must be initiated as soon as possible after the malfunction is noted.

Environmental Health and Safety

- Provide technical assistance in defining hazardous operations, designating safe practices and selecting proper devices.
- When necessary, recommend the development of standard operating procedure for electrical equipment and devices in use from the principal supervisor.
- In coordination with Facilities Management and other supervisors, review and approve standard operating procedures upon request.
- Evaluate potential electrical hazards during facility inspections to insure compliance with existing policy and other safety guidelines.
- Support employees training relative to electrical safety.
- Develop and revise DU's electrical safety policy periodically, or when regulatory changes occur.

Qualified Persons

- Comply with DU's electrical safety program and take all required training.
- Be designated as the only people allowed to work on or near exposed electrical parts greater than 50 volts.
- Be designated as the only people who can test exposed electrical currents and equipment.
- Test equipment for damages and defects before use.
- Must be trained on how to work on energized currents, be familiar with proper precautionary work practices, personal protective equipment, insulating and shielding materials, and the use of insulated tools.

Procedures

Electrical Installation Requirements

Electrical equipment must be free from recognized hazards that are likely to cause death or serious physical harm. Equipment must be suitable for the installation and use, and must be installed and used in accordance with the National Electrical Code (NEC) and/or Occupational

Occupational Safety and Health Administration (OSHA).

Labelling of Disconnects -Each disconnecting means, must be clearly labeled to indicate the circuit's function unless it is located and arranged so the purpose is evident. Identification should be specific rather than general and all labels and marking must be durable enough to withstand the environment to which they may be exposed and must include nominal voltage being utilized by the device.

- Guarding of Live Parts - Live parts of electric equipment operating at 50 volts or more must be guarded by use of an approved cabinet or in a room or vault that is accessible to qualified persons only.
- Entrances to rooms and other guarded locations that contain exposed live parts operating at 50 volts or more shall be marked with conspicuous warning signs forbidding unqualified persons to enter.
- New electrical wiring, and the modification, extension or replacement of existing wiring must conform to the requirements of NEC, the National Fire Protection Association (NFPA), OSHA and any other applicable codes or regulations.

Working on Electrical Systems

Live parts to which an employee may be exposed will be de-energized, using approved lockout/tag out (LOTO) procedures, before the employee works on or near them!

Unless it can be demonstrated that:

- De-energizing is not possible due to equipment design or operational limitations
- De-energizing creates a greater hazard (e.g. deactivation of emergency alarm)
- Parts operate at less than 50 volts
- Equipment can be unplugged and the plug is continuously under the exclusive control of the employee performing the work

Lockout/Tag out

Specific energy control procedures shall be written for each hazardous energy source. Below are the general requirements of LOTO. Please review the DU lockout/tag out detailed policy and procedures before locking out any energy source.

- Preparation – Notify all affected employees that servicing or maintenance is required on a machine or equipment and that the machine or equipment must be shut down and locked out to perform the servicing or maintenance.
- Machine or Equipment Shutdown If the machine or equipment is operating, shut it down by the normal stopping procedure.
- Machine or Equipment Isolation - Operate the switch, valve, or other energy isolating device(s) so that the equipment is disconnected or isolated from it energy source(s).
- Release of Energy - Ensure that all energy is dissipated orrestrained (such as that in capacitors, springs, elevated machine members, rotating flywheels, hydraulic systems, air, gas, steam, water pressure, etc.) by methods such as grounding, repositioning, blocking, bleeding down, etc.
- Application of Lockout/Tagout - Lockout the energy isolating device(s) with the assigned individual lock.
- Verification of Isolation – After ensuring that no personnel can be exposed, operate the push button or other normal operating control(s) or by testing to make certain the equipment will not operate.
- Removal of Lockout Devices – Before lockout or tag out devices are removed and energy is restored to the machine or equipment, the authorized person must take the following actions:
- Inspect the work area to ensure that nonessential items have been removed and that machine or equipment components are intact and capable of operating properly.
- Check the area around the machine or equipment to ensure that all employees have been safely positioned or removed.
- Notify affected employees immediately after removing locks or tags and before starting equipment or machines.
- Ensure that locks or tags are removed ONLY by those employees who attached them. (In the very few instances when this is not possible, the device may be removed under the direction of the employer, provided that he or she strictly adheres to the specific procedures outlined in the standard).

Jobs involving more than one employee- If more than one individual is needed for a job that requires lockout/tagout, each shall place his/her own personal lockout/tag out device on the energy isolating device(s). When an energy isolating device cannot accept multiple locks or tags; a multiple lockout or tagout device (hasp) should be used.

Working with Energized Parts

- If the exposed live parts are not de-energized (i.e., for reasons of increased or additional hazards or infeasibility), other safety-related work practices shall be used to protect employees who may be exposed to the electrical hazards involved.
- Such work practices shall protect employees against contact with energized circuit parts directly with any part of their body or indirectly through some other conductive object. The work practices that are used shall be suitable for the conditions under which the work is to be performed and for the voltage level of the exposed electric conductors or circuit parts.
- This section applies to work performed on exposed live parts (involving either direct contact or by means of tools or materials) or near enough to them for employees to be exposed to any hazard they present.
- Only qualified persons may work on electric circuit parts or equipment that has not been de-energized under the procedures of this section. Such persons shall be capable of working safely on energized circuits and shall be familiar with the proper use of special precautionary techniques, personal protective equipment, insulating and shielding materials, and insulated tools.

Overhead Power Lines

- When work is to be performed near over headlines, the lines must be de- energized and grounded whenever possible.
- If it is not possible to de-energize and ground overhead lines, then other protective measures, such as guarding, isolating or insulating, must be taken before the work is started. These protective measures must prevent direct contact by the qualified person or indirect contact through conductive materials, tools, or equipment.
- Only qualified persons are allowed to install insulating devices on overhead power transmission and distribution lines.
- All other persons, and any conductive object used by these employees, may not approach closer than the minimum approach distance of 10 feet when the voltage to ground is 50 kV or less, and 10 ft. + 4 inches for every 10 kV over 50 kV when the voltage to ground is >50 kV.
- Qualified persons working in the vicinity of energized overhead lines, whether in an elevated position or on the ground, are not allowed to approach any exposed energized parts closer than allowed in the table below unless:
- The person is insulated from the energized part by using voltage rated gloves, (with sleeves and or hot stick if necessary); or
- The energized part is insulated from all other conductive objects at a different potential and from the person; or

- The person is insulated from all conductive objects that are at a potential different from the energized part.

Self-Check -1	Written Test

Directions: Answer all the questions listed below. Use the Answer sheet provided in the next page:

1. What is OH&S Policy &Procedure?
1. Write at list three Basic Rules of Bio Safety?
1. What are the advantages of OH&S for an organization?
1. Write at list three Basic Laboratory Safety Issues?
1. Write Ethiopia Electrical Code colour identification of bare conductors and cable cores (EELP's Regulation)?

Answer Sheet

Score = ____________

Rating: _____________

Name: _________________________ Date: _______________

Information Sheet-2	3.2 Checking readings of electrical measuring instruments

3.2.1 Test electrical parts

Electrical test

In electrical test there are few areas that contribute to a large percentage of trouble

- Fuses
- Loose connection
- Faulty contact
- Incorrect wire marking
- Combination problem
  - Electrical mechanical
  - Electrical pressure
  - Electrical temperature
- Low voltage
- Ground

3.2.2 Electrical measuring instrument

Electrical measuring instrument consists of:

Multi tester

Insulation tester

High potential tester

Low resistance tester

Phase sequence tester

Multi tester

Multi-tester: A multitester is a tool that can be used to check resistance, continuity, and voltage in electrical components.

These meters come in digital or analog. Analogs been the cheaper in price and the digitals been the more accurate.

- **How I check resistance or continuity:** To check for resistance or continuity you will need to set the multi-tester to red ohms. You will check for resistance in a heating elements, motor windings, and solenoids. You will check for continuity on switches, thermostats, thermal fuses, house fuses, etc.
- **How I check for voltage:** To check for voltage you need to set the multi-tester in to AC volts. My multi-tester has 3 settings 15 volts, 150 volts, and 1000 volts.
- **Why I do need different scales:** If you are checking an appliance that runs on 120 volts, then you can use the 150 scale. If you are checking an electric dryer that use

Insulation Resistance Tester

The **Insulation Resistance Test** consists in measuring the **Insulation resistance** of a device under test, while phase and neutral are short circuited together. The measured resistance has to be higher than the indicated limit from the international standards.

A mego-hmmeter (also called **insulation resistance tester**, Tera-ohmmeter) is then used to measure the ohmic value of an insulator under a direct voltage of great stability.

To measure a high value resistance, techniques for measuring a low value current are used. A constant voltage source is applied to the resistance to be measured and the resulting current is read on a highly sensitive ammeter circuit that can display the resistance value.

High Potential tester

A High Potential test is a voltage applied across an insulation at or above the DC equivalent of the 60 Hertz operating crest voltage. This test can be applied as a dielectric absorption test, or a step voltage test. When applied as a dielectric absorption test the maximum voltage is applied generally over a period of from sixty to ninety seconds. The maximum voltage is then held for five minutes with leakage current readings being taken each minute. When applied as a step voltage test, the maximum voltage is applied in a number of equal increments, usually not less than eight with each voltage step being held for an equal interval of time. The time interval between steps should be long enough to allow the leakage current to reach approximate stability usually one or two minutes. A leakage current reading is taken at the end of each interval before the voltage is raised to the next level. A plot of the test voltage versus insulation resistance is drawn as the test progresses. After the maximum test voltage is reached, a dielectric absorption test may be performed at that voltage, usually for a five minute period.

Low resistance tester

Low resistance ohm meters are also known as micro-ohmmeter, microohmmeter, microhmmeter, milli ohm meter, milliohmmeter, milliohm meter. They also have application specific names such as bond meters, bondmeters, dlro, digital low resistance meter, safety ohmmeter, safety ohm meter, aircraft bond meter, aircraft ohmmeter. These micro ohm and milli ohm meters utilize the kelvin measurement method which virtually eliminates errors caused by resistance in the test leads, test pins and test clips as well as the contact resistance of the pin or clip to the device under test. See application note Accurately Measuring Low Resistance for further information.

Free running test

NO-LOAD RUNNING TESTS

Center as they are at the factory. Procedures useful to the motor designer. Test limits-measured values establishing cause for acceptance or rejection of the product-exist for factory tests.

Typically, no-load current is allowed to deviate from the limit (based on design and reference tests) by no more than 10%. Besides some error in the winding, a deviation can result from an out-of-tolerance air gap. This can easily be checked by running a no-load saturation curve-applying a range of voltage values and plotting the corresponding current (see Figure 5).

Friction and wind age variations

No-load power input goes mostly into two motor losses: friction & wind age, and the iron or core loss. Again, factory test limits are imposed based on calculation and experience. Besides metallurgical variations (lamination steel is sold based on a maximum internal hysterics loss, but most lots average at least 10% below that maximum), core loss deviations may occur because of excessive force used in assembling the core, or damage to the insulating coating on laminations.

Friction and wind age is much more variable. Wind age in a fan-cooled motor is higher than in a drip-proof machine; friction is higher in a vertical high-thrust motor with special bearings. For those reasons, the spread in no-load power input far exceeds that in current; see Figure 6 as an extremely general guide.

Tolerances on no-load power have ranged from 10% to 25%, depending on motor size and manufacturer. Occasionally, a service center may be able to compare tolerances using two sources of information: previous work on the same (or a duplicate) motor, and customer records. But such instances are uncommon.

A few industrial customers have established lengthy procedures for "acceptance testing" and inspection of motors, generally for ratings above 250 hp. But that testing, normally conducted before shipment of a new motor, is meant to compare motor behavior with design criteria, to prove that the machine has the characteristics called for on the order.

Those characteristics won't be known, other than what can be gleaned from the nameplate, for most motors coming into a shop for evaluation or repair. Even "captive shops" owned by a manufacturer will only enjoy ready access to factory design and test information for the motors made by the parent company. And the number of captive shops has dwindled drastically over the last 15 years, with many being closed or transferred to independent ownership.

Checklist for no-load testing

In the absence of background information on the motor design, what can a service center conclude from "routine" testing? Here are the basic results that should be expected: No-load testing will show that the motor runs and has the correct polarity.

"Unusual" noises or excessive heating will be detected. Evaluating those conditions (especially in bearings) is, of course, subjective-a judgment call.

Vibration can be measured and recorded. This is perhaps the most important behavior in any no-load shop test. These are the only tangible results of a no-load test that can help in judging a motor's existing condition.

Earth resistance Testing

The purpose of electrical ground testing is to determine the effectiveness of the grounding medium with respect to true earth. Most electrical systems do not rely on the earth to carry load current (this is done by the system conductors) but the earth may provide the return path for fault currents, and for safety, all electrical equipment frames are connected to ground.

The receptivity of the earth is usually negligible because there so much of it available to carry current. The limiting factor in electrical grounding systems is how well the grounding electrodes contact the earth, which is known as the *soil / ground rod interface*. This interface resistance component, along with the resistance of the grounding conductors and the connections, must be measured by the ground test.

In general, the lower the ground resistance, the safer the system is considered to be. There are different regulations which set forth the maximum allowable ground resistance, for example: the National Electrical Code specifies 25 ohms or less; MSHA is more stringent, requiring the ground to be 4 ohms or better.

Phase Sequence test

The K-3 Phase Sequence Indicator is used to determine the phase sequence (A-B-C or C-B-A) of three-phase voltages. (***A-B-C is clockwise rotation***) It is important that phase sequence is known prior to energizing electrical motors and other equipment, as incorrect connection could cause damage to the equipment.

The K-3 Phase Sequence Indicator is of the rotating-disk design; there are no lights to burn out. All internal connections are soldered and there are no exposed metal parts on the housing.

Its three leads are color-coded (red **(A)**, white **(B)**, and blue **(C)**) for easy connection (other colors are available upon request). The leads are 36 inches in length (other lengths available upon request).

The K-3 is designed for operation from 25 to 60 Hertz and from 60 to 600 Volts. Other models (including a panel-mount version and a 400 Hz. version) are available.

Load test

Load testing is the process of putting demand on a system or device and measuring its response.

When the load placed on the system is raised beyond normal usage patterns, in order to test the system's response at unusually high or peak loads, it is known as stress testing. The load is usually so great that error conditions are the expected result, although no clear boundary exists when an activity ceases to be a load test and becomes a stress test.

Mechanical load testing

The purpose of a Mechanical Load Test is to verify that all the component parts of a structure including materials, base-fixings are fit for task and loading it is designed for.

The *Supply of Machinery (Safety) Regulation 1992 UK* state that load testing is undertaken before the Equipment is put into service for the first time.

Load testing can be either **Performance**, **Static** or **Dynamic**.

Performance testing is when the stated safe working load (SWL) for a configuration is used to determine that the item performs to the manufactures specification. If an item fails this test then any further tests are pointless.

Static testing is when a load at a factor above the SWL is applied. The item is not operated through all configurations as that is not the requirement of this test.

Dynamic testing is when a load at a factor above the SWL is applied. The item is then operated fully trough all configurations and motions. Care must be taken during this test as there is a great risk of catastrophic failure if incorrectly carried out.

The design criteria, relevant legislation or the *Competent Person* will dictated what test is required.

Under the *Lifting Operations and Lifting Equipment Regulations 1998 UK* load testing after the initial test is required if a major component is replaced, if the item is moved from one location to another or as dictated by the *Competent Person*

The loads required for a test are stipulated by the item under test, but here are a few to be aware off. Powered lifting equipment **Static** test to 1.25 SWL and **dynamic** test to 1.1 SWL. Manual lifting equipment **Static** test to 1.5 SWL

For lifting accessories. 2 SWL for items up to 30 tone capacity. 1.5 SWL for items above 30 tone capacity. 1 SWL for items above 100 tone

High Potential test

Hi-Potting is the most dangerous of all acceptance and general maintenance tests performed. It must be performed by **qualified, experienced personal.** This test is however, one of the most important to be performed. The tester **must** be well trained in the use of his own equipment.

Southern Substation, Inc., technicians use only Hypotronics or Associated Research Test equipment. Each man is well trained in the use of this equipment and takes all necessary safety precautions before applying high voltage to the equipment under test.

A) A High Potential test is a voltage applied across an insulation at or above the DC equivalent of the 60 Hertz operating crest voltage. This test can be applied as a dielectric absorption test, or a step voltage test. When applied as a dielectric absorption test the maximum voltage is applied generally over a period of from sixty to ninety seconds. The maximum voltage is then held for five minutes with leakage current readings being taken each minute. When applied as a step voltage test, the maximum voltage is applied in a number of equal increments, usually not less than eight with each voltage step being held for an equal interval of time. The time interval between steps should be long enough to allow the leakage current to reach approximate stability usually one or two minutes. A leakage current reading is taken at the end of each interval before the voltage is raised to the next level. A plot of the test voltage versus insulation resistance is drawn as the test progresses. After the maximum test voltage is reached, a dielectric absorption test may be performed at that voltage, usually for a five minute period.

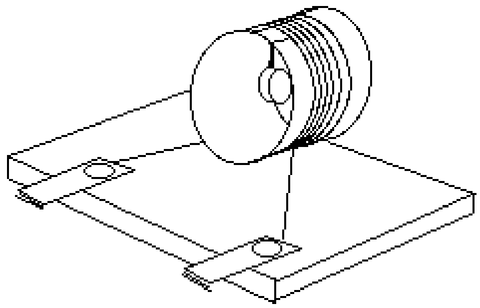
AC TESTING

AC High Potential Tests are made at voltages above the normal system voltage for a short time, such as one minute. The test voltages to be used vary depending upon whether the device or circuit is low or high voltage, a primary or control circuit and whether tested at the factory or in the field. In a test such as this, only the manufacturer's instructions and his applicable standards should be used to obtain the proper values. Southern Substation, Inc., does not perform any AC High voltage testing in the field and does not recommend that it be done.

Ammeter

Introduction

An ammeter is a device that detects an electric current. With some readily available materials, you can build your own ammeter and use it to measure current produced by batteries including homemade batteries and generators.



Ammeter

Material

- Magnet wire, 10 meters or more of 22 gauge or higher, (available from Radio Shack). (The higher the gauge, the finer the wire, and the harder it will be to wind.)
- two small disk magnets (1 cm diameter available from Radio Shack)
- thread or fishing line
- a cardboard tube (e.g. from a toilet paper roll.)
- a Base, a piece of corrugated cardboard about 10 cm x 10 cm (For a more rugged meter use wood.)
- Hot melt glue (or staples)
- Aluminum foil, two 5 cm squares
- Tacks or pushpins
- Two alligator clip leads (available at Radio Shack)
- Sandpaper
- AA battery (almost any battery will work)

D'arsonval movement and DC measurement

I. D'Arsonval Meter Movement

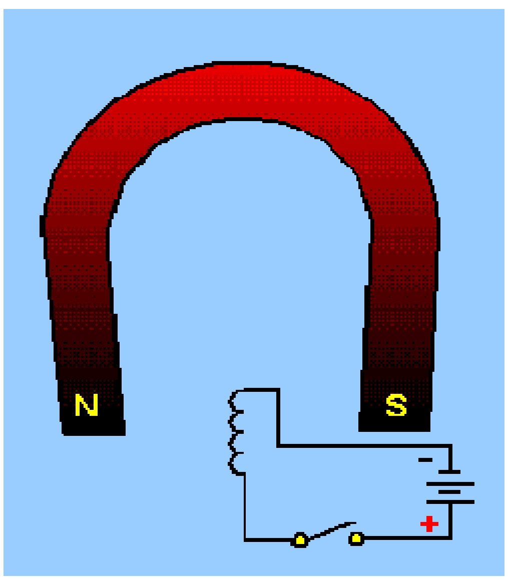
Whenever electrons flow through a conductor, a magnetic field proportional to the current is created. This effect is useful for measuring current and is employed in many practical meters.

Since most of the meters in use have D'Arsonval movements, which operate because of the magnetic effect, only this type will be discussed in detail.

The basic dc meter movement is known as the D'Arsonval meter movement because it was first employed by the French scientist, D'Arsonval, in making electrical measurement.

This type of meter movement is a current measuring devicewhich is used in the ammeter, voltmeter, and ohmmeter. Basically, both the ammeter and the voltmeter are current measuring instruments, the principal difference being the method in which they are connected in a circuit. While an ohmmeter is also basically a current measuring instrument, it differs from the ammeter and voltmeter in that it provides its own source of power and contains other auxiliary circuits.

- The Structure of Permanent-magnetic moving-coil movement the compass and conducting wire meter can be considered a fixed-conductor moving-magnet device since the compass is, in reality, a magnet that is allowed to move. The basic principle of this device is the interaction of magnetic fields: the field of the compass (a permanent magnet) and the field around the conductor (a simple electromagnet).
- A permanent-magnet moving-coil movement is based upon a fixed permanent magnet and a coil of wire which is able to move, as in figure 1. When the switch is closed, causing current through the coil, the coil will have a magnetic field which will react to the magnetic field of the permanent magnet. The bottom portion of the coil in figure 1-4 will be the north pole of this electromagnet. Since opposite poles attract, the coil will move to the position shown in figure 2.



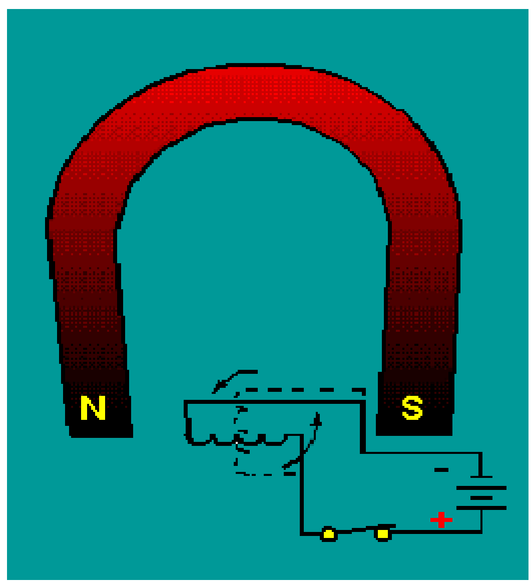


Fig. 1. A movable coil in a magnetic field (no current)   Fig.2. - A movable coil in a magnetic field (with current).

The coil of wire is wound on an aluminum frame, or bobbin, and the bobbin is supported by jeweled bearings which allow it to move freely. This is shown in figure 3. To use this permanent-magnet moving-coil device as a meter, two problems must be solved. First, a way must be found to return the coil to its original position when there is no current through the coil.

Second, a method is needed to indicate the amount of coil movement.

The first problem is solved by the use of hairsprings attached to each end of the coil as shown in figure 4. These hairsprings can also be used to make the electrical connections to the coil.

With the use of hairsprings, the coil will return to its initial position when there is no current. The springs will also tend to resist the movement of the coil when there is current through the coil.

When the attraction between the magnetic fields (from the permanent magnet and the coil) is exactly equal to the force of the hairsprings, the coil will stop moving toward the magnet.

As the current through the coil increases, the magnetic field generated around the coil increases.

The stronger the magnetic field around the coil, the farther the coil will move. This is a good basis for a meter.

But, how will you know how far the coil moves? If a pointer is attached to the coil and extended out to a scale, the pointer will move as the coil moves, and the scale can be marked to indicate the amount of current through the coil. This is shown in figure 5.

Fig. 3. - A basic coil arrangement.

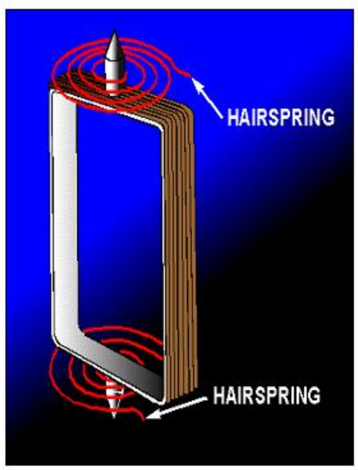


Fig. 4. - Coil and hairsprings.

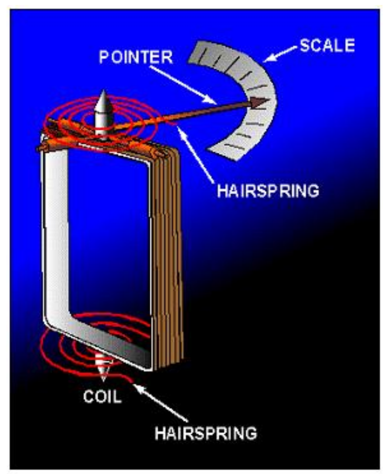


Fig. 5. - A complete coil.

Two other features are used to increase the accuracy and efficiency of this meter movement. First, an iron coreis placed inside the coil to concentrate the magnetic fields. Second, curved pole piecesare attached to the magnet to ensure that the turning force on the coil increases steadily as the current increases.

The meter movement as it appears when fully assembled is shown in figure 6. This permanentmagnet moving-coil meter movement is the basic movement in most measuring instruments. It is commonly called the d'Arsonval movement because it was first employed by the Frenchman

d'Arsonval in making electrical measurements. Figure 7 is a view of the d'Arsonval meter movement used in a meter.

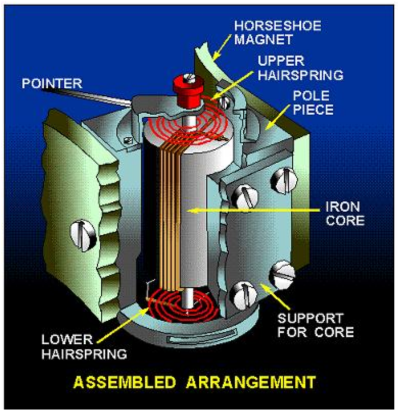


Fig. 6. - Assembled meter movement.

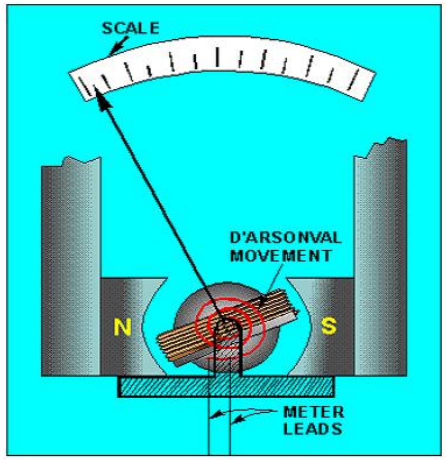


Fig. 7. - A meter using d'Arsonval movement.

Meter Sensitivity and Scale Change

The sensitivity of a meter movementis usually expressed as theamount of current required to give full scale deflection. In addition, the sensitivity may be expressed as the number of millivolts across the meter when full scale current flows through it. This voltage drop is obtained by multiplying the full scale current by the resistance of the meter movement. A meter movement, whose resistance is 50 ohms and which requires 1 milli-ampere (mA) for full scale reading, may be described as a 50 mV 0 - 1 mA.

Extending the Range of an Ammeter:A 0 - 1 mA movement may be used to measure currents greater than 1 ma. By connecting a resistor in parallel with the movement. The parallel resistor is called a shunt because it bypasses a portion of the current around the movement, extending the range of the ammeter. A schematic drawing of a meter movement with a shunt connected across it to extend its range is shown in figure 8.

Determining the Value of a Shunt: The value of a shunt resistor can be computed by applying the basic rules for parallel circuits. If a 50 mV 0 - 1 mA is to be used to measure values of current up to 10 ma., the following procedure can be used: The first step involves drawing a schematic of the meter shunted by a resistor labeled Rs(shunt resistor), as shown in figure 9.

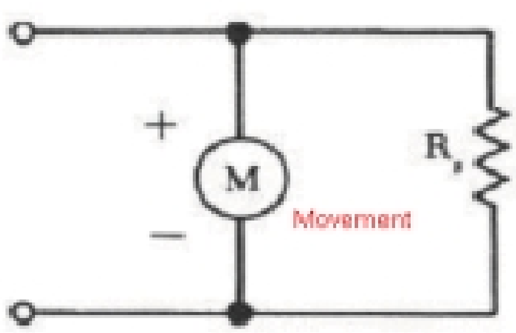


Fig. 8

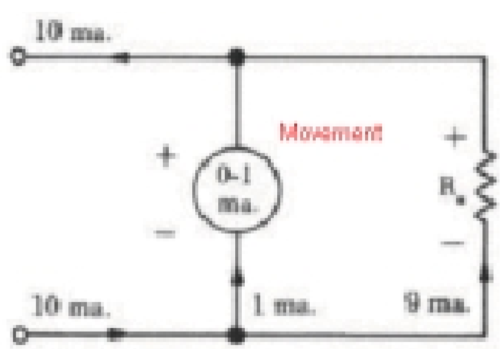


Fig. 9

Since the sensitivity of the meter is known, the meter resistance can be computed. The circuit is then redrawn as shown in figure 10, and the branch currents can be computed, since a maximum of 1 ma. Can flow through the meter.

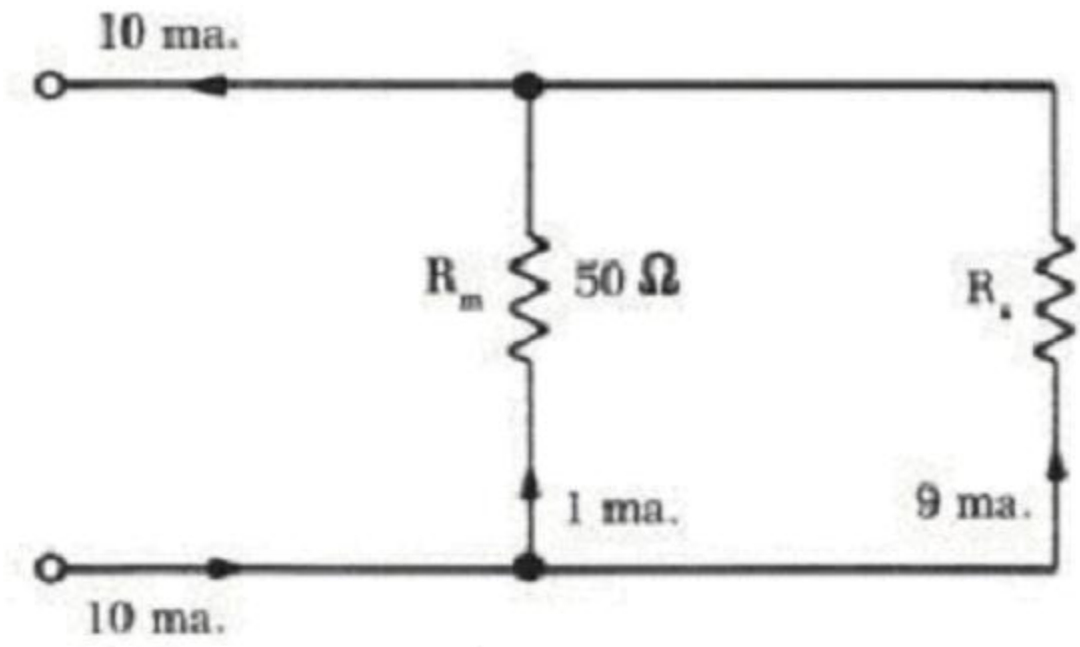


Fig. 10

The voltage drop across Rs is the same as that across the meter internal resistance, Rm:

$$E = IR = 0.001 * 50 = 0.05\ [\mathrm{V}]$$

Rs can be found by applying Ohm's law:

$$R_s = \frac{R_{rs}}{I_{rs}} = \frac{0.05}{0.009} = 5.55\ [\Omega]$$

Multi-Range Meters: Ammeters having a number of internal shunts are called multi-range ammeters. Some multimeters avoid internal switching through the use of external shunts. Changing ammeter ranges involves the selection and installation on the meter case of the proper size shunt. See Fig. 10 below.

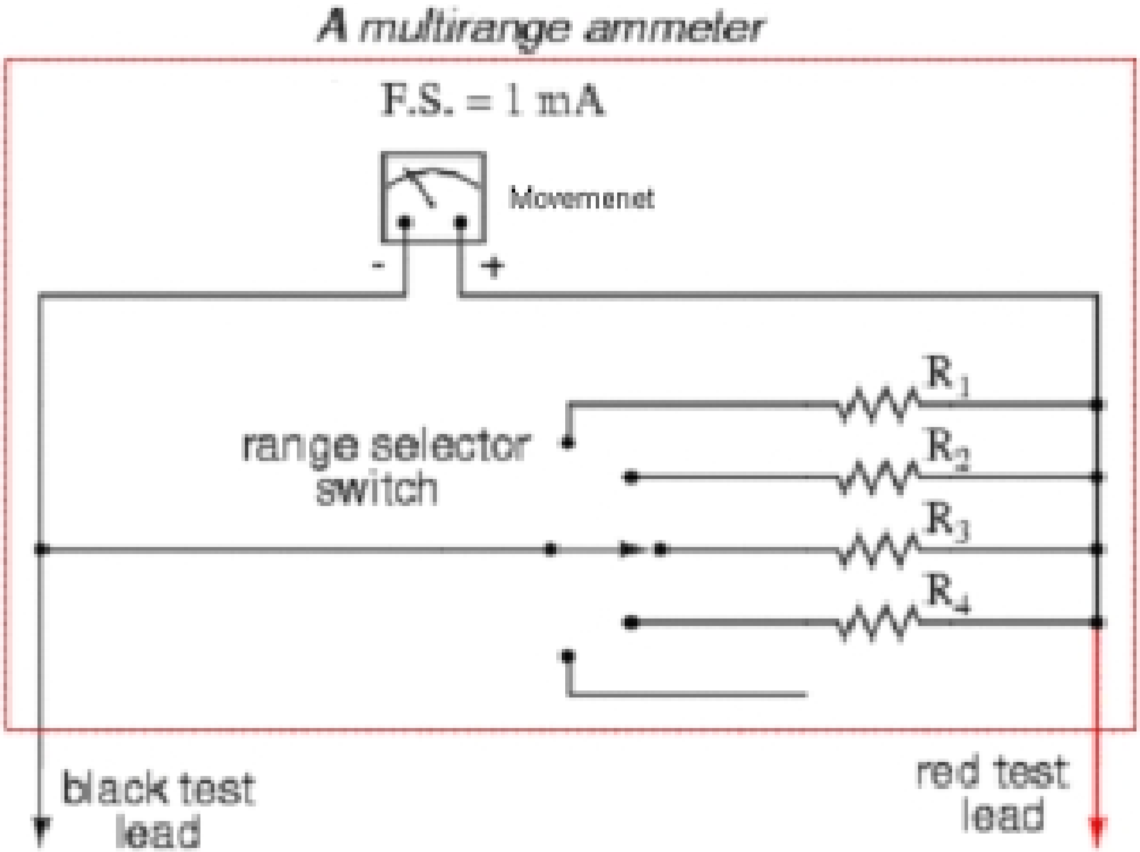
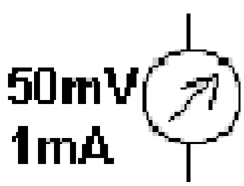


Fig. 10

Meter Scale Change Problems

1. d'Arsonval Movement Fundamental



1.1. Movement has rated current (through) Im, and rated voltage (across), Vm

1.2. Hence, the movement has an internal resistance, Rm:

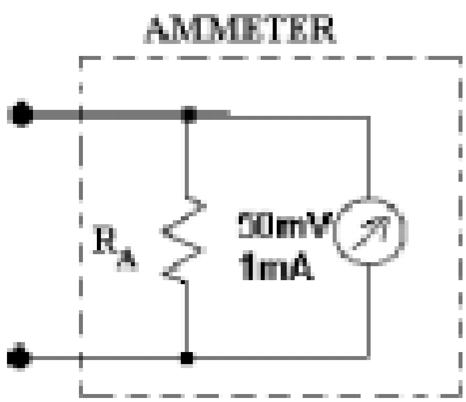
$$R_m = \frac{V_m}{I_m}$$

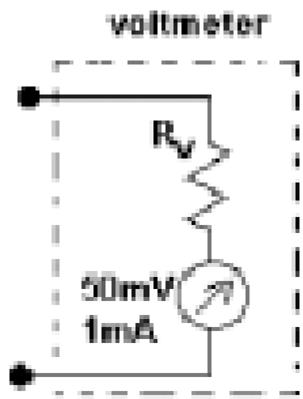
1.3. When current through the movement is the same as the rated current, then the needle indicates the maximum scale.

1.4. Remember that: in any circumstance, the current through the movement must be below the rated current, and the voltage across the meter must be below the rated voltage.

2. Scale Change Fundamental

2.1. The full scale of a meter (using the meter movement) can be changed by inserting a shunt resistor RA for an Ammeter and a series resistor RVfor a Voltmeter.





The main idea behind:

2.2.1 Divert excessive current to RA by current-division principle (Ammeter)

2.2.2 Divert excessive voltage to RV by voltage-division principle (Voltmeter)

2.2.3. So that the voltage and the current of the movement keep the rated values.

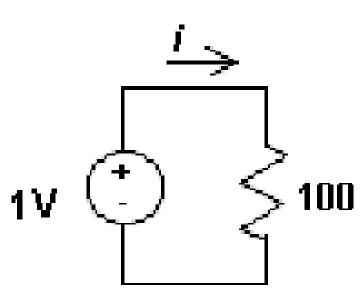
3. The effect of the meter resistance in DC measurement Fundamental

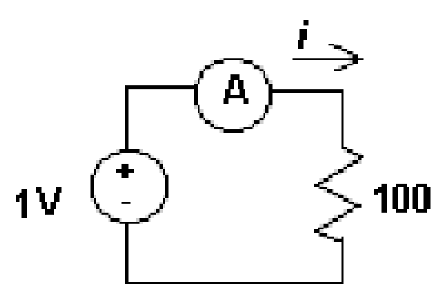
3.1. A meter has internal resistance introduced by the d'Arsonval movement resistor (Rm) and the shunt (RA) or series (RV) resistor brought by scale change.

3.2. When the meter is inserted to a circuit for current or voltage measurement, the meter resistance is also inserted to the circuit, and it changes the circuit configuration or behavior.

4. Examples of meter effect

4.1. Ammeter Example: An Ammeter with 50mV@1mA movement, with full scale of 10 mA is used to measure the circuit below. (a) What is the current I without the Ammeter insertion, and (b) with the Ammeter insertion (i.e., the Ammeter reading)?





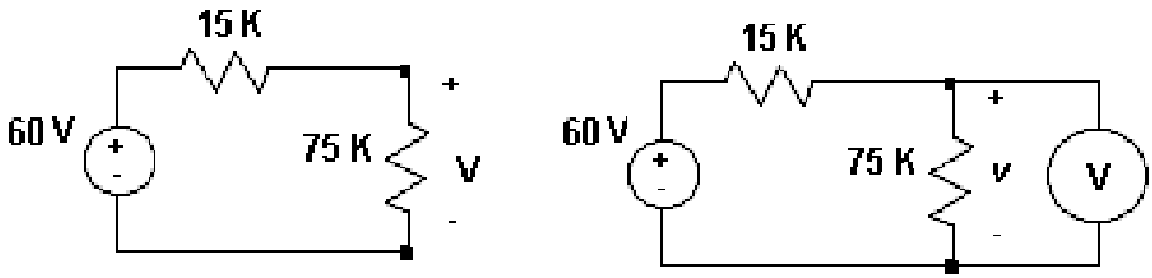
SOLUTION:

(a) I=1/100=0.01[A] =10[mA]

(b) Since the rated current and the full scale current are different, we know that there is a shunt resistor to divert the excessive current (i.e., 10 – 1 = 9 [mA]). Since the voltage across the movement must be 50mV (no matter what), then the total internal resistance of the meter (Rm+ RA) =50[mV]/10[mA] =5[Ω]. Therefore, the actual current (or the Ammeter reading) is

$$\frac{1}{100+5} = \frac{1}{105} = 9.52\,[\text{mA}]$$

Voltmeter Example: A voltmeter with 50mV@1mA movement, with full scale of 150V is used to measure the circuit below. (a) What is the voltage V without the Voltmeter insertion, and (b) with the Voltmeter insertion (i.e., the Voltmeter reading)?



SOLUTION:

(a) By voltage division: $$v = 60\frac{75}{75+15} = 50\,[\text{V}]$$

(b) Since the rated voltage and the full scale voltage are different, we know that there is a series resistor to divert the excessive voltage (i.e., 150 – 0.05 = 149.95 [V]). Since the current through the movement must be 1mA (no matter what), then the total internal resistance of the meter is

$$(R_m\,//R_V)\text{ or } \frac{150}{1\times10^{-3}} = 150\,[\text{k}\Omega]$$ (guess where this comes from?).

Therefore, the effect of the voltmeter insertion is adding 150kΩto the 75K resistor in parallel.

Then, the new resistance value is:

$$75//150 = \frac{(75)(150)}{75+150} = 50\,[\text{k}\Omega]$$

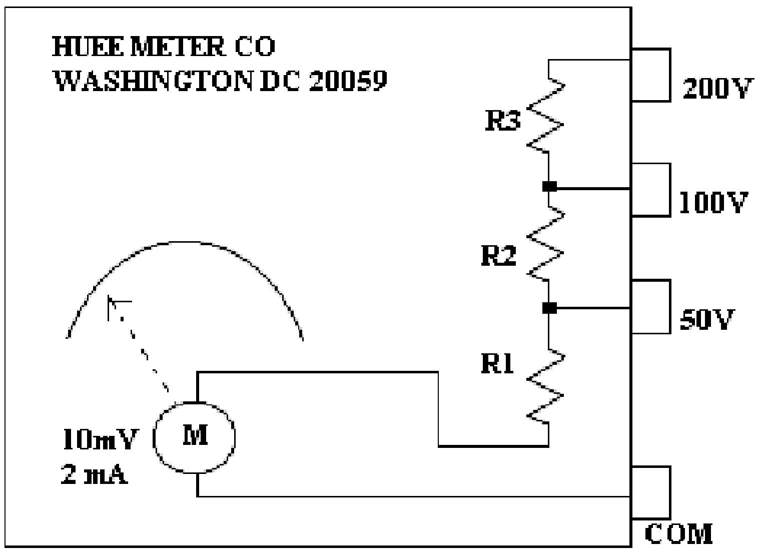
Finally, the voltage by voltage-division is:

$$v = 60 \frac{50}{15+50} = 46.15 \, [\mathrm{V}]$$

Multi-Range Voltmeter Example

Problem Setting:

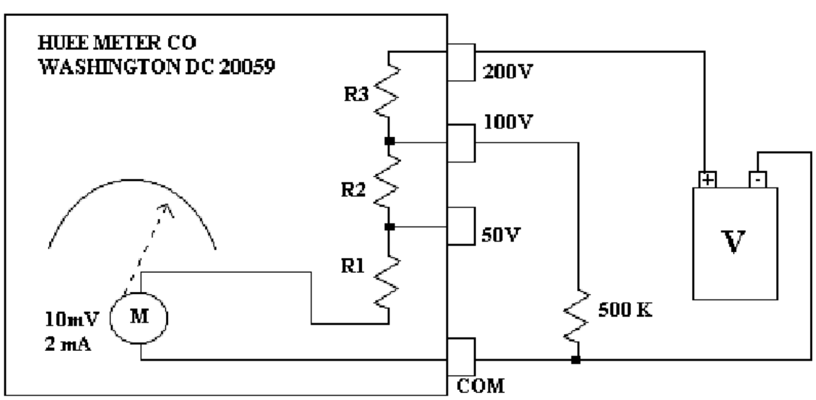
1. We are going to design a multi-range voltmeter (full scales of 200, 100, and 50 V) using a d'Arsonval-movement with rating 10mV@2 mA. Find R1, R2, and R3



SOLUTION:

2. After finishing the design, a 500KΩresistor is connected between the COM and the 100V terminals. Then, an unknown voltage source is connected to the COM and +200V terminals.

If the voltmeter reading is 188[V], what is the exact voltage levelof the unknown voltage source?



Self-Check -2	Written Test

Directions: Answer all the questions listed below. Use the Answer sheet provided in the next page:

4. Write the difference of analog and digital multi-meter
5. Explain No load and On load test
6. Explain the Load testing of Performance teste, Static test and Dynamic.

Information Sheet-3	3.3. Testing electrical system or equipment parts

3.3.1 Testing electrical equipment

Introduction

The procedures stated in this document cover the activities in preliminary tests and inspections, functional performance tests and the commissioning of newly completed installations and existing ones after major alteration. They are so compiled to facilitate the work of Project Building Services Engineer (PBSE) and Project Building Services

Inspector (PBSI) in the following aspects with respect to testing and commissioning (T&C):

(i) To vet and approve the T&C procedures proposed and submitted by the Contractor;

(ii) To witness those T&C procedures as specified; and

(iii) To accept the T&C certificates and other supporting data.

The Contractor shall carry out the T & C works as detailed in this document.

Supplementary T&C plans may be proposed by the Contractor as appropriate and agreed by PBSE, e.g. for special equipment supplied and/or installed by the Contractor.

The administrative requirements for T & C works are in general as specified in the latest General Specification for Electrical Installation (the General Specification) issued by the Building Services Branch of the Architectural Services Department. If there is any discrepancy between this procedure and the General Specification, the General Specification shall take precedence.

"Major Alteration" of an existing electrical installation means alteration involving work on any distribution board or electrical equipment having an electrical current rating exceeding 100A single phase or 60A three phases in an existing electrical installation.

This procedure is also intended to lay down the minimum testing and commissioning requirements to be carried out by the Contractor on a new Low Voltage Cubicle

Switchboard Installation up on completion or on an existing Low Voltage Cubicle

Switchboard Installation after a major alteration involving modification of the main

Bus bar such as upgrading, reposition and extension.

2. Objectives of the Testing and Commissioning (T&C) Works

The objectives of the T & C works are:

(i) To verify proper functioning of the equipment/system after installation; and

(ii) To verify that the performance of the installed equipment/systems meet with the specified design intent through a series of tests and adjustments.

(iii) To capture and record performance data of the whole installation as the baseline for future operation and maintenance.

For the avoidance of doubt, depending on the specific demands of individual installation, the PBSE may require additional or substitute T & C works in regard to any elements in the installation other than those indicated in this Procedure.

3. Scope of the Testing and Commissioning (T&C) Works

3.1 Preliminary Steps for Testing and Commissioning

Before carrying out T&C, the Contractor shall take the following steps:

(a) Submit draft T&C procedures to the PBSE for approval. The draft

T&C procedures shall include essential procedures mentioned in this procedure plus additional T&C procedures required for specific installations as well as manufacturer's recommendation;

(b) Obtain design drawings and specifications and to be thoroughly acquainted with the design intent;

(c) Obtain copies of approved shop drawings and equipment schedules;

(d) Review approved shop drawings and equipment schedules;

(e) Check manufacturer's operating instructions and statutory requirements;

(f) Physically inspect the installation and equipment to determine variations from designs and/or specifications.

(g) Check individual components, e.g. key switches, control equipment, circuit breaker status, etc. for proper position and settings for completeness of installation.

(h) Check inclusion of manufacturer's typical equipment testing data or factors before T&C of particular equipment.

3.2 Testing and Inspection during Construction

The purpose of these tests is to ensure that all components and systems are in a satisfactory and safe condition before start up. Preliminary adjustment and setting of equipment at this stage shall also be carried out at the same time to pave way for the coming functional performance tests.

Before carrying out any test, the Contractor shall ensure that the installation complies with all relevant statutory requirements and regulations. The T&C works shall comply with all site safety regulatory requirements currently in force, including but not limited to:

(i) Electricity Ordinance, Chapter 406, and other subsidiary legislation herein;

(ii) The Code of Practice for the Electricity (Wiring) Regulations (COP)

(iii) IEC 60364 “Electrical Installations of Building”

(iv) Electricity supply rules of the relevant power supply companies

Statutory Test and Inspection

The statutory test and inspection herein stated in this T&C procedure shall referto the Regulations Nos. 19, 20, 21 and 22 of the Electricity (Wiring)

Regulations under the Electricity Ordinance Chapter 406E.

3.4 Functional Performance Tests

The purpose of functional performance tests is to demonstrate that the equipment/installation can meet the functional and performance requirements as specified in the General/Particular Specifications. Functional performance test should proceed from the testing of individual components to the testing of different systems in the installation.

The Contractor may have to make temporary modifications as the test proceeds. The specific tests required and the order of tests will vary depending on the type and size of systems, number of systems, sequence of construction, interface with other installations, relationship with the building elements and other specific requirements as indicated in the General/Particular

Specifications. The testing of systems may have to be carried out in stages depending on the progress of work or as proposed by the Contractor.

Part of the tests may be required to be carried out in suppliers’ premises in accordance with the provisions in the General/Particular Specification.

Any performance deficiencies revealed during the functional performance tests must be evaluated to determine the cause and whether they are part of the contractual obligations. After completion of the necessary corrective measures, the Contractor shall repeat the tests.

If any test cannot be completed because of circumstances that are beyond the control of the Contractor, it shall be properly documented and reported to the

PBSE, who shall then liaise with the relevant parties to resolve the situation.

The Contractor shall resume his testing work immediately upon the attainment of a suitable testing environment.

Documentation and Deliverables

The Contractor shall submit his proposed T&C procedures together with the

Testing and Commissioning Progress Chart shown in Annex I to Annex IV, where applicable, to PBSE for approval.

All inspection and T&C results shall be recorded by the Contractor in the appropriate test record forms, the reference of which is shown against each individual test. Sample of these forms can be found in Annex I and AnnexIII.

Data recorded in other formats may also acceptable subject to agreement between the PBSE and the Contractor. Upon completion of all the required

T&C works, the Contractor's project engineer shall complete and sign the testing and commissioning certificate as shown in Part 1 and 2 of Annex I and/or Annex III to the effect that the agreed T&C works have been duly carried out.

Functional test reports covering all measured data, data sheets, and a comprehensive summary describing the operation of the system at the time of the functional tests shall be prepared and submitted to the PBSE. Deviations in performance from the General/Particular Specifications or the design intent should be recorded, with a description and analysis included.

Where required in the General/Particular Specification, the Contractor shall conduct a final evaluation of the performance of the Electrical Installation, the results of which shall be included in the commissioning report.

The Contractor shall sign work completion certificate(s) and issue to the PBSE after completion of the electrical installation or any work subsequent to repair, alteration or addition to an existing installation. This should be done before the installation is energized.

Testing and Commissioning (T&C) Procedures

Tests and Inspections during Construction

For those tests to be carried out on different systems of the installation during construction to ensure their suitability for operating at the design conditions, certificates of such tests shall be issued together with certificates of any work tests.

The Contractor shall submit the details of the tests and inspection during construction to PBSE for approval on commencement of the installation work.

The tests and inspection shall include, but not limited to, the followings:

(a) Visual inspection;

(b) Earth electrode resistance; and

(c) Continuity of protective conductor.

Details of these tests shall be in accordance with relevant sections of this procedure.

Statutory Inspection and Test for Low Voltage Installations

Inspection before Test

A visual inspection shall be made to verify that the electrical installation /equipment as installed is correctly selected and erected in accordance with the COP Code 21A and COP Appendix 13, and that there is no apparent damage. The visual inspection shall include a check on the following items, where appropriate:

(a) Adequacy of working space, access, and maintenance facilities;

(b) Connections of conductors;

(c) Identification of conductors;

(d) Adequacy of the sizes of conductor in relation to current carrying capacity and voltage drop;

(e) Correct connections of all equipment with special attention to socket outlets, lamp holders, isolators, and switches, residual current devices, miniature circuit breakers, and protective conductors,

(f) Presence of fire barriers and protection against thermal effects;

(g) Methods of protection against direct contact with live parts (including measurement of distances where appropriate), i.e. protection by insulation of live parts, or protection by barriers or enclosures;

(h) Presence of appropriate devices for isolation and switching;

(i) Choice and setting of protective and indicative devices;

(j) Labelling of circuits, fuses, protective devices, switches, isolators and terminals;

(k) Selection of equipment and protective measures appropriate to adverse environmental conditions;

(l) Presence of danger and warning notices;

(m) Presence of diagrams, instructions and other similar information;

(n) Connection of single pole devices for protection or switching in phase conductors only;

(o) Method of protection against indirect contact;

(p) Prevention of mutual detrimental influence;

(q) Presence of under voltage protective devices;

(r) Erection method; and

(s) Any other appropriate inspection as listed in COP Appendix

Sequence of Tests

The following items, where relevant, are to be tested preferably in the sequence indicated below:

(a) Continuity of protective conductors, including main and supplementary equipotential bonding,

(b) Continuity of ring final circuit conductors,

(c) Insulation resistance,

(d) Polarity,

(e) Earth electrode resistance,

(f) Earth fault loop impedance,

(g) Functions of all protective devices,

(h) Functions of all items of equipment.

In the event of any test indicating failure to comply, that test and those preceding, the results of which may have been influenced by the fault indicated, shall be repeated after the fault has been rectified.

Conductor Continuity

(a) Continuity of Protective Conductors

The test shall be in accordance with COP Code 21B (3).

Every protective conductor, including all conductors and any extraneous conductive parts used for equipotential bonding should be tested for continuity. The test should be made by connecting together the neutral and protective conductors at the mains position and checking between earth and neutral at every outlet by a continuity tester, which should show a reading near zero.

Continuity of Ring Final Circuit

The test shall be in accordance with COP Code 21B (4).

The ring circuit should be tested from the distribution board.

The ends of the two cables forming the phase conductor should be separated, and a continuity test should show a reading near zero between the two; the same tests to be made between the two cables that form the neutral conductor, and between the two cables that form the protective conductor.

The testing method in above paragraph is only applicable when the ring circuit has been inspected throughout, prior to the test, to ascertain that no interconnection (multi-loops) exists on the ring circuit.

Insulation Resistance

The test shall be in accordance with COP Code 21B (5).

A suitable direct current (d.c.) insulation tester should be used to measure insulation resistance. Care should be taken to ensure that the insulation of the equipment under test could withstand the test voltage without damage.

To carry out this test, it is acceptable to divide large installation into sections with groups of outlets, each group containing not less than 50 outlets.

A socket outlet or appliance or luminaire incorporating a switch is regarded as one outlet.

When measured with all fuse links in place, all switches and circuit breakers (including, if practicable, the main switch) closed and all poles or phases of the wiring electrically connected together, the insulation resistance to earth should not be less than the appropriate values given. For best practice, the insulation resistance shall not be lower than 1.0 mega ohm for low voltage installation under a test voltage of d.c. 500V.

When measured between all conductors connected to any one phase or pole of the supply and, in turn, all conductors connected to each other phase or pole, the insulation resistance should not be less than the appropriate values in Table 21(1) of COP. For best practice, the insulation resistance shall not be lower than 1.0 mega ohm for low voltage installation under atest voltage of d.c. 500V.

For the sake of enhanced safety, when the value of insulation resistance measured is near the minimum values as required in this T&C procedure, or at a relatively low valves where considered abnormal to trade’s practice, the concerned circuit /installation shall be re-checked to improve and re-test shall be conducted afterward.

In carrying out the test:

(a) Wherever practicable, all lamps should be removed and all current using equipment should be disconnected and all local switches controlling lamps or other equipment should be closed;

(b) Where the removal of lamps and/or the disconnection of current using equipment is impracticable, the local switches controlling such lamps and/or equipment should be open;

(c) Electronic devices connected in the installation should be isolated or short circuited where appropriate so that they are not damaged by the test voltage.

(d) Where the circuits contain voltage sensitive devices, the test should measure the insulation resistance to earth with all live conductors (including the neutral) connected together.

The sequence of test shall be as follows:

(1) Main switch/switchboard and outgoing circuits with sub-main switches being isolated;

(2) Sub-main switches/switchboards and outgoing circuits with final circuits boards being isolated; and

(3) Final circuit boards and final circuits.

Where equipment is disconnected for the test and the equipment has exposed conductive parts require to be connected to protective conductors, the insulation resistance between the exposed conductive parts and all live parts of the equipment should be measured separately and should have a minimum insulation resistance not less than 0.5 Mega Ohm.

For Site Built Assemblies, the insulation applied to the live parts of the assemblies for protection against direct contact shall be tested with an applied voltage equivalent to that specified in the appropriate

Regulation and/ or COP for similar factory-built equipment. The supplementary insulation of Site Built Assemblies for protection against indirect contact shall be tested for degree of protection not less than IP 2X, and the insulation enclosure shall be tested with an applied voltage equivalent to that specified in the appropriate Regulation and/or COP for similar factory-built equipment.

Polarity

The test shall be in accordance with COP Code 21B (6).

A test of polarity should be carried out to verify that:

(a) Every fuse and single-pole control and protective device is connected in the phase conductor only,

(b) center-contact bayonet and Edison-type screw lamp holders to

IEC 60238 in circuits having an earthed neutral conductor, have their outer or screwed contacts connected to that neutral conductor, and

(c) Wiring has been correctly connected to socket outlets and similar accessories.

Earth Electrode Resistance

The test shall be in accordance with COP Code 21B (7).

A proper earth electrode resistance tester should be used to measure earth electrode resistance. An alternating current at 50 Hz of a steady value is passed between the earth electrode T and an auxiliary earth electrode T1 placed at a separation distance recommended by the manufacturer of the tester but in any case should not be less than 20 metres away. A second auxiliary earth electrode T2, which may be a metal spike driven into the ground, is then inserted half-way between T and T1, and the voltage drop between T and T2, divided by the current flowing between T and T1, gives a measured earth electrode resistance of earth electrode T.

For an electrical installation having four or more earth electrodes which are installed more or less in line, following a general direction not exceeding 15' deviation and with separation between adjacent electrodes not less than the recommended distance by the manufacturer of the tester but in any case not less than 20 metres, these electrodes can be used in turn as the auxiliary electrodes for the purpose of measuring the earth electrode resistances.

The following alternative method for measuring the earth electrode resistance may be used if the electricity supply is connected. A loop impedance tester should be connected between the phase conductor at the origin of the installation and the earth electrode with the test link open, and a test performed. This impedance reading could be treated as the electrode resistance.

Earth Fault Loop Resistance

The test shall be in accordance with COP Code 21B (8).

The earth fault loop impedance should be measured by a phase-earth loop tester with a scale calibrated in ohms. The earthling conductor and all relevant earth connections are in place, and that the bonding connection to electricity supplier's earthling facilities is disconnected. Measures should be taken, during the impedance tests especially when the earth leakage protective devices are effectively removed for the duration of the tests, to ensure that the installation is not being used other than by person(s) carrying out the tests.

Statutory Inspection and Test for High Voltage Installations

Inspection before Test

The inspection shall be in accordance with COP Code 21C.

Inspection of H.V. installations should follow those for L.V. installations listed in section 3.5 of this procedure with additional checks on the following items where relevant:

(a) Provision of suitable locking facilities for every entry to an H.V. switch room/substation;

(b) Continuity of protective conductors especially the bonding of all exposed conductive parts; and

(c) Provision of padlock facilities for shutters, key boxes etc.

Safety

Precautionary measures should be taken and the methods of tests should be such that no danger to persons or property can occur even if the circuit being tested is defective.

Before carrying out the T&C for high voltage installations, the

Contractor shall submit risk assessment, safety plan and implementation procedure to PBSE for approval.

Testing Requirements

Testing for High Voltage installations should be referred to relevant recognized standards, manufacturers' recommendation, operations and maintenance instructions.

Circuitry Check

All circuits shall be verified through switching operation to ensure that the circuits are installed in accordance with the designated circuit. The tests shall include but not be limited to the following:

(a) on/off switching of the lighting circuit to ensure that the lighting circuit is installed corresponding to the lighting switch, protective device and labelling;

(b) Switching of the general power circuit to ensure that the circuit corresponds to the protective device such as RCD,

RCBO and MCB, and that the protective device performs in accordance with the designated duty;

(c) Switching of the main switch / isolator to ensure the corresponding circuit is properly controlled by the main switch / isolator;

(d) Switching of all sub-main and main distribution circuits, e.g. busducts, cable feeders, underground cables, etc. to ensure the correct isolation of the connected circuit;

(e) Switching of all changeover switches to ensure the changing over sequence corresponds to the design criteria;

(f) Ensuring all the protective devices perform properly against

Equipment and Appliances

Testing on electrical equipment and appliances supplied within the electrical installation, e.g. meters, fans, etc. shall be carried out in accordance with the relevant sections of other Building Services Branch Testing and Commissioning Procedures for other building services installations and manufacturer's recommended testing procedures.

For any other system /equipment that are not covered by this T&C Procedure, the contractor shall submit full details of testing requirements as recommended by the relevant manufacturer to PBSE for approval.

Before carrying out the T&C, the Contractor shall conduct assessment for any characteristics of equipment likely to have harmful effects upon other electrical equipment or other services, or impair the supply. Those characteristics include the following:

(a) Over voltages;

(b) Under voltages;

(c) Fluctuating loads;

(d) Unbalanced loads

(e) Power factor;

(f) Starting currents;

(g) Harmonic currents;

(h) Direct current (d.c.) feedback;

(i) High frequency oscillations; and

(j) Necessity for additional connection to earth.

Test and Inspection for Low Voltage Cubicle Switchboard (LVSB)

The following sections stipulated the additional inspection and testing requirements for LVSB installation. For comprehensive testing and commissioning, the Contractor shall also refer to relevant sections of this T&C

Procedure and carry out inspection /test accordingly.

Visual Inspection

Visual inspection shall be carried out for the proper installation of the

LVSB Installation in accordance with the Specification. The following components shall be included:

(a) Construction of type tested assembly;

(b) Main bus bars and droppers/risers;

(c) Air circuit breakers/fuse switches;

(d) Power factor correction capacitor bank;

(e) Harmonic filter;

(f) Automatic Changeover Switch;

(g) Instrumentation and protection devices;

(h) incoming/outgoing busbars and cables;

(i) Portable earthing equipment;

(j) Operating handles/keys;

(k) Hydraulic truck;

(l) rubber insulation mat.

Site Test before Connection of Incoming Supply

The following tests shall be carried out on site after completion of installation of the LVSB and before the connection of the incoming supply cable:

(a) Dielectric Test

Dielectric test shall be carried out to verify the dielectric properties of the LVSB. The test requirements shall be in accordance to IEC 60439-1.

(b) Insulation Test

This shall be carried out by means of a 1000V insulation tester or similar instrument.

(c) Secondary Injection Test

This shall be carried out using a.c. and shall check (approximately) that protection relays or devices function in accordance with their performance curves by a test at the lowest setting and two further tests of current and timing.

(d) Primary Injection Test

This shall be carried out to prove the correct operation of protective devices or system when set at the agreed setting.

(e) Polarity Check for Current Transformer (C.T.)

This shall be carried out to ensure that all C.T. are correctly connected.

(f) Functional Test of All Devices

This shall be carried out to ensure that all devices can operate properly as intended.

The equipment to be tested shall include, but not limited to, all circuit breakers, isolating switches, changeover switches, contactors, interlocking facilities, protective relays, earth leakage tripping devices, metering facilities and instruments.

(g) Contact Resistance Test

This shall be carried out by means of "Ductor" tester or similar instrument to ensure that contacts and joints for switchgears, cables, bus bars as well as the contacts and joints for outgoing cables and busbars are maintained in good condition.

(h) Temperature Rise Limits Test

This shall be carried out as defined in IEC 60439-1.

With the prior approval by the PBSE, the primary injection test and temperature rise limits test can be carried out in factory due to site constraints.

Site Test after Connection of Incoming Supply

The following tests shall be carried out after the incoming supply cables are connected and the "Switchboard" successfully commissioned on no load:

(a) phase-to-phase voltage test;

(b) phase-to-neutral voltage test;

(c) phase-to-earth voltage test;

(d) neutral-to-earth voltage test;

(e) Phase sequence test on each and every outgoing circuit.

Power Energization

Notification of Completion

After the proper testing and commissioning of the electrical installation, the Contractor shall notify the appropriate Authority, through the PBSE, on the completion of the installation and its readiness for inspection and testing.

Preliminary Steps for Power Energization

The followings shall be checked before power energization:

(a) Bus bar chambers, main and sub-main switch connections i.e. bolts and nuts tightness;

(b) Earthling connections at compartments, all switches and earth electrodes;

(c) Clearance of live parts from direct contact with or any likelihood of contact with tools, spurious bare conductors remaining in switches, air circuit breakers (ACB) and switch cubicles;

(d) Polarity, phase sequence of all switches and relevant fuse ratings;

(e) stand-by battery supply and the operation of shunt trip mechanism;

(f) Settings of overcurrent, earth fault relays and current transformer (C.T.) polarity;

(g) Vacuum cleaning of switches and ACBs;

(h) Provision of danger and warning signs.

(i) Certified Work Completion Certificate in accordance to the requirement of COP Code 19.

Switch On Process

Whenever there is any break of time e.g. the next day, in carrying out the switch on process, re-test of insulation resistance is required. The following procedures shall be followed in the switch on process:

(a) Switch on the main switch/ACB with all other sub-main switches off;

(b) If normal, switch on other sub-main switches one by one with all other outgoing switches off;

(c) If normal, then switch on allother out-going switches one by one;

(d) Observe the disc of the overcurrent (o/c) and earth fault protection relays for any movement for IDMT relays or for digital protection relays check whether there are any fault indications;

(e) Keep vigilance for about 30 minutes to see if any smell or abnormal noise being generated.

Calibrated Equipment

The Contractor shall supply the calibrated equipment relevant for T&C of the electrical installation as stipulated in the particular specification of the contract or the General Specification whichever appropriate. The equipment shall be calibrated by the recognized laboratories accredited with the Hong Kong Laboratory Accreditation Scheme (HKOLAS) or other worldwide-recognized laboratories during the active period of the contract.

Self-Check -3	Written Test

Directions: Answer all the questions listed below. Use the Answer sheet provided in the next page:

1) Visual inspection;
2) Earth electrode resistance; and
3) Continuity of protective conductor

Answer Sheet

Name: ___________________________ Date: ________________

Information Sheet-4	4 Identifying and calibrating defective machine, drive and instruments

3.3.1 Identifying instrumentation and control device to be calibrated

- **Nonlinear instruments**

The calibration of inherently nonlinear instruments is much more challenging than for linear instruments. No longer are two adjustments (zero and span) sufficient, because more than two points are necessary to define a curve. Examples of nonlinear instruments include expanded-scale electrical meters, square root characterizers, and position-characterized control valves. Every nonlinear instrument will have its own recommended calibration procedure, so I will defer you to the manufacturer's literature for your specific instrument. I will, however, offer one piece of advice.

When calibrating a nonlinear instrument, document all the adjustments you make (e.g. how many turns on each calibration screw) just in case you find the need to re-set the instrument back to its original condition. More than once I have struggled to calibrate a nonlinear instrument only to find myself further away from good calibration than where I originally started. In times like these, it is good to know you can always reverse your steps and start over.

- ❖ **Discrete instruments**

Discrete sensor is one that is only able to indicate whether the measured variable is above or below a specified set point. Examples of discrete instruments are process switches designed to turn on and off at certain values. A pressure switch, for example, used to turn an air compressor on if the air pressure ever falls below 85PSI, is an example of a discrete instrument. Discrete instruments need regular calibration just like continuous instruments. Most discrete instruments have one calibration adjustment: the set-point or trip-point. Some process switches have two adjustments: the set-point as well as a dead band adjustment.

The purpose of a dead band adjustment is to provide an adjustable buffer range that must be traversed before the switch changes state. To use our 85PSI low air pressure switch as an example, the set-point would be 85PSI, but if the dead band were 5PSI it would mean the switch would not change state until the pressure those above 90PSI (85PSI+ 5PSI).

When calibrating a discrete instrument, you must be sure to check the accuracy of the set-point in the proper direction of stimulus change. For our air pressure switch example, this would mean checking to see that the switch changed states at 85PSI falling, not 85PSI rising. If it were not for the existence of dead band, it would not matter which way the applied pressure changed during the calibration test. However, dead band will always be present in a discrete instrument, whether that dead band is adjustable or not.

Given a dead band of 5PSI for this example switch, the difference between verifying a change of state at 85PSI falling versus 85PSI rising would mean the difference between the air compressors turning on if the pressure fell below 85PSI versus turning on if the pressure fell below 80PSI.

A procedure to efficiently calibrate a discrete instrument without too many trial-and-error attempts is to set the stimulus at the desired value (e.g. 85PSI for our hypothetical low-pressure switch) and then move the set-point adjustment in the opposite direction as the intended direction of the stimulus (in this case, increasing the set-point value until the switch changes states).

The basis for this technique is the realization that most comparison mechanisms cannot tell the difference between arising process variable and a falling set point (or visa-versa). Thus, a falling pressure may be simulated by arising set-point adjustment. You should still perform an actual changing-stimulus test to ensure the instrument responds properly under realistic circumstances, but this trick will help you achieve good calibration in less time.

- LRV and URV settings, digital trim (digital transmitters)

The advent of smart field instruments containing microprocessors has been a great advance for industrial instrumentation. These devices have built-in diagnostic ability, greater accuracy (due to digital compensation of sensor nonlinearities), and the ability to communicate digitally with host devices for reporting of various parameters.

A simplified block diagram of a smart pressure transmitter looks something like this:

It is important to note all the adjustments with in this device, and how this compares to the relative simplicity of an all-analog pressure transmitter:

Note how the only calibration adjustments available in the analog transmitter are the zero and span settings. This is clearly not the case with smart transmitters.

Not only can we set lower- and upper-range values (LRV and URV) in a smart transmitter, but it is also possible to calibrate the analog-to-digital and digital-to-analog converter circuits independently of each other.

What this means for the calibration technician is that a full calibration procedure on a smart transmitter potentially requires more work and a greater number of adjustments than an all-analog transmitter.

A common mistake made among students and experienced technicians a like is to confuse the range settings (LRV and URV) for actual calibration adjustments.

Just because you digitally set the LRV of a pressure transmitter to 0.00PSI and the URV to 100.00PSI does not necessarily mean it will register accurately at points within that range!

The following example will illustrate this fallacy.

Suppose we have a smart pressure transmitter ranged for 0 to 100PSIwith an analog output range of 4 to 20mA, but this transmitters pressure sensor is fatigued from years of use such that an Actual applied pressure of 100PSI generates a signal that the analog-to-digital converter interprets as only 96PSI.

Assuming everything else in the transmitter is in perfect condition, with perfect calibration, the output signal will still be in error:

As the saying goes, a chain is only as strong as its weakest link. Here we see how the calibration of the most sophisticated pressure transmitter maybe corrupted despite perfect calibration of both analog/digital converter circuits, and perfect range settings in the microprocessor. The microprocessor thinks the applied pressure is only 96PSI, and it responds accordingly with a 19.36mA output signal. The only way anyone would ever know this transmitter was in accurate at 100PSI is to actually apply a known value of 100PSI fluid pressure to the sensor and note the in correct response. The lesson here should be clear: digitally setting a smart instrument LRV and URV points does not constitute a real calibration of the instrument.

For this reason, smart instruments always provide a means to perform what is called a digital trim on both the ADC and DAC circuits, to ensure the microprocessor sees the correct representation of the applied stimulus and to ensure the microprocessors output signal gets accurately converted into a DC current, respectively. Some technicians use the LRV and URV settings in a manner not unlike the zero and span adjustments on an analog transmitter to correct errors such as this.

Following this methodology, we would have to set the URV of the worn-out transmitter to 96PSI instead of 100 PSI, so an applied pressure of 100PSI would give us the 20mA output signal we desire.

In other words, we would let the microprocessor think it was only seeing 96PSI, then skew the URV so it outputs the correct signal anyway. Such an approach will work to an extent, but any digital queries to the transmitter (e.g. using a digital-over-analog protocol such as HART) will result in conflicting information, as the current signal represents full scale (100PSI) while the digital register inside the transmitter shows 96PSI.

The only comprehensive solution to this problem is to trim the analog-to-digital converter so the transmitter’s microprocessor knows the actual pressure value applied to the sensor.

Once digital trims have been performed on both input and output converters, of course, the technician is free to re-range the microprocessor as many times as desired without re-calibration**.**

This capability is particularly useful when re-ranging is desired for special conditions, such as process start-up and shut-down when certain process variables drift into uncommon regions.

An instrument technician may use a hand-held digital communicator device to re-set the LRV and URV range values to whatever new values are desired by operations staff without having to re-check calibration by applying known physical stimuli to the instrument. So long as the ADC and DAC trims are both fine, the overall accuracy of the instrument will still be good with the new range. With analog instruments, the only way to switch to a different measurement range was to change the zero and span adjustments, which necessitated there-application of physical stimuli to the device (a full re-calibration). Here and here alone we see where calibration is not necessary for a smart instrument. If overall measurement accuracy must be verified, however, there is no substitute for an actual physical calibration, and this entails both ADC and DAC trim procedures for a smart instrument.

Self-check 4	Written- test

Instructions: Answer all the questions listed below. Illustrations may be necessary to aid some explanations/answers. Write your answers in the sheet provided in the next page.

1. What is the unique future of nonlinear and discrete instrument?
2. Compare and contrast analog pressure transmitter and smart ones?
3. What is LRV and URV?

Answer Sheet

Name: ________________________ Date: ______________

Information Sheet	3.5. Checking connectors, bolts, nuts and screws

Tightening

When you are tightening a threaded fastener a significant amount of torque is needed to overcome friction in the threads and under the nut face (or the bolt head, if the bolt is rotated).

The proportion of the torque that is used to overcome friction depends upon the friction value but is typically in the 85% to 90% region. This is illustrated in Figure one, which shows that when tightening a nut/bolt with a coefficient of friction of 0.12, only about 14% of the torque is used to stretch the fastener producing the clamp load with 86% of the torque being lost overcoming friction. The torque needed to stretch the fastener always acts in the untightening direction and it’s for this reason that the untightening torque is less than the tightening torque.

In many applications the clamping force provided by tightening fasteners is of critical importance in determining the success, or otherwise, of the structural integrity of an assembly. A great deal of attention is often placed on ensuring that bolted connections are installed in a controlled manner so that a predictable clamping force is achieved. The most popular controlled method of tightening a threaded fastener is by applying a specific tightening torque.

Torque auditing is usually completed by one of three torque methods:

1. On-torque method: Measuring the torque needed to rotate the bolt/nut by a small angle (typically 2 to 10 degrees) in the tightening direction. This is the most frequently used method of torque auditing.

2. Off-torque method: Measuring the torque needed to rotate the bolt/nut in the untightening direction (which will normally be less than the tightening torque).

3. Marked fastener method: Marking the position of the bolt/nut relative to the joint, untightening it by an angle of approximately 30 degrees, then measuring the torque needed to tighten the bolt back to the marked position.

CONNECTORS

Connectors are devices attached to the ends of cables and sets of wires to make them easier to connect and disconnect. Each connector consists of a plugassembly and a receptacle assembly. The two assemblies are coupled by means of a coupling nut.

Each consists of an aluminum shell containing an insulating insert that holds the current-carrying contacts. The plug is usually attached to the cable endand is the part of the connector on which the coupling nut is mounted. The receptacle is the half of the connector to which the plug is connected. It is usually mounted on a part of the equipment.

Figure Basic types of solderless terminals.

Lock-Bolt Fasteners

Lock-bolt fasteners are designed to meet high-strength requirements. Used in many structural applications, their shear and tensile strengths equal or exceed the requirements of AN and NAS bolts.

The lock-bolt pin, shown in View a Figure below, consists of a pin and collar. It is available in two head styles: protruding and countersunk. Pin retention is accomplished by swaging the collar into the locking grooves on the pin.

Figure Lock bolts.

Bolts

Many types of bolts are used on machinery. Before discussion of some of these types, it might be helpful to view a list containing information about commonly used bolt terms. Important information about the names of bolt parts and bolt dimensions that must be considered in selecting a bolt is shown in Figure below.

The three principal parts of a bolt are the head, thread, and grip. The head is the larger diameter of the bolt and may be one of many shapes or designs.

The head keeps the bolt in place in one direction, and the nut used on the threads keeps it in place in the other direction

Figure Bolt terms and dimensions.

BOLT HEADS —the most common type of head is the hex head. This type of head may be thick for greater strength or relatively thin in order to fit in places having limited clearances. In addition, the head may be common or drilled to lock wire the bolt. A hex-head bolt may have a single hole drilled through it between two of the sides of the hexagon and still be classed as common. The drilled head-hex bolt has three holes drilled in the head, connecting opposite sides of the hex. Seven additional types of bolt heads are shown in Figure below.

Figure Different types of bolts

Nuts

Just as bolts do, because they are designed to do a specific job with the bolt. For instance, some of the nuts are made of cadmium-plated carbon steel, stainless steel, brass, or aluminum alloy. The type of metal used is not identified by markings on the nuts themselves. Instead, the material must be recognized from the luster of the metal.

Nuts also differ greatly in size and shape. In spite of these many and varied differences, they all fall under one of two general groups: self-locking and non-self-locking. Nuts are further divided into typessuch as plain nuts, castle nuts, check nuts, plate nuts, channel nuts, barrel nuts, and internal-wrenching

nuts, external-wrenching nuts, shear nuts, sheet spring nuts, wing nuts, and Klincher locknuts.

NONSELF-LOCKING NUTS —Non self-locking nuts require the use of a separate locking device for security of installation. There are several types of these locking devices mentioned in the following in connection with the nuts on which they are used. Since no single locking device can be used with all types of non self-locking nuts, one must be selected that is suitable for the type of nut being used.

SELF-LOCKING NUTS —Self-locking nuts provide tight connections that will not loosen under vibrations. Self-locking nuts approved for use on aircraft meet critical strength, corrosion-resistance, and temperature specifications. The two major types of self-locking nuts are prevailing torque and free spinning. The two general types of prevailing torque nuts are the all-metal nuts and the nonmetallic insert nuts.

Figure nut

Self-Check -5	Written Test

Directions: Answer all the questions listed below. Use the Answer sheet provided in the next page:

1. Write three types of torque methods:
   a) _________________
   b) _________________
   c) _________________
1. Write the purpose of connector, bolt and nut

Answer Sheet

Name: _________________________ Date: _______________

Information Sheet	3.6. Identifying worn-out/malfunctioning electrical system or equipment parts

Introduction

Unguarded moving parts of machines/equipment and the sudden or uncontrolled release of their power systems can result in serious injuries/ worn-out.

Personnel working with machines must be aware of the risks involved and follow safe work practices.

Causes of accidents while working with machinery

• Loose clothing, hair, jewelry being caught in moving parts.

• Materials ejected from the machine when it is operational.

• Inadvertent starting of the machine.

• Slipping and falling into an unguarded nip.

• Contact with sharp edges, e.g., cutting blade.

• Making adjustments while the machine is operational.

• Unauthorized operation of machines.

• Lack of preventive maintenance.

Rotating machine parts give rise to nip points.

Examples are

• Rotating gears

• Belt and its pulley

• Chain and sprocket

• Between grinding wheel and tool rest

• Between rotating and fixed parts

- Rotating parts operating alone

• Shafts

• Couplings

- Reciprocating and sliding motions

Dangerous parts of machinery

- Running nips between parts rotating in opposite directions, for e.g., gear wheels.
- Rotating parts operating alone e.g., couplings.
- Between rotating and tangentially moving parts e.g., belt drives.
- Wherever there is a rotating part operating close to a fixed structure there is a danger of trapping or crushing.
- Reciprocating and sliding motions.

Self-Check	Written Test

Directions: Answer all the questions listed below. Use the Answer sheet provided in the next page:

1. List out Causes of accidents while working with machinery

   a) ___________________
   b) ___________________
   c) ___________________
   d) ___________________
   e) ___________________
   f) ___________________

Answer Sheet

Name: ______________________ Date: _____________

Information Sheet	3.7. Replacing worn-out equipment parts

Introduction

Unguarded moving parts of machines/equipment and the sudden or uncontrolled release of their power systems can result in serious injuries/ worn-out.

Machine Guarding

Any machine part which can cause injury, must be guarded. Machine guards help to eliminate personnel hazards created by points of operation, ingoing nip points, rotating parts and flying chips.

Types of guards

Commonly used machine guards are

• Fixed guard

• Interlocked guard

• Adjustable guard

• Self adjusting guard

• Pull back device

• Two-hand control

Fixed guard- is kept in place permanently by fasteners that can only be released by the use of a tool.

- Interlocked guard- shuts off or disengages power to the machine and prevents it from starting when the guard is removed/opened.
- Adjustable guard- provides a barrier which can be adjusted to suit the varying sizes of the input stock.
- Self-adjusting guard-provides a barrier which moves according to the size of the stock entering the danger area.

Two hand control - concurrent use of both hands is required to operate the machine, preventing the operator from reaching the danger area.

- Pull back - the device is attached to the wrist of the operator which pulls the operator's hands away from the point of operation or other hazardous areas when the machine operates.

Safety precautions while working with machinery

- Ensure that the guards are in position and in good working condition before operating.
- Know the location of emergency stop switch.
- Do not wear loose clothing or jewelry that can be caught in the rotating parts.
- Confine long hair.
- The keys and adjusting wrenches must be removed from the machine before operating it.
- Stop the machine before measuring, cleaning or making any adjustments.
- Do not handle metal turnings by hand as they can cause injury. Use brush or rake to remove turnings.
- Keep hands away from the cutting head and all moving parts.
- Cutting tools and blades must be clean and sharp, so that they can be used without force.
- Avoid awkward operations and hand positions. A sudden slip could cause the hand to move into the cutting tool or blade.
- Keep work area clean. Floors must be level and have a non-slip surface.
- There must be enough space around the machine to do the job safely.
- The person working with the machine must not be distracted.
- Machines must not be left unattended. Switch off the machine before leaving.
- Rotating parts of machines must not be stopped with hands after switching off.
- Compressed air must not be used to clean machines, as this can force small particles to fly off and can cause injury.

Self-Check -2	Written Test

Directions: Answer all the questions listed below. Use the Answer sheet provided in the next page:

1. **Write Commonly used machine guards**

    a) ________________
    b) ________________
    c) ________________

Answer Sheet

Name: __________________________ **Date:** _______________

Instruction Sheet	LG29. Troubleshooting Electrical System or equipment

This learning guide is developed to provide you the necessary information regarding the following content coverage and topics –

- Instruments are checked/ inspected to ensure safe operation
- Conduct appropriate functional test(s) and inspection to ensure that the testing conducted on the device conforms with the manufacturer's instruction/manual
- Work site is cleaned and cleared of all debris and left in safe condition in accordance with company procedures
- Test results are recorded in Instrument/ control devices history cards
- Report is prepared and completed according to company requirements.

This guide will also assist you to attain the learning outcome stated in the cover page. Specifically, upon completion of this Learning Guide, you will be able to –

- Instruments are checked/ inspected to ensure safe operation
- Conduct appropriate functional test(s) and inspection to ensure that the testing conducted on the device conforms with the manufacturer's instruction/manual
- Work site is cleaned and cleared of all debris and left in safe condition in accordance with company procedures
- Test results are recorded in Instrument/ control devices history cards
- Report is prepared and completed according to company requirements.

Appropriate personal protective equipment is used in line with standard procedures.

Learning Instructions:

13. Read the specific objectives of this Learning Guide.

14. Follow the instructions described below 3 to 72.

15. Read the information written in the information "Sheet 1, Sheet 2, Sheet 3 and Sheet 4"

16. Accomplish the "Self-check 1, Self-check t 2, Self-check 3 and Self-check 4" **in page -11, 18, 26,35,52,56, and 71** respectively.

Information Sheet-4	4.1. Following safety policies and procedures

4.1.1 Inspection and Testing Techniques

The testing of an installation implies the use of instruments to obtain readings. However, a test is unlikely to identify a cracked socket outlet, a chipped or loose switch plate, a missing conduit-box lid or saddle, so it is also necessary to make a visual inspection of the installation.

All new installations must be inspected and tested during erection and upon completion before being put into service. All existing installations should be periodically inspected and tested to ensure that they are safe and meet the regulations of the IEE (Regulations 610–634).

The method used to test an installation may inject a current into the system. This current must not cause danger to any person or equipment in contact with the installation, even if the circuit being tested is faulty. The test results must be compared with any relevant data, including the IEE Regulation tables, and the test procedures must be followed carefully and in the correct sequence, as indicated by Regulation 612.1. This ensures that the protective conductors are correctly connected and secure before the circuit is energized.

4.1.5 Visual Inspection

The installation must be visually inspected before testing begins. The aim of the visual inspection is to confirm that all equipment and accessories are undamaged and comply with the relevant British and European Standards, and also that the installation has been securely and correctly erected Regulation 611.3 gives a checklist for the initial visual inspection of an installation, including:

- Connection of conductors;
- Identification of conductors;
- Routing of cables in safe zones;
- Selection of conductors for current carrying capacity and volt drop;
- Connection of single-pole devices for protection or switching in phase conductors only;
- Correct connection of socket outlets, lamp holders, accessories and equipment;
- Presence of fi re barriers, suitable seals and protection against thermal effects;
- Methods of 'basic protection' against electric shock, including the insulation of live parts and placement of live parts out of reach by fitting appropriate barriers and enclosures;
- Methods of 'fault protection' against electric shock including the presence of earthing conductors for both protective bonding and supplementary bonding.
- Prevention of detrimental influences (e.g. Corrosion);
- Presence of appropriate devices for isolation and switching;
- Presence of under voltage protection devices;
- Choice and setting of protective devices;
- Labeling of circuits, fuses, switches and terminals;
- Selection of equipment and protective measures appropriate to external influences;
- Adequate access to switchgear and equipment;
- Presence of danger notices and other warning notices;
- Presence of diagrams, instructions and similar information;
- Appropriate erection method.

4.1.5 Approved Test Instruments

The test instruments and test leads used by the electrician for testing an electrical installation must meet all the requirements of the relevant regulations. The HSE has published Guidance Notes GS 38 for test equipment used by electricians. The IEE Regulations (BS 7671) also specify the test voltage or current required to carry out particular tests satisfactorily.

All test equipment must be chosen to comply with the relevant parts of BS EN 61557.

All testing must, therefore, be carried out using an ‘approved’ test instrument if the test results are to be valid. The test instrument must also carry a calibration certificate, otherwise the recorded results may be void. Calibration certificates usually last for a year. Test instruments must, therefore, be tested and recalibrated each year by an approved supplier. This will maintain the accuracy of the instrument to an acceptable level, usually within 2% of the true value. Let us now look at the requirements of three often used test meters.

4.1.5 Continuity tester

To measure accurately the resistance of the conductors in an electrical installation we must use an instrument which is capable of producing an open circuit voltage of between 4 and 24V ac. or dc., and deliver a short-circuit current of not less than 200mA (Regulation 612.2.1). The functions of continuity testing and insulation resistance testing are usually combined in one test instrument.

I. Insulation resistance tester

The test instrument must be capable of detecting insulation leakage between live conductors and between live conductors and earth. To do this and comply with Regulation 612.3 the test instrument must be capable of producing a test voltage of 250, 500 or 1000V and deliver an output current of not less than 1mA at its normal voltage.

II. Earth fault loop impedance tester

The test instrument must be capable of delivering fault currents as high as 25A for up to 40 ms using the supply voltage. During the test, the instrument does an Ohm’s law calculation and displays the test result as a resistance reading.

III. Inspection Requirements

Verify that selected elements associated with the applicant’s program for inspection, test control, and controls of M&TE (as identified in an approved inspection plan) are in accordance with the applicant’s approved QA Plan.

Elements chosen for inspection may include three or more of the following:

Verify that inspection requirements and acceptance criteria are contained in the applicable design documents approved by the responsible design organization. Verify that inspection activities are documented and controlled by instructions, procedures, drawings, checklists, travelers, or other appropriate means.

- Verify that tests required to verify conformance of an item to specified requirements, and to demonstrate satisfactory performance for service, are planned and executed. Verify that the characteristics to be tested and test methods to be employed are specified. Verify that test results are documented and their conformances with acceptance criteria are evaluated.
- Verify that the applicant has established controls for tools, instruments, gauges, and other M&TE used for quality-affecting activities. Verify that M&TE is controlled, calibrated (at specified periods), and adjusted to maintain accuracy within necessary limits.
- Verify that the applicant has established the requirements to identify the status of inspection and test activities. Verify that the status is indicated either on the items or in documents traceable to the items, where it is necessary to assure that required inspections and tests are performed, and to assure that items that have not passed the required inspections and tests are not inadvertently installed, used, or operated. Verify that the status is maintained through indicators (i.e., physical location and tags, markings, shop travelers, stamps, inspection records, computerized logs, or other suitable means). Verify that authority for application and removal of tags, markings, labels, and stamps is specified. Verify that status indicators provide for indicating the operating status of systems and components of the facility (i.e., tagging valves and switches) to prevent inadvertent operation.

4.1.5 Inspection Guidance

The inspector should refer to the applicant's approved QA Plan for specific requirements and commitments. Verify that the following inspection activities are documented and controlled by instructions, procedures, drawings, checklists, travelers, or other appropriate means:

a. Inspection Planning.

Verify that documented inspection planning includes the following:

1. Identification of each work operation where inspection is necessary to ensure quality;
2. Identification of documents that are used to perform the inspections;

3. Identification of the characteristics for inspection and the identification of when, during the work process, inspections are to be performed for those characteristics;

4. Identification of inspection or process-monitoring methods employed;

5. Sufficient information from the final inspection, to provide a conclusion regarding conformance of the item to specified requirements;

6. Identification of the functional-qualification level (category or class) of personnel performing inspections;

7. Identification of acceptance criteria;

8. Identification of sampling requirements;

9. Methods to record inspection results; and Selection and identification of the M&TE to be used to perform the inspection to ensure that the equipment is calibrated and is of the proper type, range, accuracy, and tolerance to accomplish the intended function.

b. Selecting Inspection Personnel to Perform Inspections.

1. Determine that the individual who performs an inspection to verify conformance of an item to specified acceptance criteria is qualified to the requirements specified in the applicant's approved QA Plan.

2. Verify that inspections are performed by personnel other than those who performed or directly supervised the work being inspected. Verify that inspection personnel do not report directly to the immediate supervisor responsible for the work being inspected.

c. Inspection Hold Points.

1. If mandatory inspection hold points are used to control work, then verify that specific hold points are indicated in documents.

2. When applicable, verify that consent to waive hold points are documented and approved before to continuing work beyond the designated hold point.

d. In-Process Inspections and Monitoring.

1. If inspection of processed items is not practicable, then verify that indirect control is provided by the monitoring of processing methods, equipment, and personnel.

2. Verify that both inspection and process monitoring are conducted, when control is inadequate with only one method.

3. Verify that controls are established and documented for the coordination and sequencing of the work at established inspection points during successive stages of the process.

e. Final Inspection.

1. Verify that finished items are inspected for completeness, markings, calibration, adjustments, protection from damage, or other characteristics, as required to verify the quality and conformance of the item to specified requirements.
2. Verify that final inspections include a review of the results and resolution of nonconformance's identified by earlier inspections. If modifications, repairs, or replacements of items are performed subsequent to the final inspection, then verify that appropriate re-tests or re-inspections are performed.

f. Accepting Items.

Verify that the acceptance of an item is documented and approved by qualified and authorized personnel.

g. . **Inspection Documentation.**

Verify that inspection documentation includes the following:

1. The item inspected, date of inspection, the name of the inspector, or the inspector's unique identifier, who documented, evaluated, and determined acceptability;
2. The name of the data recorder, as applicable, and the type of observation or method of inspection;
3. The inspection criteria, sampling plan, or reference documents used to determine acceptance;
4. Results indicating acceptability of characteristics inspected;
5. M&TE used during the inspection, including the identification number and the most recent calibration date; and
6. Reference to information on actions taken in connection with nonconformance.

Verify that the following test control activities are conducted and documented in accordance with the applicant's approved QA Plan:

a. Test Planning.

Verify that test planning includes the following:

1. Identification of documents to be developed to control and perform tests;
2. Identification of items to be tested, test requirements, and acceptance limits, including required levels of precision and accuracy;
3. Identification of test methods to be employed and instructions for performing the test;

4. Identification of test prerequisites addressing, calibration for instrumentation, adequacy of test equipment and instrumentation, qualifications of personnel, condition of test equipment and the item to be tested, suitably controlled environmental conditions, and provisions for data acquisition;

5. Identification of mandatory hold points and methods to record data and results; and

6. Selection and identification of the M&TE to be used to perform the test to ensure that the equipment is of the proper type, range, accuracy, and tolerance to accomplish the intended function.

b. Performing Tests.

Verify that tests are performed in accordance with the applicant's QA procedures, and, as applicable, include the following:

1. Provisions for determining when a test is required, describing how tests are performed, and ensuring that testing is conducted by trained and appropriately qualified personnel.

2. Test objectives and provisions for ensuring that prerequisites for the given test have been met, adequate calibrated instrumentation is available and used, necessary monitoring is performed, and suitable environmental conditions are maintained.

3. Test requirements and acceptance criteria provided or approved by the organization responsible for the design of the item to be tested, unless otherwise designated.

4. Test requirements and acceptance criteria based on specified requirements contained in applicable design or other pertinent technical documents.

5. Potential sources of uncertainty and error.

c. Use of Other Testing Documents.

Other testing documents (e.g., American Society for Testing and Materials specifications, vendor manuals, or other related documents containing acceptance criteria) may be used instead of preparing special test procedures. If the applicant uses other documents, then verify that the information is incorporated directly into the approved test procedure, or incorporated by reference in the approved test procedure.

d. Tests Results.

Verify that test results are documented and their conformance with acceptance criteria evaluated by a qualified individual within the responsible organization, to ensure that the test requirements have been satisfied.

e. Test Documentation.

Verify that test documentation includes the following:

1. Item or work product tested, date of test, names of tester and data recorders, type of observation, and method of testing;

2. Test criteria or reference documents used to determine acceptance;

3. Results and acceptability of the test;

4. Actions taken in connection with any nonconformance's noted;

5. The individual evaluating the test results; and M&TE used during the test, including the identification number and the most recent calibration date.

f. Qualification of Test Personnel.

Verify that the individual who directs a test to verify conformance of an item to specified acceptance criteria is qualified in accordance with the applicant's approved QA Plan. Verify that tests are directed by personnel other than those who performed or directly supervised the work being tested. Verify that test directors do not report directly to the immediate supervisor responsible for the work being tested.

Self-Check 1	Written Test

Direction: Answer the following questions accordingly

1. List the initial visual inspection of an installation checklist. (at least 4)
2. What is the aim/purpose of visual inspection?
3. What are the elements chosen for visual inspection?

Answer Sheet

Score = ___________

Rating: ____________

Name: _________________________ Date: _______________

Information Sheet-2	4.2. Preparing maintenance records

4.2.1 Introducing on Maintenance

Maintenance is a set of organised activities that are carried out in order to keep an item in its best operational condition with minimum cost acquired. The combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function.

Maintenance Activities

Activities of maintenance function could be either repair or replacement activities, which are necessary for an item to reach its acceptable productivity condition or these activities, should be carried out with a minimum possible cost.

4.2.2 Job Orders

Definition: Job order is a documented task specifications that an individual is required to complete the task at a given unit of time.

Job orders are very much and highly recommended for each and every skilled worker in his/her work environment particularly in almost all industries. In which, most of these industries required it for the purpose of written report or a documented report of the task being perform.

There are several kinds of job orders as well as formats and required information that may vary depending upon the nature of the industry or a service center.

JOB ORDER CONTENTS

Job Order Control Number is basically non-identical number usually located at the upper left or right corner of the sheet usually written in different color.

Name of Client This field contains the clients name usually divided in three (3) parts, the family name, first/given name and the middle initial. But some job orders may only have one (1) single field that requires the complete name of the client.

Contact Number requires the client contact number either a cellular phone number or a landline telephone

Client's Address requires the current address of the client

Job Description represents the overall overview of the task to be perform

Date and Time The date when the job order is requested of delivered

Date Finished The date when the task is completed.

Signature Signatures are areas of the job order form that requires the signature of the technician and the client that serves as the specimen of agreement between the two parties

JOB ORDER

Job Order No:			**Date:**	
Name of Client:	*(Family Name):*	*(Given Name):*	*MI:*	Contact No:
Client's Address:				

<table>
<tr><td>Appliance Type:</td><td>Brand name:</td><td>Model:</td><td colspan="2">Serial:</td><td>Color:</td></tr>
<tr><td colspan="3">Appliance Physical Pre-Conditions:
1. ___________________________________
2. ___________________________________
3. ___________________________________</td><td colspan="3">Symptoms:
1. __________________________
2. __________________________
3. __________________________</td></tr>
<tr><td colspan="2">Date & Time Received:
Date__________/Time__________</td><td colspan="2">Expected Date & Time to be released:
Date___________/Time___________</td><td colspan="2">Received by:</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="2">Assigned Technician:
________________________________</td><td>Date Received:</td><td colspan="3">Technician's Pre-Condition Findings:
1. ______________________________
2. ______________________________</td></tr>
<tr><td colspan="6">Diagnose Results:
1. ____</td></tr>
</table>

_______ 2. ____ _______ 3. ____ _______
Replacements: (*If any)*

No. of Items	Description	Price/Unit	Total/Unit	Remarks
TOTAL AMOUNT:				

Report: ____ ____ ______________________________		*Signature of Technician:*
Total Billing: (Amount in words)		(w/ Service Charge)
Date & Time Released: Date__________/Time____ _____	*Released by:*	*Received by: (Owner)*

Figure 1: Sample Job Order

4.2.3 Preparing Job Orders

For most service centers, preparation of job before the start of every task is required. Basically, preparing job orders are just filling out the information required. In addition, a short conversation should take place between the owner and the one who prepares the job order.

Most of the questions that should be ask:

1. When was this equipment started to show irregular operation or malfunctioning.

2. Events took place before the fault happened

3. Repair history of the equipment if any.

These questions are most likely to be asking, since this information could lead some conclusions and future awareness.

4.2.4 Interpreting Job Orders

For most of the industry they provide job orders to their skilled workers to have a concrete formal request of the task to be done. Before each task to be done the worker should be able to secure the job order, "**no job order means NO task to be done**". Upon receiving the job order make sure that all required fields are correctly and clearly written.

First, check date and Job Order control number for its validity. Next, is to check the client's name, address and contact number, this information is highly required, which means that if this required information are missing, the worker should refer to the immediate supervisor.

The most important part of the job order is the task description in which each worker should be able to understand and be able to attain the task requirement within the specific period of time which is also can be seen under the date and time of completion.

4.2.5 As a worker, time consciousness is very important to be able to attain the required span of it **Record-keeping**

In order for an eye care unit to manage its equipment effectively, it needs good maintenance and repair records. It is very difficult to manage the unknown!

A central maintenance and repair record will help you to keep track of the maintenance and repair work done. Ideally, this system should correspond to the eye unit's equipment inventory (mentioned on page 34); this means that you will have maintenance and repair records for each of the items listed in the inventory.

4.2.6 Record-keeping for maintenance

The preventative maintenance schedule for users can be accompanied by a weekly or monthly ‘tick sheet’ near the item of equipment, with a space for each day so that users can date and sign it, thereby showing that they have carried out the required tasks. This may include a space for users to indicate what spare parts, such as bulbs, were used. On a regular basis, the list of spare parts used should be noted in the central maintenance and repair record so that more spare parts can be ordered.

The central maintenance and repair record can be used to keep track of all other maintenance, including maintenance done by the in-house team, by vendors, or by service agents. The information captured should include the date, the equipment reference number, what was done, who did the work, and when next maintenance is due.

Self-Check 1	Written Test

Part I: Define the following terms

Directions: Answer all the questions below. Illustrations may be necessary to aid some explanations/answers.

1. What is a job order?

2. What should be the first thing to check before performing the task specifications?

3. Why it is that time consciousness is important when performing the task?

4. What is the main principle of a worker when dealing with task/job orders?

5. Why it is that job order number and the date should be check first when receiving the job order?

Part II: Matching Item

Directions: Match the terms with the following statements found on the right side. Write the corresponding letter

<u>Column A</u>

_____1. Job Order Control Number

_____2. Name of Client

_____3. Contact Number

_____4. Client's Address

_____5. Job Description

_____6. Date and Time

_____7. Date Finished

_____8.   Signature

Column B

a. The date when the task is completed.

b. This field contains the clients name usually divided in three(3) parts, the family name, first/given name and the middle initial. But some job orders may only have one(1) single field that requires the complete name of the client.

c. is basically non-identical number usually located at the upper left or right corner of the sheet usually written in different color.

d. requires the current address of the client

e. represents the overall overview of the task to be perform

f. requires the client contact number either a cellular phone number or a landline telephone

g. Signatures are areas of the job order form that requires the signature of the technician and the client that serves as the specimen of agreement between the two parties.

h. The date when the job order is requested of delivered

4.3.1 Isolation Equipment to be diagnosis

Electrical test equipment is available for rent from **Technical Diagnostic Services.** We offer for rent a wide variety of instruments for high voltage equipment, equipment calibration, clamp on millimeters, motor winding testing, high voltage relays, buddle test equipment, transformer power factor, predictive maintenance, digital millimeters, power factor test equipment for industrial applications

The electrical equipments operation status monitoring, operating performance analysis and assessment is to ensure the safe operation of its important components. A new trouble pattern analysis was put forward based on thought of data mining. The trouble information dimensionality tables come into being by collecting and cleaning up the fault phenomenon. The association rule dimensionality table was made up of the technique parameters and the trouble causes. We analyzed the trouble information by frequent item set of the Apriori arithmetic based on the trouble information dimensionality table and the association rule dimensionality table. We made sure the causes of the trouble and chose the priority resolving scheme by matching the trouble and building and filtrating the candidates. A process of data mining was designed for status information and fault information, Practical results show that the automation level of the management and diagnosis for electrical equipment is improved and it is of great practical value.

4.3.2 **Fault indicator**

A **fault indicator** is a device which provides visual indication of an electrical fault. They are used in electric power distribution networks as a means of automatically detecting and identifying faults.

- **Overhead**

Overhead indicators are used to visualize the occurrence of an electrical fault on an overhead electrical system.

- **Underground**

Underground indicators are used to visualize the occurrence of an electrical fault on an underground electrical system. Often these devices are located in an underground vault. Some vendors provided a wireless interface to eliminate the need of entering the underground vault in order to check the status of the indicators

- **Overhead Fault Indicators**

SEL offers a variety of fault indicators for use on un fused taps, long feeders with midline re closers or sectionalizes, overhead to underground transitions, and feeders that experience recurring faults.

Choose from manual, timed, or automatic reset models, line- or battery-powered. Easy to install and maintenance-free, SEL fault indicators help identify and locate temporary and permanent faults faster, enabling the utility to make repairs and restore power faster.

- **Fault Indicators and Sensors**

The E. O. Schweitzer Manufacturing Division of SEL (Schweitzer Engineering Laboratories) designs and manufactures fault indicators and sensors, supplying utilities around the world with products that help reduce fault-finding time so that power can be restored quickly after a fault occurs. In business since 1950, this division of SEL is the electric power industry's leader in fault indicator technology, producing the widest variety of fault indicator products.

4.3.3 Heating of electrical parts

Check panels with the covers off and power at ideally at least 40 % of the maximum load. Measure the load, so that you can properly evaluate your measurements against normal operating conditions. Caution: only authorized and qualified personnel using the appropriate personal protective equipment (PPE) should remove electrical panel covers. Capture thermal images of all connections that have higher temperatures than other similar connections under similar loads

In general, look for connections that are hotter than others. They signal high resistance possibly due to looseness, tightness or corrosion. Connection-related hot spots usually (but not always) appear warmest at the spot of high-resistance, cooling with distance from that spot. As noted, overheating connections can, with additional loosening or corrosion, lead to a failure and should be corrected. The best solution is to create a regular inspection route that includes all key electrical panels and any other high-load connections, such as drives, disconnects, controls, and so on. Save a thermal image of each one on the computer and track your measurements over time, using the software that comes with the thermal imager. That way, you'll have baseline images to compare to, that will help you determine whether a hot spot is unusual or not, and to verify repairs are successful.

4.3.4 Loose connections

The reason thermograph is so applicable to the monitoring of electrical systems is that new electrical components begin to deteriorate as soon as they are installed. Whatever the loading on a circuit, vibration, fatigue and age cause the loosening of electrical connections, while environmental conditions can hasten their corroding. Briefly stated, all electrical connections will, over time, follow a path toward failure. If not found and repaired, these failing connections lead to faults. Fortunately, a loose or corroded connection increases resistance at the connection and since increased electrical resistance results in an increase in heat, a thermal image will detect the developing fault before it fails. Detecting and correcting failing connections before a fault occurs averts fires as well as impending shutdowns that can be critical to manufacturing, commercial and institutional operations. Such predictive actions are important because when a critical system does fail,it inevitably increases costs, requires the reallocation of workers and material, reduces productivity, threatens corporate profitability and impacts the safety of employees, customers and/or clients. The following discussion focuses on using thermal imaging to troubleshoot loose, over-tight or corroded connections in electrical systems by comparing the temperatures of connections within panels.

4.3.5 Malfunction logic controls

Malfunction of burn-in test caused by a failure of setting a determined test mode due to a "line defect" of the test is prevented. A semiconductor memory device having a logic unit including a control circuit C2 to control an output of an "on-chip compare" signal OCC indicating pass/fail of a data that is read from a memory array on the basis of a scan signal SCAN upon burn-in test. A specified terminal PAD from a plurality of terminals for power potential provided in the semiconductor memory device is used for the burn-in test. The logic unit comprises a control circuit C1 on an input path of the scan signal SCAN to control an output of the scan signal SCAN on the basis of a signal (VDD/OPEN) from the specified terminal PAD.

1. A semiconductor memory device comprising: a logic unit that controls an output of an "on-chip compare" signal indicating pass/fail of a data that is read from a memory array on the basis of a scan signal upon a burn-in test; and a plurality of input terminals for power potential; wherein a specified terminal is selected from said plurality of terminals for power potential for said burn-in test; and said logic unit comprises a control circuit on an input path of said scan signal to control an output of said scan signal on the basis of a signal from said specified terminal.

2. The semiconductor memory device as defined in claim 1, wherein said input path from said specified terminal of said control circuit is branched and electrically connected to a ground potential via a resistance.

3. The semiconductor memory device as defined in claim 1, wherein said logic unit does not output said "on-chip compare" signal as an output signal when said specified terminal is open.

4. The semiconductor memory device as defined in claim 2, wherein said logic unit does not output said "on-chip compare" signal as an output signal when said specified terminal is open.

5. The semiconductor memory device as defined in claim 1, wherein said control circuit has an input terminal for the scan signal termed "SCAN" and said input path termed "PAD" as input signals, respectively, and an output signal termed "SCAN'" supplied to said logic unit said logic unit being controlled by said output signal SCAN' of said control circuit and another control signal termed "OCC" said control circuit being controlled under Truth

4.3.6 Tripping of breaker

A Circuit breaker, if it is working properly, detects electrical leakages through the earthling of the equipment we are using, especially if the equipment is made of or encased with a metal body like a kettle. a refrigerator or an oven. It is of utmost importance that all electrical appliances with a metal body be properly earthed. This means there should be an earth wire attached to the body of the electrical equipment.

If the earth wire is properly attached, the circuit breaker will detect that there is current present at the earth source and the built in protective coils will automatically trips the circuit, preventing any mishaps.

6.3.7 Intermittent operations

Condition, in which a device operates normally for a time, then becomes defective for a time, with the process repeating itself at regular or irregular intervals. Control apparatus for electric windshield wipers including a thermal switch having a heating winding for intermittent operation, and a resistor inserted in parallel with the heating winding in an electric braking circuit at the end of a wiping cycle

- **Cause of trouble**

The circuit breakers in our homes are designed to give us protection against 3 things, but this protective equipment has almost always been overlooked and taken for granted. 90% of house owners never bother to check if their circuit breaker is in good working condition regularly.

A Circuit breaker, if it is working properly, detects electrical leakages through the earthling of the equipment we are using, especially if the equipment is made of or encased with a metal body like a kettle. a refrigerator or an oven. It is of utmost importance that all electrical appliances with a metal body be properly earthed. This means there should be an earth wire attached to the body of the electrical equipment.

A lot of DIY enthusiast forgot this practice because they are ignorant of the consequences. Sometimes they just leave the earth wire disconnected. No doubt the equipment will work without a hitch without the earth wire. The problem is, if there is a leakage, it will also keep running. Only this time the whole metal body will be “electrified” and anyone who touches the apparatus when it is switched on will be electrocuted.

If the earth wire is properly attached, the circuit breaker will detect that there is current present at the earth source and the built in protective coils will automatically trips the circuit, preventing any mishaps.

Circuit overload can happen from lightning strikes, or more commonly loose connections in electrical appliances, starters or fuses. Electrical connections can loosened over years of use. Once these terminals becomes loose, the contact points will gets heated up due to improper contact with each other. Most of the time, it will gets so hot that it will melt the part where the terminals are loose and in worse scenario, a small fire will start to burn. When that happens, the duty if the circuit breaker is to trip of the electrical supple automatically.

Many a times, if a cable is too short, we resort to joining the cables ourselves. If we are not careful or in many cases, they simply don't know, they will twist the live wire and the neutral wire together. This will cause a serious short circuit and if the circuit breaker is not functioning, you will certainly experience a small explosion at the mains.

1. How to determine a faulty electrical circuit Assuming that you have done all the 3 basic steps when checking for a faulty light and you fail to repair that light because there is no electricity supply going to the light itself. You should have confirmed this with your test pen. Let's discuss what else could be at...

2. Pin Pointing An Electrical Problem Fazili asked, when i switch on the plug connected to my pc suddenly the circuit breaker trip, what are the problem, really appreciate your help There could be a variety of reason why the circuit breaker trips when certain electrical items are switched on. To pin point where the problem...

3. A Simple Electrical Circuit I have some enquiries about how a circuit work. A circuit consist of 2 parralel wires running side by side. One brings the current and the other lets the current flows back, creating a simple circuit. The one that brings the current is the live wire and the other one...

4. How to isolate a Faulty Switch Socket Sometimes in the middle of the night or maybe out of the blue, you get a total blackout in your house. If yours is the only house affected,

then you can be pretty sure that there is a short circuit somewhere in your electrical system. That doesn't mean you have...

How to Prevent an Electrical Contractor from shortchanging you. A problem that I always encounter during my sub-contracting days is the pricing of my projects. Lots of my customers complains that I over charges them. At that time, the market rate for installing an additional 13 amps switch socket was 50 bucks for one additional point. Mo

Self-Check 3	Written Test

Part II: Enumeration

Direction: Write/List down the following

1 Fault indicator

a) ________________

b) ________________

c) ________________

d) ________________

1 Cause a serious short circuit

a) ________________

b) ________________

c) ________________

d) ________________

e) ________________

Answer Sheet

Score = ___________

Rating: ____________

Name: _________________________ Date: _______________

Information Sheet-4	4.4.1 Identifying Indicators/Symptoms of fault or failure.

4.4.1 Introduction

The operators of electrical drive systems are under continual pressure to reduce maintenance costs and prevent unscheduled down times, which result in lost production and financial income. Many operators now use on-condition based maintenance strategies in parallel with conventional planned maintenance schemes. This has reduced unexpected failures, increased the time between planned shutdowns for standard maintenance and reduced operational costs.

The operation of electrical machines in an unsafe condition can also be avoided. Since the incidence of unexpected failures is reduced the operator is able to exercise greater control in the prevention of incidents which may have environmentally damaging consequences. In hazardous installations, this requires continuous on-line monitoring to prevent a catastrophic failure.

During the past fifteen years there has been a substantial amount of research into the creation of new condition monitoring techniques for electrical machine drives. New methods have been developed which are now being used by the operators and research is continuing with the development of new and alternative on-line diagnostic techniques. However, it is still the operators who have to make the selection of the most appropriate and effective monitoring systems to suit their particular electric motor drive systems.

An operator must treat each motor drive as a unique entity and the potential failure modes, fundamental causes, mechanical load characteristics, and operational conditions have all to be taken into consideration when a monitoring system is being selected.

Lately, the focus has been on the use of on-line condition monitoring to detect degradation processes and failure mechanisms of induction motors. Figure 1 presents an overview of problems and possible on-line monitoring techniques. In some cases there are several signals which may contain information on the failure mechanism. If possible, parameters, which will provide information on possible causes of failures, should also be monitored in addition to monitoring signals to identify fault mechanisms.

These will ultimately lead to more intelligent drive systems, which are highly reliable, since the fundamental causes of premature failure can be substantially reduced.

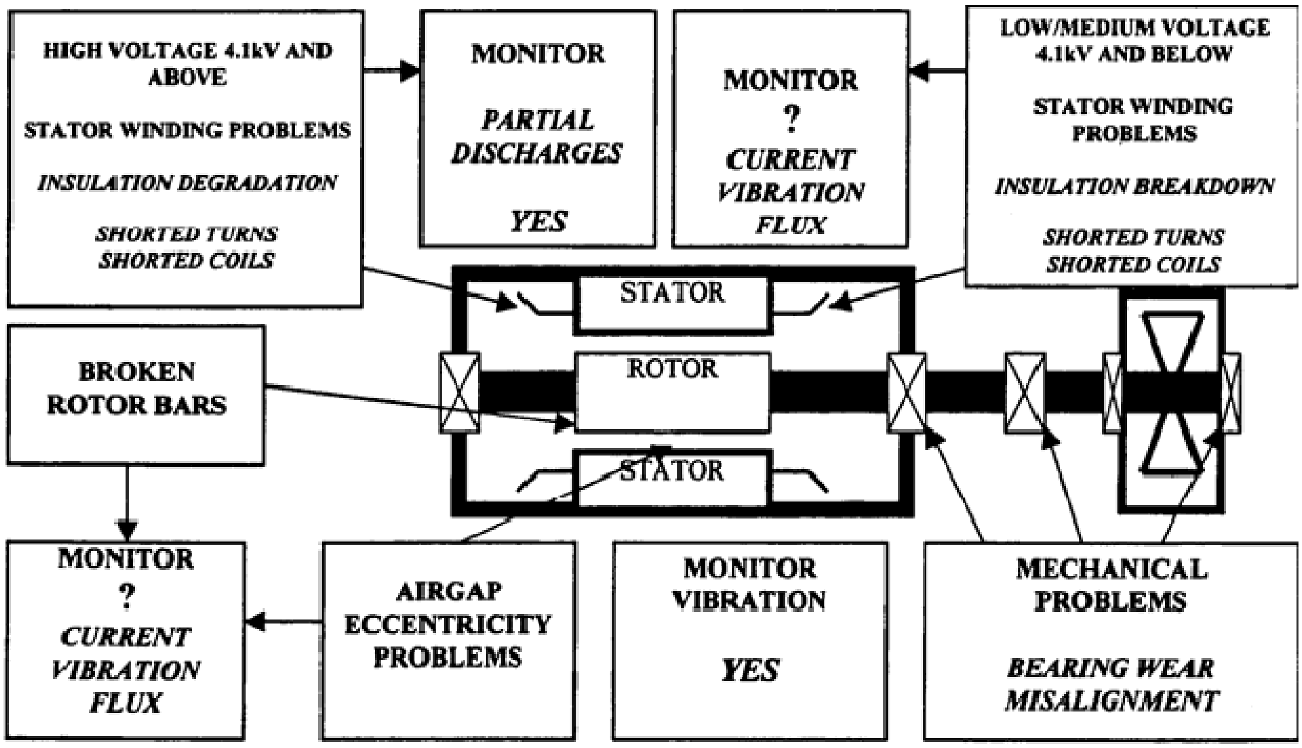


Figure 4.4.1 Problems, failures and possible on-line monitoring techniques for IM drives

Classification of the major faults of electrical machines and their symptoms

Most of the surveys of failures in electrical rotating machines indicate that in general, failures are dominated by bearing and stator winding failures with rotor winding problems being less frequent.

The major faults of electrical machines can broadly be classified as the following:

a) Stator faults resulting in the opening or shorting of one or more of a stator phase winding,

b) Abnormal connection of the stator windings,

c) Broken rotor bar or cracked rotor end-rings,

d) Static and/or dynamic air-gap irregularities,

e) Bent shaft (dynamic eccentricity) which can result in a rub between the rotor and stator, causing serious damage to stator core and windings

f) Shorted rotor field winding, and

g) Bearing and gearbox failures.

These faults produce one or more of the symptoms as given below:

a) Unbalanced air-gap voltages and line currents,

b) Increased torque pulsations,

c) Decreased average torque,

d) Increased losses and reduction in efficiency, and

e) Excessive heating.

The diagnostic methods to identify the above faults may involve several different types of fields of science and technology. They can be described as:

a) Electromagnetic field monitoring, search coils, coils wound around motor shafts (axial flux related detection),

b) Temperature measurements,

c) Infrared recognition,

d) Radio frequency (RF) emissions monitoring,

e) Noise and vibration monitoring,

f) Chemical analysis,

g) Acoustic noise measurements,

h) Motor current signature analysis (MCSA),

i) Model, artificial intelligence and neural network based techniques.

Of the above types of faults

i) the stator or armature faults,

ii) the broken bar and end ring faults of induction machines,

iii) bearing,

iv) The eccentricity related faults are the most prevalent ones and thus demand special attention in our research.

Various types of faults and their detection techniques.

A. Bearing faults

The majority of electrical machines use ball or rolling element bearings. Each of these bearings consists of two rings, one inner and the other outer. A set of balls or rolling elements placed in raceways rotate inside these rings. Even under normal operating conditions with balanced load and good alignment, fatigue failures may take place. These faults may lead to increased vibration and noise levels. Flaking or spalling of bearings might occur when fatigue causes small pieces to break loose from the bearing.

Other than the normal internal operating stresses, caused by vibration, inherent eccentricity, and bearing currents due to solid state drives, bearings can be spoiled by many other external causes such as:

a) Contamination and corrosion caused by pitting and sanding action of hard and abrasive minute particles or corrosive action of water, acid etc.

b) Improper lubrication; which includes both over and under lubrication causing heating and abrasion.

c) Improper installation of bearing. By improperly forcing the bearing onto the shaft or in the housing (due to misalignment) indentations are formed in the raceways (brine ling).

Though almost 40-45% of all motor failures isbearing related, very little has been reported in literature regarding bearing related fault detection. Bearing faults might manifest themselves as rotor asymmetry faults, which are usually covered under the category of eccentricity related faults.

Experiments were conducted on defective bearings with scratches on the outer races and bearing balls and cage defects. It has been claimed that all defective measurements were correctly classified as defective. However, the detection procedure required extensive training for feature extraction.

B. Stator or armature faults

These faults are usually related to insulation failure. In common parlance they are generally known as phase-to-ground or phase-to –phase faults. It is believed that these faults start as undetected turn-to-turn faults, which finally grow and culminate into major ones. Almost 30-40% of all reported induction motor failures falls in this category.

Armature or stator insulation can fail due to several reasons. Primaries among these are:

a) High stator core or winding temperatures,

b) Slack core lamination, slot wedges and joints.

c) Loose bracing for end winding.

d) Contamination due to oil, moisture and dirt.

e) Short circuit or starting stresses

f) Electrical discharges

g) Leakage in cooling systems

There are a number of techniques to detect these faults. [Penman 1997] was able to detect turn to turn faults by analyzing the axial flux component of the machine using a large coil wound concentrically around the shaft of the machine. Even the fault position could be detected by mounting four coils symmetrically in the four quadrants of the motor at a radius of about half the distance from the shaft to the stator end winding.

[Tolyiat 1995] has shown through both modelling and experimentation that these faults result in asymmetry in the machine impedance causing the machine to draw unbalance phase currents. This is the result of negative sequence currents flowing in the line as also have been shown in [Williamson 1984]. However, negative sequence currents can also be caused by voltage unbalance, machine saturation etc.

[Kliman 1996] model these unbalance which also includes instrument asymmetries. It is reported that with these modifications it is possible even to detect a one turn “bolted” fault out of a total 648 turns. Statistical process control (SPC) techniques have also been applied to detect stator faults [Dister 1994]

C. Broken rotor bar and end ring faults

Unlike stator design, cage rotor design and manufacturing has undergone little change over the years. As a result rotor failures now account for around 5-10% of total induction motor failures.

Cage rotors are of two types: cast and fabricated. Previously cast rotors were only used in small machines. However, with the advent of cast ducted rotors; casting technology can be used even for the rotors of machines in the range of 3000 kW. Fabricated rotors are generally found in larger or special application machines. Cast rotors though more rugged than the fabricated type, can almost never be repaired once faults like cracked or broken rotor bars develop in them.

The reasons for rotor bar and end ring breakage are several. They can be caused by:

a) Thermal stresses due to thermal overload and unbalance, hot spots or excessive losses, sparking (mainly fabricated rotors).

b) Magnetic stresses caused by electromagnetic forces unbalanced magnetic pull, electromagnetic noise and vibration.

c) Residual stresses due to manufacturing problems.

d) Dynamic stresses arising from shaft torques, centrifugal forces and cyclic stresses.

e) Environmental stresses caused by for example contamination and abrasion of rotor material due to chemicals or moisture.

f) Mechanical stresses due to loose laminations, fatigued parts, bearing failure etc.

[Kliman 1988], [Thomson 1988], [Filippetti 1996], [Elkasabgy 1992] used spectrum analysis of machine line current (MCSA) to detect broken bar faults. They investigate the sideband components around the fundamental for detecting broken bar faults.

D. Eccentricity related faults

Machine eccentricity is the condition of unequal air-gap that exists between the stator and rotor [Vas 1993], [Cameron 1986]. When eccentricity becomes large, the resulting unbalanced radial forces (also known as unbalanced magnetic pull or UMP) can cause stator to rotor rub, and this can result in the damage of the stator and rotor. There are two types of air-gap eccentricity: the stati cair-gap eccentricity and the dynamic air-gap eccentricity. In the case of the static air-gap eccentricity, the position of the minimal radial air-gap length is fixed in space. Static eccentricity may be caused by the ovality of the stator core or by the incorrect positioning of the rotor or stator at the commissioning stage. If the rotor-shaft assembly is sufficiently stiff, the level of static eccentricity does not change.

In case of dynamic eccentricity, the centre of the rotor is not atthe centre of the rotation and the position of minimum air-gap rotates with the rotor. This misalignment may be caused due to several factors such as a bent rotor shaft, bearing wear or misalignment, mechanical resonance at critical speed, etc. Dynamic eccentricity in a new machine is controlled by the total indicated reading (TIR) or “run-out” of the rotor [Thomson 1997]. An air-gap eccentricity of up to 10 % is permissible. However, manufacturers normally keep the total eccentricity level even lower to minimise UMP and to reduce vibration and noise.

The presence of static and dynamic eccentricity can be detected using motor current signature analysis - MCSA [Vas 1993], [Cameron 1986]. Modelling based approaches to detect eccentricity related components in line current have been described in [Nandi 1998-1], [Nandi 1998-2]. The simulation results obtained through the models are also well supported by permeance analysis and experimental results.

Vibration signals can also be monitored to detect eccentricity-related faults. The high frequency vibration components for static or dynamic eccentricity are given by [Cameron 1986].

Time stepping finite element methods have been employed recently to compare simulated results with experimentally obtained static eccentricity components in line currents [Barbour 1997]. Static eccentricity has also been modelled using Winding Function Approach [Toliyat 1996].

Other approaches, such as monitoring the stator voltage and Current Park's Vector [Cardoso 1993] to detect eccentricity in induction motor, can also be found in literature. [Tolyiat 1997] has provided simulation and experimental results for synchronous machines with dynamic eccentricity related faults.

Fault detection techniques

Modern measurement techniques in combination with advanced computerised data processing and acquisition show new ways in the field of induction machines monitoring by the use of spectral analysis of operational process parameters (e.g., temperature, pressure, steam flow, etc.). Time-domain analysis using characteristic values to determine changes by trend setting, spectrum analysis to determine trends of frequencies, amplitude and phase relations, as well as cepstrum analysis to detect periodical components of spectra are usedas evaluation tools (Fig. 2). In many situations, vibration-monitoring methods were utilised for incipient fault detection.

1) Classical Fast Fourier Transform (FFT)

For this method, the stator current monitoring system contains the four following processing sections shown in Fig.4.4.1

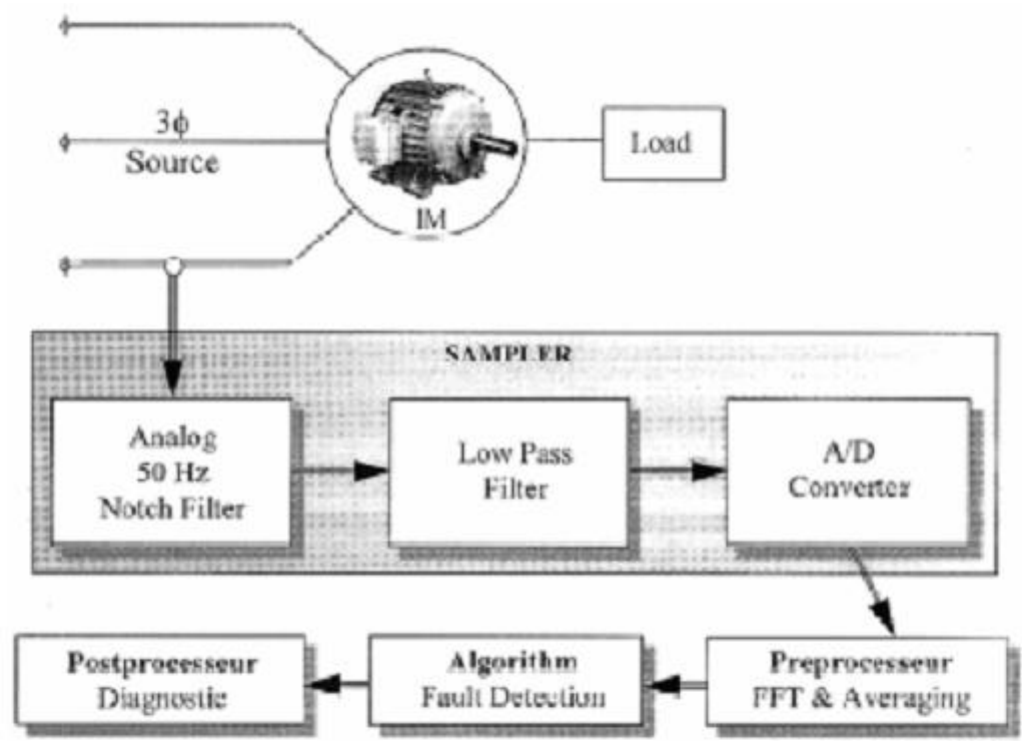


Fig. 4.4.1 One phase stator current monitoring system

1) Sampler: Its purpose is to monitor a single-phase stator current. This is accomplished by removing the 50-Hz excitation component through low-pass filtering, and sampling the resulting signal. The single-phase current is sensed by a current transformer and sent to a 50-Hz notch filter where the fundamental component is reduced. The analogue signal is then amplified and low-pass filtered. The filtering removes the undesirable high-frequency components that produce aliasing of the sampled signal while the amplification maximises the use of the analog-to-digital (A/D) converter input range.

The A/D converter samples the filtered current signal at a predetermined sampling rate that is an integer multiple of 50 Hz. This is continued over a sampling period that is sufficient to achieve the required FFT.

2) Pre-processor: It converts the sampled signal tothe frequency domain using an FFT algorithm. The generated spectrum includes only the magnitude information about each frequency component.

Signal noise that is present in the calculated spectrum is reduced by averaging a predetermined number of generated spectra. This can be accomplished by using either spectra calculated from multiple sample sets or spectra computed from multiple predetermined sections (or windows) of a single large sample set. Because of the frequency range of interest and the desired frequency resolution, several thousand frequency components are generated by the processing section.

3) Fault Detection Algorithm: In order to reduce the large amount of spectral information to a usable level, an algorithm, in fact a frequency filter, eliminates those components that provide no useful failure information. The algorithm keeps only those components that are of particular interest because they specify characteristic frequencies in the current spectrum that are known to be coupled to particular motor faults. Since the slip is not constant during normal operation, some of these components are bands in the spectrum where the width is determined by the maximum variation in the motor slip.

4) Postprocessor: Since a fault is not a spurious event but continues to degrade the motor, the postprocessor diagnoses the frequency components and then classifies them (for each specified fault).

Self-Check 4	Written Test

Part II: Enumeration

Direction: Write/List down the following

1. **Various types of faults and their detection techniques**

a) ________________

b) ________________

c) ___________________

d) ______________

2. **Cause a serious short circuit**

a. ________________

b. ________________

c. ________________

d. _______________

Answer Sheet

Score = ___________
Rating: ____________

Name: __________________________ Date: _______________

Operation Sheet	4.5. Performing necessary electrical test on the system or equipment

4.5.1 A healthy electrical circuit.

Current flows in a closed circuit between two electrically unequal potential points. Points A and B are any two points across which voltage is measured. The conductor offers resistance to this flow of electrons (i.e., current) depending upon the material.

Generally electrical problems can be classified under two broad types.

1. A connection does not exist where it should. This is an open circuit fault and can be detected using a continuity tester (Figure 3.2 illustrates this type of fault).

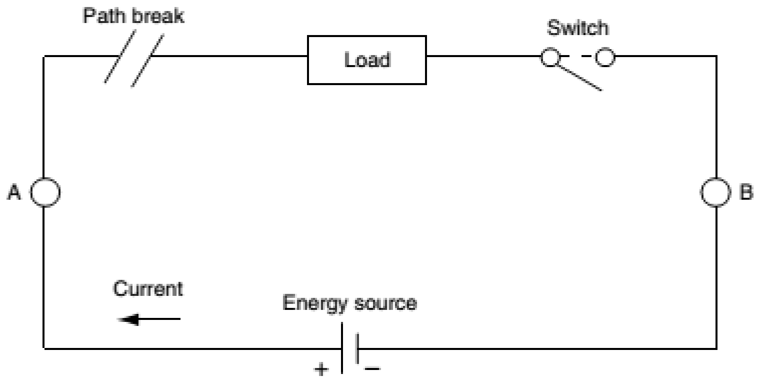


Figure 4.5.1 A typical open circuit fault

2. A connection exists where none should. This is called a short-circuit fault and can lead to excessive current accompanied by mechanical forces and heating of circuit conductors. Such fault happen due to insulation failures and can be detected using insulation testing instruments.

The process of detecting these faults and rectifying the circuit to restore normal operating condition is called troubleshooting. We will discuss about the open circuit fault first.

Current has a tendency to flow between two points that are at an unequal potential (electrically), provided the path between the two points is electrically conductive.

- Resistance offered by the path is known as 'Resistance' ohm)
- Electrical potential is denoted as 'volts'
- Flow of electrons between two points is termed as 'Current' (amp).

Therefore, while troubleshooting, the following points have to be checked:

Continuity of path (i.e., resistance)

Electric potential at two points of the path (i.e., voltage)

Flow of electrons through the path (i.e., current).

An electrical circuit is made up of different paths and works on different voltages. Let us, therefore, identify the path that should be complete, also, when and how it is completed. Moreover, if it does not complete, let us identify the reason.

4.5.2 Basic principles in using a drawing and meter in troubleshooting circuits

To identify a faulty section, follow the guidelines given below, along with a drawing and a meter:

- Check the incoming supply voltages first

- Check for voltages at the specific test points in circuit (as per manufacturers test point data sheet)
- Do dead test of circuit for integrity of protection devices and others
- In dead test, check for continuity of circuits, as intended, and check for insulation resistance
- If it's not possible to perform a dead test, connect the supply to the circuit and do a live test of circuit.

Generally, any electrical circuit can be differentiated in two sections:

- Power circuit
- Control circuit.

It is always advisable to first check the power circuit. So, if the power circuit works, as it should, then troubleshoot the control circuit.

Power circuit check list:

Incoming power to circuit and its integrity check for correct functioning of protection devices

Check visual cable continuity

Check for any signs of flash or burning smell of devices.

Control circuit check list:

Control circuit power first

Check for proper functioning of relays, timers, and switches

Check visual cable continuity

Check for wire interconnections and terminal connections of circuit

Check logical operational sequence of contactor switching

Check for timer duration settings.

If the above criteria are checked and still the motor (final device) is not working, thentest the motor (final device).

4.5.3 Checks for circuit continuity with disconnected supply

Dead circuit testing is testing performed with the power disconnected from the circuit. The main benefit of disconnecting power supply while tests with an external energy source are performed is to eliminate hazardous risks to the environment or the person conducting the test. A continuity test, as well as, an insulation test can be performed in the dead circuit test.

(a) Continuity test

This is to be performed on a dead circuit for checking continuity. Using an 'Audible Continuity Tester' can do it. This tester consists of a battery as a source of energy, an audible device, and two test leads. Figure 3.3 shows an example of this test with an audible continuity tester.

By this test, the continuity of an electrical circuit is checked to ensure that the electrical path is complete.

If the path is continuous, then an audio sound is emitted to confirm path continuity and the non-existence of an open circuit.

In some devices, along with the audio indication, an LED or some other visual indication is provided.

Similarly, an ohmmeter or multi-meter can also be used to check continuity. An ohmmeter or multi-meter consists of a battery as a source of energy, along with a meter to display the value of resistance.

In an ohmmeter, the scale is calibrated from zero to an infinite range of resistance.

When the meter shows a zero reading, it indicates that the path between two test leads has zero resistance. This, in turn, indicates that the path is a continuous one. If the path or the conductor is open, then it will show resistance value as infinite.

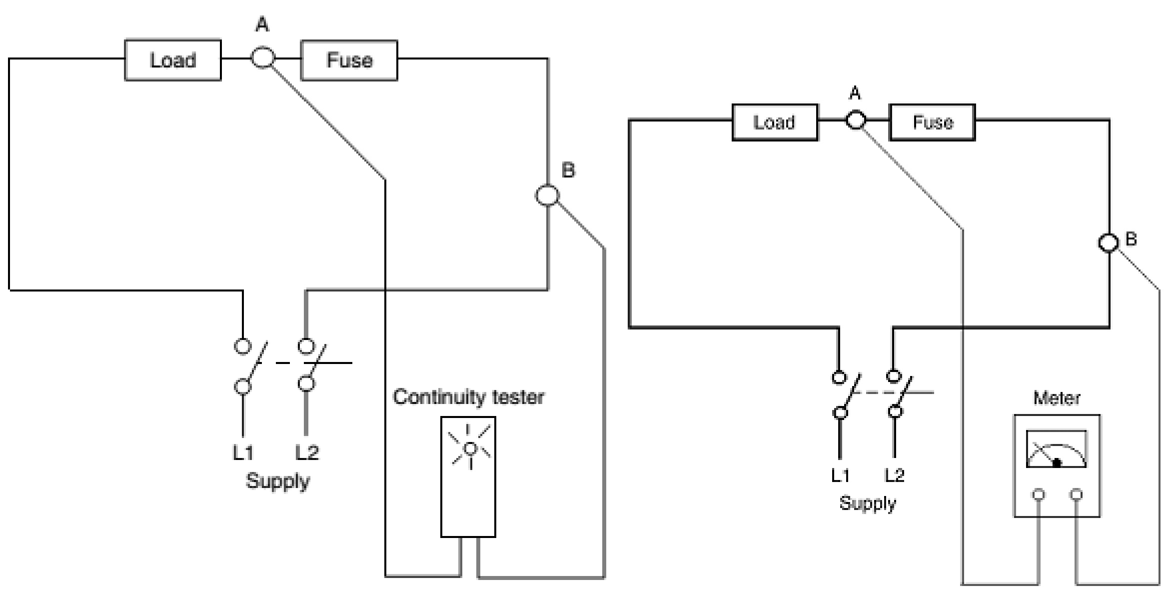


Figure 4.5.2 Continuity test with audio tester   Figure 4.5.3 Continuity test with ohmmeter

In short, continuity testing is used to check the following purposes:

- Integrity of cables

Integrity of electrical circuit path

Integrity of the earthling system (i.e., electrical continuity and low-resistance value to earth)

Accurate wiring of a control and power circuit to the correct terminals

Differentiate active and neutral conductors before connecting them to a device

Check for wrong wiring interconnections between different control and power circuits; thus indirectly, checking for short-circuit paths

Integrity of switches, fuses, and other devices.

A few words of caution are warranted here. Checking for continuity in a control circuit can give erratic results due to the existence of parallel circuits. It is better to disconnect appropriate terminals to ensure correct results. Continuity test in power circuits can be tricky. Often, a circuit where there is an open circuit fault can register excellent continuity with a low power tester or ohmmeter. But when a voltage is applied, current may not flow. The reason for this is that the circuit may be partially continuous (Example: a partially burnt cable where one or two conductor strands may be making contact) but when feeding a heavy load it will behave as a high impedance.

This type of fault will be detected by testing on load using voltage measurements (as illustrated later in this chapter).

(b) Insulation test

This is another test performed on a dead circuit only. The objective is to check for insulation of cables or a power circuit. The device used to check integrity of insulation is known as an 'Insulation-Resistance Tester'. Generally, this is used during the installation of high-voltage power cables and terminations.

In Figure 4.5.6 a general motor circuit is shown with breaker, fuses, and overload relay.

To check insulation of the circuit (excluding motor), disconnect the power supply by opening the breaker

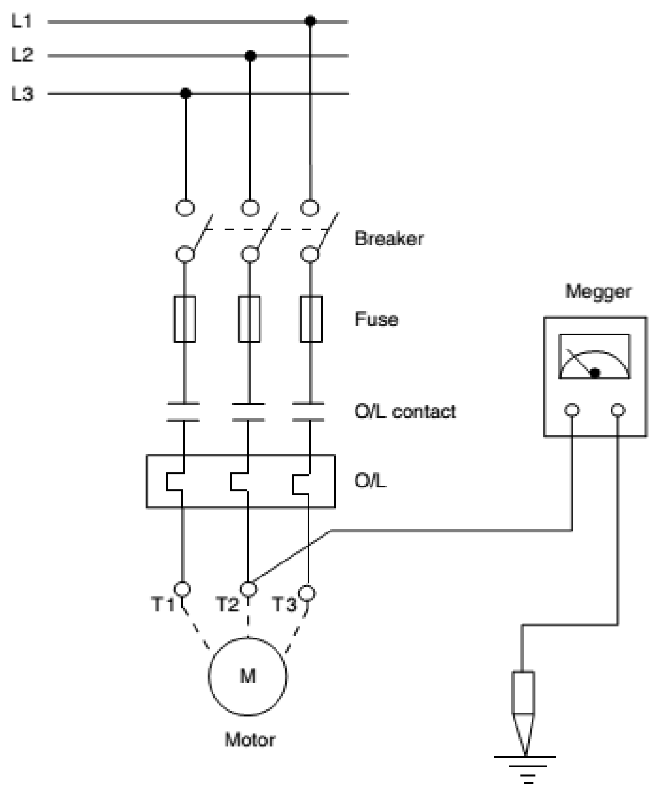


Figure 4.5.4 Insulation test with insulation-resistance tester

Then, isolate the motor from the circuit through terminals T1, T2, and T3. First checking insulation resistance between earth and T1, then earth and T2, and finally earth and T3 checks insulation resistances of conductors, as well as other devices.

If the insulation resistance of any branch shows zero or a very low reading, then it can be concluded that there is an insulation failure.

This test is also used in fault finding, to check for earthed motors or cables and for checking insulation failure of conductors. Individual phases of three-phase motor winding can be insulation-tested only if all six leads of the winding are brought out. The winding being tested should be connected to the tester's output with the other two windings connected together and to the earthed frame of the motor. Where only three leads are available, the insulation of the machine winding as a whole can only be tested with reference to the earthed frame of the motor.

These insulation testers are also called Meggers and have a built-in energy source (either DC generator or battery) to produce test voltages of rating 500 V DC or more.

This is required since the electrical circuit to be tested applies voltage of different ratings.

For example, when the insulation resistance of HV cables is checked, 1000 V minimal voltage is applied, whereas for a domestic circuit 500 V is sufficient for testing.

Testing on a live circuit requires extreme caution and should be restricted to LV circuits.

Precautions should be taken to prevent inadvertent contact of the technician with live parts.

The probes and tools must be insulated with minimum exposure of conducting parts.

This will minize inadvertent bridging of two terminals which are at different potentials which can cause a short-circuit and arcing leading to burn injuries to the technician.

Checks for circuit continuity with live supply

Generally, if possible, troubleshooting is done with a disconnected power supply, but in some circumstances, faultfinding is only possible if the circuit is live.

Therefore, the circuit under testing remains connected with the power supply. This uses the circuit power supply itself as a source of energy for testing.

This kind of testing should be done with extreme care following safety precautions.

As shown in Figure 3.6, the integrity of a power supply or continuity of electric path can be checked by using test lamps. Test lamps are connected in between two phases. Thus, as with the dead circuit test, a continuity test can be performed. In addition, a lamp-type visual tester can be used for simple continuity testing. Alternatively, voltage indicators or multi-meters can be used for checking voltage and the continuity of the conductors or electrical path.

While checking three-phase voltage, use two lamps connected in series and not a single lamp. Currently, most manufacturers give test voltage details for test points that helps to check the integrity of a particular section. Generally, equipments consisting of electronic cards follow this kind of practice.

While checking the voltage at these test points, measuring instruments must be accurate. Therefore, a comparison of voltages at these test points is sufficient to draw conclusions.

Diagnostics for a single-phase motor can be undertaken with this kind of visual indicators. This requires a sound knowledge of circuit and wiring arrangements depending upon the test done, interpretation varies and so does an accurate fault diagnosis.

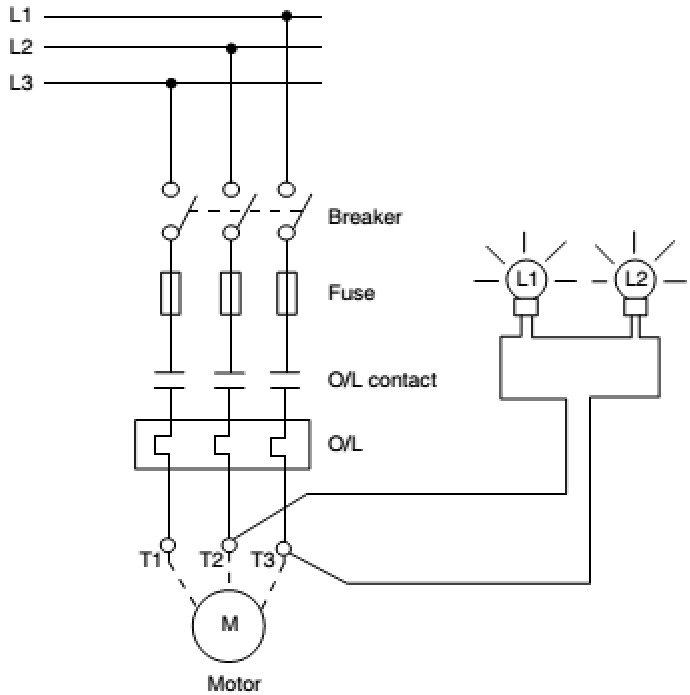


Figure 4.5.5 Continuity test with series test lamps

It is always advisable to check voltage between line-to-line than line-to-earth, since for the latter, the results may be misleading.

Testing on a live circuit requires extreme caution and should be restricted to LV circuits. Precautions should be taken to prevent inadvertent contact of the technician with live parts.

The probes and tools must be insulated with minimum exposure of conducting parts. This will minimize inadvertent bridging of two terminals which are at different potentials which can cause a short-circuit and arcing leading to burn injuries to the technician.

Tests and methods

Although most of the tests have been detailed above, there still remain certain tests that are common and critical to an electrical system. Parameters such as the resistance of leakage paths and resistance of a conductor have to be known for some applications.

The tests include the following:

- Effectiveness of the power earth

- Effectiveness of the electronic earth

Continuity of the earthing system and the required equipotentiality (so as to check the possibility of earth current loops)

Earth pit locations, resistance of earth conductor, material, and size

Location of protection devices, so that the path taken by fault current is minimum and insures the activation of a protection device under fault conditions

Ratings of fuse and other protection devices

Selection of suitable cable types with proper current ratings keeping in mind environmental conditions and length of run

Materials prone to environmental hazards which may be mechanical or chemical, which might be present, such as dampness, high temperature, explosive gases, vapors

Electrical equipments, to ensure that its operation will not cause overload conditions

Location of installation of electrical equipment and accessories.

If all the above points are considered during the installation of an electrical system, there will be a reduced need for troubleshooting. The quality of the system will also be good.

Testing devices

To successfully troubleshoot in a short time, an understanding of the measurement meters that can be used and their various functions is mandatory. This is detailed in the following few sections.

Lamp indicators

A lamp indicator is the most basic tool used for troubleshooting by a practicing electrician. It is also known as a ‘Voltage Tester’. It consists of two 240 V lamps connected in series.

Description

As shown in Figure 4.5.6 both lamps are connected in series along with the fuse and probe that form a testing set. The low-wattage lamps comprise of equal power rating, not greater than 25 W per lamp. Use of two lamps is advisable as the tester may at times be subjected to line voltage (380/400/480) during testing. Single lamp if used may fail and erroneously indicate that the circuit is not live. As a precaution, all voltage testers should be checked before and after the test using a known live source.

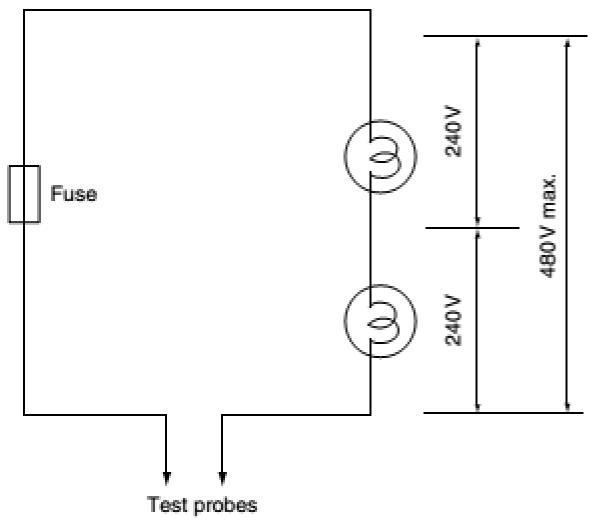


Figure 4.5.6 the two 240 V lamps housed in the housing

<u>Testing of a motor</u>

To check the earth condition, one lead of test lamps is connected to a live terminal of a single-phase supply and the second lead to a winding terminal. If the winding is earthed, the lamps will glow, else they will not glow.

Checking a three-phase supply voltage

To ensure there is no missing phase, connect both leads across the two phases. One of the following three instances will occur:

- If there is no supply then lamps will not glow
- If anyone phase is missing then the lamps will glow at half brightness
- If both phases are connected then the lamps will glow at full brightness.

Present day voltage testers (duly approved types), when correctly handled, are safe live testing devices due to their impedance and rating that a user cannot even mistakenly cause a short-circuit.

One such voltage tester available in the market is known as the ‘high-impedance tester’, this device gives an audible visual indication on detection of the presence of voltage.

A common handy device that is used by technicians for detection of voltage is the ‘Neon Tester’. This consists of a neon indicator with current-limiting resistor in series. When you put its conductive front portion over an active conductor, it will give an indication.

However, in most cases, this indication is faint and this confuses the user. In addition, it cannot be assumed that a lack of indication is the result of a lack of supply. In that case, a neon bulb may be inoperative.

A device used for the detection of electrical potential or for a polarity test is the 'neon test pencil'. It is manufactured in a variety of types and designs. The intensity of glow will increase if a finger is placed on the cap or if the cap is earthed.

Therefore, it is advisable to use a good-quality neon tester from a safety and reliability point of view. It should be noted that the neon tester indicates the voltage of a conductor with reference to earth (because it has only one test lead and the circuit gets completed through the body of the person using it and earth). This test is sometimes not conclusive because an open circuit may exist in the neutral and remain undetected by this test. Also, neon testers sometimes give a glow at very low voltages and results are thus erratic.

A proper voltage measurement using a voltmeter or multi-meter is always more reliable and conclusive.

Figure 4.5.6 high impedance test

Different wiring diagrams

In order to troubleshoot electrical equipments two things are required. One is the location of the equipment to be tested and the other is the interconnection between all the devices (contactors, timers, relay).

The wiring diagram of electrical equipment gives information as stated above. In addition, it shows the identification tags of wires, connectors, relays, etc.

In Figure 4.5.7 the wiring diagram of a DOL starter is shown along with the physical location of the devices. The terminal numbers of overload relays are also shown in the wiring diagram. This enables accurate device wiring and wire tracing during troubleshooting.

Generally, this kind of wiring diagram is given inside an electrical equipment panel cover. This diagram shows the actual position of different devices as closely as possible. The bold line indicates the heavy current carrying conductors, while the thin line indicates the control circuit.

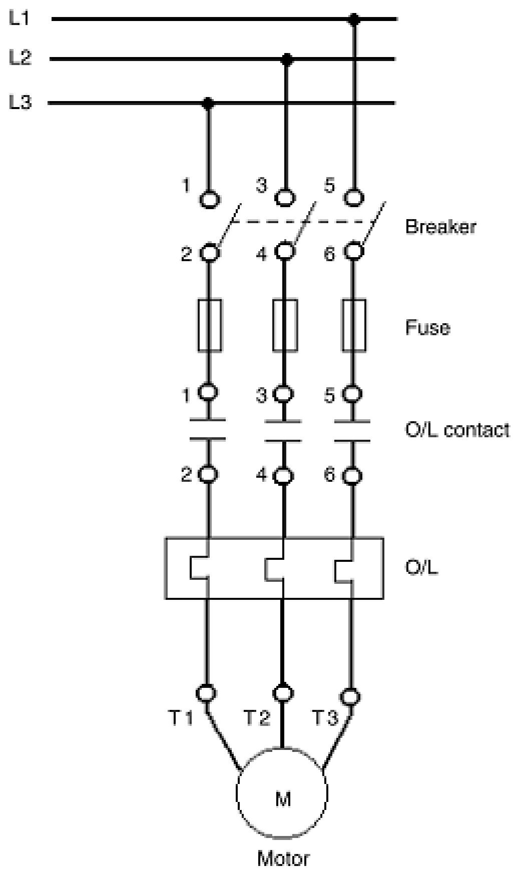


Figure 4.5.7 Simple motor circuit

Accurate wiring of circuits and connections While troubleshooting electrical equipments, continuity tests of circuits and wiring are done by performing the following procedure:

- Checking correct polarity and ensuring that supply polarity follows the correct circuit route.
- Ensuring that there are no short-circuits in supply due to a wrong connection or termination of wires.

- Identifying different conductors before making connections to a device toensure correctness of circuits and connections.
- Ensuring that there are no interconnections between two different circuits.
- Correctly identifying circuit loads such as contactors, relays, and their contacts.
- Identifying active conductors and their corresponding neutral conductors to check the integrity of the circuit.

A continuity test is particularly useful to help detect a short-circuit condition, which is a result of cross-linking of wires between two different circuits.

An interconnection between circuits is likely to be due to the following reasons:

- Incorrect termination of wires
- Result of insulation breakdown
- Incorrect connection at field junction box.

Figure 4.5.8 is an example of an electrical appliance connected with a supply system. If, due to any reason, a fault occurs within the appliance causing current flow in its body, the fault current flows back to the mains supply. The circuit shown here is a TN-C-S type of supply where the earth is derived from the supply neutral at the service entrance. In the case of other supply systems the earth lead may not be interconnected at service entrance but go right back to the source (TN-S). However the general principles are still valid.

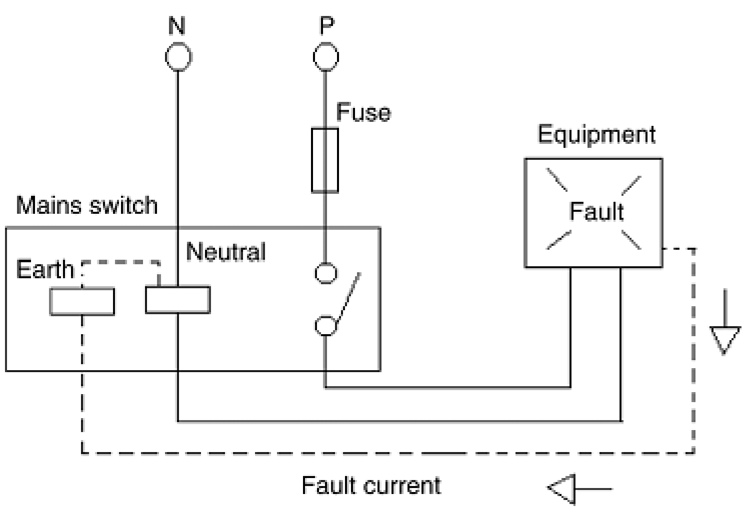


Figure 4.5.8 Earth fault within an installation

It is required to conduct tests between neutral conductors of all other circuits and the active conductor of the same circuit at the mains supply distribution to reveal any interconnection faults.

Before conduction of tests, perform the following steps:

- Disconnect neutral link from circuit
- Keep circuit protective
- Close all contactors or switches.

Check all direct interconnections with the low-range ohmmeter. If resistance shown in the ohmmeter is very low then it indicates a short-circuit condition. Suppose, the load is connected with an active phase and is neutral from different circuits, then it can be detected only with connected loads. If these steps are performed prior to the start of the test, then check the resistance between the neutral and the active conductors.

To check for insulation resistance of cables, take insulation resistance with megger or insulation-resistance tester, especially if insulation breakdown is suspected. If the resistance shown is less than 1 MΩ then it can be said that the wiring or device terminal has an insulation problem.

To identify each electrical circuit and its active and neutral conductors, calculate load resistance with the ohmmeter and accordingly, identify each active and neutral conductor.

Conducting an insulation-resistance test:

To conduct an insulation-resistance test, perform the procedure listed below:

1. Check the insulation tester by shorting its test leads. It should show zero resistance. If test leads are kept open, it should show infinite resistance.
2. Isolate the section to be tested from the power supply.
3. Disconnect all lamps or electronic devices from the circuit to be tested.
4. Select the proper operating voltage for conducting the test, depending upon the rating of the system.
5. Check for connections while conducting tests so that only the section to be tested is included in the test.
6. There should not be any stray parallel leakage paths.

7. Check the instrument for pointer index or any other pre-adjustment necessary.
8. Test leads to be used should have good-quality insulation.
9. Before starting the test, insure that all the capacitors in the circuit are discharged by shorting their two leads together. Similarly, after the test ensure that they are in discharge condition. If this is not done they may give false readings.
10. Before touching cable ends after testing, discharge any energy that might have been stored in the cables during the test. This is most likely to occur in long runs of larger cables due to their capacitance.
11. Checking continuity of an earthing system requires the use of low-reading ohmmeters, which should be zero-adjusted before each test and calibrated on regular intervals.
12. Where the testing of the earth electrode resistance is required (i.e., the resistance between the electrode and the general mass of earth), one of the special types of earth-resistance testers must be used.

Optional tests

There still remain a few useful tests using the measuring devices.

These tests are used for checking single- or three-phase systems and other electrical devices. Some of the tests we have discussed in the next few sections. These can be used to strengthen troubleshooting techniques.

(a) Megger testing cables and auxiliary devices of a single-phase system

Disconnect P and N from the supply side, as well as from the other end.

Now we have isolated our test circuit, making it dead. Short P and N with a temporary short link. Close switch and protection devices.

As shown in Figure 4.5.9, open motor terminals, so that the motor remains isolated from the test circuit. Check resistance with the insulation tester between the neutral link and earth. If the value shown in the meter is less than 1 MΩ, then there is a fault with either the cable insulation or device terminals.

(b) Megger testing cables and auxiliaries of a three-phase system

Disconnect L1, L2, and L3 from the supply side, as well as from the other end. This makes it a dead circuit.

Short L1, L2, and L3 terminals with a temporary link. Close the breaker device and protection devices. As shown in Figure 3.22, open motor terminals T1, T2, and T3, so that the motor remains isolated from the test circuit.

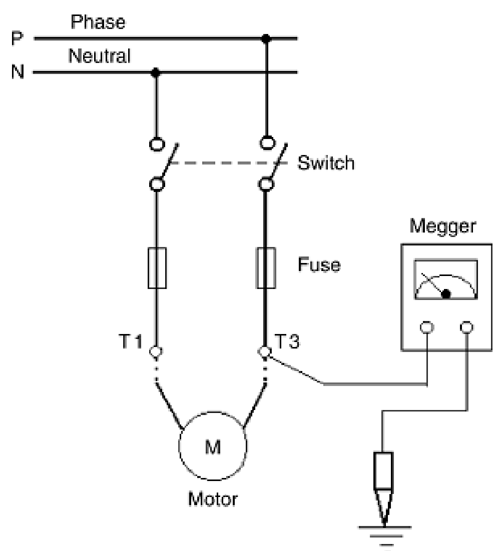
Check resistance with insulation tester between each conductor and earth.

If the meter shows a low value less than 1 MΩ, there is a fault in either cable insulation or device terminals.

(c) Megger testing of motor

A pre-condition for megger testing of a motor is to isolate the motor from the supply totally. Take the megger value of a motor between each conductor and earth, as shown in Figure 3.23, to check the earthing of the stator winding. This will help us to conclude on earthing status of the stator winding. Similarly, check for shorting between two windings by checking the megger value between two stator-winding terminals, as shown in Figure 4.5.12

Thus, a low reading can identify insulation failure of any winding inside the motor.



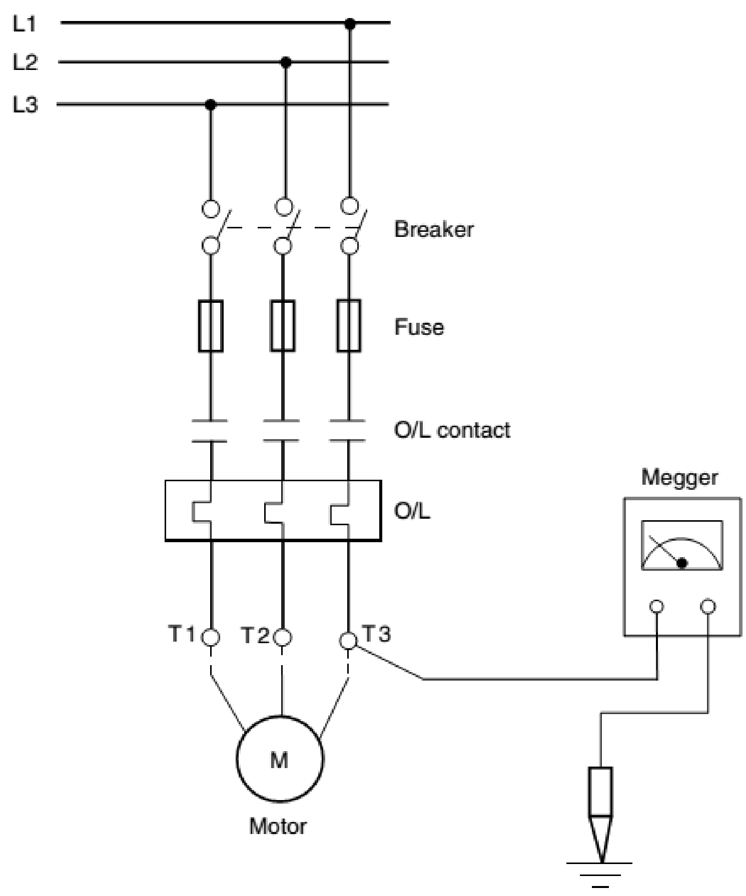


Figure 4.5.9 Megger of a single-phase system   Figure 4.5.10 Megger of a three-phase system

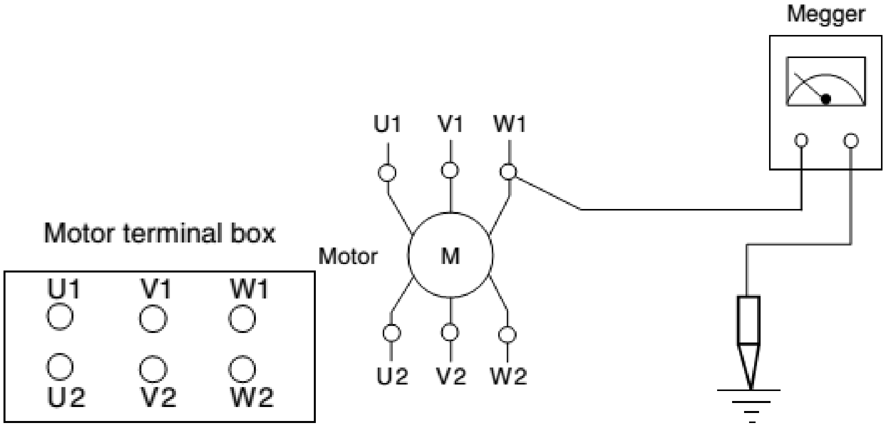


Figure 4.5.11 Megger testing for an earthed winding condition

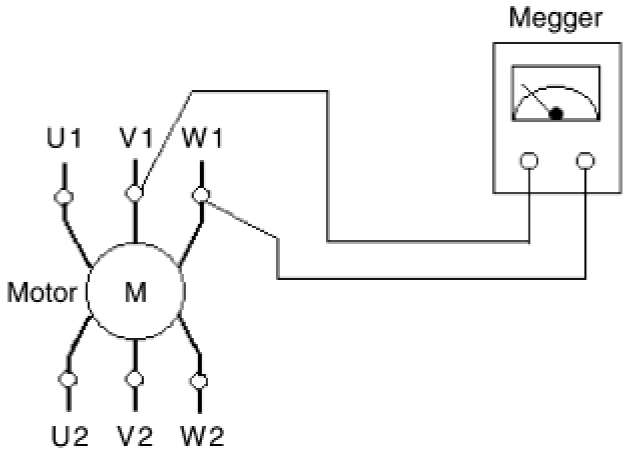


Figure 4.5.12 Megger testing for winding-to-winding short condition

Fault finding on an underground cable generally, underground cables are prone to insulation failure, although due care is taken.

Since they are buried underground, it is difficult to exactly pinpoint the fault location. Resistance values between earth and a conductor from the two ends can be checked. If the value reduces drastically, then the faulty location can be isolated.

Tests for installation and troubleshooting

The following are a few tests used during commissioning and troubleshooting:

1. Insulation test: This is the most important test for troubleshooting of any electrical equipment. Depending on the system, a suitable test voltage is applied to check the insulation resistance between the live conductors and earth.

2. Earth continuity test: For electrical equipment, continuity between the exposed portion (metallic) of earthed equipment and the earth terminal is checked. Resistance value should be low. If resistance value is high, then it is indicative of poor earthing.
3. Flash test: To check the insulation strength of cables, a high voltage (as specified by the cable manufacture) is applied in the same way as for the insulation test. This determines the withstand capability of the cable insulation.

4. Electronic earth test: Generally, for microprocessor-based or electronic based sensitive devices, separate earthing is provided. This is called electronic earth. The voltage between the electronic earth and the power earth should be lower than 2 V.

Self-Check 5	Written Test

Part II: Enumeration

Direction: Write/List down the following

1. Classification of electrical problems.

a) ________________

b) ________________

2. List insulation-resistance test procedure

a) ________________

b) ________________

c) ________________

d) _______________

Answer Sheet

Score = ___________

Rating: ____________

Name: _________________________ Date: _______________

Information Sheet-6	4.6. Coordinating other works with other concerned group associated with the problem.

4.6.1 Coordinating other works

Many of us have looked for and found a job in industry in the hope of getting secure employment. Another equally important reason is to develop new skills with good career prospects. We expect the job to be rewarding and free from harmful effects. We also want it to give us stimulation and personal development.

Work with the discussion topics:

Reading the manual will help you discuss safety, health and working conditions in your country. Special boxes have been provided containing discussion topics which relate to the text preceding each box.

The "Discussion Topics" are designed to enable a comparison of the information given in the manual with your experience in your own country. We would like to hear what you think and what you have experienced.

Better quality of working life

In our daily working life, the way work is done and scheduled is fundamental. When a worker's skills and abilities do not match the job, or when schedules of work do not leave sufficient time for rest and leisure, serious problems arise for both the worker and the employing organisation.

In the family and among friends and acquaintances, it is vitally important to feel that our work is meaningful, that we can exercise some influence, and that we really have the opportunity to develop our own individual abilities and to provide a service to society.

The pattern of work organisation, which has a direct influence on job content, largely determine whether work is arduous or enhancing, unpleasant or satisfying.

The duration of work – every day, every month, every year and for the whole of our working life – can also greatly affect the safety, health and value of our daily life.

Work organization and job content

CHANGE IN JOB TASKS

Technological change in modern society has also changed the way individual jobs are performed. Organization of work, including use of skills, control over work and communications, has been greatly affected by a high degree of "division of labour".

Until recently, it was assumed that job characteristics were predetermined by technical and economic considerations. Managers were supposed to find the "one best way" to define jobs. The idea was to break the work up into task and assign each worker the simplest possible combination of tasks.

It was often thought that in order to make sure any worker could do the work, it was necessary to design tasks that call for minimum skills. However, if our jobs do not provide the possibility for developing useful skills and self-respect, we can all too often lose our sense of self-esteem. Such jobs are not very productive, either.

We now know that better jobs can be provided by improved methods of work organisation. These methods are important not only because they improve jobs from the workers' point of view, but because they lead to higher productivity and better use of technology.

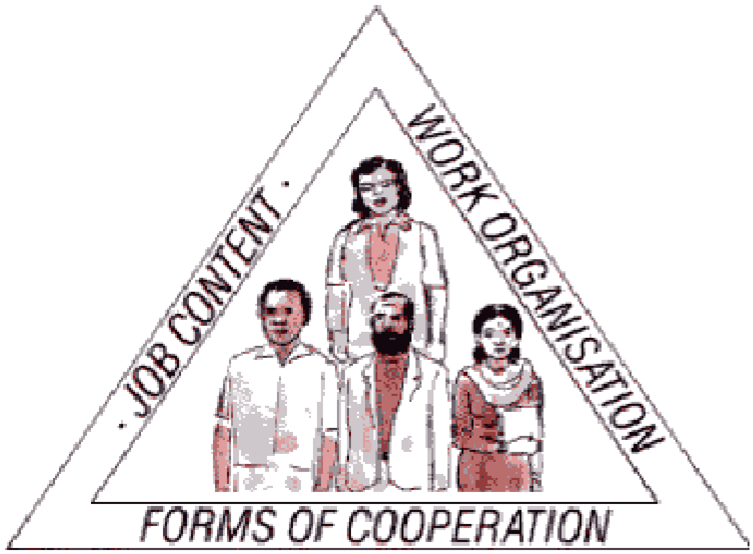
Poorly organized work

Before considering how jobs can be improved, we should consider some of the disadvantages of work which is poorly organised. For example: oversimplified jobs require little skill and provide few opportunities to learn anything useful. The worker is

- "underutilized";
- repetitive jobs are monotonous and boring;
- jobs for learning or growth limit the workers'
- career possibilities;
- jobs which have no real responsibilities require continuous supervision;
- Jobs where performance is measured by repetition of a simple task are frustrating and stressful.

A good job

To improve work organisation and job content, it is useful to consider the characteristics of good jobsfree from excessive stress, fatigue or pressure. The right tools equipment, supplies and assistance and enough time to do good work will be necessary. In addition, a good job should have:



Group work

A very flexible way of improving work organisation and job content, with many advantages for both management and workers, is group work. Most people like to work together and co-operate. Moreover, in cooperative work, the weaknesses of one worker can be compensated by the strengths of another. Similar adjustments can be done for differing preferences, temporary problems including absences, etc.

There are various ways of organising effective group work. Many of the traditional types of work take into account the advantages of group work. A typical new form of work is a semi-autonomous work group which can decide, to a considerable extent, work methods, scheduling, work assignment and problem solving

Self-Check 1 Written Test

Direction: Answer the following questions accordingly

1. Write the purpose of Coordinating other works
2. List out Poorly organized work

Answer Sheet

Name: ____________________________ Date: ________________

Information Sheet-7	4.7.1 Recording details of:

4.7.1 Fault

TROUBLE SHOOTING

- **The Electro Technical Officer** in a control area is a member in the Engine department and reports to the **Chief Engineer**.
- The ETO is responsible for the proper upkeep and maintenance of the systems and equipments in his charge.
- When faults develop in equipments or circuits **faulty**, it is the responsibility of the ETO to quickly rectify the faults and restore normalcy. He must use all the resources available to him (tools, spares etc.), in rectifying the defects, restoring equipment to normal service and also take such preventive measures to **avoid recurrence of such faults**.
- If immediate rectification of the fault is not possible due to, say. want of spares etc. ETO must initiate necessary action to procure spares or **arrange for external help**.

FAULT FINDING OR TROUBLE SHOOTING

- Trouble shooting/Fault-finding can be a nerve-racking (at times, nerve-wrecking) experience if done in **a haphazard manner**, but
- Fault-finding can be interesting and rewarding (a knowledge- booster) if done **methodically.**
- A logical approach supported by **knowledge** and **experience** will certainly help.

PLANNING

- A ***Planned strategy*** as to how to go about the trouble shooting ***in a sequence*** is to be decided before deciding what action is to be taken to solve the problem.
- Acting on impulses will fail most of the time.

BACKGROUND KNOWLEDGE

- When we analysis the fault, it is necessary to go through the manuals, drawings etc., to gain necessary knowledge about the equipment fitted, the operation of the equipment /system and do’s and don’ts about the operation.
- Acquiring a fairly good knowledge about various equipment, their general operating procedures, study of relevant drawings and technical manuals is a must for the Technical personnel.

MEMORY

- Retaining the knowledge gathered about the equipment gained in advance will speed up the trouble-shooting.
- Retention can not only be improved by a good memory but also by going through the drawings and manuals again and again when the time permits.

LOGICAL THINKING

- Jumping to conclusions based on impulses will not only delay the trouble-shooting but can make one go on a **"Wild goose chase"** resulting in extension of downtime.
- Logical thinking beginning with the ***"least probable fault"*** and proceeding to a "more serious kind of probable fault" can help a lot

DIAGNOSTIC AIDS

- Relevant Drawings
- Technical Manuals
- Trouble –Shooting Charts
- Evidence collected (Operators feedback, Symptoms) etc.
- Test equipments

SOCIAL SKILLS

- A **good inter-personal relationship** with Operators, allied technicians from other departments can many a times save the situation by getting
  - a) A historical account about past performance of the equipment and defects occurred.
  - b) Performance of allied equipment which can cause the electrical equipment to fail (e.g. a Pump not performing properly leading to a motor failure)

BASIC STEPS

- A six-step approach combined with points brought forth earlier are
  1. Collect Evidence
  2. Analyse evidence
  3. Locate fault
  4. Determine and remove cause
  5. Rectify fault
  6. Test system for normal operation

- OBSERVE SAFETY PRECAUTIONS

PREVENTION

- It is as important to prevent recurrence of fault as it is important to rectify the fault.
- Many a times, it may be possible to prevent recurrence along with rectification of the fault
- If time or operational requirements do not permit, the defect may be noted down and prevention of recurrence attempted at the immediate future.
- Maintaining a Log book for defects and the corrective actions taken can be of valuable assistance in the maintenance of the equipment

TEST EQUIPMENT

- Insulation Resistance Tester - Meggers (Hand/motor cranking)

Multimeters (Digital/Analogue)

- Clamp-on Ammeter/Tong Testers
- LV/HV Live-Line Testers
- TEST & PROVE THE TEST EQUIPMENT FOR CORRECT OPERATION BEFORE USE.
- FAULTY TEST EQUIPMENTS CAN OFTEN MISLEAD DURING TROUBLE-SHOOTING

Fault and Possible cause

Various types of faults and their detection techniques.

A. Bearing faults

The majority of electrical machines use ball or rolling element bearings. Each of these bearings consists of two rings, one inner and the other outer. A set of balls or rolling elements placed in raceways rotate inside these rings. Even under normal operating conditions with balanced load and good alignment, fatigue failures may take place. These faults may lead to increased vibration and noise levels. Flaking or spalling of bearings might occur when fatigue causes small pieces to break loose from the bearing. Other than the normal internal operating stresses, caused by vibration, inherent eccentricity, and bearing currents due to solid state drives, bearings can be spoiled by many other external causes such as:

a) Contamination and corrosion caused by pitting and sanding action of hard and abrasive minute particles or corrosive action of water, acid etc.

b) Improper lubrication; which includes both over and under lubrication causing heating and abrasion.

c) Improper installation of bearing. By improperly forcing the bearing onto the shaft or in the housing (due to misalignment) indentations are formed in the raceways (brine ling).

Though almost 40-45% of all motor failures isbearing related, very little has been reported in literature regarding bearing related fault detection. Bearing faults might manifest themselves as rotor asymmetry faults, which are usually covered under the category of eccentricity related faults.

Experiments were conducted on defective bearings with scratches on the outer races and bearing balls and cage defects. It has been claimed that all defective measurements were correctly classified as defective. However, the detection procedure required extensive training for feature extraction.

B. Stator or armature faults

These faults are usually related to insulation failure. In common parlance they are generally known as phase-to-ground or phase-to –phase faults. It is believed that these faults start as undetected turn-to-turn faults, which finally grow and culminate into major ones. Almost 30-40% of all reported induction motor failures falls in this category.

Armature or stator insulation can fail due to several reasons. Primaries among these are:

a) High stator core or winding temperatures,

b) Slack core lamination, slot wedges and joints.

c) Loose bracing for end winding.

d) Contamination due to oil, moisture and dirt.

e) Short circuit or starting stresses

f) Electrical discharges

g) Leakage in cooling systems

There are a number of techniques to detect these faults. [Penman 1997] was able to detect turn to turn faults by analyzing the axial flux component of the machine using a large coil wound concentrically around the shaft of the machine. Even the fault position could be detected by mounting four coils symmetrically in the four quadrants of the motor at a radius of about half the distance from the shaft to the stator end winding.

[Tolyiat 1995] has shown through both modelling and experimentation that these faults result in asymmetry in the machine impedance causing the machine to draw unbalance phase currents. This is the result of negative sequence currents flowing in the line as also have been shown in [Williamson 1984]. However, negative sequence currents can also be caused by voltage unbalance, machine saturation etc.

[Kliman 1996] model these unbalance which also includes instrument asymmetries. It is reported that with these modifications it is possible even to detect a one turn "bolted" fault out of a total 648 turns. Statistical process control (SPC) techniques have also been applied to detect stator faults [Dister 1994]

C. Broken rotor bar and end ring faults

Unlike stator design, cage rotor design and manufacturing has undergone little change over the years. As a result rotor failures now account for around 5-10% of total induction motor failures.

Cage rotors are of two types: cast and fabricated. Previously cast rotors were only used in small machines. However, with the advent of cast ducted rotors; casting technology can be used even for the rotors of machines in the range of 3000 kW. Fabricated rotors are generally found in larger or special application machines. Cast rotors though more rugged than the fabricated type, can almost never be repaired once faults like cracked or broken rotor bars develop in them.

The reasons for rotor bar and end ring breakage are several. They can be caused by:

a) Thermal stresses due to thermal overload and unbalance, hot spots or excessive losses, sparking (mainly fabricated rotors).

b) Magnetic stresses caused by electromagnetic forces unbalanced magnetic pull, electromagnetic noise and vibration.

c) Residual stresses due to manufacturing problems.

d) Dynamic stresses arising from shaft torques, centrifugal forces and cyclic stresses.

e) Environmental stresses caused by for example contamination and abrasion of rotor material due to chemicals or moisture.

f) Mechanical stresses due to loose laminations, fatigued parts, bearing failure etc.

[Kliman 1988], [Thomson 1988], [Filippetti 1996], [Elkasabgy 1992] used spectrum analysis of machine line current (MCSA) to detect broken bar faults. They investigate the sideband components around the fundamental for detecting broken bar faults.

D. Eccentricity related faults

Machine eccentricity is the condition of unequal air-gap that exists between the stator and rotor [Vas 1993], [Cameron 1986]. When eccentricity becomes large, the resulting unbalanced radial forces (also known as unbalanced magnetic pull or UMP) can cause stator to rotor rub, and this can result in the damage of the stator and rotor. There are two types of air-gap eccentricity: the stati cair-gap eccentricity and the dynamic air-gap eccentricity. In the case of the static air-gap eccentricity, the position of the minimal radial air-gap length is fixed in space. Static eccentricity may be caused by the ovality of the stator core or by the incorrect positioning of the rotor or stator at the commissioning stage. If the rotor-shaft assembly is sufficiently stiff, the level of static eccentricity does not change.

In case of dynamic eccentricity, the centre of the rotor is not atthe centre of the rotation and the position of minimum air-gap rotates with the rotor. This misalignment may be caused due to several factors such as a bent rotor shaft, bearing wear or misalignment, mechanical resonance at critical speed, etc. Dynamic eccentricity in a new machine is controlled by the total indicated reading (TIR) or “run-out” of the rotor [Thomson 1997]. An air-gap eccentricity of up to 10 % is permissible. However, manufacturers normally keep the total eccentricity level even lower to minimise UMP and to reduce vibration and noise.

The presence of static and dynamic eccentricity can be detected using motor current signature analysis - MCSA [Vas 1993], [Cameron 1986]. Modelling based approaches to detect eccentricity related components in line current have been described in [Nandi 1998-1], [Nandi 1998-2]. The simulation results obtained through the models are also well supported by permeance analysis and experimental results.

Vibration signals can also be monitored to detect eccentricity-related faults. The high frequency vibration components for static or dynamic eccentricity are given by [Cameron 1986].

Time stepping finite element methods have been employed recently to compare simulated results with experimentally obtained static eccentricity components in line currents [Barbour 1997]. Static eccentricity has also been modelled using Winding Function Approach [Toliyat 1996].

Other approaches, such as monitoring the stator voltage and Current Park’s Vector [Cardoso 1993] to detect eccentricity in induction motor, can also be found in literature.

[Tolyiat 1997] has provided simulation and experimental results for synchronous machines with dynamic eccentricity related faults.

PROTECTION SYSTEM

A Protection System

• A power system is designed to generate sufficient power to meet present and future needs, to transmit it to areas where it will be used and distribute it within the area on a continuous basis without major breakdowns.

• There are two ways of achieving the above requirement a. By choosing fail-safe equipment which require little or no maintenance - not an economical proposition.

b. By foreseeing any possible failures in the power system and restrict the disturbances to a limited area and continue power distribution in the remaining areas.

• The special equipment adopted to detect such possible faults is referred as "PROTECTIVE EQUIPMENT" and the system that uses such equipment is termed as "PROTECTION SYSTEM"

Basic requirements of a Protection equipment

- Requirements of Protection equipment

a. Safeguard the entire power system to maintain continuity of power supply

b. Minimize damage and repair cost where it senses the fault.

c. Ensure safety of personnel.

- The above requirements are necessary for

a. Early detection and localization of fault.

b. Prompt removal of faulty eqpt. from service

- In order to carry out the above duties, the protection system must have the following qualities

a. Sensitivity – To detect even the smallest fault and operate correctly before the fault causes irreparable damage

b. Selectivity – To detect and isolate only the faulty eqpt/area.

c. Stability – to leave all healthy circuits intact to ensure continuity of supply.

d. Speed – To operate speedily when called upon, minimizing damage to eqpt.& surroundings and ensure safety of personnel.

Speed of Protection system

- Protection System must act fast to isolate faulty sections to prevent

a. Increased damage at fault location (Fault energy = square of fault current x fault resistance x duration of fault)

b. Danger to operating personnel (flash over due to high fault energy)

c. Higher mechanical & Thermal stressing of all items of the plant carrying the fault current

d. Sustained voltage dips resulting in instability of operation of motors and generators.

Reliability of a Protection System

- A Protection system is said to be reliable when it assures dependability and security.
- A dependable system must trip when called upon to trip
- A secure system must not trip when it is not supposed to trip.

Basic Components of A Protection system

- Fuses – Self-destructing device to save the eqpt being protected.
- Voltage and current transformers – to monitor and give accurate feedback about the healthiness of power system
- Relays – to convert the signals from the monitoring devices and give signals to

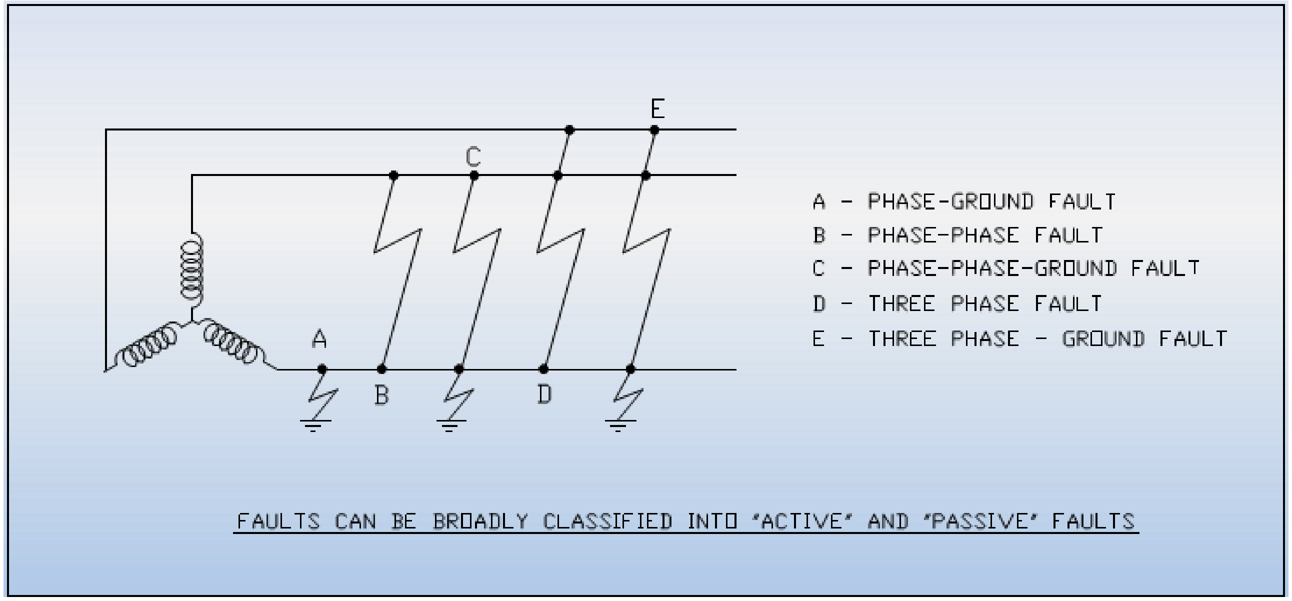
a. Open a circuit breaker or

b. Give an alarm when the eqpt being protected is approaching towards possible destruction

Circuit Breakers – capable of making and breaking circuits during fault and to break the circuit in a short time based on feedback from relays.

- DC Batteries – Give uninterrupted power supply to relays & breakers and is independent of the main power source being protected.

Types of faults in Power systems



<u>"Active" faults</u>

 Active faults are when there is a current flow from phase-phase or phase-ground.

 Active faults can further be classified as "solid" faults and "incipient faults"

 Solid faults occur as a result of complete breakdown of insulation. The fault current magnitude will be very high and must be cleared as quickly as possible to avoid detrimental effects.

 Incipient faults are those which start as a small fault but magnifies into a solid fault over a period of time e.g.

1. Partial discharge- Corona
2. High resistance joints/contacts
3. Pollution of insulators causing "tracking"

"Passive" faults

 Passive faults are not real faults but are conditions that are stressing the system beyond its design capacity, so that ultimately, active faults will occur .e.g.

1. Overloading- leading to overheating of the ` `
insulation (deteriorating, reducing life and causing ultimate

failure)

2. Overvoltage- Stressing the insulation beyond its withstand capacity

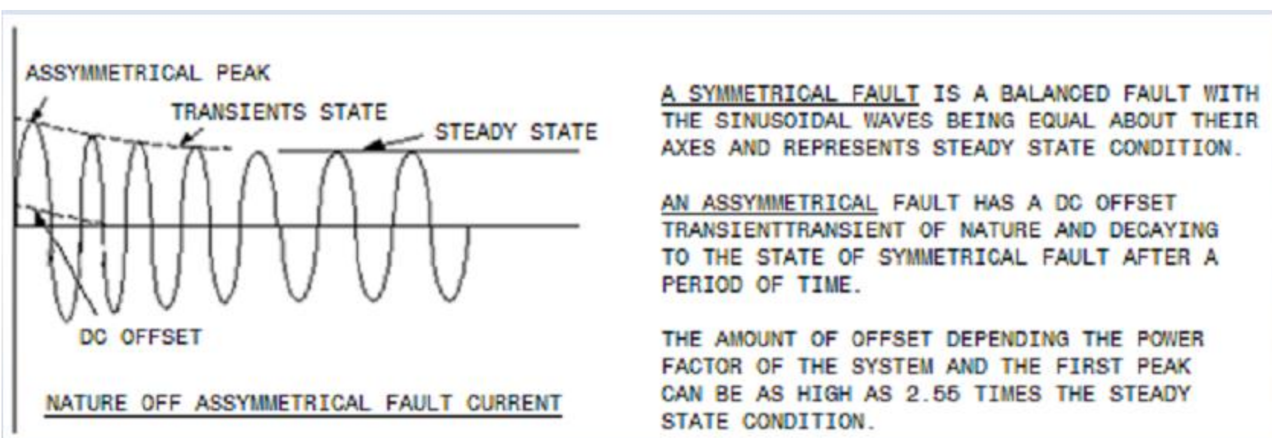
3. Power swings – Generator going out of step or out-of-synchronism with each other.

- It is therefore, necessary to monitor these conditions to protect the system against these conditions.

Transient & Permanent Faults

- Transient faults are faults, which do not damage the insulation permanently and allow the circuit to be safely re-energised after a short period.
- For example, a flashover of the insulator after a lightning strike will be successfully cleared on opening of the Circuit Breaker, which could then be auto re-closed.
- Transient faults occur mainly on outdoor eqpt. where air is the medium of insulation.
- Permanent faults are the result of permanent damage to the insulation. In this case, the eqpt. has to be repaired and re-charging must not be entertained before repair/replacement.

Symmetrical & Asymmetrical Faults



Calculation of Fault levels

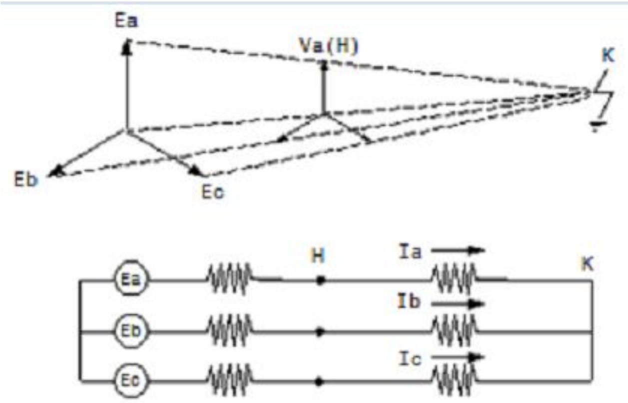
- Accurate method of calculating fault currents is by using an analysis method called “Symmetrical Components” involving the use of high maths.

- Other methods include

1. Ohmic reactance method
2. Percentage impedance method
3. Per unit method

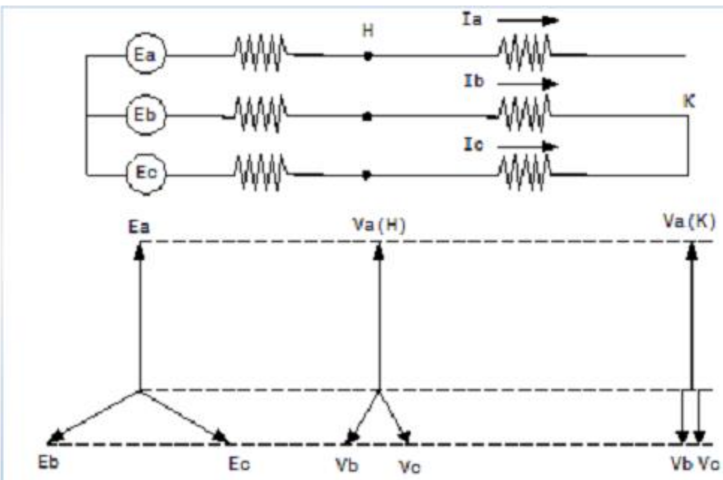
- Besides the above there are certain “Thumb rules” applied to calculate fault currents in smaller power system.

Three Phase short circuit



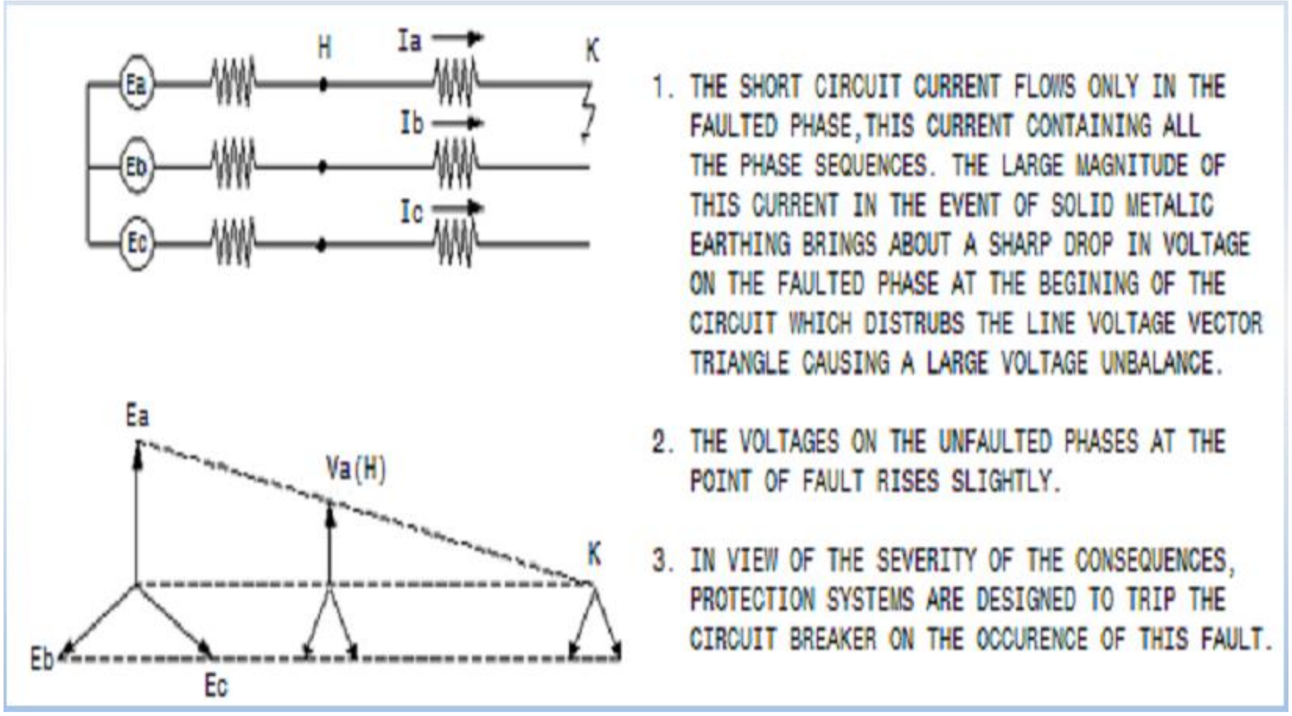
1. THE SYSTEM OF VOLTAGES AND CURRENTS RETAIN ITS SYMMETRY DURING SHORT CIRCUIT.
2. THE MAGNITUDE OF THE SHORT CIRCUIT CURRENT CONSIDERABLY EXCEEDS THAT OF NORMAL LINE CURRENT.
3. THE VOLTAGE AT THE SOURCE END OF THE CIRCUIT IS LESS THAN THE NORMAL PHASE VOLTAGE, AND AT THE FAULT, EQUAL TO ZERO.
4. THE PHASE RELATIONS BETWEEN THE SHORT CIRCUIT CURRENT AND THE VOLTAGES AT THE SOURCE END ARE DEPENDANT ON THE LINE IMPEDANCE. PHASE ANGLE IS USUALLY GREATER THAN THAT EXISTING DURING NORMAL CONDITIONS.

Phase – to – Phase Fault

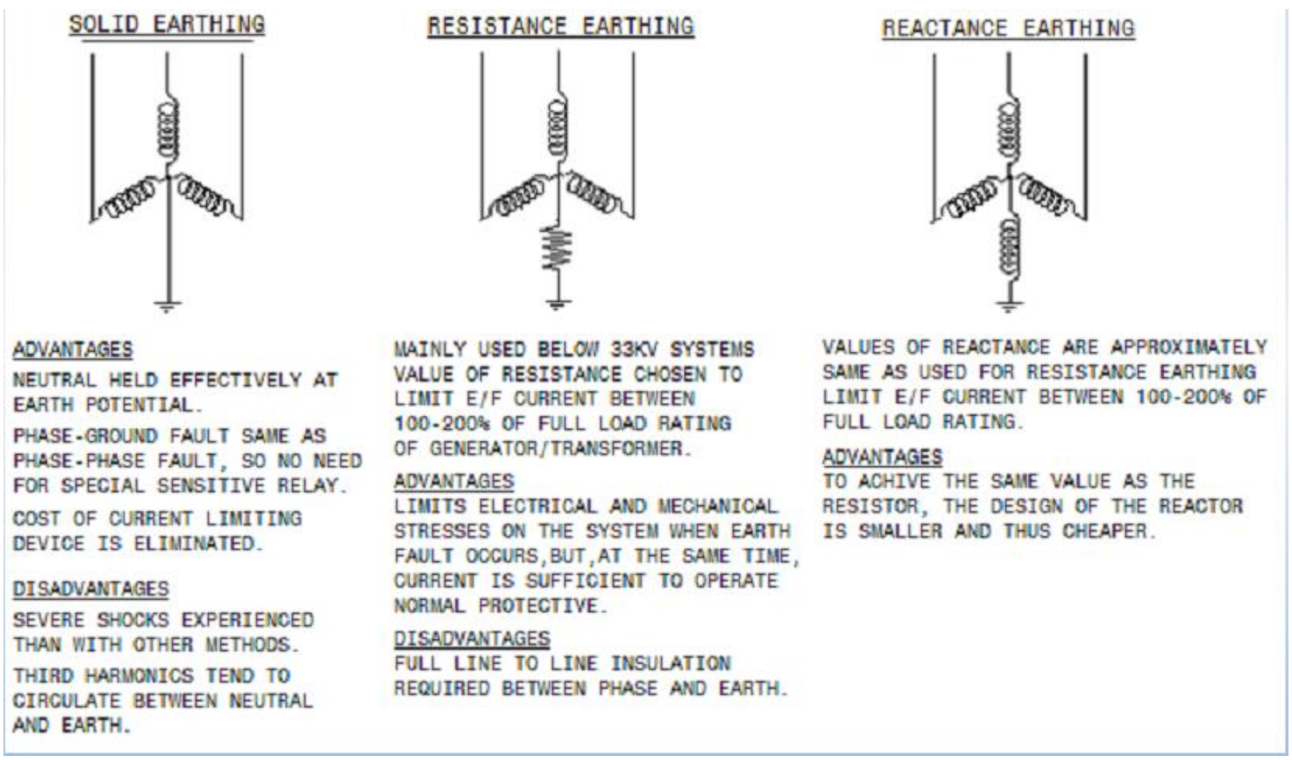


1. PHASE TO PHASE SHORT CIRCUITS SHARPLY DISTRUB CURRENT AND VOLTAGE SYMMETRY.
2. IN THE FAULTED PHASE, HEAVY SHORT-CIRCUIT CURRENTS FLOW.
3. AT THE FAULT, THE VOLTAGES IN THE SHORTED PHASES ARE EQUAL TO ONE HALF THE NOMINAL PHASE VOLTAGE.
4. AT THE SOURCE END, THE VOLTAGES ARE HIGHER BUT LESS THAN NORMAL VALUE.
5. THE LINE VOLTAGE VECTOR IS DISTRUBED.
6. THE PHASE RELATIONS BETWEEN VOLTAGES AND CURRENT CHANGE RADICALLY.
7. PHASE TO PHASE SHORT CIRCUITS MUST BE SWITCHED OUT BY THE PROTECTION SCHEME.

Phase – to – Ground fault



Methods of Neutral Earthing



CONTROL EQUIPMENT

The faults liable to occur in this equipment will depend upon the design of the control scheme supplied. It is only possible to give general recommendations regarding fault findings on this equipment.

Fault	Possible cause
Circuit fuses blowing	a) Incorrect rating of fuse used. b) Short circuit between panel wires and/or between wires and frame.

Action

a) Check circuit rating and fit new fuse of the recommended rating.
b) From circuit diagram check wiring of components. Rewire or replace components found faulty.

Fault	Possible cause
Circuit operating satisfactorily only intermittently	Faulty or out of adjustment relay or auxiliary contacts.

Action

Replace and/or readjust auxiliary and clean where necessary.

Corrective action

Corrective Action

Corrective action (CA) is to remove the root cause and prevent a problem from ever happening again.

The corrective action should correspond to the root cause identified earlier in order to eliminate the real root cause and prevent recurrence of the problem.

Method such as brainstorming is recommended as it can help to select appropriate corrective action for identified root cause.

If Corrective Action is needed –what to do?

• Decide whether the Corrective Action needs to involve:

- New products (design and manufacturing changes) ;
- Products in the supply chain and potentially;
- Products in the hands of consumers.

• Decide what Corrective Actions need to be carried out ;

• Agree responsibilities and actions with distributors ;

• Inform market surveillance authorities.

If the action involves products in the hands of consumers you need to:

• Determine how to trace the products and their owners ;

• Set up a communication programme;

• Draft any Corrective Action message clearly and simply;

• Decide how to communicate the message;

• Deal with your consumers;

• Communicate with others who need to know;

• Carry out Corrective Actions or recall the products concerned;

• Deal with products that have been returned;

• Monitor the response to the Corrective Action and decide if further action is needed.

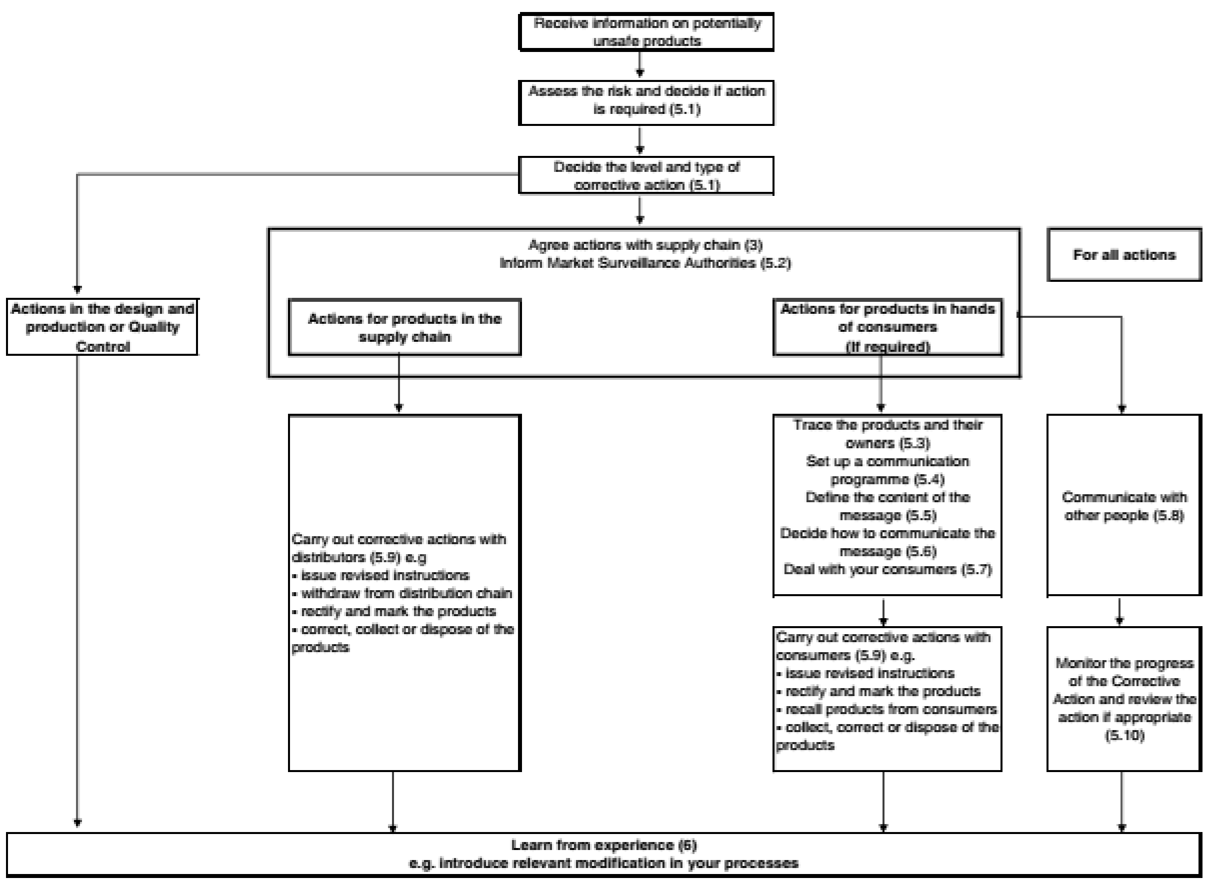
4. After Corrective Action –learn from experience

• Review design requirements and improve quality system to try to avoid future problems (if not already fully covered as part of the Corrective Action programme) ;

• Assess the success of your Corrective Action procedure and make any improvements ;

• Send comments and thanks to key participants.

Corrective Action Procedure Flowchart



Self-Check 1	Written Test

Direction: Answer the following questions accordingly

4. Methods of Fault finding or trouble shooting
5. Various types of faults and their detection techniques
6. Write Basic Components of A Protection system

Answer Sheet

Score = ___________
Rating: ____________

Name: _________________________ Date: _______________

Instruction Sheet	LG30: Troubleshooting Electrical System or equipment

This learning guide is developed to provide you the necessary information regarding the following content coverage and topics –

- Notifying completion of work to immediate superior
- Performing performance tests to ensure the work
- Checking, cleaning and returning tools, equipment and any surplus material
- Cleaning work area and make safe in accordance with OSHA requirements.
- Preparing service report and submit to appropriate officer

This guide will also assist you to attain the learning outcome stated in the cover page. Specifically, upon completion of this Learning Guide, you will be able to –

- Notify completion of work to immediate superior
- Perform performance tests to ensure the work
- Check, clean and return tools, equipment and any surplus material
- Clean work area and make safe in accordance with OSHA requirements.
- Prepar service report and submit to appropriate officer

Appropriate personal protective equipment is used in line with standard procedures.

Learning Instructions:

17. Read the specific objectives of this Learning Guide.

18. Follow the instructions described below 3 to 6.
19. Read the information written in the information “Sheet 1, Sheet 2, Sheet 3 and Sheet 4”.
20. Accomplish the “Self-check 1, Self-check t 2, Self-check 3 and Self-check 4” **in page -9, 28, 32 and 35** respectively.
21. If you earned a satisfactory evaluation from the “Self-check” proceed to “Operation Sheet 1,” **in page -36.**
22. Do the “LAP test” **in page – 37** (if you are ready).
23.

Information Sheet-1	5.1 Notify completion of work to immediate superior

Self-Check 1	**Written Test**

Direction: Answer the following questions accordingly

7. List the initial visual inspection of an installation checklist. (at least 4)
8. What is the aim/purpose of visual inspection?
9. What are the elements chosen for visual inspection?

Answer Sheet

Score = ____________

Rating: _____________

Name: ___________________________ Date: ________________

Information Sheet-2	**Conduct appropriate functional test(s)**

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