BE8254 BASIC ELECTRICAL AND INSTRUMENTATION ENGINEERING

UNIT I AC CIRCUITS AND POWER SYSTEMS

PART A

1. **Give the relation between V_{ph}, I_{ph}, and I_{ph} for a star circuit. (Dec-2006)**

   $V_L = \sqrt{3}$ Vph $\qquad I_L = I_{ph}$

2. **Write the expression for determining real, reactive and apparent power in a three phase circuit. (May-2007)**

   Real Power: $P = \sqrt{3}\ V_L\ I_L\ Cos\theta$ **Reactive power:** $Q = \sqrt{3}\ V_L\ I_L\ Sin\theta$
   Apparent power: $S = \sqrt{3}$ V I

3. **Which type of connection of three phase system is preferred at the point of utilization? Why? (May-2007)**

   Three phase star connected system is preferred at the point of utilization. Because this connection has netural point. In this utilization side, most of the loads are single phase loads. Three loads require one phase and netural point. Therefore 3-phase star connected system is mainly used in utilization side.

4. **What is the level of voltage for a) generation b) Transmission c) Distribution ? (Dec-2004)**

   a) Generation = 11 kv b) Transmission= 132 kv or 440 kv c) Distribution= 440 v or 230 v

5. **What are the advantages of three phase power system?**
   - Generation, transmission and utilization of power are more economical.
   - The three phase induction motor is self starting.
   - For the same size, the capacity has better power factor and efficiency.

6. **What are the major sources of energy used for generation of electric power? (Dec-2005)**

   i) Coal ii) Water iii) Nuclear

7. **What is the voltage level of a sub transmission system? (Dec-2007)**

   33 kv or 66 kv

8. **What is sub transmission system? (Dec-2005)**

The primary transmission line goes upto receiving station. The voltage is stepped down to 33 kv to by step down transformer. This 33kv is transmitted by 3-phase, 3-wire, overhead system. It is secondary transmission.

9. **What are the principle divisions of an electric power system? (June-2007) (May-2005)**

i) Generating station ii) Transmission system iii) Distribution system

10. **Mention the various types of power factor improvement.**

i) Static capacitor Synchronous ii) Condenser iii) Phase advancers

PART B

1. **Explain the two wattmeter method measurement of three phase power with neat phasor diagram. (May-2007)**

Various methods are used measurement of three phase power in three phase circuits on the basis of number of wattmeter used. There are three methods

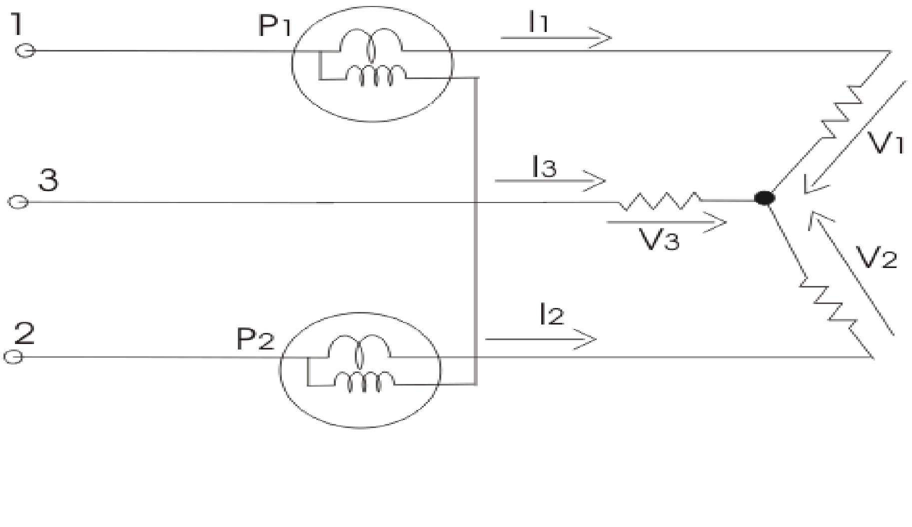
1. Three wattmeter method
2. Two wattmeter method
3. Single wattmeter method

Measurement of Three Phase Power by Two Wattmeters Method

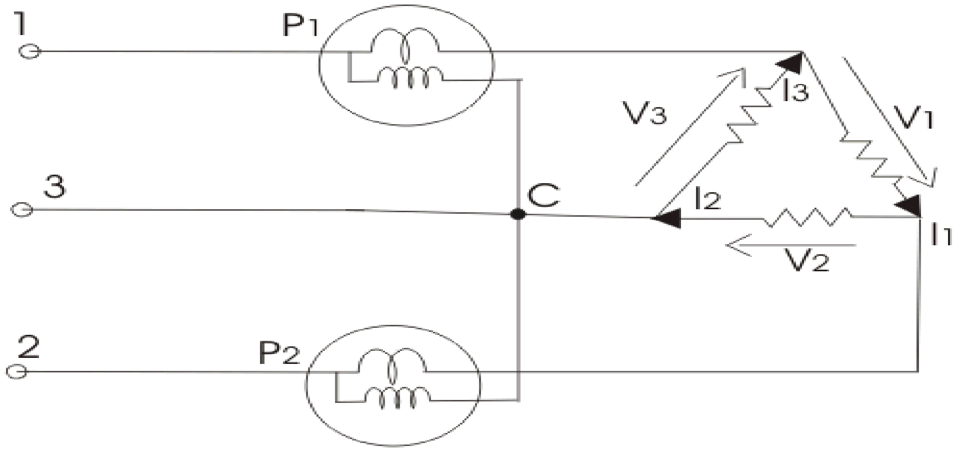
In this method, there two types of connections

1. Star connection of loads
2. Delta connection of loads.

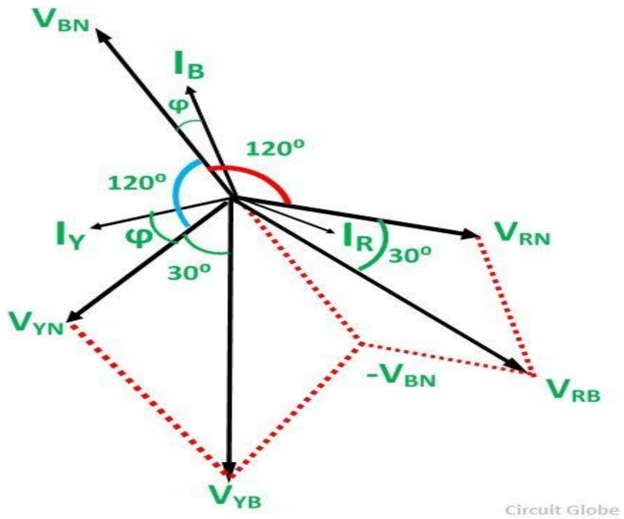
When the star connected load,



When delta connected load, the diagram is shown in below



Phasor diagram,



Power angle is given by

$$\varnothing = tan^{-1}\sqrt{3} \times \frac{(W1 - W2)}{(W1 + W2)}$$

Then the power factor of the load can be calculated as:

$$\boldsymbol{cos\varnothing = \cos\left[tan^{-1}\sqrt{3} \times \frac{(W1 - W2)}{(W1 + W2)}\right]}$$

2. Write the expression for calculating real, reactive and apparent power of a three phase system. (May-2007)

Real Power formulas

$P = V I$ (In DC circuits)

$P = VI \cos\theta$ (in Single phase AC Circuits)

$P = \sqrt{3}\, V_L I_L \cos\theta$ or (in Three Phase AC Circuits)

$P = 3\, V_{Ph} I_{Ph} \cos\theta$

Reactive power formulas:

$Q = V I \sin\theta$ (in Single phase AC Circuits)

$P = \sqrt{3}\, V_L I_L \sin\theta$ or (in Three Phase AC Circuits)

$P = 3\, V_{Ph} I_{Ph} \sin\theta$

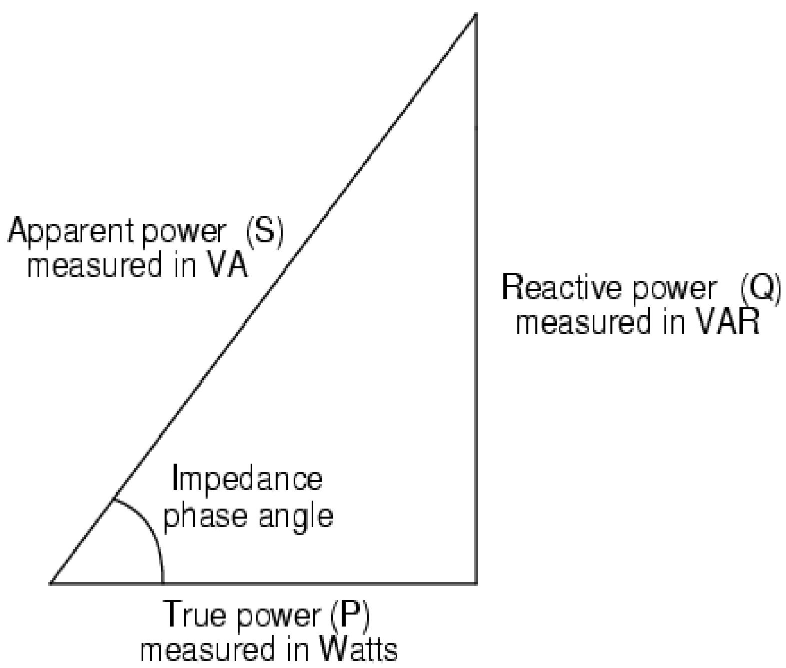
Apparent power formulas:

$S = V I$

Apparent Power = $\sqrt{(\text{True power}^2 + \text{Reactive Power}^2)}$

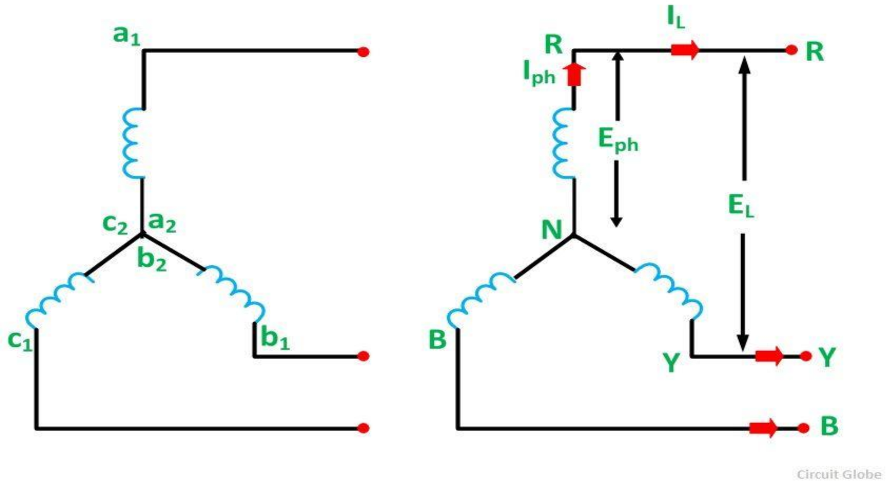
$kVA = \sqrt{kW^2 + kVAR^2}$

The "Power Triangle"



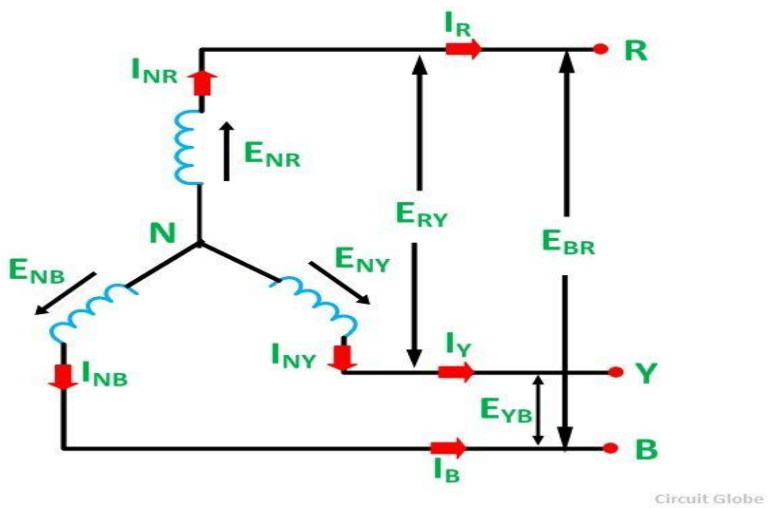
3.Give the relation between V_{ph}, I_{ph}, and I_{ph} for a star circuit. (Dec-2006)

In the **Star Connection**, the similar ends (either start or finish) of the three windings are connected to a common point called star or neutral point. The three line conductors run from the remaining three free terminals called **line conductors**



The current flowing through each phase is called **Phase current I_{ph}**, and the current flowing through each line conductor is called **Line Current I_L**. Similarly, the voltage across each phase is called **Phase Voltage E_{ph}**, and the voltage across two line conductors is known as the **Line Voltage E_L.**

Relation between Phase Voltage and Line Voltage in Star Connection



$$\text{Line voltage} = \sqrt{3} \times \text{Phase voltage}$$

The line current will be

$$I_R = I_Y = I_B = I_L$$

4. What is meant by tariff? Explain in detail.

Electrical energy produced by the power system is delivered to a large no customers. The tariff becomes the attention for the electric supply company. The company has to ensured that the tariff such that it not only recovers total cost of producing electrical energy but also earns profit on the capital investment.

Tariff types:

1. Simple tariff
2. Flat rate tariff
3. Block rate tariff
4. Two part tariff
5. Maximum demand tariff
6. power factor tariff
7. Three part tariff

Simple Tariff:

Definition: When there is a fixed rate per unit of energy consumed, it is known as simple tariff (Uniform Rate Tariff).

- This is the most simplest of all tariff.
- In this type, the price charged per unit is constant.
- It means, the price will not vary with increase or decrease in number of units used.

Disadvantages:

- The cost per unit delivered is high.
- There is no discrimination among various types of consumers.

Flat Rate Tariff:

Definition: When different types of consumers are charged at different uniform per unit rates, it is said to be Flat rate Tariff.

- In this type, the consumers are grouped into different classes.
- Each class is charged at different uniform rate.

- The different classes of consumers may be taken into account of their diversity and load factors.
- Since this type of tariff varies according to the way of supply used, separate meters are required for lighting load, power load etc.

Block rate tariff:

When a given block of energy is charged at a specified rate and the succeeding blocks of energy are charged at progressively reduced rates is called as block rate tariff.

- In this type, the energy consumption is divided into many blocks and price per unit is fixed in each block.

Two Part tariff:

When the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed it is called two-part tariff.

- In this type, the total charge to be made from the consumer is split into two components i.e., fixed charges and running charges.
- The fixed charges depend upon the number of units consumed by the customer. Thus the consumer is charged at a certain amount per kW of maximum demand + a certain amount per kWh of energy consumed.
- Total charges = Rs (X x kW + Y x kWh)
- It is easily understood by the consumer.
- It recovers fixed charges which depend upon the maximum demand of the consumer independent of the units consumed.

Disadvantages

- Consumer has to pay the fixed charges irrespective of the fact whether he has consumed or not the electrical energy.
- There is always error in assessing the maximum demand of the consumer.

Maximum demand tariff:

It is similar to two-part tariff. The only difference is the maximum demand of the consumer is calculated by installing a maximum demand meter at his premises. This type of tariff is mostly applied to the bulk consumers.

Power factor tariff:

The tariff in which the power factor of the consumers is taken into account is known as power factor tariff.

Three part Tariff:

When the total charges to be made from the consumer is split into three parts, fixed charge, semi fixed charge and running charge, it is known as three-part tariff. This type of tariff is applied to big consumers. The principle objection of this type of tariff is charges are split into three components (fixed charge, charge per kW of maximum demand, charge per kWh of energy consumed)

5. Explain in detail about power factor improvement.

Methods of Power Factor Improvement

Capacitors:

1. Improving power factor means reducing the phase difference between voltage and current
2. Since majority of loads are of inductive nature, they require some amount of reactive power for them to function.
3. This reactive power is provided by the capacitor or bank of capacitors installed parallel to the load.
4. They act as a source of local reactive power and thus less reactive power flows through the line. Basically they reduce the phase difference between the voltage and current.

Synchronous Condenser:

- They are 3 phase synchronous motor with no load attached to its shaft.
- The synchronous motor has the characteristics of operating under any power factor leading, lagging or unity depending upon the excitation.
- For inductive loads, synchronous condenser is connected towards load side and is overexcited.
- This makes it behave like a capacitor. It draws the lagging current from the supply or supplies the reactive power.

Phase Advancer:

- They are mounted on shaft of the motor and is connected in the rotor circuit of the motor.
- It improves the power factor by providing the exciting ampere turns to produce required flux at slip frequency.
- Further if ampere turns are increased, it can be made to operate at leading power factor.
- This is an ac exciter mainly used to improve pf of induction motor.

6.Compare overhead and underground system

Public Safety: Underground system is more safer than overhead system.

Initial Cost: Underground system is more expensive

Flexibility: Overhead system is more flexible than underground system. In overhead system new conductors can be laid along the existing ones for load expansion. In case of underground system new conductors are to be laid in new channels.

Maintenance Cost: Maintenance cost of underground system is very low in comparison with that of overhead system.

Frequency of Faults or Failures: As the cables are laid underground, so these are not easily accessible. The insulation is also better, so there are very few chances of power failures or fault as compared to overhead system.

Voltage Drop: In underground system because of less spacing between the conductors inductance is very low as compared to overhead lines, therefore, voltage drop is low in underground system.

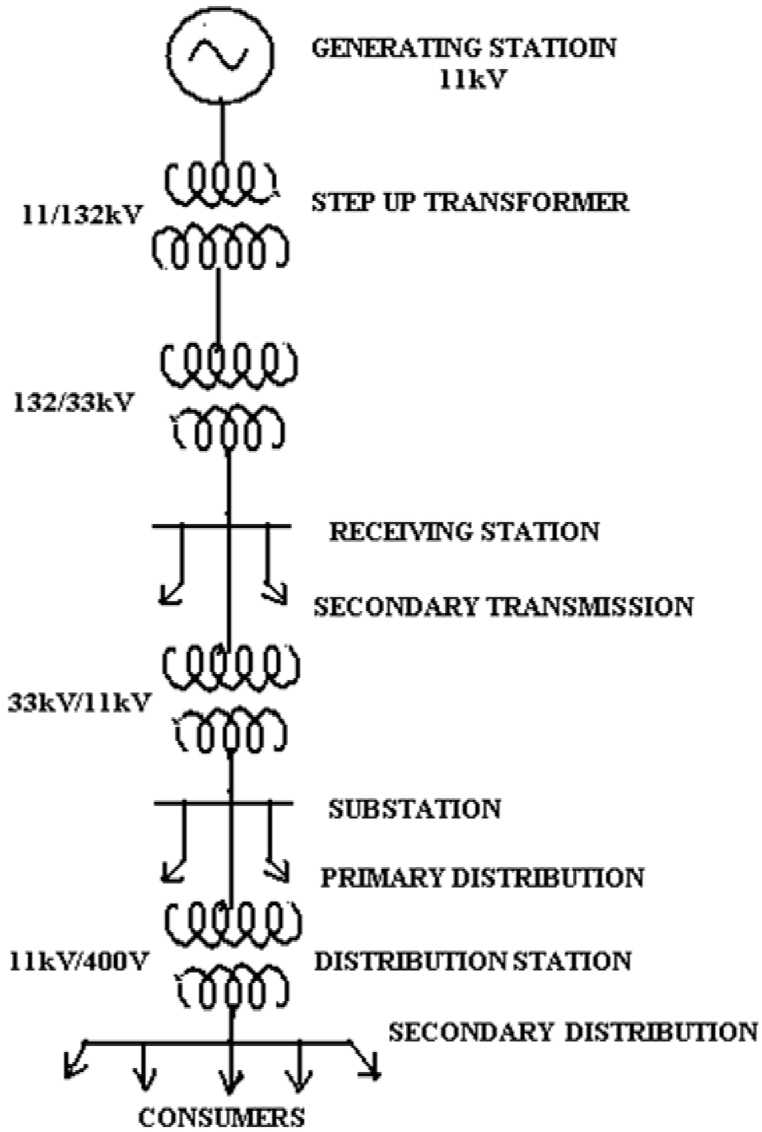
Appearance: Underground system of distribution or transmission is good looking because no wiring is visible. Due to its good looking, in spite of its higher cost it is adopted in modern cities.

Fault Location and Repairs: Though there are very rare chances of occurring fault in underground system, but if occurs it is very difficult to locate that fault and its repair is difficult and expensive.

7. Draw and explain structure of electric power system.

Electrical power system can be divided into following regions:

- Generating stations
- Transmission systems
- Receiving station
- Distribution system
- Load points



STRUCTURE OF ELECTRIC POWER SYSTEM

8.Explain in detail types of distribution system.

According to nature of current, distribution system may be classified as

a) D.C. Distribution system
b) A.C. Distribution system

AC DISTRIBUTION

- Now-a-days electrical energy is generated, transmitted and distributed in the form of alternating current.

- One important reason for the widespread use of alternating current in preference to direct current is the fact that alternating voltage can be conveniently changed in magnitude by means of a transformer.
- Transformer has made it possible to transmit a.c. power at high voltage and utilise it at a safe potential.
- High transmission and distribution voltages have greatly reduced the current in the conductors and the resulting line losses.
- There is no definite line between transmission and distribution according to voltage or bulk capacity.
- In general, the a.c. distribution system is the electrical system between the step- down substation fed by the transmission system and the consumers' meters. The a.c. distribution system is classified into
  - I. Primary distribution system
  - II. Secondary distribution system

D.C. DISTRIBUTION

- It is a common knowledge that electric power is almost exclusively generated, transmitted and distributed as a.c. However, for certain applications, d.c. supply is absolutely necessary.
- For instance, d.c. supply is required for the operation of variable speed machinery (d.c. motors), for electro-chemical work and for congested areas where storage battery reserves are necessary.
- For this purpose, a.c. power is converted into d.c. power at the substation by using converting machinery e.g., mercury arc rectifiers, rotary converters and motor-generator sets. The d.c. supply from the substation may be obtained in the form of

  i) 2-wire ii) 3-wire for distribution

9. Explain in detail about protection of power system.

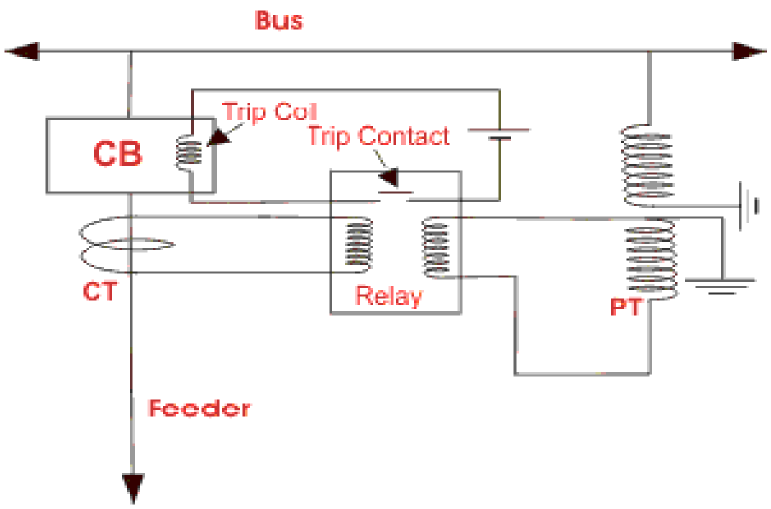
Objective of Power System Protection

- The objective of **power system protection** is to isolate a faulty section of electrical power system from rest of the live system so that the rest portion can function satisfactorily without any severer damage due to fault current.

- Actually circuit breaker isolates the faulty system from rest of the healthy system and this circuit breakers automatically open during fault condition due to its trip signal comes from protection relay.

- The main philosophy about protection is that no protection of power system can prevent the flow of fault current through the system, it only can prevent the continuation of flowing of fault current by quickly disconnect the short circuit path from the system.

- For satisfying this quick disconnection the protection relays should have following functional requirements.



Basic connection diagram of protection relay

- The secondary of current transformer is connected to the current coil of relay. And secondary of voltage transformer is connected to the voltage coil of the relay.
- Whenever any fault occurs in the feeder circuit, proportionate secondary current of the CT will flow through the current coil of the relay due to which mmf of that coil is increased.
- This increased mmf is sufficient to mechanically close the normally open contact of the relay. This relay contact actually closes and completes the DC trip coil circuit and hence the trip coil is energized.
- The mmf of the trip coil initiates the mechanical movement of the tripping mechanism of the circuit breaker and ultimately the circuit breaker is tripped to isolate the fault.

Functional Requirements of Protection Relay

i) Reliability ii) Selectivity iii) Sensitivity iv)Speed

Important Elements for Power System Protection

i) Switchgear ii) Protective Gear iii) Station Battery

UNIT II TRANSFORMER

PART A

1. Define transformer. (Dec-2006)

A transformer is a static device which changes the alternating voltage from one level to another.

2. What is an ideal transformer? (Dec-2007) (May-2004)

100% efficiency of the transformer is called ideal transformer.

3. What are the properties of an ideal transformer? (Dec-2004)

5. No winding resistance
6. No magnetic leakage flux
7. No core loss

4. What are the losses occur in a transformer?

i) Core loss a) Hysteresis loss b) Eddy current loss

ii) Copper loss

5. Define auto transformer. (Dec-2007) (May-2004)

- A transformer in which part of the winding is common to both the primary and secondary is known as an autotransformer.
- The primary is electrically connected to the secondary as well as magnetically coupled to it.

6. Define voltage regulation of transformer. (June-2007)

The change in secondary terminal voltage from no load to full load expressed as a percentage of no load or full load voltage is termed as regulation.

%regulation down = (V2noload-V2F.L)*100/V2noload

%regulation up = (V2noload-V2F.L)*100/V2F.L

7. What are the necessary tests to determine the equivalent circuit of a transformer? (Dec-2007)

i) Open circuit test ii) Short circuit test

8. Mention the two different components of core loss in a transformer? (Dec-2007)

a) Hysteresis loss b) Eddy current loss

9. Define all-day efficiency. (May-2004) (Dec-2005) (Dec-2006)

- It is computed on the basis of energy consumed during a certain period, usually a day of 24 hrs.

- All day efficiency=output in kWh/input in kWh tor 24 hrs.

10. Define voltage regulation up and voltage regulation down. (Dec-2005)

The change in secondary terminal voltage from no load to full load expressed as a percentage of no load or full load voltage is termed as regulation.

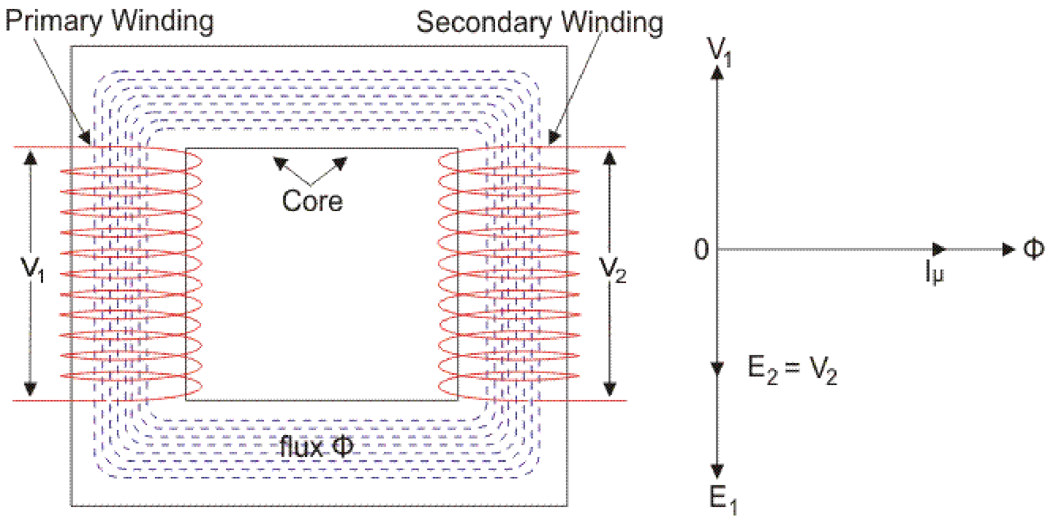
%regulation down = (V2noload-V2F.L)*100/V2noload

%regulation up = (V2noload-V2F.L)*100/V2F.L

PART B

1. Draw and explain ideal transformer. Draw its vector diagram.

- An ideal transformer is an imaginary transformer which does not have any loss in it, means no core losses, copper losses and any other losses in transformer.
- Efficiency of this transformer is considered as 100%.

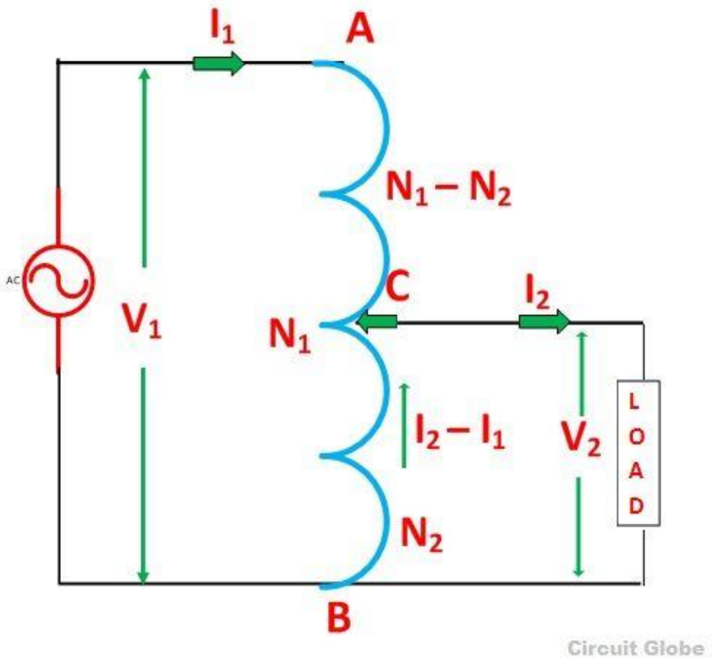


Secondary Induced Voltage Ideal Transformer

2. Explain the working of auto transformer and explain the various transformer losses.

Auto Transformer is a transformer with only one winding wound on a laminated core. An auto transformer is similar to a two winding transformer but differ in the way the primary and secondary winding are interrelated. A part of the winding is common to both primary and secondary sides. On load condition, a part of the load current is obtained directly from the supply and the remaining part is obtained by transformer action. An Auto transformer works as a **voltage regulator.**

In an ordinary transformer, the primary and the secondary windings are electrically insulated from each other but connected magnetically as shown in the figure below and in auto transformer the primary and the secondary windings are connected magnetically as well as electrically. In fact, a part of the single continuous winding is common to both primary and secondary.



The primary winding AB from which a tapping at C is taken, such that CB acts as a secondary winding. The supply voltage is applied across AB, and the load is connected across CB. The tapping may be fixed or variable. When an AC voltage V_1 is applied across AB, an alternating flux is set up in the core, as a result, an emf E_1 is induced in the winding AB. A part of this induced emf is taken in the secondary circuit. Let,

V_1 – primary applied voltage

V_2 – secondary voltage across the load

I_1 – primary current

I_2 – load current

N_1 – number of turns between A and B

N_2 – number of turns between C and B

Neglecting no load current, leakage reactance and losses,

$V_1 = E_1$ and $V_2 = E_2$

Therefore the transformation ratio

$$K = \frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$$

As the secondary ampere-turns are opposite to primary ampere turns, so the current I_2 is in phase opposition to I_1. The secondary voltage is less than the primary. Therefore current I_2 is more than the current I_1. Therefore, the resulting current flowing through section BC is $(I_2 - I_1)$

The ampere-turns due to section BC = current x turns

$$\text{Ampere turns due to section BC} = (I_2 - I_1)N_2 = \left(\frac{I_1}{K} - I_1\right) x\, N_1 K = I_1 N_1 (1 - K) \ldots\ldots\ldots (1)$$

$$\text{Ampere turns due to section AC} = I_1(N_1 - N_2) = I_1 N_1\left(1 - \frac{N_2}{N_1}\right) = I_1 N_1 (1 - K) \ldots\ldots (2)$$

Advantages of Auto transformer

- Less costly
- Better regulation
- Low losses as compared to ordinary two winding transformer of the same rating.

Disadvantages of Auto transformer

- The secondary winding is not insulated from the primary winding.
- If an auto transformer is used to supply low voltage from a high voltage and there is a break in the secondary winding, the full primary voltage comes across the secondary terminal which is dangerous to the operator and the equipment.
- So the auto transformer should not be used to for interconnecting high voltage and low voltage system.
- Used only in the limited places where a slight variation of the output voltage from input voltage is required.

Applications of Auto transformer

- It is used as a starter to give upto 50 to 60% of full voltage to the stator of a squirrel cage induction motor during starting
- It is used to give a small boost to a distribution cable, to correct the voltage drop.
- It is also used as a voltage regulator
- Used in power transmission and distribution system and also in the audio system and railways.

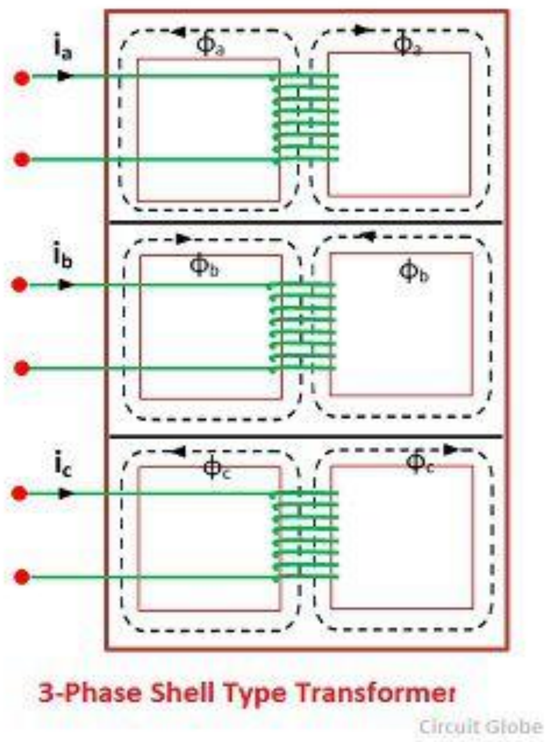
3. Explain the operation of three phase transformer.

Advantages of three phase transformers

- One 'three phase transformer' occupies less space than a gang of three 'single phase transformers'.
- Single 'three phase' unit is more economical.
- The overall bus-bar structure, switchgear and installation of 'three phase transformer' is simpler.

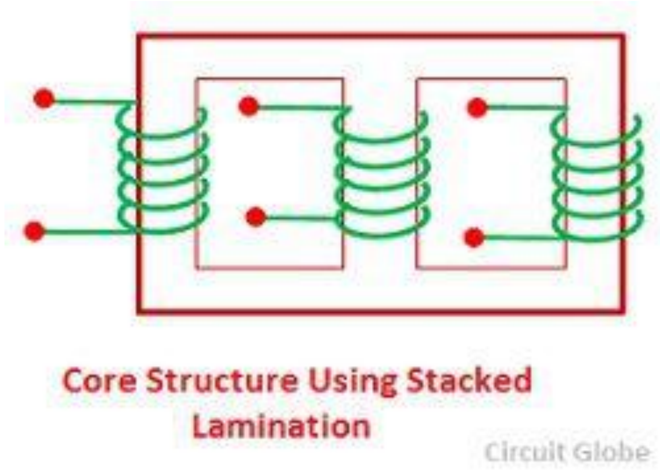
Construction of Three Phase Transformer

i) Shell type Three Phase Transformer



3-Phase Shell Type Transformer

ii) Core Type Three Phase Transformer



Disadvantage

- The main drawback in a three phase transformer is that, even if fault occurs in one phase, the whole transformer is removed from service for repairs.

4. Deduce the equivalent circuit of transformer.

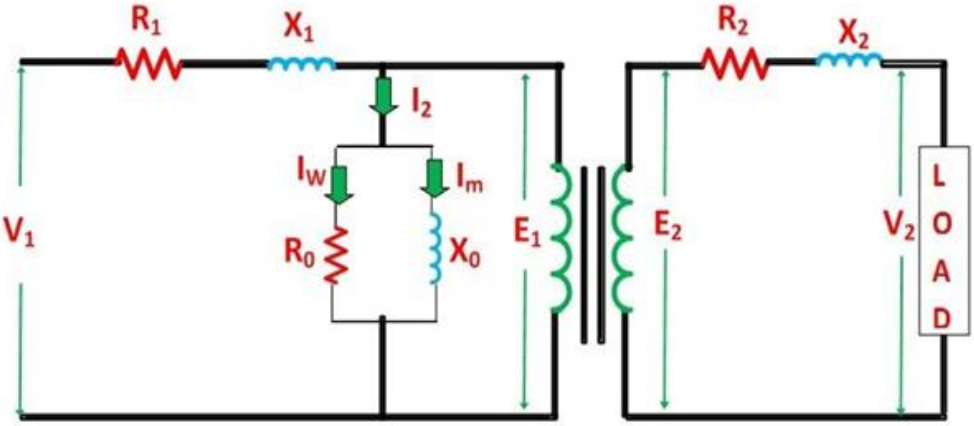
Equivalent Circuit of Transformer:

Equivalent impedance of transformer is essential to be calculated because the electrical power transformer is an electrical power system equipment for estimating different parameters of electrical power system which may be required to calculate total internal impedance of an electrical power transformer, viewing from primary side or secondary side as per requirement.

This calculation requires **equivalent circuit of transformer referred to primary** or **equivalent circuit of transformer referred to secondary** sides respectively.

Percentage impedance is also very essential parameter of transformer. Special attention is to be given to this parameter during installing a transformer in an existing electrical power system. Percentage impedance of different power transformers should be properly matched during parallel operation of power transformers.

The percentage impedance can be derived from equivalent **impedance of transformer** so, it can be said that **equivalent circuit of transformer** is also required during calculation of % impedance



Equivalent Circuit of Transformer Referred to Secondary

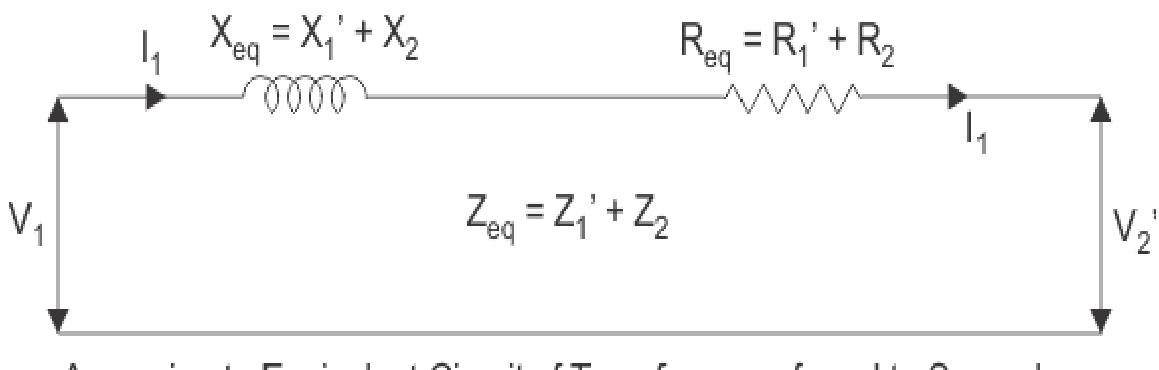
In similar way, approximate equivalent circuit of transformer referred to secondary can be drawn. Where equivalent impedance of transformer referred to secondary, can be derived as

$$Z_1 = \frac{Z_1}{K^2}$$

$$Therefore,\ R_1' = \frac{R_1}{K^2}$$

$$X_1' = \frac{X_1}{K^2}$$

$$Here,\ V_1' = \frac{V_1}{K}$$



Approximate Equivalent Circuit of Transformer referred to Secondary

UNIT III DC MACHINES

PART A

1. **Define back EMF and mention its significance. (June-2006)**
   - As the motor armature rotates, the system of conductor come across alternate North and South pole magnetic fields causing an emf induced in the conductors.
   - The direction of the emf induced in the conductors. The direction of the emf induced is in the direction opposite to the current.
   - As this emf always opposes the flow of current in motor operation it is called back emf.

2. **Mention the applications of DC motors**

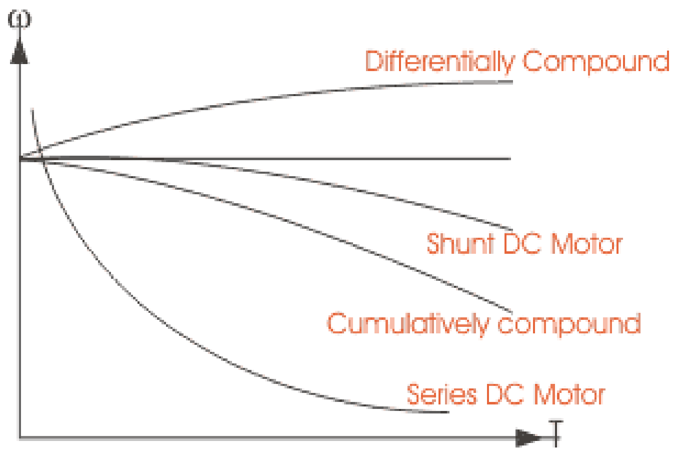
   Shunt: driving constant speed, lathes, centrifugal pumps, machine tools, blowers and fans, reciprocating pumps
   Series: electric locomotives, rapid transit systems, trolley cars, cranes and hoists, conveyors
   Compound: elevators, air compressors, rolling mills, heavy planners.

3. **Why series motor cannot be started without any load? (Dec-2007)**
   - In series motor field winding is in series to armature winding. In any DC motor, the speed depends inversely on the flux and directly proportional to emf.
   - Due to this motor will be damaged.
   - The flux produced by a DC series motor is proportional to the load current I.

4. **If speed is decreased in DC motor, what happens to the back emf and armature current? (Dec-2005)**

   If speed is decreased in DC motor, the back emf decreases and armature current increases.

5. **Draw the mechanical characteristics of DC shunt and series motor. (Dec-2005)**



6. List important parts of DC motor. (May-2006)

1. Yoke 2. Armature 3. Poles 4. Field winding 5. Armature winding 6. Commutator 7. Brushes.

7. Write down the speed equation of DC motor.(Dec-2006)

$$N \ \alpha \ \ E_b/\phi$$

8. Mention speed control DC shunt motor. (May-2006)

1. Armature control
2. Field control
3. Voltage control

9. What is universal motor?

An electric motor that can operate on AC or DC power.

10. Mention starting methods of DC motor.

1) 3 point starter 2) 4 point starter 3) no-load release coil starter

4) Thyristor controller starter

PART B

1. What is the basic principle behind the operation of DC Generators? Explain the construction and function of each part. (Dec-2006) (May-2004) (May-2005)

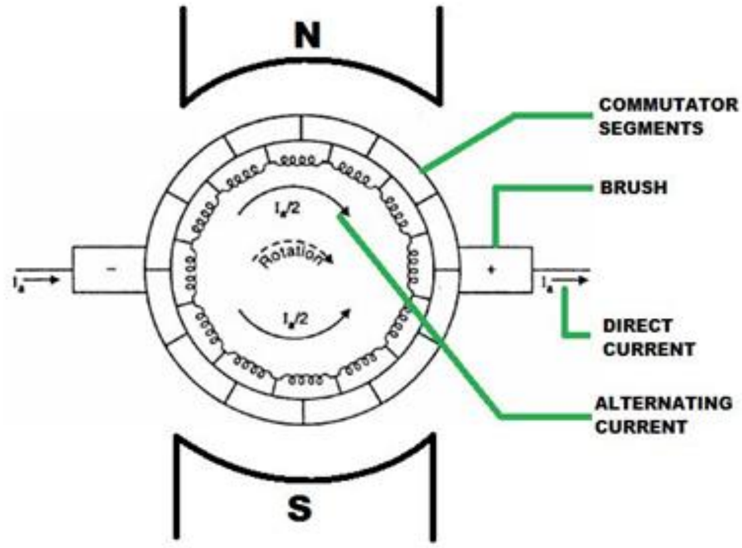
DC GENERATOR

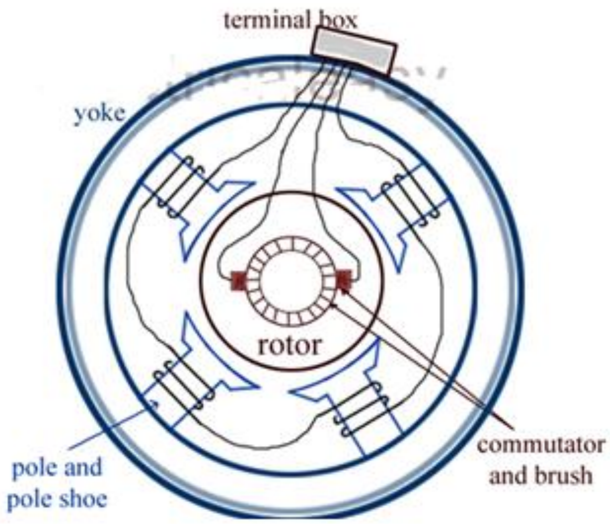
A dc generator is an electrical machine which converts mechanical energy into direct current electricity. This energy conversion is based on the principle of production of dynamically induced emf.

CONSTRUCTION:

Basic constructional parts of a DC generator are described below:

Yoke: The outer frame of a generator or motor is called as yoke. Yoke is made up of cast iron or steel. Yoke provides mechanical strength for whole assembly of the generator (or motor). It also carries the magnetic flux produced by the poles.





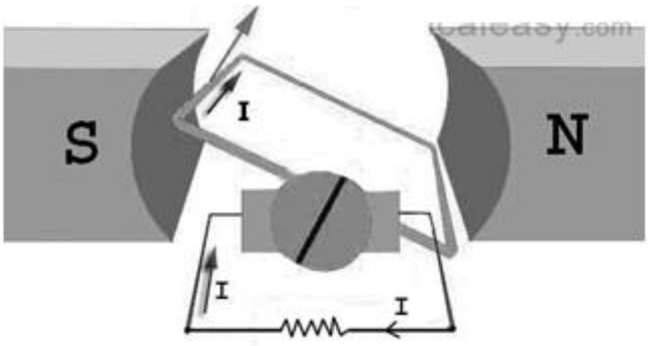
Poles: Poles are joined to the yoke with the help of screws or welding. Poles are to support field windings. Field winding is wound on poles and connected in series or parallel with armature winding or sometimes separately.

Pole shoe: Pole shoe is an extended part of the pole which serves two purposes, (i) to prevent field coils from slipping and (ii) to spread out the flux in air gap uniformly.

Armature core: Armature core is the rotor of a generator. Armature core is cylindrical in shape on which slots are provided to carry armature windings.

Commutator and brushes: As emf is generated in the armature terminals, it must be taken out to make use of generated emf. But if we can't directly solder wires to commutator conductors as they rotate. Thus commutator is connected to the armature conductors and mounted on the same shaft as that of armature core. Conducting brushes rest on commutator and they slides over when rotor (hence commutator) rotates. Thus brushes are physically in contact with armature conductors hence wires can be connected to brushes.

WORKING PRINCIPLE OF A DC GENERATOR:



According to Faraday's law of electromagnetic induction, when a conductor moves in a magnetic field (thereby cutting the magnetic flux lines), a dynamically induced emf is produced in the conductor. The magnitude of generated emf can be given by emf equation of DC generator. If a closed path is provided to the moving conductor then generated emf causes a current to flow in the circuit.

Thus in DC generators, when armature is rotated with the help of a prime mover and field windings are excited (there may be permanent field magnets also), emf is induced in armature conductors. This induced emf is taken out via commutator-brush arrangement.

2. Derive the EMF equation of DC machine from the basic principle.

Let Ø = flux/pole in Wb (weber)

Z = total no. of armature conductors

P = no. of generator poles

A = no. of parallel paths in armature

N = rotational speed of armature in revolutions per min. (rpm)

E = emf induced in any parallel path in armature

Now,

Generated e.m.f Eg = e.m.f generated in any one of the parallel paths i.e E.

Average e.m.f geneated /conductor = **dΦ/dt** volt (n=1)

Now, flux cut/conductor in one revolution **dΦ** **= ΦP** Wb

No.of revolutions/second = N/60

Time for one revolution, **dt** **= 60/N** second

Hence, according to Faraday's Laws of Electroagnetic Induction,

E.M.F generated/conductor is

$$\frac{d\varnothing}{dt} = \frac{\varnothing PN}{60}$$

For a simplex wave-wound generator, No.of parallel paths = 2

No.of conductors (in series) in one path = Z/2

E.M.F. generated/path is

$$\frac{\varnothing PN}{60} \times \frac{Z}{2} = \frac{\varnothing ZPN}{120} \text{ volt}$$

For a simplex lap-wound generator

No.of parallel paths = P

No.of conductors (in series) in one path = Z/P

E.M.F.generated/path

$$\frac{\varnothing PN}{60} \times \frac{Z}{P} = \frac{\varnothing ZN}{60} \text{ volt}$$

In general generated e.m.f

$$E_g = \frac{\varnothing ZN}{60} \times \left(\frac{P}{A}\right) \text{ volt}$$

where A = 2 - for simplex wave-winding

A= P - for simplex lap-winding

3. Explain the starting methods of DC machine

Basic operational voltage equation of a DC motor is given as

$E = E_b + I_aR_a$ and hence $I_a = (E - E_b) / R_a$

Now, when the motor is at rest, obviously, there is no back emf E_b, hence armature current will be high at starting.

This excessive current will-

1. Blow out the fuses and may damage the armature winding and/or commutator brush arrangement.
2. Produce very high starting torque (as torque is directly proportional to armature current), and this high starting toque will produce huge centrifugal force which may throw off the armature windings.

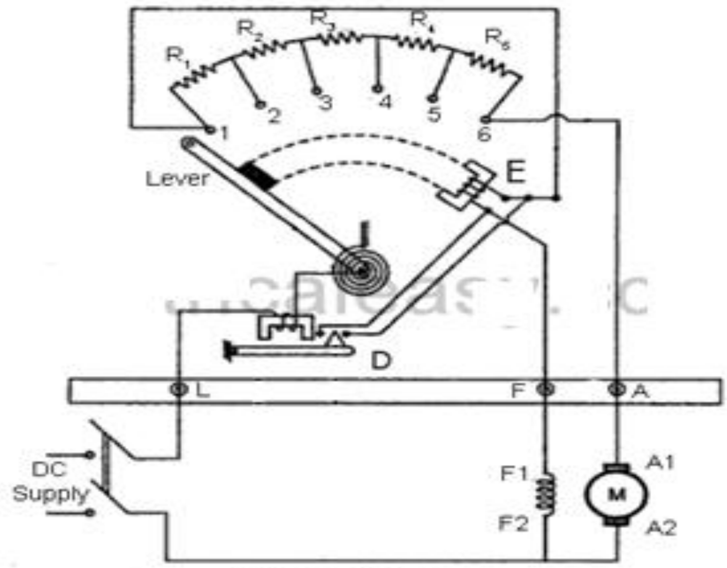
Thus to avoid above two drawbacks, starters are used for **starting of DC machine.**

Starting Methods of a DC Motor

Thus, to avoid the above dangers while **starting a DC motor**, it is necessary to limit the starting current. For that purpose, starters are used to start a DC motor. There are various starters like, 3 point starter, 4 point starter, No load release coil starter, thyristor starter etc. The main concept behind every **DC motor starter** is, adding external resistance to the armature winding at starting.

3 POINT STARTER:

The internal wiring of a **3 point starter** is as shown in the figure.



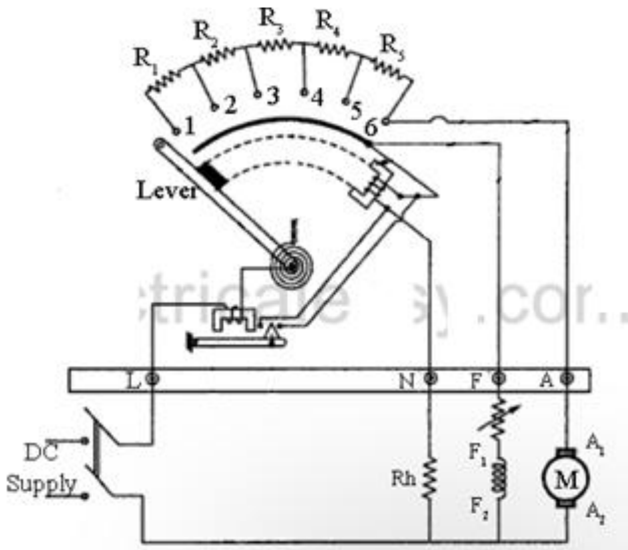
3 Point Starter

When motor is to be started, the lever is turned gradually to the right. When lever touches point 1, the field winding gets directly connected across the supply, and the armature winding gets connected with resistances R1 to R5 in series. Hence at starting full resistance is added in series with armature.

Then as the lever is moved further, the resistance is gradually is cut out from the armature circuit. Now, as the lever reaches to position 6, all the resistance is cut out from the armature circuit and armature gets directly connected across the supply. The electromagnet E (no voltage coil) holds the lever at this position. This electromagnet releases the lever when there is no (or low) supply voltage.

When the motor is overloaded beyond a predefined value, over current release electromagnet D gets activated, which short circuits electromagnet E , and hence releases the lever and motor is turned off.

4 POINT STARTER:



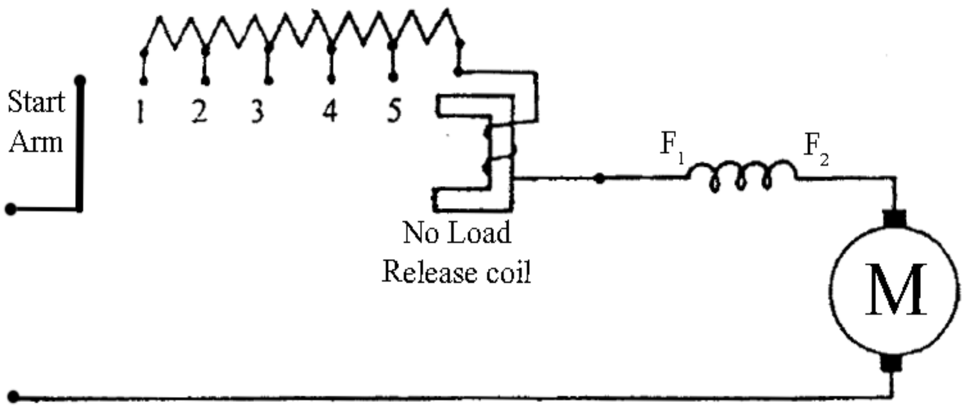
4 Point Starter

The main **difference between a 3 point starter and a 4 point starter** is that the no voltage coil is not connected in series with field coil. The field gets directly connected to the supply, as the lever moves touching the brass arc. The no voltage coil (or Hold on coil) is connected with a current limiting resistance Rh. This arrangement ensures that any change of current in the shunt field does not affect the current through hold on coil at all. This means that electromagnet pull of the hold-on coil will always be sufficient so that the spring does not unnecessarily restore the lever to the off position.

This starter is used where field current is to be adjusted by means of a field rheostat.

2 POINT STARTER: **(DC Series motor starter)**

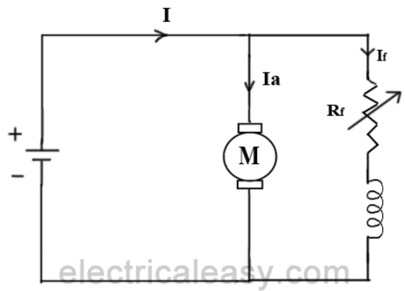
Construction of DC series motor starters is very basic as shown in the figure. A start arm is simply moved towards right to start the motor. Thus at first maximum resistance is connected in series with the armature and then gradually decreased as the start arm moves towards right. The no load release coil holds the start arm to the run position and leaves it at no load.



4. **Discuss various speed control techniques of DC machines.**

Speed Control of Shunt Motor

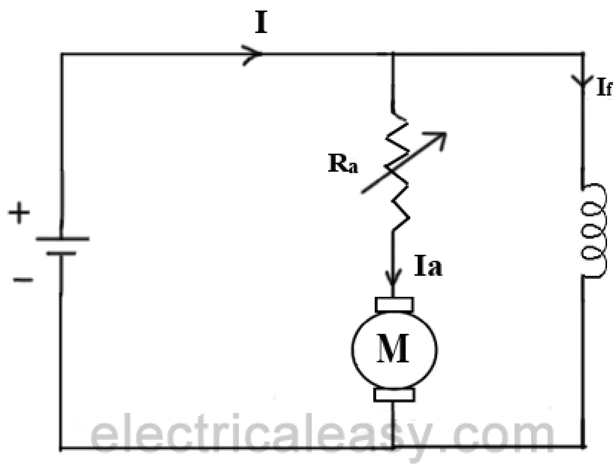
1. Flux Control Method



It is seen that **speed of the motor** is inversely proportional to flux. Thus by decreasing flux speed can be increased and vice versa.

To control the flux, a rheostat is added in series with the field winding, as shown in the circuit diagram. Adding more resistance in series with field winding will increase the speed, as it will decrease the flux. Field current is relatively small and hence I^2R loss is small, hence this method is quiet efficient. Though speed can be increased by reducing flux with this method, it puts a limit to maximum speed as weakening of flux beyond the limit will adversely affect the commutation.

2. Armature Control Method



Speed of the motor is directly proportional to the back emf E_b and $E_b = V - I_aR_a$.

That is when supply voltage V and armature resistance R_a are kept constant, speed is directly proportional to armature current I_a. Thus if we add resistance in series with armature, I_a decreases and hence speed decreases.Greater the resistance in series with armature, greater the decrease in speed.

3. Voltage Control Method

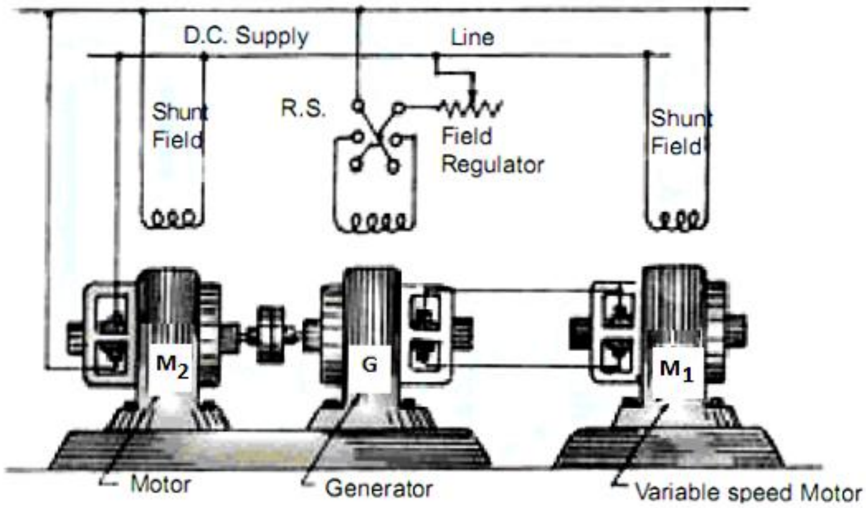
a) Multiple voltage control: In this method the, shunt filed is connected to a fixed exciting voltage, and armature is supplied with different voltages. Voltage across armature is changed with the help of a suitable switchgear. The speed is approximately proportional to the voltage across the armature.

b) WARD-LEONARD SYSTEM:

Ward Leonard control system is introduced by Henry Ward Leonard in 1891. Ward Leonard method of speed control is used for controlling the speed of a DC motor. It is a basic armature control method. This control system is consisting of a dc motor M_1 and powered by a DC generator G. In this method the speed of the dc motor (M_1) is controlled by applying variable voltage across its armature. This variable voltage is obtained using a motor-generator set which consists of a motor M_2(either ac or dc motor) directly coupled with the generator G. It is a very widely used method of speed control of DC motor.

Principle of Ward Leonard Method

Basic connection diagram of the Ward Leonard speed control system is shown in the figure below.



WARD LEONARD SYSTEM OF SPEED CONTROL

The speed of motor M_1 is to be controlled which is powered by the generator G. The shunt field of the motor M_1 is connected across the dc supply lines. Now, generator G is driven by the motor M_2. The speed of the motor M_2 is constant. When the output voltage of the generator is fed to the motor M_1 then the motor starts to rotate. When the output voltage of the generator varies then the speed of the motor also varies. Now controlling the output voltage of the generator the speed of motor can also be controlled. For this purpose of controlling the output voltage, a field regulator is connected across the generator with the dc supply lines to control the field excitation. The direction of rotation of the motor M_1 can be reversed by excitation current of the generator and it can be done with the help of the reversing switch R.S. But the motor-generator set must run in the same direction.

Advantages of Ward Leonard System

1. It is a very smooth speed control system over a very wide range (from zero to normal speed of the motor).
2. The speed can be controlled in both the direction of rotation of the motor easily.
3. The motor can run with a uniform acceleration.
4. Speed regulation of DC motor in this ward Leonard system is very good.

Disadvantages of Ward Leonard System

1. The system is very costly because two extra machines (motor-generator set) are required.
2. Overall efficiency of the system is not sufficient especially it is lightly loaded.

Application of Ward Leonard System

This speed control system is mainly used in colliery winders, cranes, electric excavators, mine hoists, elevators, steel rolling mills and paper machines etc.

Speed Control Of Series Motor

1. Flux Control Method

a) Field diverter

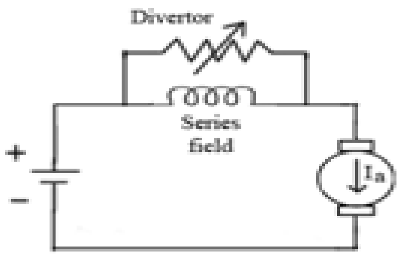


fig (a) Field Divertor

A variable resistance is connected parallel to the series field as shown in fig. This variable resistor is called as diverter, as desired amount of current can be diverted through this resistor and hence current through field coil can be decreased. Hence flux can be decreased to desired amount and speed can be increased.

b) Armature diverter

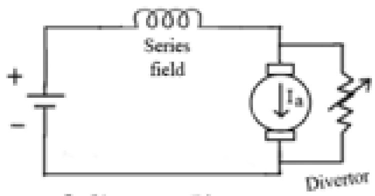


fig (b) Armature Divertor

Diverter is connected across the armature as in fig .

For a given constant load torque, if armature current is reduced then flux must increase. As,

$$T_a \propto \phi I_a$$

This will result in increase in current taken from the supply and hence flux Ø will increase and subsequently **speed of the motor** will decrease.

c) Tapped field control:

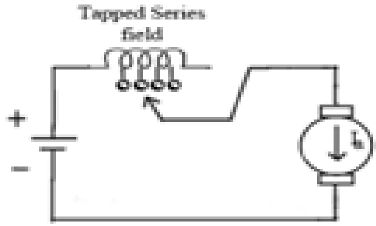


fig (c) Tapped field

As shown in fig field coil is tapped dividing number of turns. Thus we can select different value of Ø by selecting different number of turns.

d) Paralleling field coils:

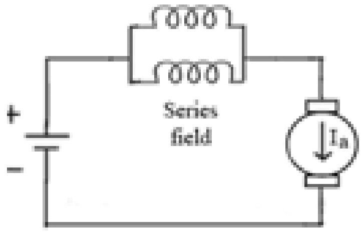


fig (d) Paralleling Field coils

In this method, several speeds can be obtained by regrouping coils as shown in fig

2. Variable ResistanceiIn Series with Armature

By introducing resistance in series with armature, voltage across the armature can be reduced. And hence, speed reduces in proportion with it.

3. Series-Parallel Control

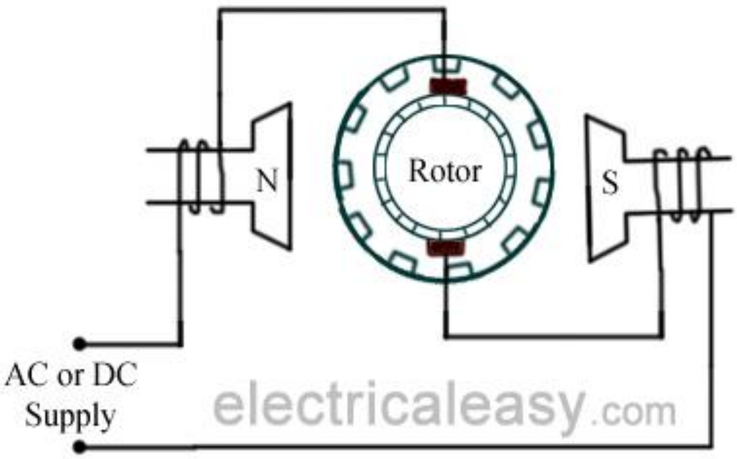
This system is widely used in electric traction, where two or more mechanically coupled series motors are employed. For low speeds, motors are joined in series, and for higher speeds motors are joined in parallel.

When in series, the motors have the same current passing through them, although voltage across each motor is divided. When in parallel, voltage across each motor is same although current gets divided.

5. Explain the construction, principle and operation of Universal motor.

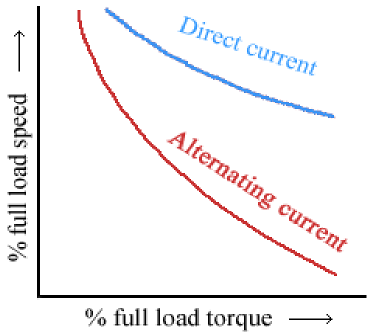
A **universal motor** is a special type of motor which is designed to run on either DC or single phase AC supply. These motors are generally series wound (armature and field winding are in series), and hence produce high starting torque.

Working of Universal Motor



- A universal motor works on either DC or single phase AC supply. When the universal motor is fed with a DC supply, it works as a DC series motor. When current flows in the field winding, it produces an electromagnetic field. The same current also flows from the armature conductors.
- When a current carrying conductor is placed in an electromagnetic field, it experiences a mechanical force. Due to this mechanical force, or torque, the rotor starts to rotate. The direction of this force is given by Fleming's left hand rule.
- When fed with AC supply, it still produces unidirectional torque. Because, armature winding and field winding are connected in series, they are in same phase. Hence, as polarity of AC changes periodically, the direction of current in armature and field winding reverses at the same time.
- Thus, direction of magnetic field and the direction of armature current reverses in such a way that the direction of force experienced by armature conductors remains same. Thus, regardless of AC or DC supply, universal motor works on the same principle that DC series motor works.

Speed/Load Characteristics



Applications of Universal Motor

- Universal motors used in various home appliances like vacuum cleaners, drink and food mixers, domestic sewing machine etc.
- The higher rating universal motors are used in portable drills, blenders etc.

6. Derive the torque equation of DC motor. (Dec-2005) (May-2005)

It is seen that the turning or twisting force about an axis is called torque. Consider a wheel of radius R meters acted upon by a circumferential force F newtons as shown in the Fig. 1.

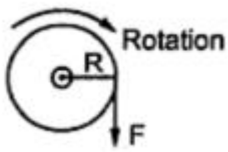


Fig. 1

The wheel is rotating at a speed of N r.p.m. Then angular speed of the wheel is,

$\omega = (2\pi N)/60$ rad/sec

So workdone in one revolution is,

W = F x distance travelled in one revolution

= F x 2 R joules

And P = Power developed = Workdone/Time

$= (F \times 2\pi R) / (\text{Time for 1 rev}) = (F \times 2\pi R) / (60/N) = (F \times R) \times (2\pi N/60)$

∴ $P = T \times \omega$ watts

Where T = Torque in N - m

ω = Angular speed in rad/sec.

Let T_a be the gross torque developed by the armature of the motor. It is also called armature torque. The gross mechanical power developed in the armature is $E_b I_a$, as seen from the power equation. So if speed of the motor is N r.p.m. then,

Power in armature = Armature torque x ω

$$T_{a0} = T_f$$

∴ $E_b I_a = \times (2N/60)$

but E_b in a motor is given by,

$E_b = (\Phi PNZ) / (60A)$

∴ $(\Phi PNZ / 60A) \times Ia = T_a \times (2\pi N/60)$

$$T_a = \frac{1}{2\pi}\phi I_a \times \frac{PZ}{A}$$

$$T_a = 0.159\,\phi I_a \cdot \frac{PZ}{A}\ \text{N-m}$$

This is the torque equation of a d.c. motor.

TORQUE SPEED EQUATIONS:

Before analysing the various characteristics of motors, let us revise the torque and speed equations are applied to various types of motors.

∴ $T \propto \Phi I_a$ from torque equation.

This is because, 0.159(PZ)/A is a constant for a given motor.

Now Φ is the flux produced by the field winding and is proportional to the current passing through the field winding.

$$\Phi \propto I_{field}$$

But for various types of motors, current through the field winding is different. Accordingly torque equation must be modified.

For a d.c. shunt motor, I_{sh} is constant as long as supply voltage is constant. Hence Φ flux is also constant.

∴ $T \propto Ia$ for shunt motors

For a d.c. series motor, I_{se} is same as I_a. Hence flux Φ is proportional to the armature current I_a.

∴ $T \propto I_a \propto I_a^2$ for series motors.

Similarly as $E_b = (\Phi PNZ)(60A)$, we can write the speed equation as,

$$E_b \propto \Phi N$$

∴ $N \propto E_b/\Phi$

But $V = E_b + I_a R_a$ neglecting brush drop

∴ $E_b = V - I_a R_a$

∴ Speed equation becomes,

$$N \propto (V - I_a R_a)/\Phi$$

So for shunt motor as flux is constant,

∴ $N \propto V - I_a R_a$

While for series motor, flux Φ is proportional to I_a.

$$N \propto \frac{V - I_a R_a - I_a R_{se}}{I_a}$$

UNIT IV AC MACHINES

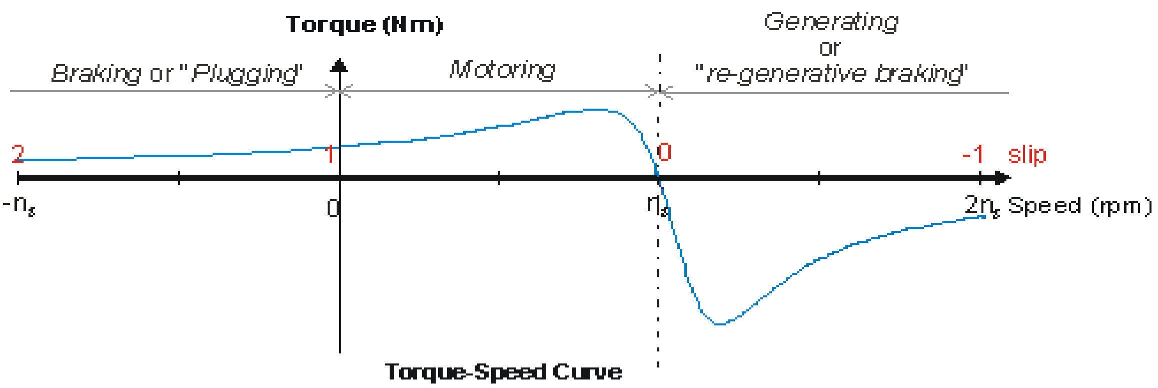
PART A

1. **Define Slip of a 3-phase induction motor. (Nov-2016)**

   The ratio of difference between synchronous speed (N_s) and rotor speed (N) to synchronous speed.

   % slip = N_s-N/ N_s x 100

2. **Draw the torque/speed curve of an induction motor.**



3. **Is a single phase induction motor self starting? Why?**
   - The single phase induction motor is not self starting.
   - When a single phase supply is fed to the stator winding, it produces only an alternating flux only. Due to this torque will be zero. Hence motor does not rotate.

4. **List the various types of single phase induction motor.**

   i) Resistance start   iv) Capacitor start- Capacitor run

   ii) Capacitor start   v) Shaded pole

   iii) Capacitor run

5. **Name the starting methods for cage motors.**
   - Changing Applied Voltage.
   - Changing Applied Frequency.
   - Changing Number of Stator Poles.

6. **How the direction of rotation of a 3 phase induction motor could be reversed.**

   The direction of rotation of three phase induction motor can be changed by interchanging any two terminals of the input supply. The direction of the synchronously rotating field reverses and hence the direction of rotor reverse.

7. **Define the regulation of an alternator. How is it expressed?**

   Increase in terminal voltage when full load is thrown off, assuming field current and speed remaining the same.

8. **Name the types of alternators.**

   i) Rotating armature type ii) rotating field and stationary armature type

9. **Mention some application of synchronous motor.**

   i) Power factor correction

   ii) Constant speed, constant load drives

   iii) Voltage regulation of transmission lines

10. **Define the term step angle. (May-2007)**

    The angle through which the stepper motor shaft rotates for each command pulse.

PART B

1. **Explain the construction of the three phase induction motor. What are its types and give the equivalent circuit of the same**

Types :

There are two types of 3-phase induction motor based on the type of rotor used:

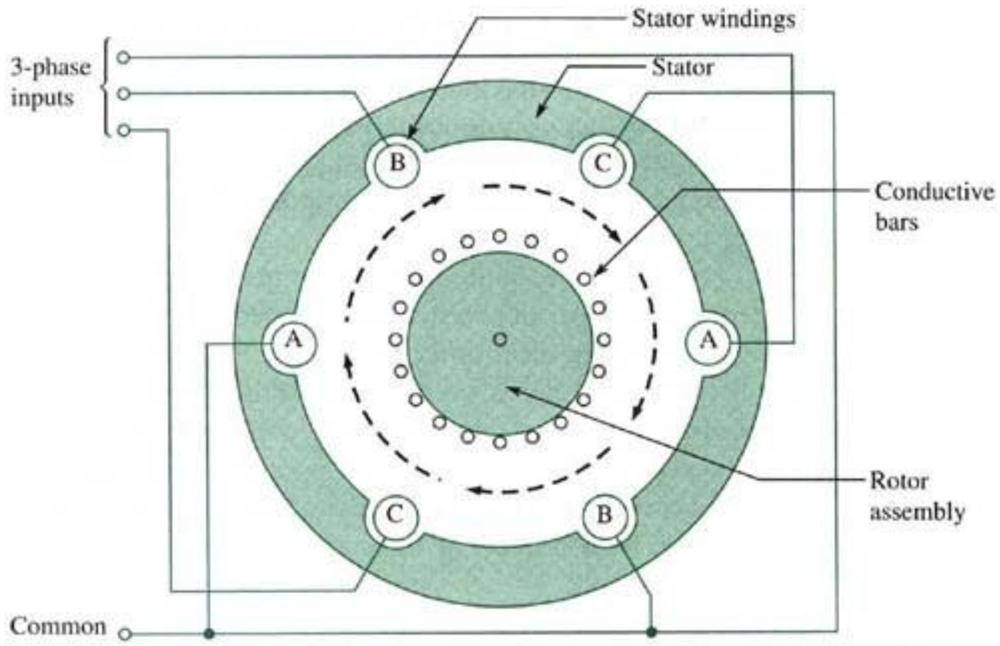
1. Squirrel cage induction motor.
2. Slip ring induction motor.

CONSTRUCTION

Conversion of electrical power into mechanical power takes place in the rotating part of an electric motor. In A.C. motors, rotor receives electric power by induction in exactly the same way as the secondary of a two-winding transformer receives its power from the primary. Hence such motors are known as a rotating transformer i.e. one in which primary winding is stationary but the secondary is free to rotate.

An induction motor essentially consists of two main parts:

Stator and Rotor.



Stator:

The stator of an induction motor is in principle, the same as that of a synchronous motor (or) generator. It is made up of a number of stampings, which are slotted to receive the windings. The stator carries a 3-phase winding and is fed from a 3-phase supply. It is wound for a definite number of poles, the exact number of poles being determined by the requirements of speed. The number of poles are higher, lesser the speed and vice-versa. The stator winding, when supplied with a 3-phase currents, produce a magnetic flux, which is of constant magnitude but which revolves at synchronous speed ($N_s = 120 \times f / p$).This revolving magnetic flux induces emf in rotor by mutual induction.

Rotor:

Squirrel cage Rotor:

Motors employing this type of rotor are known as squirrel cage induction motor.

Frame:

Made of close-grained alloy cast iron.

Stator and Rotor core:

Built from high quality low loss silicon steel laminations and flash enameled on both sides.

Stator and Rotor windings:

Stator and rotor have moisture proof tropical insulation and embodying mica and high quality varnishes. These are carefully spaced for most effective air circulation and are rigidly braced to withstand centrifugal forces and any short circuit stresses.

Air gap:

The stator rabbets and bore are machined carefully to ensure uniformity of air gap.

Shaft and Bearings:

Ball and roller bearings are used to suit heavy duty, trouble free running and for enhanced service life.

Fans:

Light aluminium fans are used for adequate circulation of cooling air and are securely keyed onto the Rotor shaft.

Slip-Rings and Slip-Ring Enclosures:

Slip rings are made of high quality phosphor bronze and are of molded construction.

WORKING PRINCIPLE

Production of Rotating Magnetic Field

- The stator of the motor consists of overlapping winding offset by an electrical angle of 120°. When the primary winding or the stator is connected to a 3 phase AC source, it establishes a rotating magnetic field which rotates at the synchronous speed.
- According to Faraday's law an emf induced in any circuit is due to the rate of change of magnetic flux linkage through the circuit. As the rotor winding in an induction motor are either closed through an external resistance or directly shorted by end ring, and cut the stator rotating magnetic field, an emf is induced in the rotor copper bar and due to this emf a current flows through the rotor conductor.
- Here the relative speed between the rotating flux and static rotor conductor is the cause of current generation; hence as per Lenz's law the rotor will rotate in the same direction to reduce the cause i.e. the relative velocity.
- Thus from the working principle of three phase induction motor it may observed that the rotor speed should not reach the synchronous speed produced by the stator. If the speeds

equals, there would be no such relative speed, so no emf induced in the rotor, and no current would be flowing, and therefore no torque would be generated.

- Consequently the rotor cannot reach the synchronous speed. The difference between the stator (synchronous speed) and rotor speeds is called the slip. The rotation of the magnetic field in an induction motor has the advantage that no electrical connections need to be made to the rotor. Thus the three phase induction motor is:

  - Self-starting.
  - Less armature reaction and brush sparking because of the absence of commutator and brushes that may cause sparks.
  - Robust in construction.
  - Economical.
  - Easier to maintain.

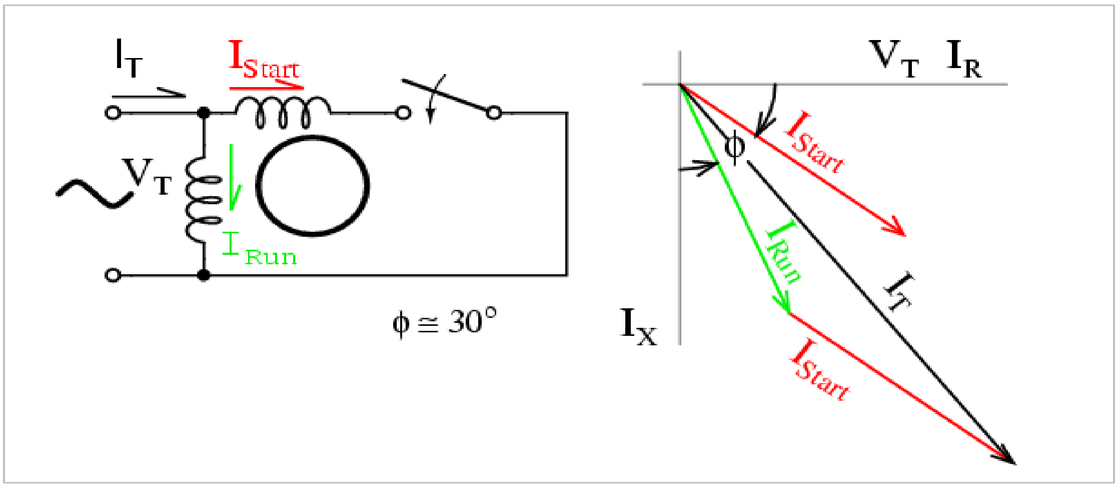
2. **Discuss the operation of types of 1-phase induction motors with neat circuit diagrams and speed-torque characteristics.**

The single phase induction motors are made self starting by providing an additional flux by some additional means. Now depending upon these additional means the single phase induction motors are classified as:

1. **Split phase induction motor**.
2. **Capacitor start inductor motor**.
3. **Capacitor start capacitor run induction motor (two value capacitor method)**.
4. **Permanent split capacitor (PSC) motor**
5. **Shaded pole induction motor**.

Split Phase Induction Motor

In addition to the main winding or running winding, the stator of single phase induction motor carries another winding called auxiliary winding or starting winding. A centrifugal switch is connected in series with auxiliary winding. The purpose of this switch is to disconnect the auxiliary winding from the main circuit when the motor attains a speed up to 75 to 80% of the synchronous speed. We know that the running winding is inductive in nature. Our aim is to create the phase difference between the two winding and this is possible if the starting winding carries high resistance. Let us say I_{run} is the current flowing through the main or running winding, I_{start} is the current flowing in starting winding, and V_T is the supply voltage.



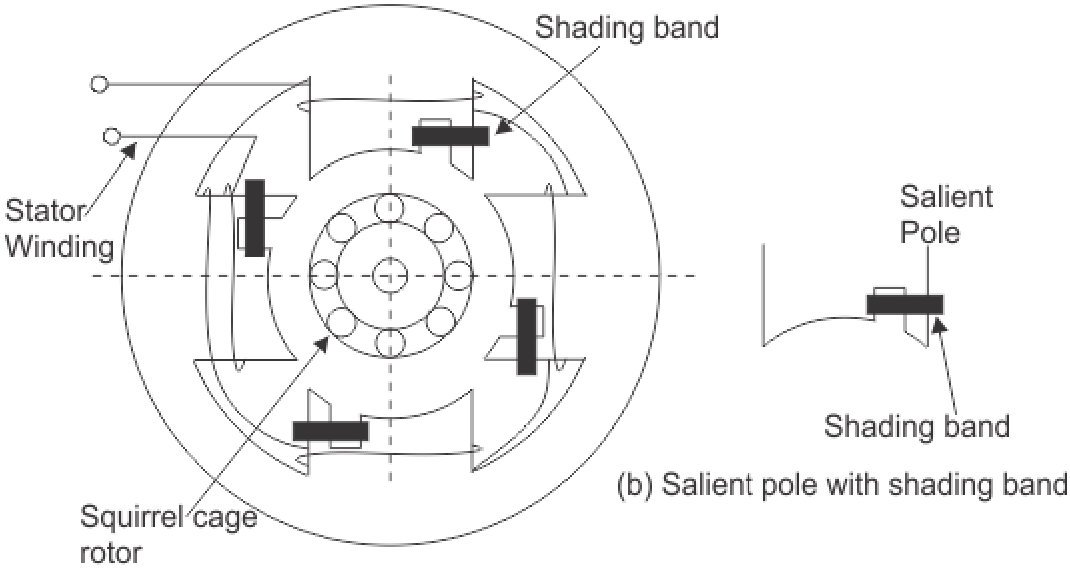
For highly resistive winding the current is almost in phase with the voltage and for highly inductive winding the current lag behind the voltage by large angle. The starting winding is highly resistive so, the current flowing in the starting winding lags behind the applied voltage by very small angle and the running winding is highly inductive in nature so, the current flowing in running winding lags behind applied voltage by large angle. The resultant of these two current is I_T. The resultant of these two current produce rotating magnetic field which rotates in one direction. In **split phase induction motor** the starting and main current get splitted from each other by some angle so this motor got its name as split phase induction motor.

Applications of Split Phase Induction Motor

- Split phase induction motors have low starting current and moderate starting torque.
- So these motors are used in fans, blowers, centrifugal pumps, washing machine, grinder, lathes, air conditioning fans, etc. These motors are available in the size ranging from 1 / 20 to 1 / 2 KW.

Shaded Pole Single Phase Induction Motors

The stator of the **shaded pole single phase induction motor** has salient or projected poles. These poles are shaded by copper band or ring which is inductive in nature. The poles are divided into two unequal halves. The smaller portion carries the copper band and is called as shaded portion of the pole.



(b) Salient pole with shading band

(a) 4-pole shaded pole construction

ACTION: When a single phase supply is given to the stator of shaded pole induction motor an alternating flux is produced. This change of flux induces emf in the shaded coil. Since this shaded portion is short circuited, the current is produced in it in such a direction to oppose the main flux. The flux in shaded pole lags behind the flux in the unshaded pole. The phase difference between these two fluxes produces resultant rotating flux. We know that the stator winding current is alternating in nature and so is the flux produced by the stator current. In order to clearly understand the working of shaded pole induction motor consider three regions-

1. When the flux changes its value from zero to nearly maximum positive value.
2. When the flux remains almost constant at its maximum value.
3. When the flux decreases from maximum positive value to zero.

Advantages and Disadvantages of Shaded Pole Motor

The advantages of shaded pole induction motor are

1.Very economical and reliable.

2.Construction is simple and robust because there is no centrifugal switch.

The disadvantages of shaded pole induction motor are

1.Low power factor.

2.The starting torque is very poor.

3.The efficiency is very low as, the copper losses are high due to presence of copper band.

4.The speed reversal is also difficult and expensive as it requires another set of copper rings.

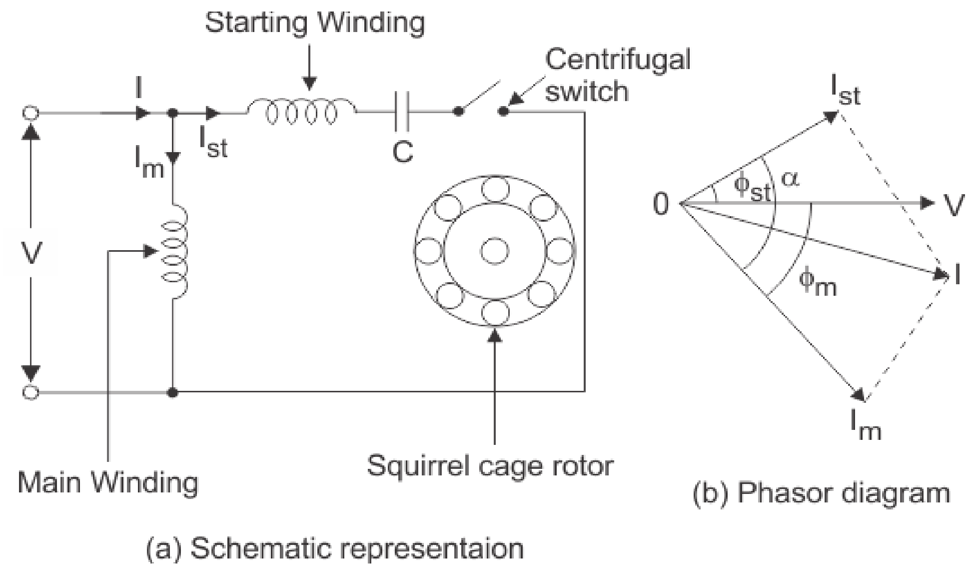
Applications of Shaded Pole Motor

Due to their low starting torques and reasonable cost these motors are mostly employed in small instruments, hair dryers, toys, record players, small fans, electric clocks etc. These motors are usually available in a range of 1/300 to 1/20 KW.

Capacitor Start Inductor Motor

The working principle and construction of Capacitor start inductor motors and capacitor start capacitor run induction motors are almost the same.

In order to produce rotating magnetic field there must be some phase difference. In case of split phase induction motor we use resistance for creating phase difference but here we use capacitor for this purpose. We are familiar with this fact that the current flowing through the capacitor leads the voltage. So, in **capacitor start inductor motor** and **capacitor start capacitor run induction motor** we are using two winding, the main winding and the starting winding. With



starting winding we connect a capacitor so the current flowing in the capacitor i.e I_{st} leads the applied voltage by some angle, φ_{st}. The running winding is inductive in nature so, the current flowing in running winding lags behind applied voltage by an angle, φ_m.

Now there occur large phase angle differences between these two currents which produce an resultant current, I and this will produce a rotating magnetic field. Since the torque produced by these motors depends upon the phase angle difference, which is almost 90^o. So, these motors produce very high starting torque.

In case of capacitor start induction motor, the centrifugal switch is provided so as to disconnect the starting winding when the motor attains a speed up to 75 to 80% of the synchronous speed but in case of capacitor start capacitors run induction motor there is no centrifugal switch so, the capacitor remains in the circuit and helps to improve the power factor and the running conditions of single phase induction motor.

3. Write down the principle of operation of alternators and their construction details. (Nov-2016)

The machine which produces 3 phase power from mechanical power is called an alternator or synchronous generator. Alternators are the primary source of all the electrical energy we consume. These machines are the largest energy converters found in the world. They convert mechanical energy into AC energy.

Construction

Stator: Unlike in DC machine stator of an alternator is not meant to serve path for magnetic flux. Instead, the stator is used for holding armature winding. The stator core is made up of lamination of steel alloys or magnetic iron, to minimize the eddy current losses.

Rotor: There are two types of rotor used in an AC generator / alternator:

(i) Salient and (ii) Cylindrical type

1. **Salient pole type:** Salient pole type rotor is used in low and medium speed alternators. Construction of AC generator of salient pole type rotor is shown in the figure above. This type of rotor consists of large number of projected poles (called salient poles), bolted on a magnetic wheel. These poles are also laminated to minimize the eddy current losses. Alternators featuring this type of rotor are large in diameters and short in axial length.
2. **Cylindrical type:** Cylindrical type rotors are used in high speed alternators, especially in turbo alternators. This type of rotor consists of a smooth and solid steel cylinder havingg slots along its outer periphery. Field windings are placed in these slots. The DC suppy is given to the rotor winding through the slip rings and and brushes arrangement.

Working Principle

An alternator operates on the same fundamental principle of electromagnetic induction as a DC generator i.e., when the flux linking a conductor changes, an e.m.f. is induced in the conductor. Like a DC generator, an alternator also has an armature winding and a field winding. But there is one important difference between the two.

In a DC generator, the armature winding is placed on the rotor in order to provide a way of converting alternating voltage generated in the winding to a direct voltage at the terminals through the use of a rotating commutator.

The field poles are placed on the stationary part of the machine. Since no commutator is required in an alternator, it is usually more convenient and advantageous to place the field winding on the rotating part (i.e., rotor) and armature winding on the stationary part (i.e., stator).

An alternator has 3,-phase winding on the stator and a DC field winding on the rotor. This DC source (called exciter) is generally a small DC shunt or compound generator mounted on the shaft of the alternator.

Alternator Operation

The rotor winding is energized from the DC exciter and alternate N and S poles are developed on the rotor. When the rotor is rotated in anti-clockwise direction by a prime mover, the stator or armature conductors are cut by the magnetic flux of rotor poles.

Consequently, e.m.f. is induced in the armature conductors due to electromagnetic induction. The induced e.m.f. is alternating since N and S poles of rotor alternately pass the armature conductors.

The magnitude of the voltage induced in each phase depends upon the rotor flux, the number and position of the conductors in the phase and the speed of the rotor.

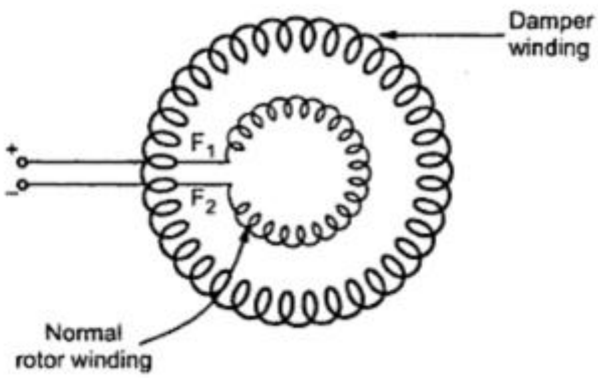
When the rotor is rotated, a 3-phase voltage is induced in the armature winding. The magnitude of induced e.m.f. depends upon the speed of rotation and the DC exciting current. The magnitude of e.m.f. in each phase of the armature winding is the same. However, they differ in phase by 120° electrical.

4. **Discuss the various methods of starting synchronous motors. Explain the working principle of synchronous motor**

Methods of Starting of Synchronous Motor

1. Motor starting with an external prime Mover : Synchronous motors are mechanically coupled with another motor. It could be either 3 phase induction motor or DC shunt motor. DC excitation is not fed initially. It is rotated at speed very close to its synchronous speed and after that DC excitation is given. After some time when magnetic locking takes place supply to the external motor is cut off.

2. Damper winding: In case, synchronous motor is of salient pole type, additional winding is placed in rotor pole face. Initially when rotor is standstill, relative speed between damper winding and rotating air gap flux in large and an emf is induced in it which produces the required starting torque. As speed approaches synchronous speed, emf and torque is reduced and finally when magnetic locking takes place, torque also reduces to zero. Hence in this case synchronous is first run as three phase induction motor using additional winding and finally it is synchronized with the frequency.

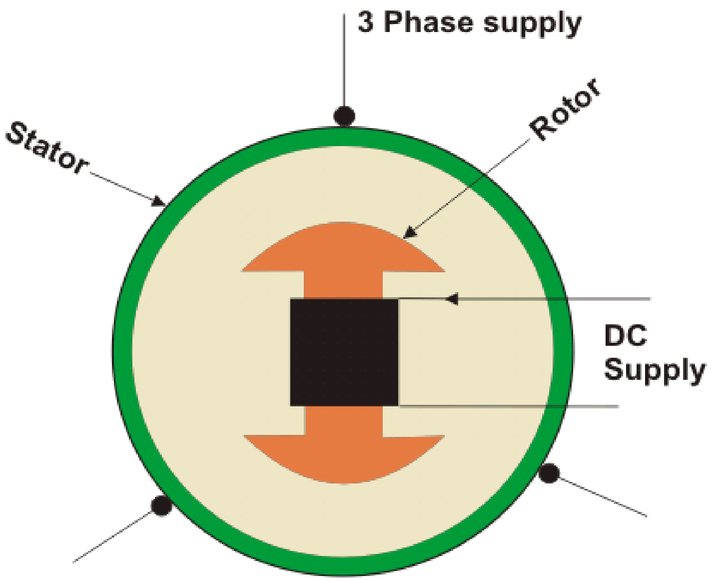


Principle of Operation Synchronous Motor

Synchronous motor is a doubly excited machine i.e two electrical inputs are provided to it. It's stator winding which consists of a 3 phase winding is provided with 3 phase supply and rotor is provided with DC supply. The 3 phase stator winding carrying 3 phase currents produces 3 phase rotating magnetic flux.

The rotor carrying DC supply also produces a constant flux. Considering the frequency to be 50 Hz, from the above relation we can see that the 3 phase rotating flux rotates about 3000 revolution in 1 min or 50 revolutions in 1 sec. At a particular instant rotor and stator poles might be of same polarity (N-N or S-S) causing repulsive force on rotor and the very next second it will be N-S causing attractive force.

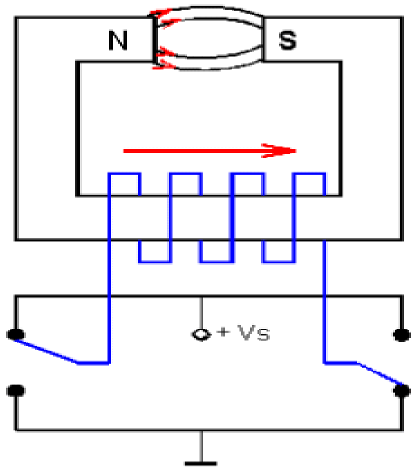
But due to inertia of the rotor, it is unable to rotate in any direction due to attractive or repulsive force and remain in standstill condition. Hence it is not self starting. To overcome this inertia, rotor is initially fed some mechanical input which rotates it in same direction as magnetic field to a speed very close to synchronous speed. After some time magnetic locking occurs and the synchronous motor rotates in synchronism with the frequency.



Synchronous Motor

5. Explain construction and operation of stepper motor

Stepper motor is a special type of electric motor that moves in precisely defined increments of rotor position (Steps). The size of the increment is measured in degrees and can vary depending on the application. Due to precise control, stepper motors are commonly used in medical, satellites, robotic and control applications. There are several features common to all stepper motors that make them ideally suited for these types of applications



TYPES OF STEPPER MOTORS

1. Variable Reluctance Motor (VRM) 2. Permanent Magnet Stepper Motor (PMSM) 3. Hybrid Stepper Motor (HSM)

6. **Explain construction and operation of brushless DC motors.**

Brushless DC motor may be described as electronically commuted motor which do not have brushes. These types of motors are highly efficient in producing large amount of torque over a vast speed range. In brushless motors, permanent magnets rotate around a fixed armature and overcome the problem of connecting current to the armature. Commutation with electronics has large scope of capabilities and flexibility. They known for smooth operation, and holding torque when stationary.

Working Principle of Motor

Before explaining working of **brushless DC motor**, it is better to understand function of brushed motor. In brushes motors, there are permanent magnets on the outside and a spinning armature which contains electromagnet is inside. These electromagnets create a magnetic field in the armature when power is switched on and help to rotates armature.

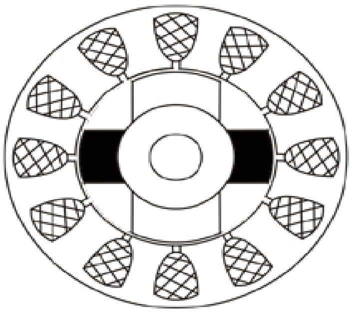
The brushes change the polarity of the pole to keep the rotation on of the armature. The basic principles for the brushed DC motor and for brushless DC motor are same i.e., internal shaft position feedback. **Brushless DC motor** has only two basic parts: rotor and the stator. The rotor is the rotating part and has rotor magnets whereas stator is the stationary part and contains stator windings. In BLDC permanent magnets are attached in the rotor and move the electromagnets to the stator. The high power transistors are used to activate electromagnets for the shaft turns. The controller performs power distribution by using a solid-state circuit.

Types of Brushless DC Motors

Basically, BLDC are of two types, one is **outer rotor motor** and other is **inner rotor motor**. The basic difference between the two are only in designing, their working principles are same.

Inner Rotor Design

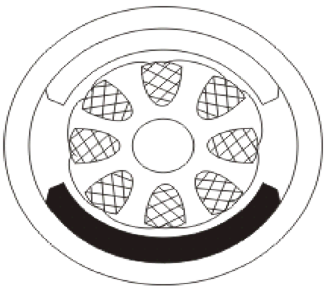
In an inner rotor design, the rotor is located in the center of the motor and the stator winding surround the rotor. As rotor is located in the core, rotor magnets does not insulate heat inside and heat get dissipated easily. Due to this reason, inner rotor designed motor produces a large amount of torque and validly used.



Inner Motor

Outer Rotor Design

In outer rotor design, the rotor surrounds the winding which is located in the core of the motor. The magnets in the rotor traps the heat of the motor inside and does not allow to dissipate from the motor. Such type of designed motor operates at lower rated current and has low clogging torque.



Outer Motor

Advantages of Brushless DC Motor

1. Brushless motors are more efficient as its velocity is determined by the frequency at which current is supplied, not the voltage.
2. As brushes are absent, the mechanical energy loss due to friction is less which enhanced efficiency.
3. BLDC motor can operate at high-speed under any condition.
4. There is no sparking and much less noise during operation.
5. BLDC motors accelerate and decelerate easily as they are having low rotor inertia.
6. BLDC motors do not have brushes which make it more reliable, high life expectancies, and maintenance free operation.

Disadvantages of Brushless DC Motors

1. BLDC motor cost more than brushless DC motor.
2. The limited high power could be supplied to BLDC motor, otherwise too much heat weakens the magnets and insulation of winding may get damaged.

UNIT V MEASUREMENT AND INSTRUMENTATION

PART A

1. **List the different types of errors in measurements. (May-2003)**

i)	Gross error	iv) Observation error
ii)	Systematic error	v) Random error
iii)	Environmental error	vi) Limiting error

2. **What is transducer? (Dec-2010)**

A device that receives energy from one system and transmits it to another, often in a different form.

3. **How the transducers are classified? (Dec-2009)**

i) On the basis of transduction form used

ii) As primary and secondary transducers

iii) As active and passive transducers

iv) As analog and digital transducers

v) As transducers and inverse transducers

4. **What is piezoelectric effect?**

- A piezoelectric material is one which an electric potential appear across certain surfaces of a crystal if the dimensions of the crystal are changed by application of mechanical force.
- The potential is produced by displacement of charges.

5. **What is meant by photoelectric transducer?**

When the radiation of lights falls on the photosensitive element, electrons are emitted from the surface of element. Thus the light energy is converted into electrical energy.

6. **Mention some applications of hall effect.**

When an electric current flows downwards in a semiconductor pellet which is placed in magnetic field perpendicular to the pellet surface, an electromotive force is created in the pellet in a direction perpendicular to both current and magnetic induction.

7. **What is thermistor?**

Thermistor is non metallic resistors made by sintering mixtures of metallic oxides such as manganese, nickel, cobalt, copper and uranium.

8. **List the main functional elements used in most of the measurement.**

   i) Primary sensing element ii) Variable conversion element iii) Variable manipulation element iv) Data transmission element

9. **Define accuracy and resolution of measuring instruments.**

   Accuracy

   It is a measure of the closeness with which an instrument measures the true value of a quantity.

   Resolution

   It is the smallest change in the measured quantity that will produce a deductible change in the instrument reading.

10. **Define 'errors' in measurement.**

    Error is the deviation from the true value of the measured quantity. Error can be expressed as a absolute quantity or as a percentage.

PART B

1. **Discuss the errors in measurements, How are the various transducers classified**

Gross Errors

This category of errors includes all the human mistakes while reading, recording and the readings. Mistakes in calculating the errors also come under this category. For example while taking the reading from the meter of the instrument he may read 21 as 31. All these types of error are come under this category. Gross errors can be avoided by using two suitable measures and they are written below:

1.A proper care should be taken in reading, recording the data. Also calculation of error should be done accurately.
2.By increasing the number of experimenters we can reduce the gross errors. If each experimenter takes different reading at different points, then by taking average of more readings we can reduce the gross errors.

Systematic Errors

In order to understand these kinds of errors, let us categorize the systematicerrors as

Instrumental Errors

These errors may be due to wrong construction, calibration of the measuring instruments. These types of error may be arises due to friction or may be due to hysteresis. These types of errors also include the loading effect and misuse of the instruments. Misuse of the instruments results in the failure to the adjust the zero of instruments. In order to minimize the gross errors in measurement various correction factors must be applied and in extreme condition instrument must be re-calibrated carefully.

Environmental Errors

This type of error arises due to conditions external to instrument. External condition includes temperature, pressure, humidity or it may include external magnetic field. Following are the steps that one must follow in order to minimize the environmental errors:

- Try to maintain the temperature and humidity of the laboratory constant by making some arrangements.
- Ensure that there should not be any external magnetic or electrostatic field around the instrument.

Observational Errors

As the name suggests these types of errors are due wrong observations. The wrong observations may be due to PARALLAX. In order to minimize the PARALLAX error highly accurate meters are required, provided with mirrored scales.

Random Errors

After calculating all systematic errors, it is found that there are still some errors in measurement are left. These errors are known as random errors. Some of the reasons of the appearance of these errors are known but still some reasons are unknown. Hence we cannot fully eliminate these kinds of error.

2. Discuss the working of Resistive, Inductive and Capacitive transducer.

The **transducer** whose **resistance varies** because of the **environmental effects** such type of transducer is known as the resistive transducer. The **change in resistance** is **measured** by the **ac or dc measuring devices**. The **resistive transducer** is used for measuring the**physical quantities like temperature, displacement, vibration etc.**

Working Principle of Resistive Transducer

The resistive transducer element works on the principle that the resistance of the element is directly proportional to the length of the conductor and inversely proportional to the area of the conductor. $R = \rho L/A$

Where R – resistance in ohms.

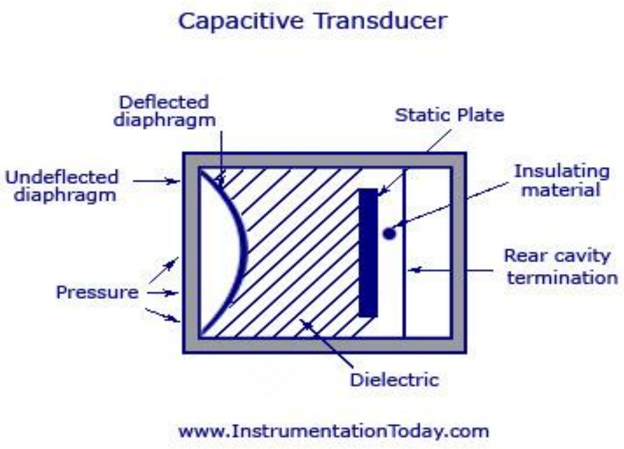
A – cross-section area of the conductor in meter square.

L – Length of the conductor in meter square.

ρ – the resistivity of the conductor in materials in ohm meter.

The resistive transducer is designed by considering the variation of the length, area and resistivity of the metal.

The capacitive transducer is used for measuring the displacement, pressure and other physical quantities. It is a passive transducer that means it requires external power for operation. The capacitive transducer works on the principle of variable capacitances. The capacitance of the capacitive transducer changes because of many reasons like overlapping of plates, change in distance between the plates and dielectric constant.



Principle of Operation

The equations below express the capacitance between the plates of a capacitor

$$C = \varepsilon A/d$$

$$C = \varepsilon_r \varepsilon_0 A/d$$

Where A – overlapping area of plates in m^2

d – the distance between two plates in meter

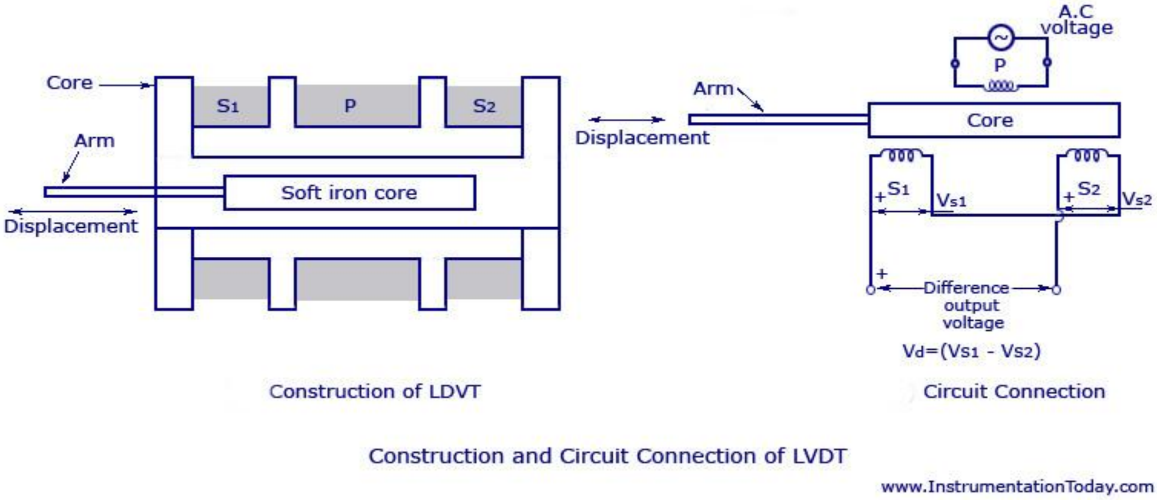
ε – permittivity of the medium in F/m

ε_r – relative permittivity

ε_0 – the permittivity of free space

Inductive transducer

Construction



Construction and Circuit Connection of LVDT

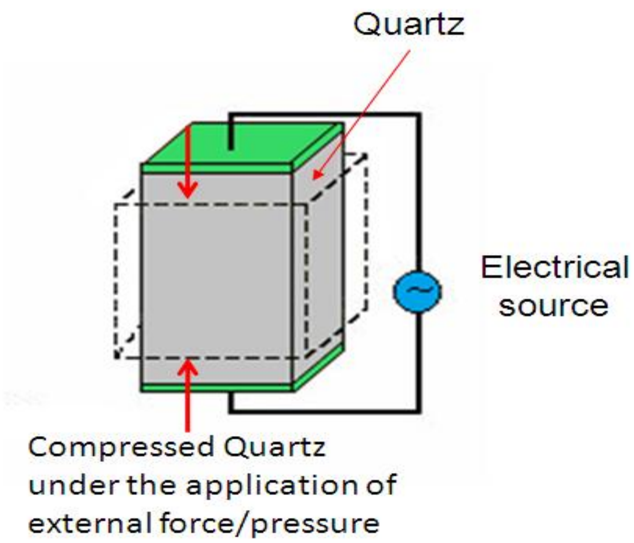
The device consists of a primary winding (P) and two secondary windings named S1 and S2. Both of them are wound on one cylindrical former, side by side, and they have equal number of turns. Their arrangement is such that they maintain symmetry with either side of the primary winding (P). A movable soft iron core is placed parallel to the axis of the cylindrical former. An arm is connected to the other end of the soft iron core and it moves according to the displacement produced.

Working

As shown in the figure above, an ac voltage with a frequency between (50-400) Hz is supplied to the primary winding. Thus, two voltages VS1 and VS2 are obtained at the two secondary windings S1 and S2 respectively. The output voltage will be the difference between the two voltages (VS1-VS2) as they are combined in series. Let us consider three different positions of the soft iron core inside the former.

- **Null Position** – This is also called the central position as the soft iron core will remain in the exact center of the former. Thus the linking magnetic flux produced in the two secondary windings will be equal. The voltage induced because of them will also be equal. Thus the resulting voltage VS1-VS2 = 0.
- **Right of Null Position** – In this position, the linking flux at the winding S2 has a value more than the linking flux at the winding S1. Thus, the resulting voltage VS1-VS2 will be in phase with VS2.
- **Left of Null Position** – In this position, the linking flux at the winding S2 has a value less than the linking flux at the winding S1. Thus, the resulting voltage VS1-VS2 will be in phase with VS1.

3. Explain the working of piezoelectric and photoelectric.



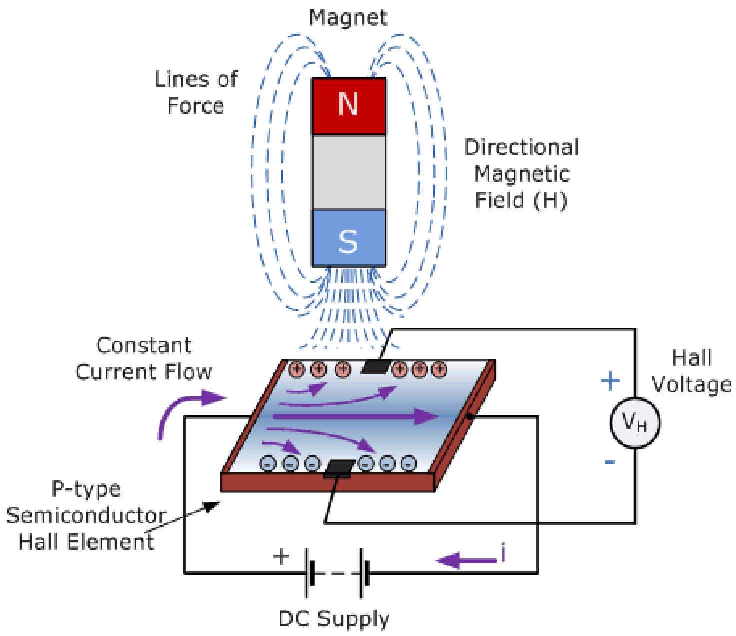
- Piezoelectric sensor is used for the measurement of pressure, acceleration and dynamic-forces such as oscillation, impact, or high speed compression or tension.
- It contains piezoelectric ionic crystal materials such as Quartz.On application of force or pressure these materials get stretched or compressed.
- During this process, the charge over the material changes and redistributes.
- One face of the material becomes positively charged and the other negatively charged. The net

charge q on the surface is proportional to the amount x by which the charges have been displaced. The displacement is proportion to force. Therefore we can write,

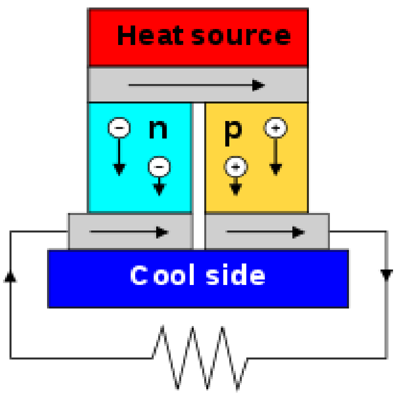
- $q = kx = SF$
- where k is constant and S is a constant termed the charge sensitivity.

4. Explain the working of thermoelectric and Hall effect

A Hall effect sensor is a transducer that varies its output voltage in response to a magnetic field. Hall effect sensors are used for proximity switching, positioning, speed detection, and current sensing applications. In its simplest form, the sensor operates as an analog transducer, directly returning a voltage.



The **thermoelectric** effect is the direct conversion of temperature differences to electric voltage and vice versa. A **thermoelectric** device creates voltage when there is a different temperature on each side. Conversely, when a voltage is applied to it, it creates a temperature difference.



5. **Explain the principle and operation of Multimeter and Oscilloscope.**

Multimeter or a multitester, also known as a VOM (volt-ohm-milliammeter), is an electronic measuring instrument that combines several measurement functions in one unit. A typical multimeter can measure voltage, current, and resistance. Analog multimeters use a microammeter with a moving pointer to display readings.

Digital multimeter is a test equipment which offers several electronic measurement task in one tool. It is also known as the voltmeter or Ohm meter or Volt Ohm meter. The standard and basic measurements performed by multimeter are the measurements of amps, volts, and ohms. Apart from that, these digital multimeters perform many additional measurements by using digital and logic technology.

A multimeter is a simple but useful device which has only three parts; Display screen, selection knob, ports.

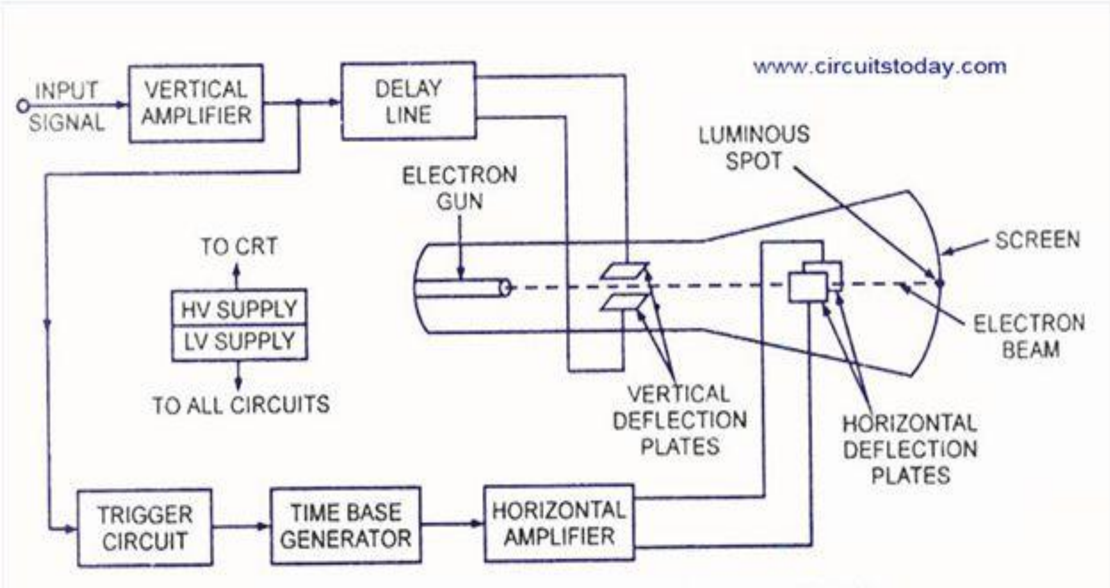
Display screen-It has illuminated display screen for better visualization. It has five digits display screen; one represent sign value and the other four are for number representation. **Selection knob-** As we know a single multimeter performs so many tasks like reading voltage, resistance, and current. The selection knob allows the user to select the different job.

Port- There is two ports on the front of the unit. One is the mAVΩ port which allows the measurement of all the three units: current up to 200 mA, voltage, and resistance. The red probe is plugged into this port. The other is COM port which means common and it normally connected to –ve of a circuit and black probe is plugged into it. There is one particular port is 10A, which is use to measures large current in the circuit.

OSCILLOSCOPE

The oscilloscope is probably the most useful and versatile laboratory instrument for the development of electronic circuits and systems. It is used for studying wave shapes of alternating currents and voltages as well as for measurement of voltage, current, power and frequency. In fact almost any quantity after suitable conversion into voltage can be analyzed as a function of time. Functionally CRO is capable of displaying two quantities Y versus X in Cartesian coordinate system, however in most cases the Y axis is amplitude and the X axis is time.

OPERATION OF AN OSCILLOSCOPE



Block Diagram of a General Purpose CRO

Construction of CRO

The oscilloscope is basically an electron beam voltmeter. The main part of oscilloscope is the Cathode Ray Tube (CRT) which makes the applied signal visible by the deflection of a thin beam of electrons striking a phosphor screen. The electron beam can be moved to follow waveforms varying at a rate of times/second using proportionate electric fields. Thus, the electron beam faithfully follows rapid variations in signal voltage and traces a visible path on the CRT screen. The major blocks in a general purpose CRO shown in figure given below are as follows: CRT, vertical amplifier, delay line, time base gnerator, horizontal amplifier, trigger circuit, and power supply.

6. **Mention the static and dynamic characteristics of a measurement system and explain any eight static characteristics.**

The performance characteristics of an instrument are mainly divided into two categories:

i) Static characteristics

ii) Dynamic characteristics

Static characteristics:

Static characteristics: The set of criteria defined for the instruments, which are used to measure the quantities which are slowly varying with time or mostly constant, i.e., do not vary with time, is called 'static characteristics'.

The various static characteristics are:

i) Accuracy
ii) Precision
iii) Sensitivity
iv) Linearity
v) Reproducibility
vi) Repeatability
vii) Resolution
viii) Threshold
ix) Drift
x) Stability
xi) Tolerance
xii) Range or span

Accuracy: It is the degree of closeness with which the reading approaches the true value of the quantity to be measured.

Precision: It is the measure of reproducibility i.e., given a fixed value of a quantity, precision is a measure of the degree of agreement within a group of measurements.

Sensitivity: The sensitivity denotes the smallest change in the measured variable to which the instrument responds. It is defined as the ratio of the changes in the output of an instrument to a change in the value of the quantity to be measured.

Reproducibility: It is the degree of closeness with which a given value may be repeatedly measured. It is specified in terms of scale readings over a given period of time.

Repeatability: It is defined as the variation of scale reading & random in nature Drift

Resolution: If the input is slowly increased from some arbitrary input value, it will again be found that output does not change at all until a certain increment is exceeded. This increment is called resolution.

Threshold: If the instrument input is increased very gradually from zero there will be some minimum value below which no output change can be detected. This minimum value defines the threshold of the instrument.

Stability: It is the ability of an instrument to retain its performance throughout is specified operating life. Tolerance: The maximum allowable error in the measurement is specified in terms of some value which is called tolerance.

Range or span: The minimum & maximum values of a quantity for which an instrument is designed to measure is called its range or span.

Dynamic characteristics: The set of criteria defined for the instruments, which are changes rapidly with time, is called 'dynamic characteristics'.

The various static characteristics are:

i) Speed of response
ii) Measuring lag
iii) Fidelity
iv) Dynamic error

Speed of response: It is defined as the rapidity with which a measurement system responds to changes in the measured quantity.

Measuring lag: It is the retardation or delay in the response of a measurement system to changes in the measured quantity.

Dynamic error: It is the difference between the true value of the quantity changing with time & the value indicated by the measurement system if no static error is assumed. It is also called measurement error.