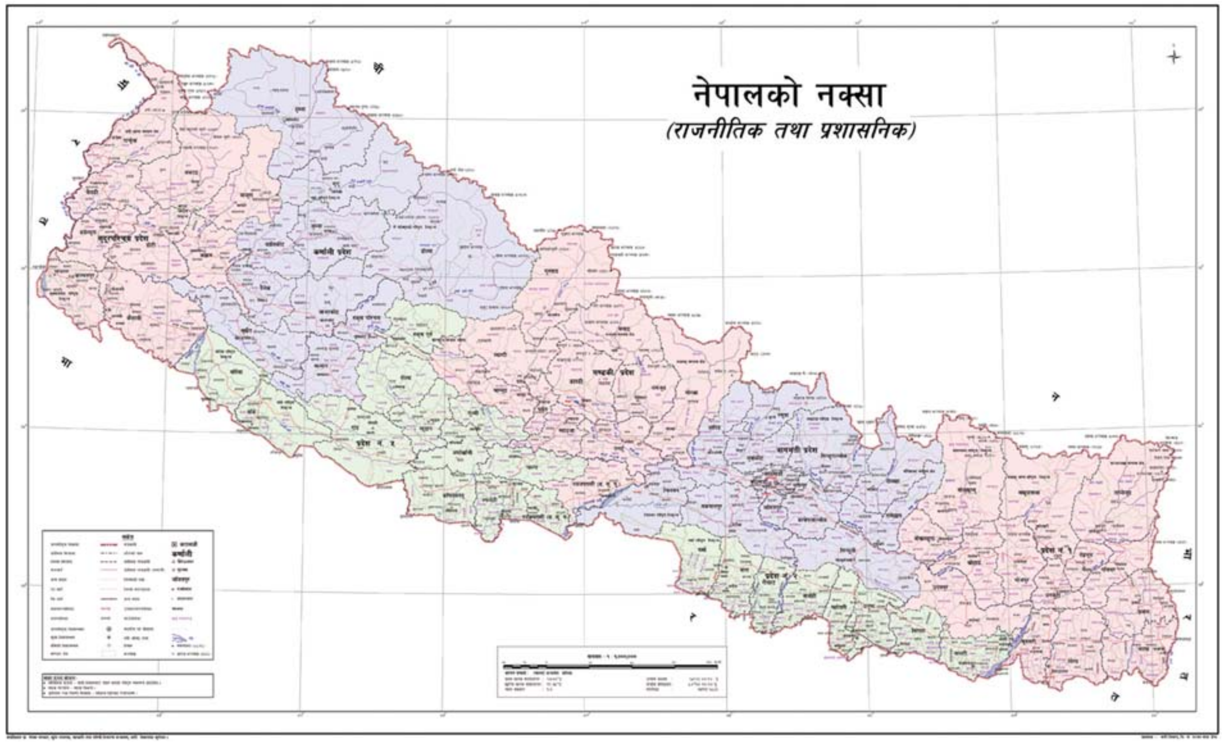

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Electrical Engineering

Electrical Machine

10

Feedback Copy

Technical and Vocational Stream
Learning Resource Material

Electrical Machine
(Class – 10)

Secondary Level
Electrical Engineering

Government of Nepal
Ministry of Education, Science and Technology
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Sanothimi, Bhaktapur

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Preface

The curriculum and curricular materials have been developed and revised on a regular basis with the aim of making education objective-oriented, practical, relevant and job oriented. It is necessary to instill the feelings of nationalism, national integrity and democratic spirit in students and equip them with morality, discipline and self-reliance, creativity and thoughtfulness. It is essential to develop in them the linguistic and mathematical skills, knowledge of science, information and communication technology, environment, health and population and life skills. it is also necessary to bring in them the feeling of preserving and promoting arts and aesthetics, humanistic norms, values and ideals. It has become the need of the present time to make them aware of respect for ethnicity, gender, disabilities, languages, religions, cultures, regional diversity, human rights and social values so as to make them capable of playing the role of responsible citizens with applied technical and vocational knowledge and skills. This Learning Resource Material for Electrical Engineering has been developed in line with the Secondary Level Electrical Engineering Curriculum with an aim to facilitate the students in their study and learning on the subject by incorporating the recommendations and feedback obtained from various schools, workshops and seminars, interaction programs attended by teachers, students and parents.

In bringing out the learning resource material in this form, the contribution of the Director General of CDC Dr. Lekhnath Poudel, Dr. Tankanath Sharma, Govinda Poudel, Sanju Shrestha, Suraj Dahal, Shisir Dahal, Shivaram Shrestha is highly acknowledged. The book is written by Rupesh Maharjan, Abin Maharjan and the subject matter of the book was edited by Badrinath Timalsina and Khilanath Dhamala. CDC extends sincere thanks to all those who have contributed in developing this book in this form.

This book is a supplimentary learning resource material for students and teachrs. In addition they have to make use of other relevnt materials to ensure all the learning outcomes set in the curriculum. The teachers, students and all other stakeholders are expected to make constructive comments and suggestions to make it a more useful learning resource material.

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Table of Contents

CHAPTER-I

Transformer

Learning outcomes:

After the completion of this chapter, the students will be able to know:

Different types of transformer

1) Working mechanism of transformer
2) Different connection of the three phase transformer
3) Losses and efficiency of transformer

1.1 Introduction:

Transformer is an a.c static electrical device as its coil is not movable. It transfers the electrical energy from one circuit to another circuit keeping the frequency on both primary and secondary side. In it, the two circuits are electrically isolated but magnetically linked having the common flux. The energy transfer usually take place with a change of voltage (which is not necessary in all the cases). Generally when the transformer raises the voltage at the secondary side with respect to the primary then such a transformer is called as step-up transformer and if it lowers voltage at the secondary side then it is known as step-down transformer. Transformer is based on the principle of "Faraday's law of electromagnetic induction".

Functions of the transformer:

i. It can raise or lower the voltage and current in A.C circuits.
ii. It can increase or decrease the value of capacitance, inductance or resistance in an a.c circuits thus it can acts as impendence transferring device.
iii. It can isolate two circuits electrically.
iv. It can be used to prevent dc passing from one circuit to another.

Applications:

Power supply, industries, substations,hydro-power etc.

1.2 Construction:

A transformer consisting an iron core is shown in figure 1.2. Two separate coils are provided on two separate limbs of the core. The horizontal member of the core is known as yoke. The coils are made by windings of enamel insulated copper wire.

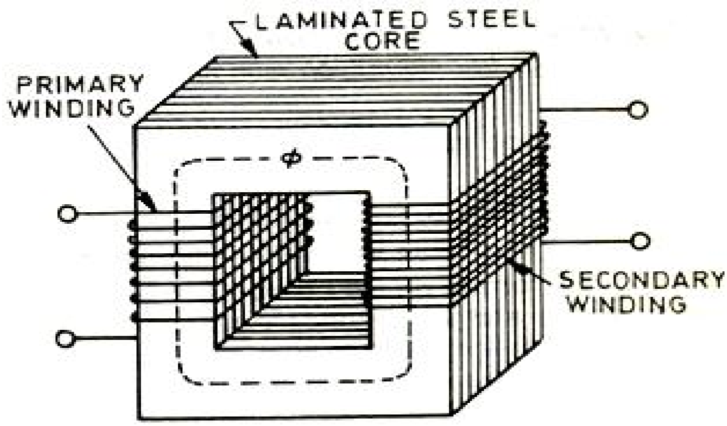


Figure 1.2 Basic construction of transformer

A transformer is very simple device consisting of two windings (primary, and secondary) having mutual inductance and laminated steel core. The winding coils are well insulated from the core.

Steel core:

The magnetic current is set up in the steel core. Due to high permeability of steel, the magnitude of the exciting current necessary to set up the required flux in the core is very small and consequently, almost 100% of the magnetic flux (generated by the primary) links with secondary. The core is built up-to thin sheets of silicon steel alloy containing 4-5% silicon). Such steels possess very high permeability and hence magnetic flux linkage is nearly 100%. A steel core is either circular or rectangular in shape and is laminated. The core has different shapes as L, I, U and E.

Lamination of steel core:

When the transformer is excited with an a.c voltage, alternating flux is set up in the steel core. If the core were made of a solid block of steel, eddy-currents will be induced, thereby causing a loss of power. Since the eddy current loss is proportional to the thickness of core, so in order to reduce such loss, thickness has to be reduced.

Hence, the core is made by stacking thin laminations (about 0.35 to 0.50 mm thick), well-insulated from each other by a light coat of core-plate varnish (or by an oxide layer on the surface) with minimum air-gap.

1.2.3 Bobbins and winding of transformer

A bobbin is a spindle or cylinder, with or without flanges, on which wire, yarn, thread or films is wound. In case of the transformer, the bobbin is a permanent container for the wire forming the shape of the coil. The bobbin supports the windings, align the cores, channels the winding and provide the termination and connection method. Each bobbin is designed for the use with a specific core shape. So, it is very important to design the best bobbin.

There are two windings in the transformer which are primary and secondary windings. In primary winding, a.c source is connected or input is given whereas in secondary winding load is connected or from where output is taken out.

1.2.4 Types of transformer

On the basis of use, the transformer is of two types which are as follows:

1. Step up transformer: The transformer which raises the voltage level is called step up transformer.

2. Step down transformer: The transformer which lowers the voltage level is called step down transformer.

On the basis of construction, the transformer is of two types which are as follows:

1. **Shell type transformer:** In this, the low voltage and high voltage windings are wound on the central limb of the core.
   - It provides double magnetic flux.
   - The core surrounds a considerable portion of the winding
   - More economical for the low voltage transformers.
   - It has 3 limbs.
   - Sandwiched winding are used.
   - Natural cooling cannot be provided.
   - Repairing and maintenance is not easy.
   - It provides better mechanical protection to the coil.

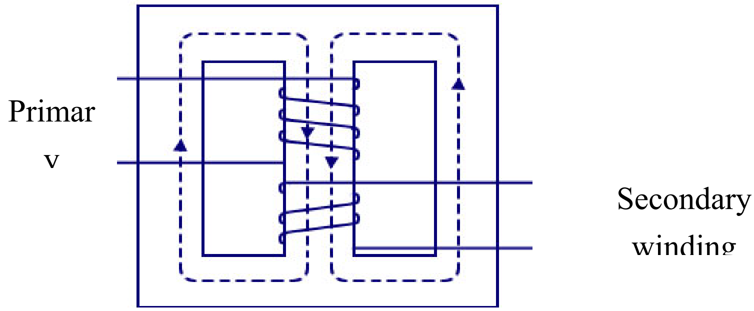


Figure: shell type

2. Core type transformer: Windings are usually cylindrical in form and concentric. It provides single magnetic flux.

- The winding surrounds a considerable part of the core.
- More suitable for high voltage transformers.
- It has 2 limbs
- Con-centric cylindrical winding are used.
- Natural cooling is provided.
- Repairing and maintenance is easy.
- It provides less mechanical protection to coil.

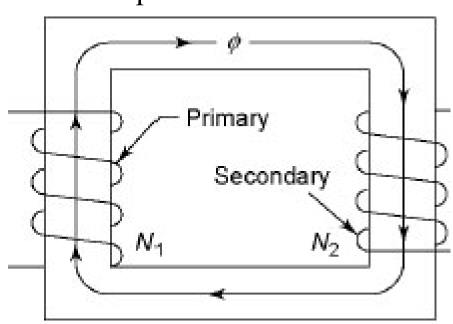


Figure: core type

1.3 Operation of transformer:

1.3.1 Working principle of transformer:

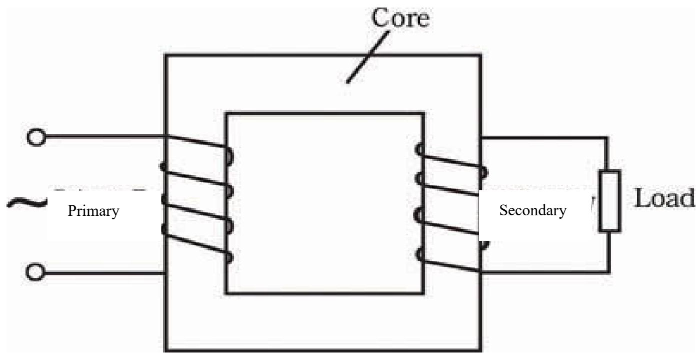


Figure 1.3.1 Transformer

An alternating voltage is applied to the primary winding (N_1) of the transformer then the coil draws the alternating current. Since this winding links with soft iron core, this alternating current through this winding produces the alternating flux (ϕ) in the core. As the flux is alternating in nature and links with the secondary winding also, induces an emf in the secondary winding. The induced emf in the secondary winding enables it to deliver current to an external load connected across it. Hence, the energy is transformed from primary winding to secondary winding by means of Faraday's law of electromagnetic induction. Therefore, the main principle of transformer is mutual induction.

For primary side,

$V_1 = -N_1 \left(\frac{d\emptyset}{dt}\right)$ ....(i)

Where, $\left(\frac{d\emptyset}{dt}\right)$ = rate of change of magnetic flux.

Also, in secondary side,

$V_2 = -N_2 \left(\frac{d\emptyset}{dt}\right)$....... (ii)

Now dividing equation (ii) by (i)

$\frac{V2}{V1} = \frac{N2}{N1}$ = K (say)

Where k= transformation ratio

So, transformation ratio is defined as the ratio of secondary voltage to primary voltage or secondary no of turns to primary no of turns.

Special cases:

- If k >1 i.e $N_2>N_1$, then transformer is called step up transformer.
- If k<1 i.e $N_2<N_1$, then transformer is called step down transformer.
- If k=1 i.e $N_2=N_1$, then transformer is called isolation transformer.

1.3.2 Emf equation

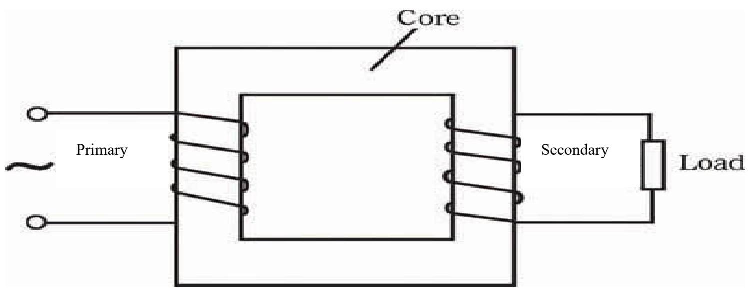


Figure 1.3.2 Transformer

Let, "V" be the a.c voltage applied at the primary side, "I" be the current that flows through primary winding of transformer. Let us consider that the coil used is purely inductive i.e"I" lags the applied voltage "V" by 90^0. The current "I" in the primary coil produce the time varying flux which is in phase with the current "I".

When time varying flux produced by the primary winding reaches the secondary coil via iron core, the time varying flux cut the stationary secondary coil so from Faraday's law of electromagnetic induction, emf "E_2" is induced in the secondary coil.

The coil on which the supply voltage is applied is called primary winding and the second coil on which the emf "E_2" is induced is called secondary coil.

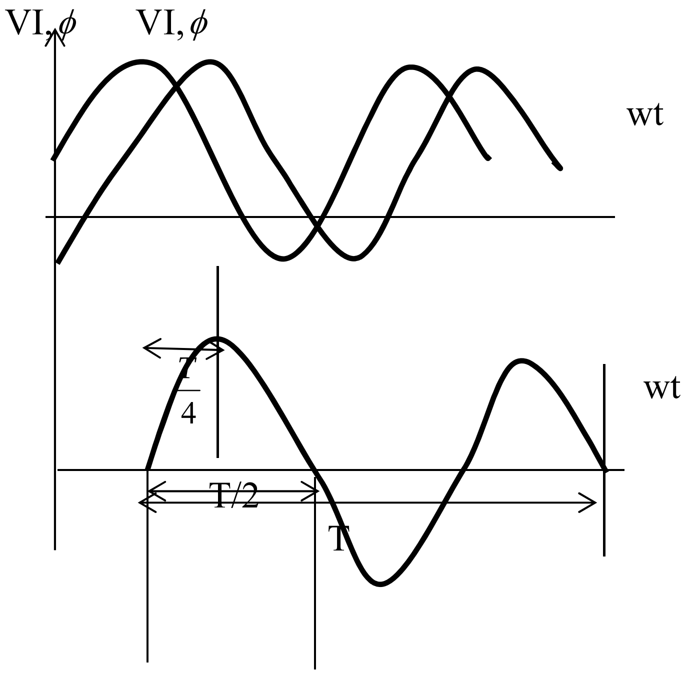


Figure 1.3.2(a) waveform

The average emf induced, $E_2 = N_2\frac{d\varnothing}{dt}$

$$= N_2\left(\frac{\varnothing m - 0}{\frac{T}{4}}\right)$$

$= 4N_2\varnothing_m f$ volts

Where $\frac{d\varnothing}{dt}$ is average value of rate of change of magnetic flux and (1/T=f)

1.3.3 Transformation ratio:

Transformation ratio is defined as the ratio of secondary voltage to primary voltage or secondary no of turns to primary no of turns.

$$K = \frac{V2}{V1} = \frac{N2}{N1}$$

Where k= transformation ratio

1.3.4 Load and no-load of transformer with equivalent circuit:

a. Transformer on NO LOAD:

If the ac source is supplied to the primary side keeping secondary side of the transformer open and then primary will draw the current known as no load current. It is denoted by I_0.

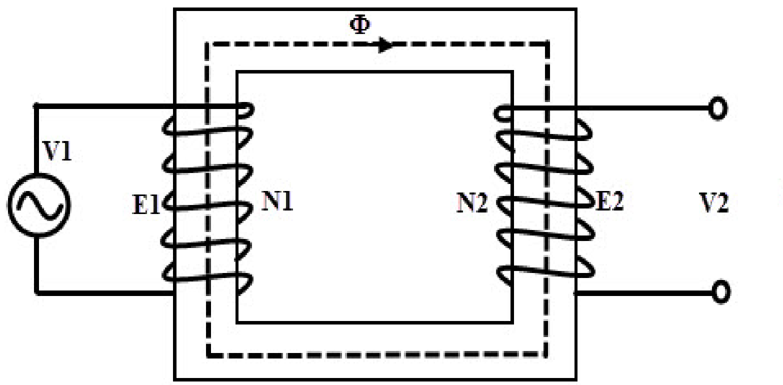


Figure1.3.4(a): Transformer on no-load

In case of real transformer, the winding consist some resistance as it is not purely inductive. Hence,the primary current I_0 will lag the applied voltage V_1 by some angle $\emptyset_0$ which will be less than 90^0 as shown in figure below:

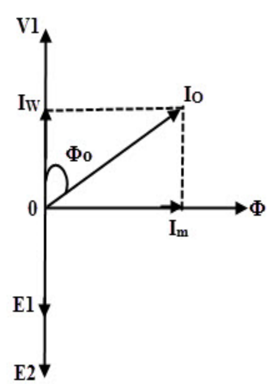


figure1.3.4(b): Phasor diagram for no-load operation

The no-load current can be resolved into two components as follows:

I_m = component of I_0 which lags V_1 by 90^0 = $I_0 \sin\emptyset_0$ = magnetizing component

I_w = component of I_0 in phase with V_1 = $I_0 \cos\emptyset_0$ = magnetizing component of I_0

The power consumed by the transformer at no-load is given by:

$W_0 = V_1 I_0 \cos\emptyset_0$ watts

Where $\cos\emptyset_0$ is known as no-load power factor of the transformer.

From phasor diagram,

$I_0 = \sqrt{Iw^2 + Im^2}$

No load equivalent circuit of the transformer is shown in figure 1.3.4(c):

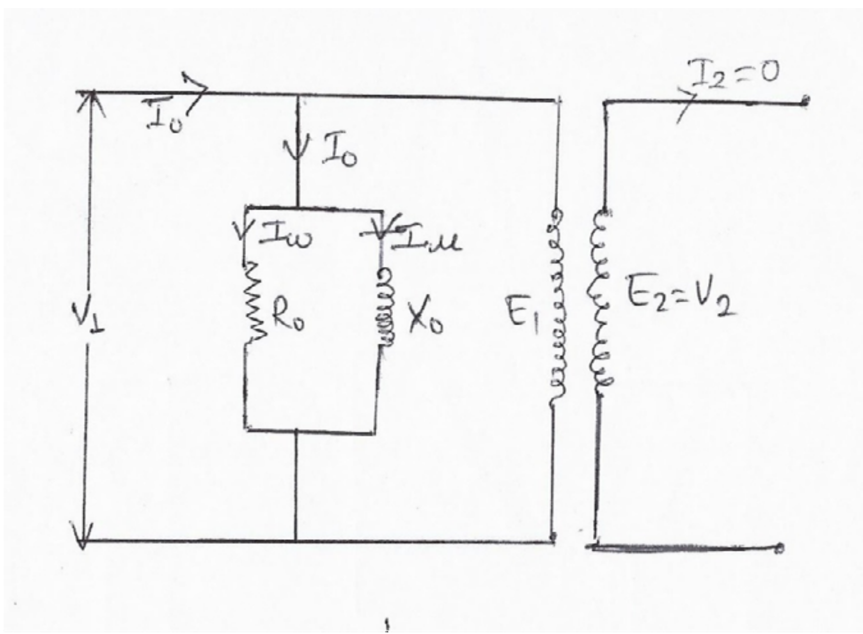


Figure 1.3.4 (c) Equivalent circuit

b. Transformer on LOAD:

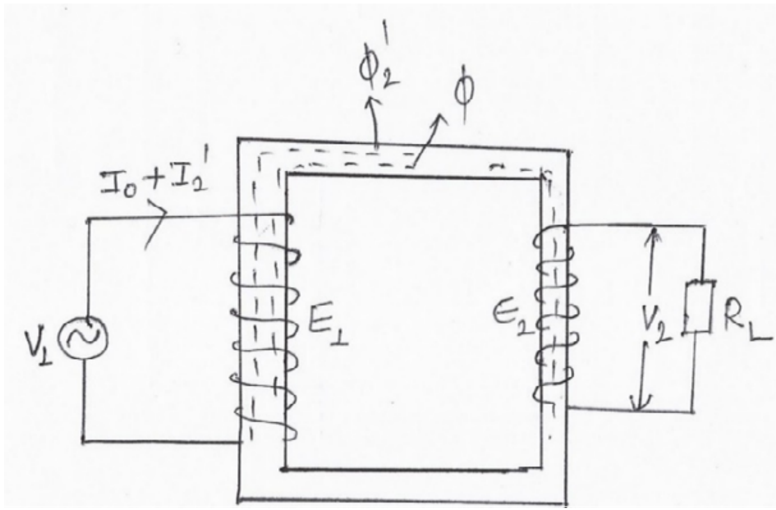


Figure 1.3.4 (ii) : Transformer on LOAD

Current "I_2" will flow while connecting the load on secondary side after supply is given through primary side. Now, the secondary mmf N_2I_2 will set up its own magnetic flux ϕ_2 whose direction is opposite to main ϕ.

The output of the transformer at no-load is zero (i.e. $V_2I_2 = 0$), but the input power is V_1I_0 which will be power loss within the transformer. When the transformer is loaded, the output of the transformer is V_2I_2 (greater than zero). Therefore, some additional currents "I_2" will flow in the primary winding to increase the power in the primary circuit so that there is power balance between primary circuit and secondary circuit. This additional current, "I'_2", in the primary winding will set up its own magnetic flux ϕ_2' whose direction will be opposite to the direction of ϕ_2. The additional power in the primary winding should be equal to the power in the secondary winding.

$V_1I_2' = V_2I_2$

Also;

$$\frac{I_2'}{I_2} = \frac{V_2}{V_1} = \frac{N_2}{N_1}$$

$N_1I_2' = N_2I_2$

Now, $\phi_2 = \dfrac{N_2I_2}{reluctance}$ and $\phi_2' = \dfrac{N_2I'_2}{reluctance}$

The reluctance for both the cases is same i.e.$\emptyset_2 = \emptyset_2'$ so, they cancel each other. Therefore, the net magnetic flux in the core is always constant at any load and is equal to$\emptyset$.

The equivalent circuit of transformer on load is shown in figure 1.3.4(d):

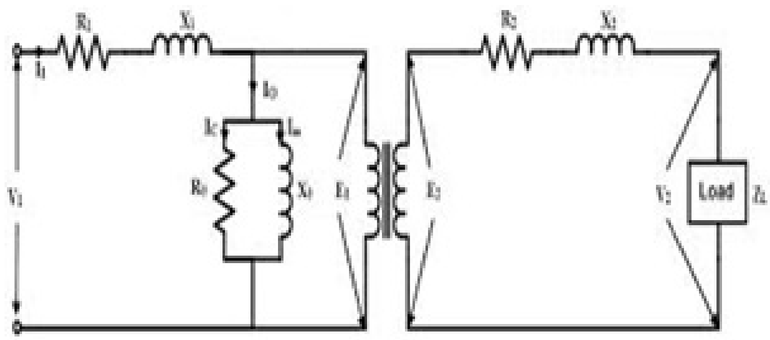


Figure 1.3.4 (d) Equivalent circuit

1.4 Losses and efficiency of transformer:

The output of a transformer is always less than input because there are some power losses within the transformer while it transfers power power from one circuit to another circuit. There are mainly two types of power losses in the transformer.

i. Copper loss
ii. Iron loss

i. Copper loss:

It is the power loss due to heating of primary and secondary coil. The main cause of copper is the heat generation due to resistance of the coils. The copper loss depends upon the load. This can be determined by short- circuited test.

Total Cu losses = $I^2_1 R_1 + I^2_2 R_2$

It is clear that copper losses vary as the square of the load current. Thus if copper losses are 400W at a load current of 10A, then they will be $(1/2)^2 \times 400 = 100$W at a load current of 5A.

Total losses in a transformer = $P_i + P_c$ where, P_i = iron loss

P_c = copper loss

= constant losses + variable losses

It may be noted that in a transformer, copper losses account for about 90% of the total losses on full-load.

ii. Iron loss:

It is the power loss due to heating of iron core and main causes for this heating are eddy current loss and hysteresis loss. This power loss is equal to the no-load power loss and remains constant at any load. This can be determined by open- circuit test.

Hysteresis loss = $k_h f B^{1.6}$ watts/m^3

Eddy current loss = $k_e f^2 B^2 t^2$ watts/ m^3

Both hysteresis loss and eddy current losses depend upon;

i. Maximum flux density B_m in the core

ii. Supply frequency "f"

Since, transformers are connected to constant- frequency, constant voltage supply; both f and B_m are constant. Hence, core or iron losses are practically the same at all loads.

Iron or Core losses, P_i = hysteresis loss + eddy current loss

= constant losses

The hysteresis loss can be minimized by using steel of high silicon content whereas eddy current loss can be reduced by using core of thin laminations.

 # Eddy current loss:

As the magnitude of magnetic flux in the core is time varying in nature, emf will induce in the core and some current will circulate within the core. This circulating current is known as eddy current. This current produces heat within the core. The power loss due to this phenomenon is known as eddy current loss. This eddy current loss depends upon the resistivity of the core and length of path of this circulating current for a given cross-section. In order to reduce eddy current loss in our practical application, we have to add silicon to steel for gaining high resistivity and path length of the eddy current is increased by dividing up the solid core into thin lamination along the flow of the flux with each lamination lightly insulated by varnish from the adjoining ones.

Eddy current loss is given by;

$W_e = KB_m^2 f^2 t^2 V$ (watts)

Where,

K= constant depending upon nature of core

B_m= maximum value of magnetic flux density in the core

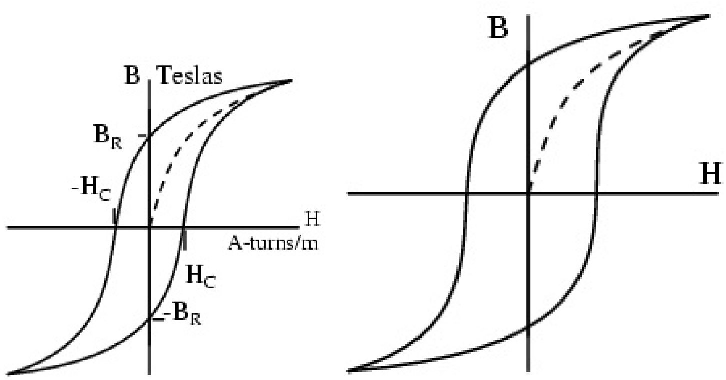
f= frequency of the exciting current

t= thickness of each lamination

V= volume of iron core

 # Hysteresis loss

Hysteresis loss is due to the reversal of magnetization of transformer core whenever it is subjected to alternating nature of magnetizing force. Whenever the core is subjected to an alternating magnetic field, the domain present in the material will change their orientation after every half cycle. The power consumed by the magnetic domain for changing the orientation after every half cycle is called Hysteresis loss.



low hysteresis loss (eg: soft magnetic material)

high hysteresis loss (eg: hard magnetic material)

Figure 1.4 Hysteris loop

1.4.3 Efficiency of a transformer:

The efficiency of a transformer is categorized into two types:

- Commercial efficiency
- All day efficiency

a. Commercial efficiency

Commercial or ordinary efficiency of a transformer is defined as the ratio of output power to the input power.

$$\text{Commercial efficiency} = \frac{\text{Output power}}{\text{Input power}}$$

b. All day efficiency

The ratio of output in kWh to the input in kWh of a transformer over a 24-hour period is known as all day efficiency. It is also known as energy efficiency.

$$n_{\text{all-day}} = \frac{\text{kwh output in 24 hour}}{\text{kwh input in 24 hour}}$$

Since the distribution transformer does not supply the rated load for the whole day so the all-day efficiency of such transformer will be lesser than ordinary or commercial efficiency.

1.5 Parallel operation of transformer:

1.5.1 Parallel operation

The process of connecting the transformer with another one if its capacity is not enough to supply the power demanded by the load is known as parallel operation of transformer. Generally, the primary windings are connected to supply bus-bars and secondary windings are connected to load bus-bars. The parallel connection of two transformers is shown in figure 1.5.1.

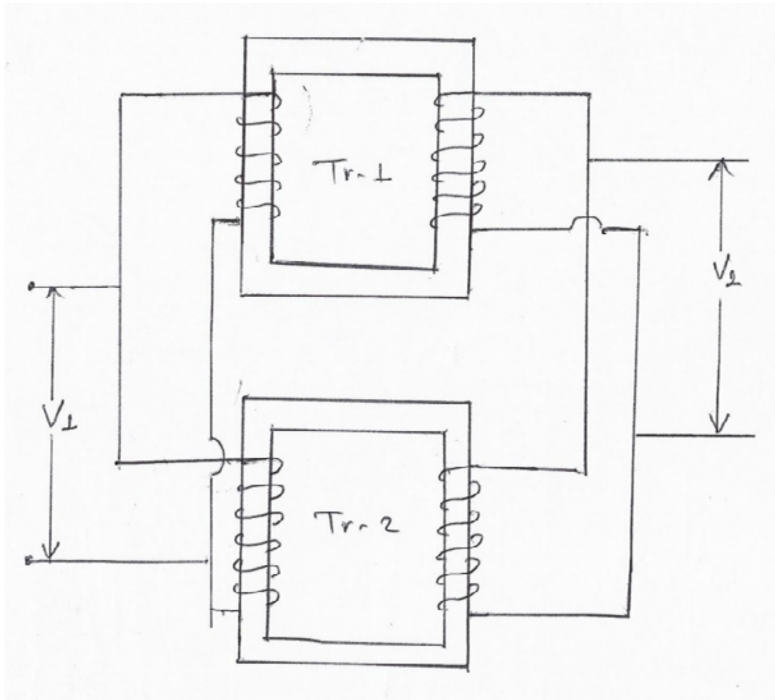


Figure 1.5.1 Parallel operation of transformer

1.5.2 Requirements for parallel operation of transformer

In order to operate the transformer in parallel certain conditions should be met which are as follows:

 # Necessary conditions:

i. Terminal voltage and frequency of both transformers should be same.
ii. Polarities of both transformers should be same.
iii. Transformation ratio should be same.

 # Desirable conditions:

i. Rating of the transformers should be same.
ii. Impedance ratio should be same.

1.5.3 Advantages of parallel operation of transformer:

i. If one transformer fails, the continuity of the supply can be maintained through other transformer.
ii. When load on the substation becomes more than the capacity of the existing transformers another transformer can be added in parallel.
iii. Any transformer can be taken out from the circuit for repair or routine maintenance without interrupting supply to the consumer.

1.6 Three-phase transformer

1.6.1 Construction of three phase transformer

A three phase transformer can be constructed by having three primary and three secondary windings on a common magnetic circuit. The basic principle of a 3-phase transformer formed from the combination of three single phase transformer is illustrated on left side whereas single three phase core type transformer is shown on right side in figure1.6.1. The three single phase core type transformers, each with windings (primary and secondary) on only one leg have their unwound legs combined to provide a path for returning flux. The primaries as well as secondaries may be connected in star or delta. If the primary is energized from a 3-phase primary windings. Since the phasor sum of three primary currents at flux exists in the central limb and it may therefore be eliminated. This modification fives a three leg core type 3-phase transformer. In this case any two legs will act as a return path for the flux in the third leg.

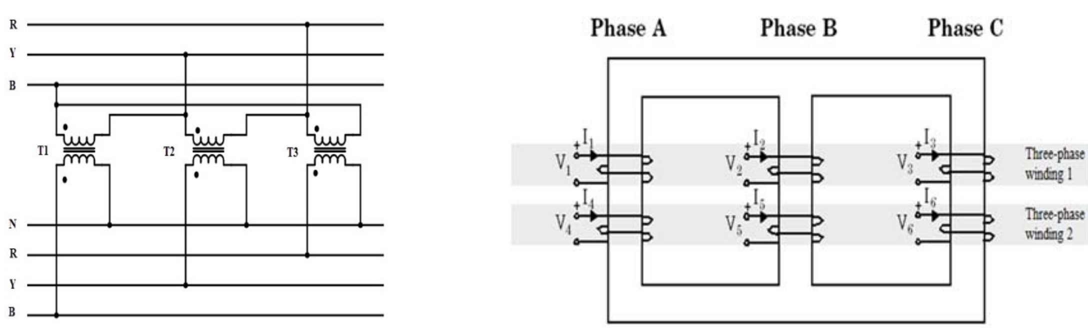


Figure 1.6.1 Three single phase transformer used as single three phase transformer

The disadvantage of the three phase transformer lies in the fact that when one phase becomes defective, the entire three-phase unit must be removed from the serviced.

When one transformer in a bank of three single-phase transformers becomes defective, it may be removed from service and the other two transformers may be reconnected to supply service on an emergency basis until repairs can be made.

1.6.2 Types and connection of three phase transformer

A three phase transformer can be made simply by connecting three single phase transformer or by one the three phase transformer. The primary and secondary windings may be connected in either star(Y) or delta (Δ) arrangement. The four most common connections are as follows:

i. Y-Y connection
ii. Y- Δ connection
iii. Δ –Δ connection
iv. Δ-Y connection

i. Y-Y connection

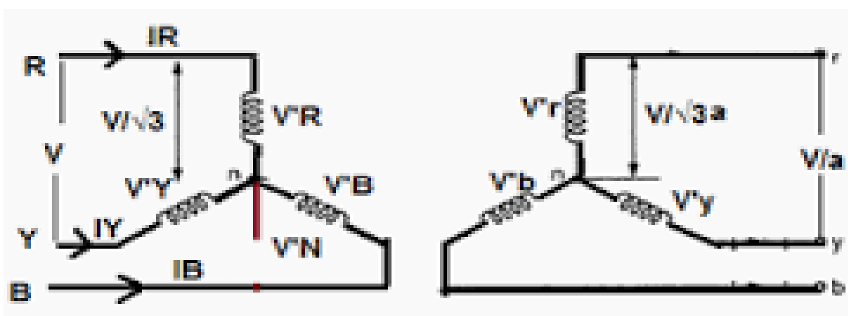


figure 1.6.2 (a): Star to star connection

Both sides of the transformers are star connected. This type of transformer is most economical for small current and high voltage transformers. Some of the advantages and the disadvantages of this type of connection are listed below:

Advantages:

1. Since the phase voltage is equal to $\frac{1}{\sqrt{3}}$ times the line voltage the number of turns per phase and the amount of insulation is minimum.
2. There is no phase displacement between primary and secondary winding.

Dis-advantage:

1. Whenever load unbalanced occurs in the secondary side of transformer, the phase voltage of load side change unless the load star point is earthed. The difficulty of shifting neutral can be overcome by connecting the primary star point to the star point of the generator.

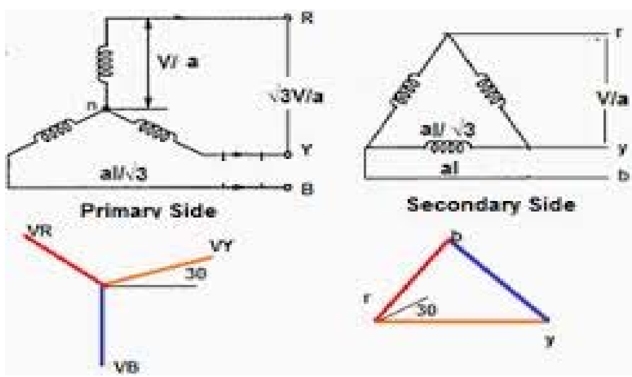


Figure 1.6.2(b) Star to delta

Primary side of transformer is star whereas secondary is delta connected. This connection is suitable for stepping down the voltage at receiving end of transmission line. In this type of connection of transformers the neutral of the primary winding is earthed. In this system line voltage ratio is $\frac{1}{\sqrt{3}}$ times of the transformer turn ratio and secondary line voltages have a phase shift of $\pm$ 300 with respect to the primary line voltage

iii. Δ- Δ connection

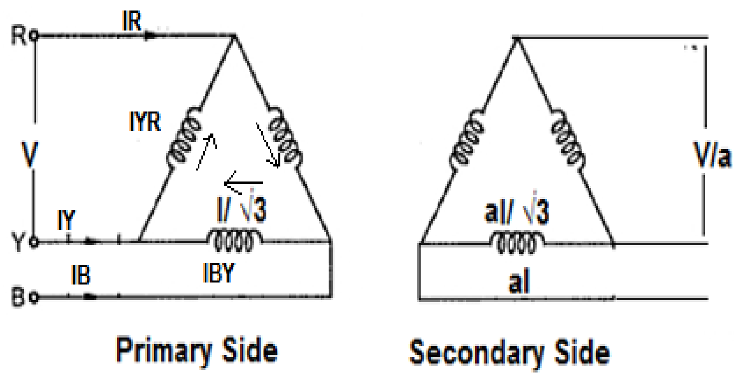


Figure 1.6.2 © Delta to delta

Both sides of transformers are delta connected. Line voltage is equal to phase voltage. Line current is equal to √3 times equivalent to phase current. Economic for low voltage transmission. An advantage of this connection is that if one transformer gets damaged or is removed from service the remaining two can be operated in what is known as the open-delta or V-V connection. There is also no phase displacement between primary and secondary voltages. In this connection, the third harmonic magnetizing current can flow in delta connected primary winding (not allowing to flow on the line), there is no distortion of flux. The cross-section of the conductor is also reduced since phase current is equal to $\frac{1}{\sqrt{3}}$ times of line current.

The disadvantage of this connection is it needs more insulation in comparing to that of star- star connection.

iv. Δ-Y connection

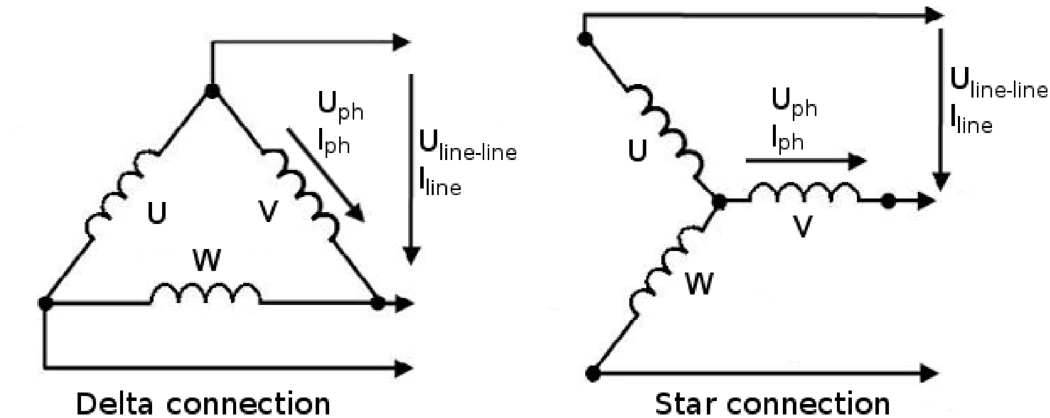


Figure 1.6.2 (d) Delta to star

Primary side of transformer is connected in delta whereas secondary with star. This connection is suitable for stepping up the voltage at the sending end of transmission line. It is also used in distribution transformer. In this scheme of connection the line voltage ratio is $\sqrt{3}$ times of transformer turn-ratio and the secondary line voltages have a phase shift of $\pm\ 30^0$ with respect to the primary line voltage.

1.6.3 Difference between single phase and three phase transformer

In single phase transformer, there are only two windings i.e primary and secondary windings whereas in three phases there are altogether six windings (three separate primary windings and three separate secondary winding having the common core). Single transformer are available in small sized and small capacity whereas three phase are available in large sized and capacity only. In-case of three phase transformer there is more iron loss due to large volume of iron core in comparison to that of single phase transformer. Three phase transformer occupy more space than that of single phase transformer.

1.6.4 Power transformer

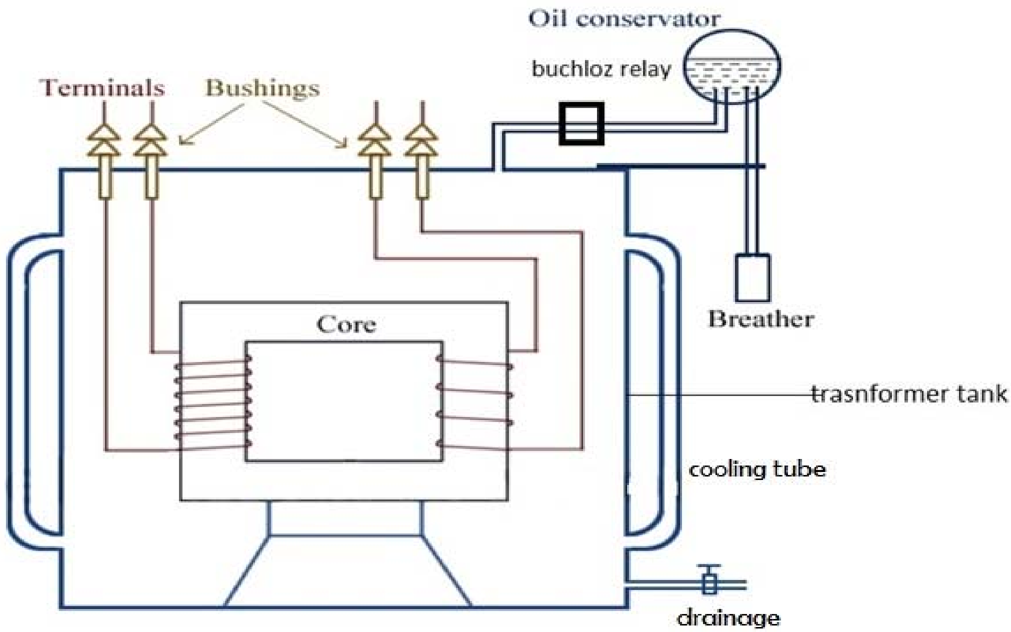


Figure 1.6.4 Power transformer

1) Transformer tank: Tanks used for the housing of core and windings and for mounting various accessories required for the operation of transformer.
2) Conservator tank: It is small cylindrical tank mounted on the top of the oil transformer and connected to the main tank by a small pipe.
3) Breather: It is a device through which all the movement of the air from the transformer takes place.
4) Buchholz relay: It is a protective device that give alarm when the oil level is low or any fault occurs when the evolution of gases take place.
5) Explosion vent: It is a bent pipe with a glass cover at the end fitted on the top of the transformer tank. It provides protection against excessive pressure build up inside the transformer.
6) Cooling tube: They are the bent pipe kept on the outside of the transformer tank which is used to cool the transformer.
7) Bushing: It consists the current carrying element in the form of conducting rod and porcelain installed in the hole of the cover of the transformer and employed

to isolate the current carry elements. Above 33kv, oil-filled or condenser type bushing are used.

1.7 Auto- transformer

1.7.1 Concept of auto transformer

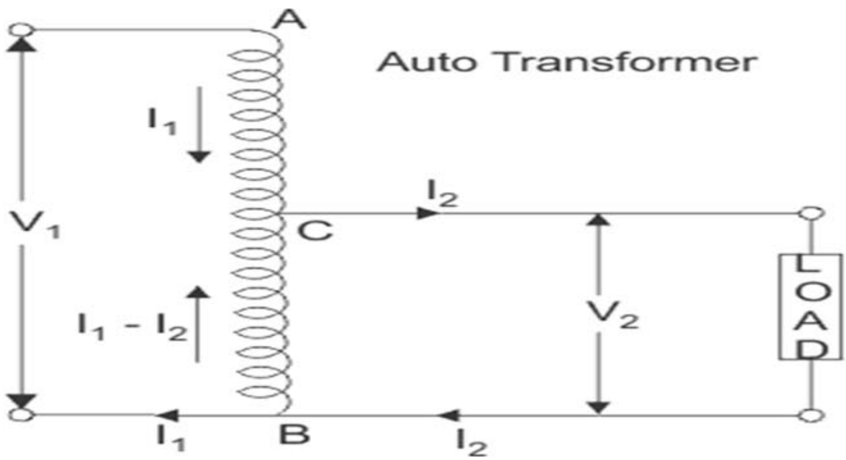


Figure 1.7.1(i) step-down auto transformer

It is a transformer with one winding only which is common to both primary and secondary side. Such a transformer is economical where the transformation ratio is very close to unity. Figure 1.7.1(i) shows the connection of step-down auto-transformer. In this case, the winding AB having N1 turns in primary winding and winding BC having N2 turns is the secondary winding. The power from primary is transferred to secondary conductively as well as inductively.

Advantages:

- An autotransformer requires less Copper than a two-winding transformer of similar rating.
- An autotransformer operates at a higher efficiency than a two winding transformer of similar rating when it is operating while the turn ratio is nearly equal to unity.
- An autotransformer has better voltage regulation than a two-winding transformer of the same rating.

- An autotransformer has smaller size than a two-winding transformer of the same rating.
- It may be noted that these advantages of an autotransformer decreases as the ratio of transformation increases. Therefore, an autotransformer has marked advantages only for relatively low values of transformation ratio. (i.e values approaching 1)

Disadvantages:

- There is a direct connection between the primary and secondary. Therefore the output is no longer isolated from the input.
- An autotransformer is not safe for stepping down a high voltage to a low voltage.
- The short circuit current is much larger than the two-winding transformer of the same rating.

1.7.2 Operating principle of Auto Transformer

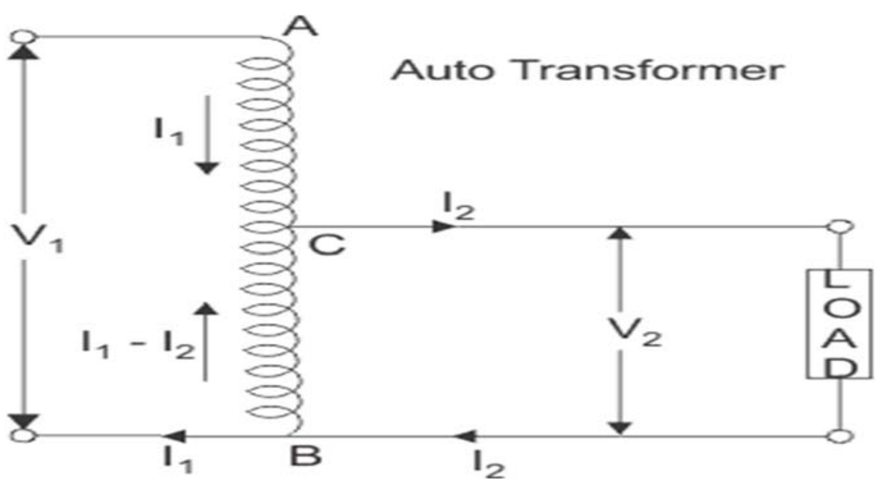


Figure 1.7.2 Auto transformer

In the auto-transformer, one single winding is share as primary winding as well as secondary winding as in transformer copper wire wound on silicon steels as shown in figure 1.7.2 .Input connected at fixed positions but on the other side we employ some tapping to get variable output voltages. Variable turns ratio at secondary can be obtained by changing the tapings of the winding.

1.7.3 Applications:

- They are used for reducing the voltage supplied to a.c motors during the starting period.
- They are used in variable voltage power supply.
- They are used to compensate for voltage drops in transmission and distribution lines.

1.8 Different methods of transformer cooling:

1.8.1 Concept of cooling

In all the electrical machines, the losses produce heat and means must be provided to keep the temperature low. In generators and motors, the rotating unit serves as a fan causing air to circulate and carry away the heat. However, a transformer has no rotating parts. Therefore, some other methods of cooling must be used. Heat is produced in a transformer by the iron losses in the core and I^2R loss in the winding. To prevent undue temperature rise, this heat is removed by cooling.

1.8.2 Types of cooling transformer

In transformer, during the transformation of the energy from one voltage level to another level, some energy is lost within the core and the winding. This lost energy must be dissipated in the form of heat. Losses in the transformer are of the order of 1% of its full load kW rating. But for the higher kVA rating, the magnitude of losses becomes higher. Greater the rating of the transformer, there will be more difficult to dissipate the heat.

There are number of methods used for cooling of transformer. Depending upon the size, type of application and the type of conditions available we can use different available cooling method of transformer. Regarding the cooling method, the transformer is of two types: dry and oil-immersed transformer.

1. **Dry type transformer:** For dry type transformer, two types of cooling method are used which are as follows:

i. **Air natural cooling:** Atmospheric air is used as cooling agent. This type of cooling method is used for small rating below 25kVA

ii. **Air blast cooling:** This type of cooling is provided for dry type transformer. The air is forced onto the tank surface to increase the rate of heat dissipation. The fans are switched on when the temperature of the winding increases above the permissible level.

2. **For oil type transformer:** For oil type transformer, following cooling method are applied:

a. **Oil natural cooling:** In this case, both core and the winding are immersed in the insulating oil within the iron tank. Thus, the heat produced in core and windings is passed onto the oil by conduction. Oil in contact with the heated parts rises whose place is taken by the cool oil. The heated oil transfers its heat to the tank surface which dissipates it to the surroundings.

b. **Oil natural air force coling:** In this case too, both the core and windings are immersed in the insulating oil within iron tank and the cooling is improved by forced air over cooling surface. The air is forced over the external surface of tank such as tubes, radiators by means of fans mounted external to the transformer. Medium to large capacity transformers are cooled by this method.

c. **Oil natural water forced cooling:** In this method forced water flow is used to dissipate heat from the heat exchangers. The cooling is increased by circulation of water through copper cooling coils mounted above the transformer core but below the oil surface. The heated water is then cooled in a spray pond or cooling tower.

d. **Oil forced air natural cooling:** In oil force air natural cooling system, the heat dissipation is accelerated by using force air on the dissipating surface but circulation of the hot oil in the transformer tank is natural convectional flow. In this method, the tank is made hollow and compressed air is blown into the hollow space to cool the space of the transformer. The oil circulating inside take the heat to the tank wall.

e. **Oil forced air forced cooling:** In this cooling method, the oil is cooled by air blast from fans in the external heat exchanger. It is not necessary that the oil pump and fans may be used at all times.

f. **Oil forced water forced cooling:** In this cooling method, the heated oil is pumped out from the main tank to the radiator where the oil is cooled by the water passing through the tubes. The pressure of the oil is kept higher than that of water in this cooling method.

Generally, in the small sized transformer (below 50kVA), natural air cooling is employed i.e the heat produced is carried away by the surrounding air. Similarly, medium size power or distribution transformer, are generally cooled by housing them in the tank with the oil. The oil does two tasks; at first it carries heat from the winding to the surface of the tank and another is it insulates the primary from the secondary. Whereas, in-case of the large transformer, external radiators are added to increase the cooling surface of the oil filled tank. The oil circulates around the transformer and moves through the radiators where the heat is released to the surrounding air. Sometimes cooling fans blow air over the radiators to accelerate the cooling process.

1.8.3 Advantage of transformer cooling

One of the major electrical machines in the distribution is power transformer and while operating transformer at high power ratings we experience heat from I^2R losses of the copper, hysteresis and eddy current and eddy current losses. So we need to reduce this heat in transformer for the efficient operation. In the electrical power transformer, we use different cooling methods which have been described above to eliminate heat quickly.

Numerical :

1. A single phase 50Hz transformer has square core of 20cm side. The permissible maximum flux density in the core is 1wb/m^2. Calculate the number of turns per limb on the high and low voltage sides for a 3000/220V ratio. To allow for insulation of stampings, assume the net iron length to be 0.9 x gross iron length.

Sol^n ;

Net iron length = 0.9 x 20 = 18cm

Net cross-sectional area, A = 18x 20= 360cm^2 = 0.036m^2

Max. flux in core $\phi_m = B_m \times A = 1 \times A = 1 \times 0.036 = 0.036$ Wb

$E_1 = 4.4\, f N_1 \phi_m$

$$N_1 = \frac{E1}{4.44\, f\phi m}$$

$$= \frac{3000}{4.44 x 50 x 0.036}$$

= 375 turns

And;

$$N_2 = \frac{E2}{4.44\, f\phi m}$$

$$= \frac{220}{4.44 x 50 x 0.036}$$

= 27 turns

2. A 3000/200 V, 50Hz single phase transformer is built on a core having an effective cross-sectional area of 150cm^2 and has 80 turns in the low voltage winding. Calculate the maximum flux density in the core.

Sol^n:

Given;

Induced emf in the low-voltage winding = $E_2 = V_2$

Supply frequency (f) = 50Hz

No of turns in low voltage winding (N_2) = 80

Area of cross-section (A) = 150 cm^2 = 150 x 10^{-4} m^2

So;

Maximum flux (ϕ_{max}) = $\frac{E_2}{4.44 fN_2}$

$= \frac{200}{4.44 \times 50 \times 80}$

= 0.01126 wb

Maximum flux density in the core (B_m) = $\frac{\phi_{max}}{A}$

$= \frac{0.01126}{150 \times 10^{-4}}$

= .075 T

3. A 200 kVA, 3000/240 V, 50Hz single phase transformer has 80 turns on the secondary winding. Assuming an ideal transformer, calculate:
   - i. primary and secondary current at full load
   - ii. maximum value of flux
   - iii. no of primary turns

Sol^n :

Primary current on the full load (I_1) = $\frac{\text{rated kVA} \times 1000}{V_1}$

$= \frac{200 \times 1000}{3300}$

= 60.6 A

Secondary current on the full load (I_2) = $\frac{\text{rated kVA} \times 1000}{V2}$

$= \frac{200 \times 1000}{240}$

= 833.33 A

Maximum flux (ϕ_{max}) = $\frac{E_2}{4.44 fN_2}$

$$= \frac{240}{4.44 \times 50 \times 80}$$

$$= 0.0135 \text{ Wb}$$

No of primary turns (N_1) = $\frac{E_1}{E_2} \times N_2$

$$= \frac{3300}{240} \times 80$$

$$= 1100 \text{ turns}$$

Numerical problems:

1. A step up transformer having 400/1100V of primary no of turns is 200. Calculate secondary no of turns? Flux density = 80wb/m^2. (ans = 550 turns)

2. A 50 kVA single phase transformer has 600 turns on primary and 40 turns of secondary. The primary winding is connected to 2.2 KV, 50Hz supply. Determine :
   Secondary voltage (ans = 0.146KV)
   Primary and secondary current (ans=22.74A, 342.35A)

3. An ideal 25KVA transformer has 500 turns on the primary winding and 40 turns in secondary winding. The primary is connected to 3000V, 50 Hz supply. Calculate
   - Primary and secondary current (ans = 8.33 A, 104.12A)
   - Secondary emf (ans = 240V)
   - Maximum core flux (ans = 2.7*10^$^{-2}$wb)

4. A single phase 2200/250V, 50Hz transformer has net core area of $36cm^2$ and maximum flux density 6 wb/m^2. Calculate the no of turns of primary and secondary. (ans = 459 turns,53turns)
5. A single phase, 50Hz transformer has 80 turns on the primary winding and 280 in the secondary winding. The voltage applied across the primary winding is 240 volts. Calculate:
   - the maximum flux density in the core (Ans=0.676 Wb/m^2)
   - induced emf in the secondary winding (Ans=840V)
   - The net cross-sectional area of the core can be taken $200cm^2$.
6. It is desired to have a 4.13 mWb maximum core flux in a transformer at 110 V and 50Hz. Determine the required number of turns in the primary.(Ans=120)

Teaching tips:

- Visualization of transformer parts
- Showing the video of working mechanism of transformer

Reference and Resources:

- S. Chand, "Principle of Electrical Machine"
- Jain and Jain, " ABC of Electrical Engineering"
- J.B. Gupta, "Electrical machines

CHAPTER 2

DC machines

Learning outcomes:

After the completion of this chapter, the students will;

1) Know about the constructional detail about dc machine.
2) Working operation of dc machine
3) Know different characteristics of dc machine.
4) Know the speed control of dc motor

2.1 Definition and its function and applications:

2.1.1 Concept and definition:

DC machines are the rotating electrical machines which can be used as either motors or generators. DC machine is a device which converts mechanical energy into electrical energy and vice-versa. When the device acts as a generator (or dynamo), mechanical energy is converted into electrical energy. On the other hand, when the device acts as the motor, the electrical energy is converted into mechanical energy. The process of the interconversion is reversible. However, during the conversion process, a part of energy is transformed into heat, which is lost, and can't be reversible. Therefore, this type of machine can work either as" motor" or "generator". Almost, generator and motor are very much similar to each other in essential parts and construction. But slight modification is done for their operation.

2.1.2 Functions and applications:

DC generators convert mechanical energy given to it into electrical energy whereas DC motors convert the electrical energy given to it into mechanical energy. These DC machines are used various field such as: DC generators are used in arc lighting, series-incandescent lighting, and power supply purpose and also for charging batteries where as DC motors are used in cutting coal, punch pressure and so on.

2.2 Constructional Details:

2.2.1 Main parts of DC machines:

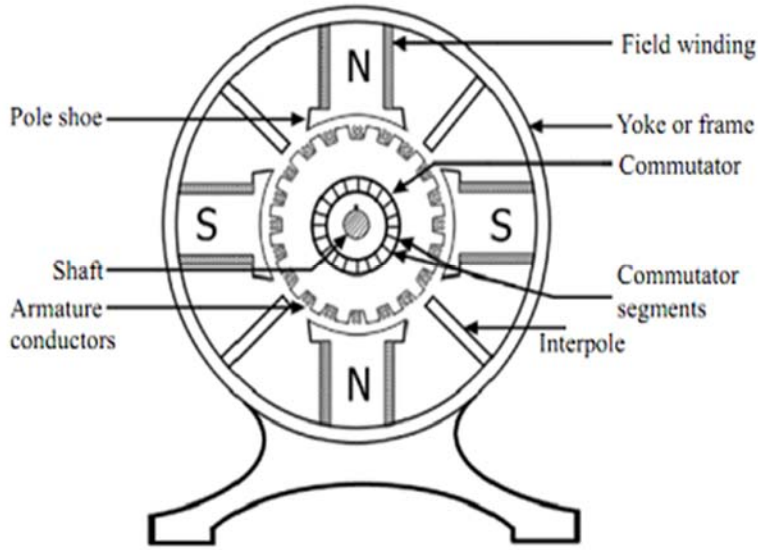


Figure 2.2.1 dc machine

The different parts of dc machines are as follows:

i. Yoke

It is the outermost frame of the machine. It provides mechanical support for the field pole and acts a protecting cover for the whole machine and also carries the magnetic flux produced by the field poles. In small machines, cast iron yokes are used because of cheapness but yoke of large machine is invariably made of fabricated steel due to its high permeability.

ii. Field poles

They are the iron core projected from yoke. The upper part of the pole, which is connected to the yoke, is known as pole -core. The lower and wider part is known as pole-shoe. The field poles are generally made from the laminated annealed steel sheet. The field poles are usually formed of laminations (thin sheet of steel) and are bolted to the frame or yoke to which are also fastened the end bells with their bearings and the brush rigging. The pole shoe serves two purposes:

- It spreads out the magnetic flux in the air gap and also being larger cross section reduces the reluctance of the magnetic path.
- It supports the field winding.

i. Field winding

It is the copper wire or strip wound on the field pole. The windings are insulated from the pole core and each turns of windings are also insulated from each other to protect from turn to turn short circuit. When DC current is passed through these coils, they will magnetize the pole core and produce magnetic field in the central space of the machine.

ii. Armature

It is rotating part of the machine and is built up in a cylindrical or drum shape. The various parts of an armature are shaft, armature core, commutator and armature winding. The bearing holds the shaft on the central empty space of the machine in such way that there is a small air gap few mm between armature and the pole- shoes the armature core is made from laminated silicon steel sheet insulated with varnish. The purpose of armature is to rotate the conductors in the uniform magnetic field. It consists of coils of insulated wires wound around an iron and so arranged that electric currents are induced in these wires when the armature is rotated in a magnetic field. In addition, its most important function is to provide a path of very low reluctance to the magnetic flux. The armature core is made from high permeability silicon-steel stampings, each stamping, being separated from its neighboring one by thin paper or thin coating of varnish as insulation.

iii. Commutator

The commutator is a form of rotating switch placed between the armature and the external circuit and so arranged that it will reverse the connections to the external circuit at the instant of each reversal of current in the armature coil. It is made of number of copper segments insulated from each other and from the shaft. It is also known as mechanical rectifier as it coverts ac into dc. It is very important part of a dc machine and serves the following purposes:

1) It provides the electrical connections between the rotating armature coils and the stationary external circuit.

2) As the armature rotates, it performs a switching action reversing the electrical connections between the external circuit and each armature coil in turn so that the armature coil voltages add together and result in a dc output voltage.

3) It also keeps the rotor or armature mmf stationary in space

iv Armature winding

Armature winding is an arrangement of conductors to develop desired emf by relative motion in a magnetic field. In winding, conductor or group of conductors are distributed in different ways in slots all over the periphery of the armature. The conductors may be connected in series and parallel combinations depending upon the current and voltage rating of the machine. It is the enamel insulated copper wire wound on the slots of the armature core.

v. Carbon Brush

Carbon brush is rectangular in shape which rest on the commutator. The main function of the carbon brush is to collect the current from the commutator and supply it to the external load circuit. The brushes are held under pressure over the commutator by the combination of brush holders and springs whose tension may be adjusted.

2.3 Operation as generator:

2.3.1 Basic operating principle of DC machine as generator:

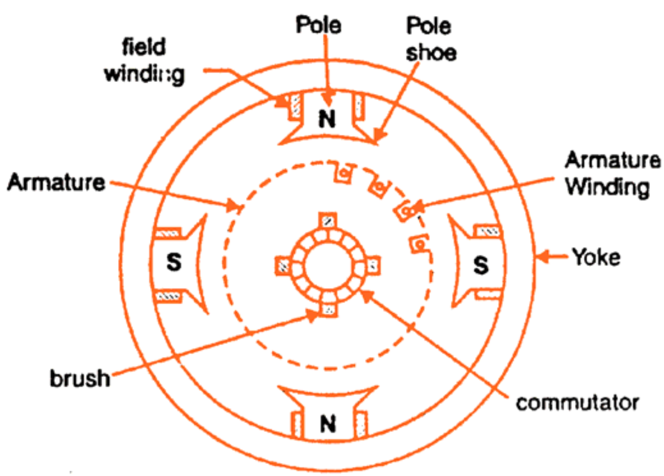


Figure 2.3.1 dc generator

An electric generator is based on the principle that whenever flux is cut by a conductor, an emf is induced which will cause the current to flow if the conductor circuit is closed. The direction of induced emf (and hence current) is given by “Fleming’s right hand rule”

When the armature of the dc generator is rotated with the help of prime mover (external force) and the field windings are excited then from the Faraday’s law of electromagnetic induction, emf is induced in the armature conductors. This induced emf is taken out from the commutator and carbon brush arrangement.

2.3.2 EMF equation:

Let,

$\emptyset$= flux per pole in weber

Z= no. of conductors in armature

A= no. of parallel paths

P= no. of poles

N= speed of armature in rpm

E_g=generated emf

Since, Z conductors are arranged in A parallel paths, so the number of conductors per path = $\frac{Z}{A}$

Emf induced per conductor per turn;

$$E = \frac{d\phi}{dt}$$

$$E=\frac{\phi P}{60/N}$$

$$E = \frac{\phi NP}{60}$$

$$\text{Then, total emf induced} = \frac{\phi NP}{60} \text{ x } \frac{Z}{A}$$

$$= \frac{\phi NZ}{60} \text{ x } \frac{P}{A}$$ which is the required emf equation.

Note:

For lap winding P=A

For wave winding A=P/2

Numerical:

1. A 6 pole lap wound dc generator has 720 conductors, flux of 80 mwb/pole is driven at 1000 rpm. Find the generated emf.

Generated emf (E) $= \frac{\phi ZN}{60} \times \frac{P}{A}$

$$= \frac{80 \times 10^{-3} \times 720 \times 1000}{60} \times \frac{6}{6}$$

= 960 V

2. A 4 pole dc generator has 51slots and each contains 20 conductors. Flux per pole is 7mWb and runs at 1500 rpm. Find the produced emf of the machine if its armature is wave wound.

Sol^{n} ;

Flux per pole (ϕ) = 7mWb = 0.007Wb

Number of poles, P =4

Speed (N)= 1500 rpm

Number of armature conductors,

Z = number of slots x number of conductors

= 51x20

= 1020

Number of parallel paths, A=2 ($\because$ armature is wave wound)

Generated emf (E) $= \frac{\phi ZN}{60} \times \frac{P}{A}$

$$= \frac{0.007 \times 1020 \times 1500}{60} \times \frac{4}{2}$$

=357V

3. A 4 pole dc machine has lap-connected armature having 60 slots and 8 conductors per slot. The flux per pole is 30 mWb. If the armature is rotated at 1000rpm, find the emf available across its armature terminals. Also calculate the frequency of emf in the armature coil.

Sol^n;

Flux per pole, Ø = 30mWb = .03Wb

Number of armature conductors

Z = number of slots x number of conductors per slot

= 60 x 8

= 480

EMF available across armature terminals;

$$E = \frac{\phi ZN}{60} \times \frac{P}{A}$$

$$= \frac{0.003 \times 480 \times 1000}{60} \times \frac{4}{4}$$

= 240V

Frequency of emf induced in armature coil,

$$f = \frac{PN}{120}$$

$$= \frac{4 \times 1000}{120}$$

= 33.33 Hz

2.4 Types of dc generators – their characteristics and uses

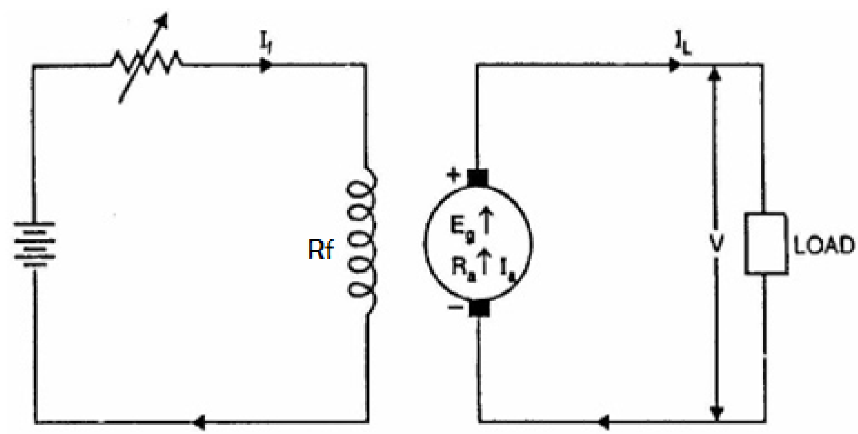
2.4.1 Types of DC Generator:

DC current which is supplied to the field winding which is known as excitation produce the required magnetic field. The magnetic field in a d.c generator is normally produced by the electromagnets rather than permanent magnets. According to the method of excitation, DC generators can be classified into two types:

- Separately excited DC generator
- Self excited DC generator
  a) Shunt dc generator
  b) Series dc generator
  c) Compound dc generator

i. Separately excited DC generator:

These are the generators whose field windings are supplied by an independent external DC voltage source. The field windings will not have electrical connection with the



armature circuit. The circuit diagram is shown in the figure 2.4.1 (i). In this case current flowing through the armature and load is same and the terminal voltage is equal to the generated emf

Figure 2.4.1(i) separately excited dc generator

In this generator, field winding and armature winding are separated. Field winding is supplied by independent dc voltage source.

Let,
Rf = field winding resistance
If = field winding current
Eg = emf induced across armature winding
Ra = armature resistance

R_l= load resistance

I_l = load current

I_a = armature current

V = terminal voltage

Here, $I_a=I_f$

From Kirchhoff's voltage law,

$E_g-I_aR_a-I_lR_l = 0$

$E_g-I_aR_a-V=0$

$V= E_g-I_aR_a$

This is the required relationship between load voltage and generated voltage.

i. Self excited dc generator

In this, field winding is excited by dc current generated by the armature of the machine itself. External dc is not required. The field winding and armature have electrical connection. In such machine the field coils are interconnected with the armature winding. According to the self -excited DC generators can be classified into three types:

a) DC shunt generator
b) DC series generator
c) DC compound generator

2.4.2 Types of dc generator according to connection of winding

a. DC shunt generator:

In this type of generator, the field winding and armature winding are connected in parallel. The figure 2.4.1(ii) shows the circuit diagram of DC generator.

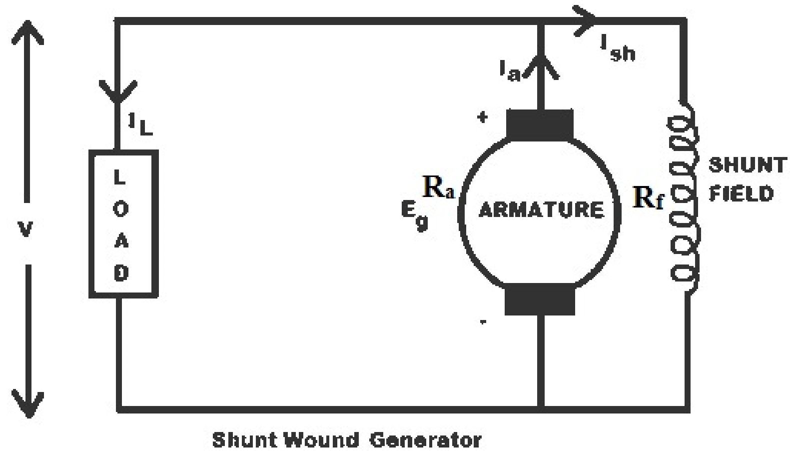


Figure 2.4.1 (ii)

I_a current is generated by the armature. A part of this current flow through the field winding and the remaining will flow through the load.

From figure, If = V/Rf

Applying KVL in loop 2,

Eg – IaRa – ILRL =0

Eg – IaRa – V =0

V= Eg – IaRa

Applying KCL,

Ia = If +IL

b. DC series generator:

In a series generator, the field winding is connected in series with armature winding so that whole armature current flows through the field winding as well as load. Dc series generators are started with load or else no current will flow through the fieldwinding and the voltage won't build up.

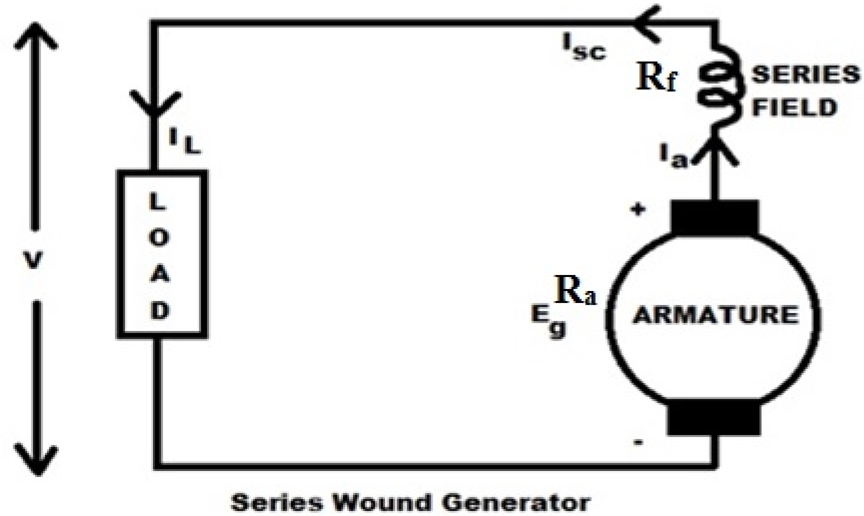


Figure 2.4.1 (iii)

$I_a = I_f = I_L$

Applying KVL,

$E_g - I_aR_a - I_LR_L - I_fR_f = 0$

$E_g - I_aR_a - V - I_fR_f = 0$

$V = E_g - I_aR_a - I_fR_f$

c. DC compound generator:

In DC compound generator, there are two sets of field windings. One of them is connected in series with the armature or load and the other set is connected with the armature circuit. In it, the series winding is made from thick wire with few turns because it has to carry full load current whereas shunt field winding is made from thin wire with many number of turns because full rated voltage appear across it. DC compound generator is of two types:

i. Long shunt DC compound generator
ii. Short shunt DC compound generator

i. Long shunt DC compound generator

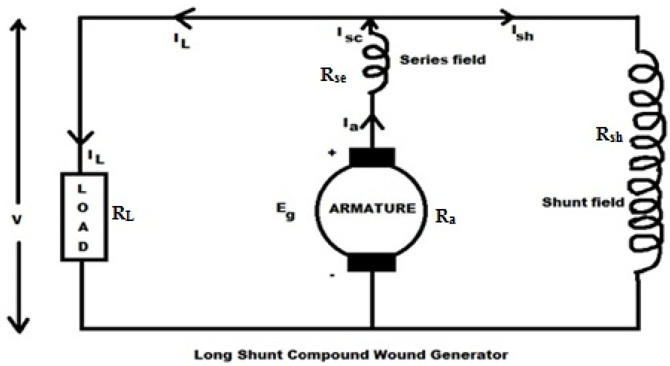


Figure 2.4.1(iv)

In it, the series field winding R_{se} is connected in series with the armature winding and the shunt field winding R_{sh} is connected across the load.

From figure,

$$I_{sh} = \frac{V}{R_{sh}}$$

Applying KVL,

$E_g - I_aR_a - I_aR_{se} - I_lR_l = 0$

$E_g - I_aR_a - I_aR_{se} - V = 0$

$V = E_g - I_aR_a - I_aR_{se}$

$V = E_g - I_a(R_a + R_{se})$

ii. Short shunt DC compound generator

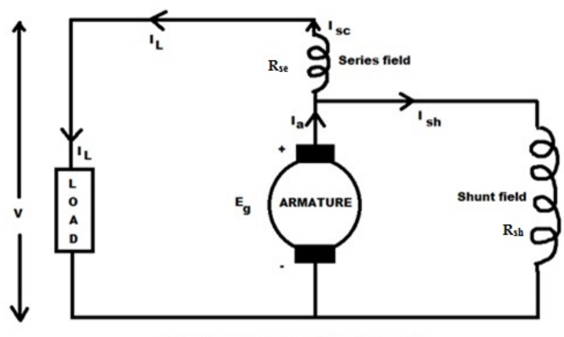


Figure 2.1.4 (v)

In it, the series field winding R_{se} is connected in series with load and shunt field winding R_{sh} is connected across the armature.

From figure,

Applying KVL to load loop;

$E_g - I_aR_a - I_LR_{se} - I_LR_l = 0$

$E_g - I_aR_a - I_LR_{se} - V = 0$

$V = E_g - I_aR_a - I_lR_{se}$

Characteristics of dc generator:

Different types of DC generators have different characteristics. Here are two main characteristics of DC generators:

i. No- load characteristics
ii. Load characteristics

i. No- load characteristics

The curve plotted between emf generated and different value of field current at constant speed at no load condition is called no load curve. No load characteristics of separately excited, shunt and series generators can be obtained practically in a similar way. The circuit arrangements for obtaining the data for no load characteristic curve is shown in figure (i). In-case of shunt and series generators the field windings have to be disconnected temporarily and connected them as shown below:

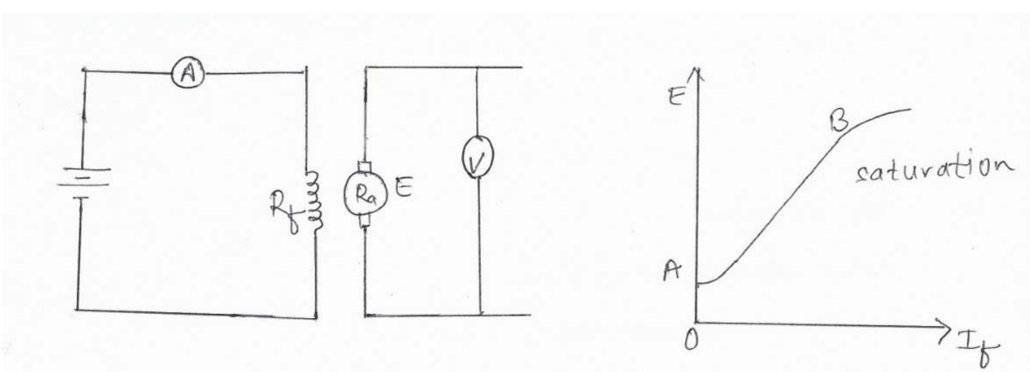


Figure (i)Figure (ii)

Prime mover is used to rotate the armature of the generator at a constant rated speed by the prime mover and emf induced across the armature at different values of field current are measured. The resulting curve is shown in figure (ii) 'OA' is the emf generated across the armature due to residual flux in the pole even in the absence of field current.

We know that, $\frac{Z\phi N}{60}\frac{P}{A}$ volts and $\phi \prec I_f$

Since the armature is driven at constant speed. $E \prec \phi$ or $E \prec I_f$

Therefore, the no-load characteristics is a curve which is straight line indicating that the emf increases proportionally with I_f up to the point "B". After point "B", the magnetic poles get saturated and emf does not increases even if $I_f$increase. It should be noted that no load characteristics curve (or OCC) for a higher speed will be above this curve and for lower speed, it will be below this curve as shown in figure (iii).

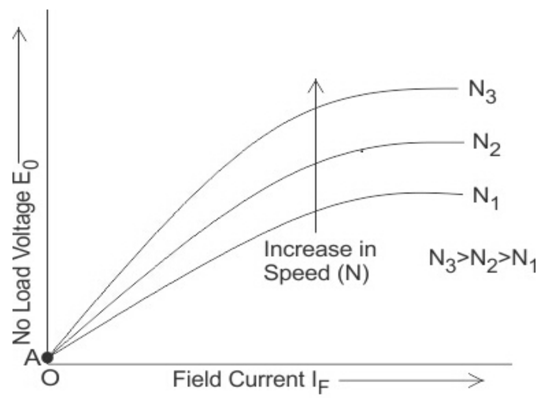


Figure (iii): no-load characteristic curves at different speed

ii. Load characteristics

a. Shunt generator:

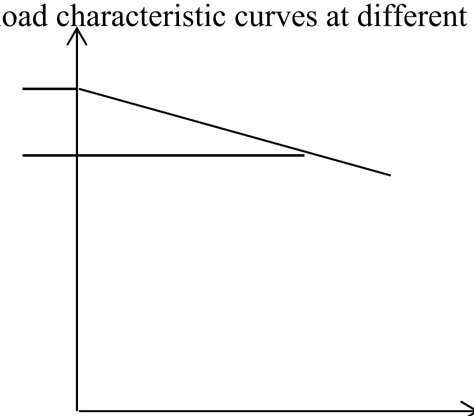


Figure ii(a) load characteristics

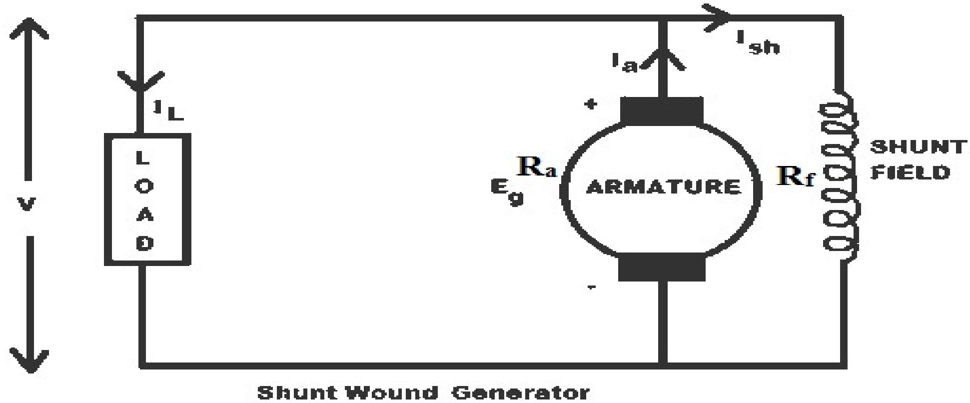


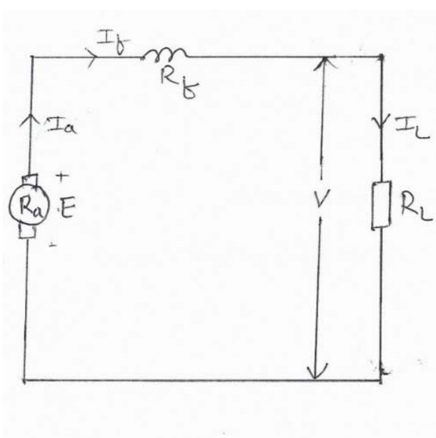
Figure ii (b)

When the generator are at no load, the armature current is equal to field current whereas load current is equal to zero. But when the generator is loaded the terminal voltage decreases and armature current ($I_a = I_f + I_L$) increases.

$V = E_g - I_aR_a$

$E_g = V + I_aR_a$

a) **Series generator**



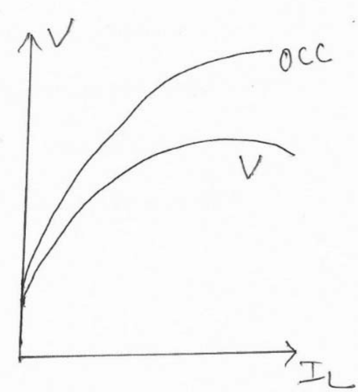


Figure i. dc series generator

Figure ii. Load characteristics

When the load current increases, the armature current as well as field current increases. Therefore, the voltage drop in the armature resistance (I_aR_a) will also increases. Hence the series generator shows the rising voltage characteristic.

b. Compound generator

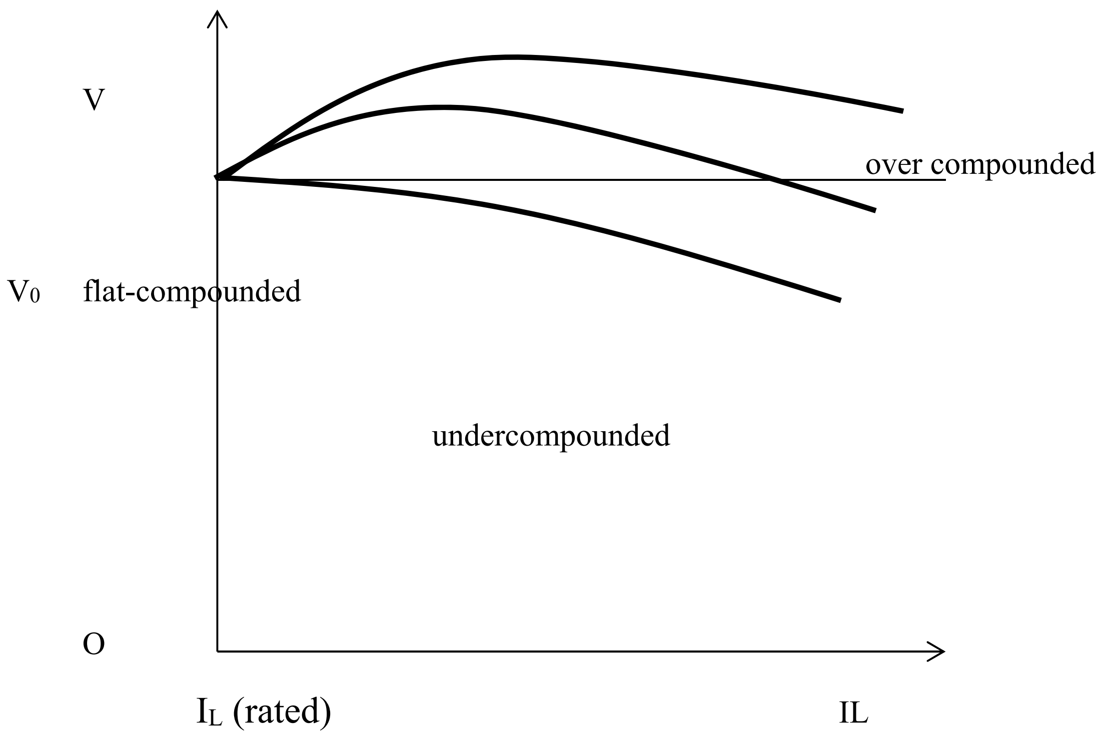


Figure i. characteristics of compound generators

We have seen that a shunt generator has a dropping characteristics and series generator has a rising voltage characteristics. Thus, compound generator has characteristics lying between shunt and series generator. A shunt generator may be modified into a compound generator to supply substantially constant voltage by adding few turns of field winding in series with load or armature. As the load current increases, the current through the series field winding also increases there by increasing the flux per pole. Due to increase in flux per pole, emf is also increased. By adjusting the number of series turns, the terminal voltage "V" can controlled in different ways.

If the series field amp-turns are such as to produce the same voltage at rated load as at no-load then the generator is called as flat-compounded.

If the series field amp-turns are such that at rated load greater than the no- load voltage, then the generator is called as over-compounded.

If the series field amp-turns are such that at rated load less than the no- load voltage, then the generator is called as under-compounded

2.4.3 Voltage build up in self-excited shunt generator

If the shunt generator is run at the constant speed, some e.m.f will be generated due to residual magnetism in the main poles. This small e.m.f circulates a field current which in turn produces additional flux to reinforce the original residual flux. This process continues and the generator builds up the normal generated voltage following the O.C.C shown in figure below:

The field resistance R_f can be represented by a straight line passing through the origin as shown in figure (ii). The two curves can be shown on the same diagram as they have the same ordinate in figure (iii).

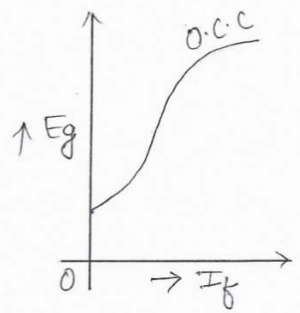
Since the field circuit is inductive, there is a delay in the increase in current upon closing the field circuit switch. The rate at which the current increases depends upon the voltage available for increasing it. Suppose at any instant, the field current is i(=OA) and is increasing at the rate di/dt. Then

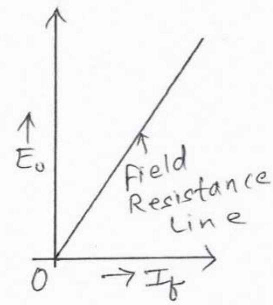
$$E_0 = iR_f + L\frac{di}{dt}$$

Where , R_f = total field resistance

L = inductance of field circuit

At the considered instant the total emf available is AC (fig (iii)). An amount AB of the emf AC is absorbed by the voltage drop iR_f and the remainder part BC is available to overcome $L\frac{di}{dt}$. Since this surplus voltage is available, it is possible for the field current to increase above the value OA. However, at point D, the available voltage is OM and is all absorbed by iR_f drop. Consequently, the field current cannot increase further and the generator builds up stops.





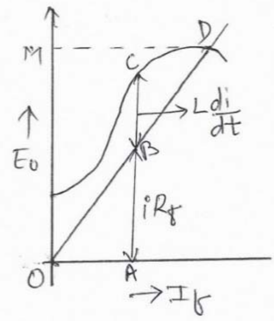


Figure (i) **Figure(ii)** **Figure(iii)**

2.4.4 Application of different types of generator

a. **Series generators:** They are used where variable voltage is needed such as in arc lighting, series incandescent lighting

b. **Shunt generators**: They are used where constant voltage is required such as in power supply purpose and also for charging batteries.

c. **Compound generators**: They are used for lighting and power services

2.5 Operation as motor - torque equation, back emf

2.5.1 Operation of dc machine as motor

The operation of dc motor 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= BIL Newtons

When the dc source is applied to the carbon brush of the dc motor, the current flows through the positive brush, commutator, armature winding and finally goes out through the negative brush. The current flows through the field winding represents magnetic field while current flowing through the conductor of the armature winding represents mechanical force.

2.5.2 Torque equation and back emf

Let,

T_q = torque developed by armature (N-m)

I_a = armature current (A)

N = no of revolution/second

W= angular frequency = $2\pi f$

$$= \frac{2\pi}{T}$$

$$= \frac{2\pi}{\frac{60}{N}}$$

$$= \frac{2\pi N}{60}$$

Now,

Power developed by motor;

$P = T_q \text{ x } w$

$= T_q \text{ x } \frac{2\pi N}{60}$ …………………(i)

And,

Power developed by armature;

$P = E_b \text{ x } I_a$

From (i) and (ii)

$$T_q \text{ x } \frac{2\pi N}{60} = E_b \text{ x } I_a$$

$$T_q \text{ x } \frac{2\pi N}{60} = \frac{Z\phi N}{60} \text{ x } \frac{P}{A} \text{ x } I_a$$

$$T_q = \frac{1}{2\pi} \times \phi I_a \frac{P}{A} \text{ N-m}$$

This is the required torque equation of dc motor.

Back emf:

When the motor rotates, the armature conductors cuts the magnetic flux produced by the field poles. Hence, according to Faraday's law of electromagnetic induction, emf will induced across the armature conductor. The direction of this emf is opposite to the applied voltage “V”. Back emf is denoted by "E_b”.

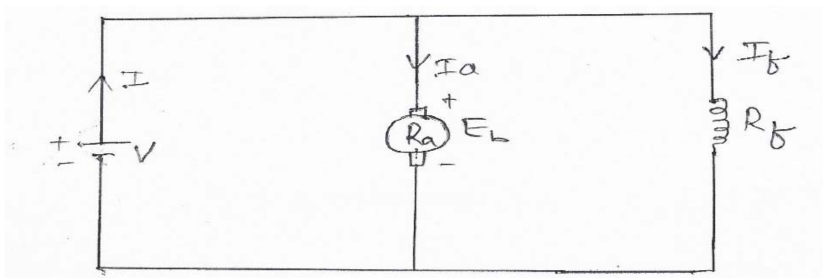


Figure 2.5.2 back emf in DC motor

Role of back emf in dc motor

1. Back emf protects armature from short circuit during normal operation.

$$I_a = \frac{V - Eb}{Ra}$$

From the above expression, it is seen that in the absence of E_b, armature current is very high which damages the coils

2. Back emf helps to produce required amount of torque according to change in load.

$$E_b = \frac{Z\phi N}{60}\frac{P}{A}.$$

$$I_a = \frac{V - Eb}{Ra}$$

Since, torque (T) is directly proportional to flux and armature current i.e $T \prec \phi, I_a$

As torque load increases, the speed of the motor decreases hence ($N \prec E_b$) thus armature current increases and hence motor will produce more torque to overcome the increased load torque. Similarly, if load torque decreases, the speed of the motor will increased hence armature current decreases. Therefore, torque will also decrease.

3. Back emf acts as energy converting opposing agent.

2.6 Types of DC motor along with their characteristics and uses

There are three types of DC motor based upon the method of excitation;

a) DC shunt motor
b) DC series motor
c) DC compound motor

1. DC shunt motor

If the field winding is connected in parallel to the armature of DC motor then such a motor is called DC shunt motor. The field winding consists of a large number of turns of comparatively fine wire so as to provide large resistance. The field current is much less than the armature current, sometimes as low as 5%. The circuit diagram is shown in figure 2.6 (a).

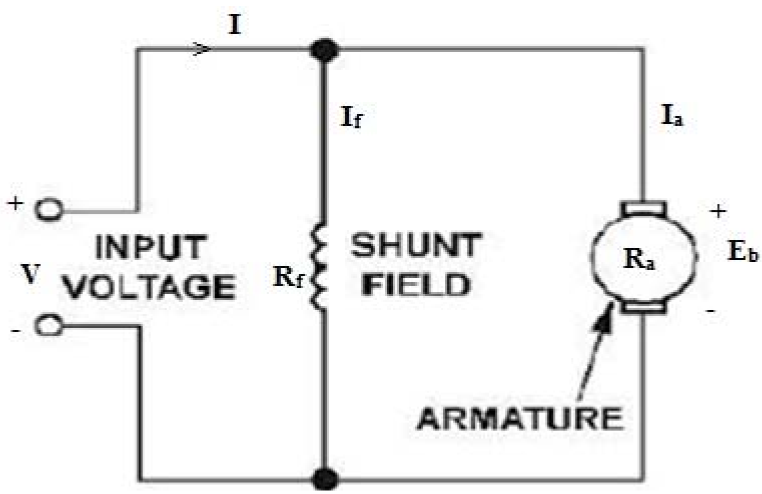


figure 2.6 (a) dc shunt motor

Let;

Eb = back emf on armature

V =input voltage applied

Ra = armature resistance

Ia = armature current

I = input current

If = field current

Rf = field resistance

Applying KVL,

$V - Eb - IaRa = 0$

$V = Eb + IaRa$……………… (i)

The above equation (i) shows relationship between applied voltage and back emf.

2. DC series motor

The field winding is connected in series with the armature winding in-case of DC series motor. In this motor the field coils consist few numbers of thick turns. The cross-sectional area of the wire used for the field coils has to be fairly large to carry the armature current, but owing to the higher current, the number of turns of wire in them needs not to be large.

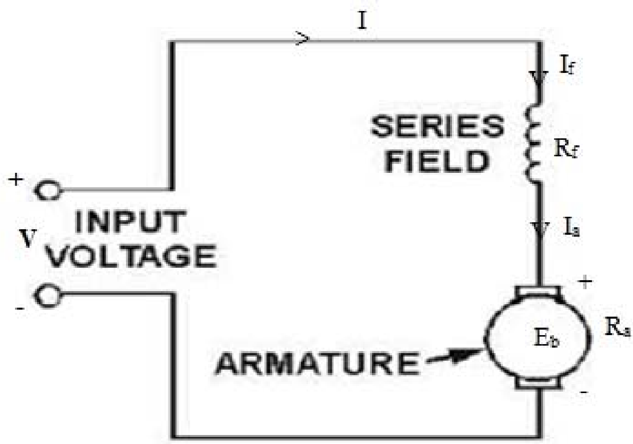


Figure 2.6(b) dc series motor

Let ;

Eb = back emf on armature

V =input voltage applied

Ra = armature resistance

Rf = field resistance

Ia = armature current

If = field current

Applying KVL, (I=Ia=If)

$V – Eb– IaRa – IfRf =0$

$V = Eb + Ia (Ra + Rf)$…………………………(ii)

This is required relationship between applied voltage and back emf.

3.DC compound motor

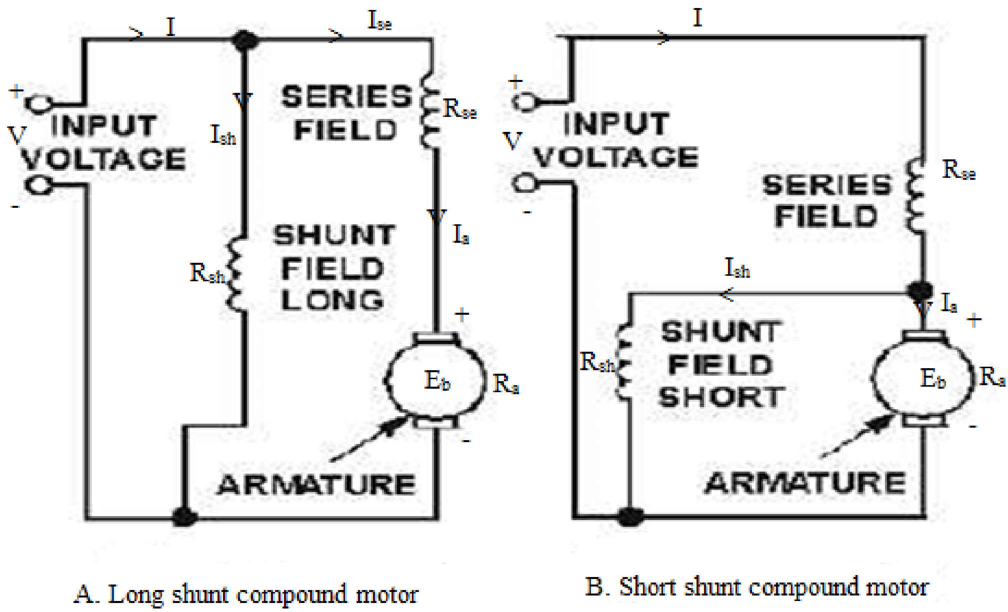


Figure 2.6

It has two field winding: series and shunt winding. When shunt field winding is connected parallel to armature and series field winding is connected series to the load then such motor is short shunt compound motor (figure 2.6(B)). When shunt field winding is connected parallel to both armature and series field winding is called long-shunt dc compound motor (figure 2.6 (A)). In long shunt compound motor, the input current is equal to the sum of armature current and the shunt field current i.e $I = I_{Sh} + I_a$ where series field current is equal to armature current i.e $I_{se} = I_a$. Similarly, in short shunt compound motor, the input current is equal to field series current which is equal to the sum of armature current and shun field current. i.e $I = I_{se} = I_{sh} + I_a$.

2.6.2 Characteristics of DC shunt, series and compound motor

Torque – speed characteristics (shunt motor)

It is a curve showing the speed of the motor at different values of armature torque developed by the motor.

We know that speed of DC shunt motor $N \prec \frac{Eb}{\phi}$

And ϕ is constant for DC shunt motor $\therefore$ $N \prec E_b$

When the speed of the motor decreases the back emf E_b will also decrease, then the armature current will increase and armarutre torque T_a will increase. Hence the N-T_a characteristics of DC shunt motor will be as shown in figure below:

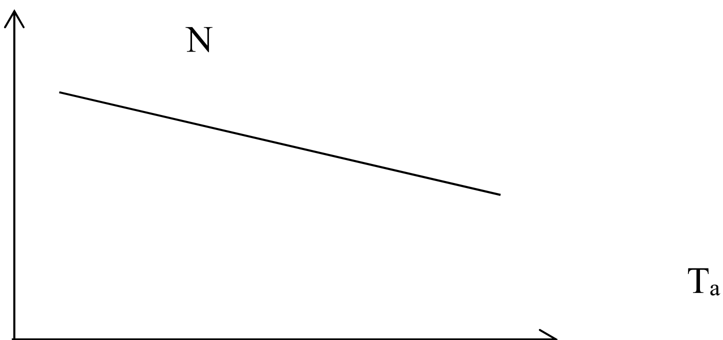


Figure 2.6.2 (a): N-T_a characteristics of DC shunt motor

As there is small change in speed in DC shunt motor from no load to full load, shunt motor is suitable to drive a load which is totally and suddenly thrown off so that there is no fair of excessive speed. Due to the constancy of speed, shunt motor is also suitable for driving shaft of machine tools, lathe machine etc. where approximately constant speed is required.

Torque – speed characteristics (series motor)

We know that the torque produced is directly proportional to flux per pole and armature current. At heavy load i.e high torque, the armature current will be increased. Since, increased in armature current lead in decreasing the back emf thus speed will also be decreased (as speed and back emf are in direct proportion)

Hence at high torque the speed of the series motor will be reduced.

$$N \prec \frac{Eb}{\phi}, \quad E_b = V - I_a R_a , \quad T_a \prec \phi I_a$$

Whereas in light load (i.e low torque), the armature current will be low which lead in increasing the back emf. Since back emf is directly proportional to the speed, it leads in increasing speed of the motor. The speed torque characteristics of a series motor are shown below:

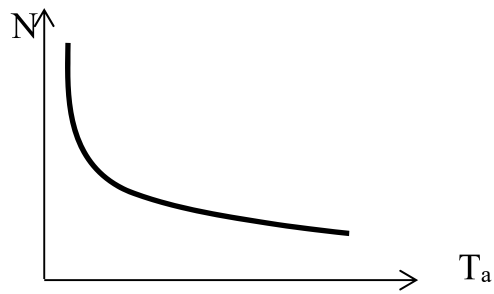


Figure 2.6.2 (b) Speed- torque characteristics

Therefore, it is clear that at starting (where speed is very low DC series motor develops a high torque. On the other hand at no load the speed will be very high. Hence a DC series motor should not be started at no load or else it may developed excessive speed and mechanical failure may occur to due to heavy centrifugal force.

Torque – speed characteristics (compound motor) :

Dc compound motors have both series and shunt field windings. If the series winding produces the magnetic field in the same direction as produced by shunt field winding (shown in figure (i)), then the motor is said to have cumulative compound motor. And if the series winding produces the magnetic field in the opposite direction as produced by shunt field winding (shown in figure(ii)), then the motor is said to have in differential compound motor.

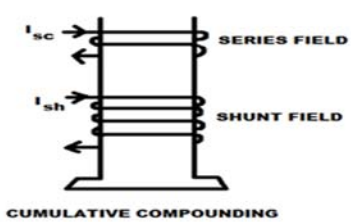


Figure (i)

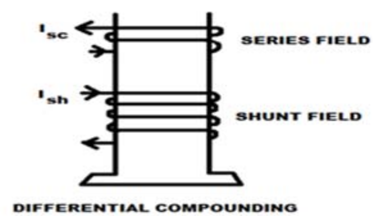


Figure (ii)

I. Cumulative compound

In cumulative compound motor, at a particular value of torque, due to cumulative action of series field, the flux per pole will be more with compare to a plain shunt motor. Therefore, the torque-speed characteristics of shunt motor are shown in figure (i).

ii. Differential compound

In differential compound motor, at a particular value of torque, due to differential action of series field, the flux per pole will be less with compare to a plain shunt motor. Therefore, the torque-speed characteristics of shunt motor are shown in figure (ii).

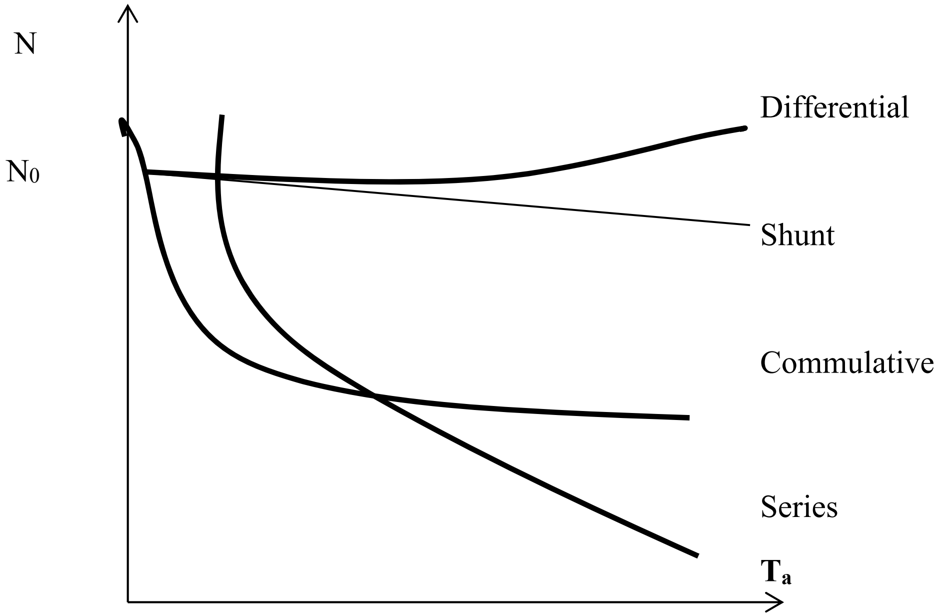


Figure 2.6.2 © N-T_s characteristics

2.6.3 Uses of dc machine as motor

a. DC shunt motor: They are used where the machines need to run at constant speed in different load condition such as in driving pumps, drills, printing press, lathes.

b. DC series motor: They are used where load needs high starting torque such as in cranes, pumps, trains, trolley etc.

c. Compound motor: they are used for drives requiring high starting torque and only fairly constant speed such as in rolling mills, crushers, cutting coals, punch presser, printing press etc.

2.7 DC motor starter

At starting; speed (N) = 0

We know,

$$E_b = \frac{Z\phi N}{60}\frac{P}{A}$$

So, $E_b = 0$

Also;

$$I = \frac{V - Eb}{Ra}$$

$$= \frac{V}{Ra} \uparrow$$

If motor is started directly, it will draw high current at starting for few seconds. Starting current could be 20 times greater than normal load current. It may produce sparking in the carbon brush and hence fuse may block out.

Therefore, we use control mechanism to reduce the magnetic of starting current i.e dc motor starter.

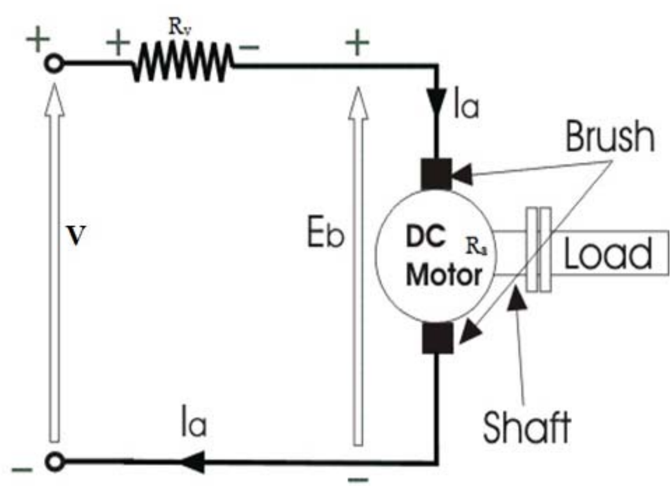
Basically, a dc motor starter is a variable resistance connected in series with armature circuit at starting.

At starting;

When R_v is used

$$I_a = \frac{V - Eb}{Rv + Ra}$$

Thus, it is cleared that by using the dc motor stator initially high flowing of current in the motor is controlled thus prevent the machine from getting damaged.



2.8 Speed control of DC motor

2.8.1 Concept of speed control:

In a practical application, it is necessary to control the speed of the motor depending upon the loading condition. There are various methods of speed control for DC motors. Usually speed controlling for the dc machine is easier in comparing to that of ac motor.

We know;

The magnitude of back emf developed by the armature is given by:

$$E_b = \frac{Z\phi N}{60}\frac{P}{A}$$

$$Or, N = \frac{Eb * 60 * A}{Z * P * \phi}$$

So,

$$N \prec \frac{Eb}{\phi}$$

But, $E_b = V - I_a R_a$

$$\therefore N \prec \frac{V - IaRa}{\phi} \text{.........................(m)}$$

Therefore, the factor controlling of DC motor are:

i. flux per pole
ii. armature resistance R_a
iii. applied voltage

2.8.2 Speed control of DC motor

a. For dc shunt motor

i. Flux control method:

The above equation (m) shows that there is inverse relation between speed and flux per pole. In this method, a variable resistance R_v is connected in series with field winding to regulate the field current thereby regulates the flux per pole. The circuit diagram is shown below:

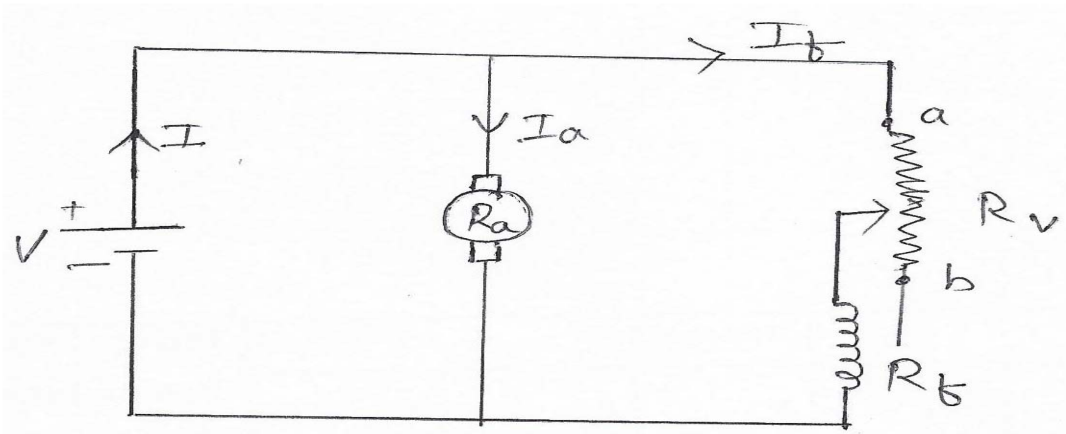


Figure 2.8.2 (a) Flux control method

In the flux control method, the variable resistance R_v can only reduce the field current below the rated value so this method is appropriate to control the speed above rated speed. When Rv is reduced to “a” position, full rated field current ($I_f = \frac{V}{Rf}$) will flow and the motor rotates with rated normal speed. When full Rv is connected at position “b”, the field current will reduced to ($I_f = \frac{V}{Rs + Rv}$), thereby reducing the flux per pole then the motor rotates with a speed higher than normal rated speed. Between the position “a” and “b” many intermediate speed can be obtained by sliding the variable point contact.

ii. Armature control method:

In this method, a variable resistance is connected in series with the armature as shown in figure 2.8.2(b).This method is used when speed below the normal rated speed is required. Since, the supply voltage is normally constant, the voltage across the armature is varied by inserting a variable resistance R_v in series with the armature circuit.

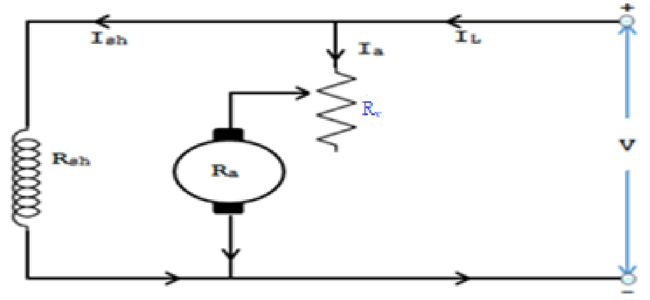


Figure 2.8.2(b) Armature control method

The field current will remain unaffected as the shunt field is directly connected across the supply. Therefore the flux per pole also remains constant. The armature torque depends on the flux per pole and armature current ($T_a \prec \phi I_a$). Although, the controller resistance R_v is increased keeping the load torque constant, the armature current remains constant, but due to voltage drop in the controller resistance, the back emf (E_b) is decreased (As, $E_b = V - I_a(R_a+R_v)$).Also we know that, the speed is directly proportional to the back emf(i.e $N \prec E_b$), the speed of the motor is reduced. The highest speed obtainable is equal to normal speed when the value of $R_v = 0$. Hence, this method can only provide the speed below the normal speed.

b. For dc series motor

i. Flux control method:

With the help of any of the following method listed below variation of flux in DC series motor can be done.

1. Field diverter method:

In this method, a variable resistance (R_v) is connected in parallel to the series field winding as shown in figure 2.8©.Any desired amount of current can be passed through the field winding by adjusting the value of diverter (R_v). Hence, flux can be decreased. Since, the speed is inversely proportional to the flux, the speed can be increased. This method gives speed above the normal value because flux is reduced by this method.

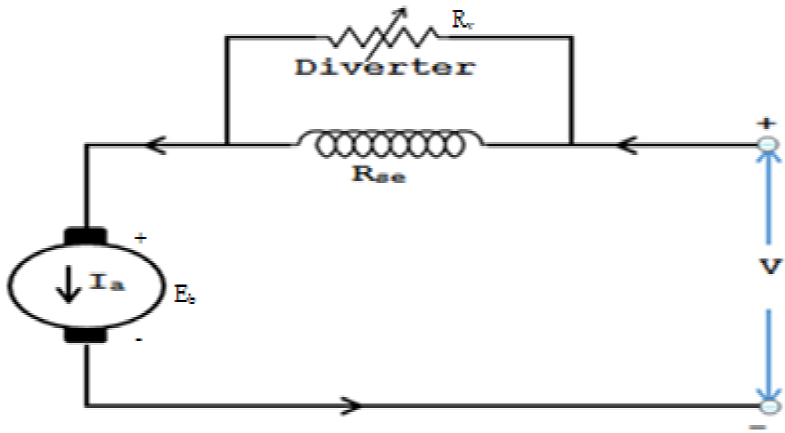


Figure 2.8 (c) Field diverter method

2. Armature diverter method:

In this method, a variable resistance (R_v) is connected in parallel to the armature winding as shown in figure (d). Due to this variable resistance (R_v), some of the armature current will get diverted and pass through diverter (R_v). For a constant load torque, if the armature current I_a is reduced due to diverter (R_v), then flux per pole must increase to produce constant torque ($\because T \prec \phi I_a$). This results in an increase in main line current taken from the supply and a fall in speed ($\because N \prec \frac{1}{\phi}$). The variation speed can be controlled by varying the value of diverter resistance R_V. This method is only suitable for controlling the speed below the normal rated speed.

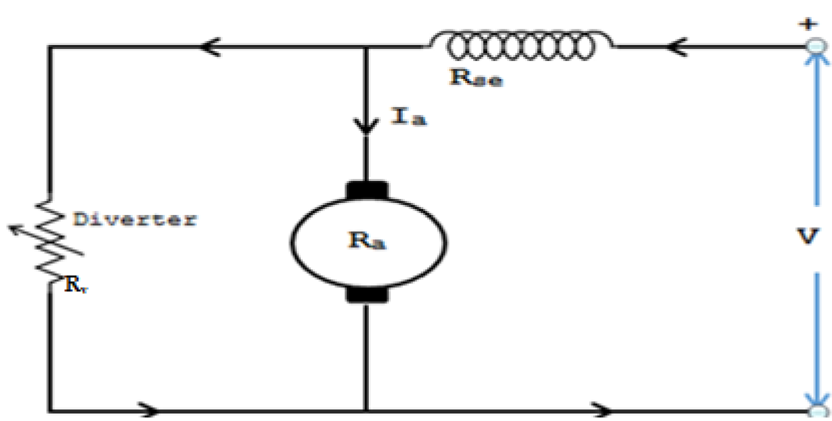


Figure 2.8 (d) : Armature diverter method

3. Tapped field control method:

In this method, the series field winding is provided with number of tapping as shown in figure 2.8(e). The number of turns of field series windings can be varied by the help of tap-changer easily from the point "a" to "b". With full field winding i.e when there is no tapping (at point "a") the motor runs at its minimum speed as the value of field current will be maximum (since, field current is inversely proportional to speed). On increasing the tapping from point "a" to "b", the field current gradually decreases i.e speed begins to increase. Finally, when the tapping is increased near-to point "b", the field current will be minimum and hence the speed will be high. Thus, in this way by the help of tap changer, the speed of the motor can be varied.

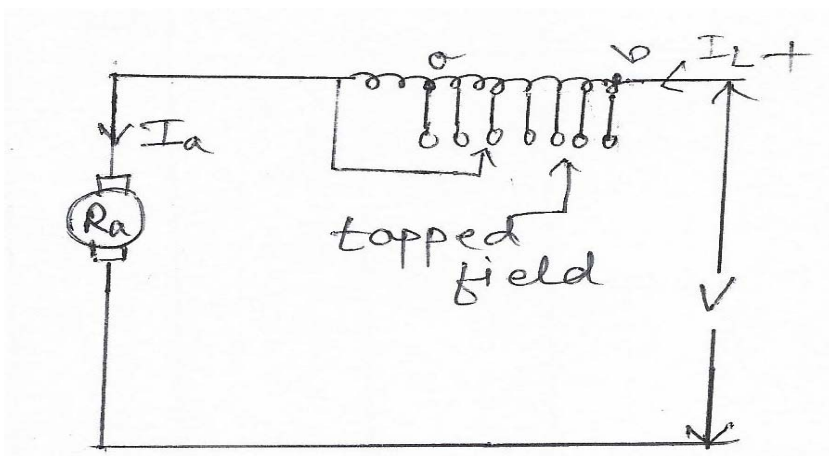


Figure 2.8 (e)

Teaching tips:

1) Visualization of different parts of dc machine
2) Showing the video of working mechanism of the three phase induction machine
3) Showing how the speed control of the dc motor is done through video and if possible through practically also.

Reference and Resources:

1) S. Chand, "Principle of Electrical Machine"
2) Jain and Jain, "ABC of Electrical Engineering"
3) J.B Gupta, "Electrical Machines"

CHAPTER 3
"THREE PHASE INDUCTION MACHINE"

Learning outcomes:

After the completion of this chapter, the students will;

1) Know about the constructional detail about three phase induction machine.
2) Working operation of three phase induction machine
3) Know the relationship between torque and slip both in standstill and running condition.
4) Starting method of three phase induction machine

Definition and its function and applications

3.1.1 Concept on 3 phase induction motor

Three phase Induction motors are the most widely used electric motor in the industry.

Normally, they run at constant speed from no load to full load. The speed is frequency dependent. The speed control of three phase induction machine is difficult. These motors are simple, low price, easy to maintain. Generally, three phase induction motors are self-started.

Regarding the construction, it is very simple. The essential features of induction motor are: laminated stator core carrying a poly-phase winding, a laminate rotor core carrying a cage or poly-phase winding, the latter with mounted slip rings, a stiff shaft to preserve the very short air gap.

3.1.2 Function and Applications

When three phase supply is given to the stator of the induction machine hen emf is induced in the rotor from the electromagnetic induction.

It is used in different types of industries where speed control is not required. Such as: printing machines, flour mills and other shaft drives of small power.

3.2 Constructional details

3.2.1 Different parts three phase induction motor

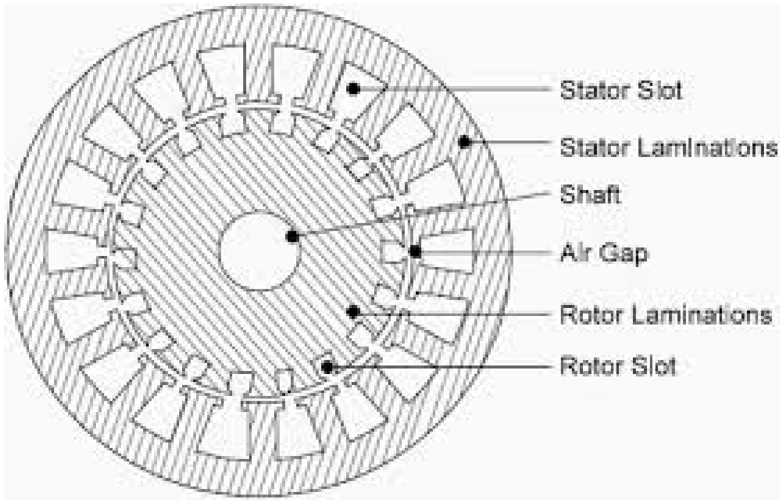


Figure 3.2 construction of 3 phase induction motor

There are mainly 3 parts of induction machine:

a. Stator
b. Rotor
c. Yoke

a. Stator

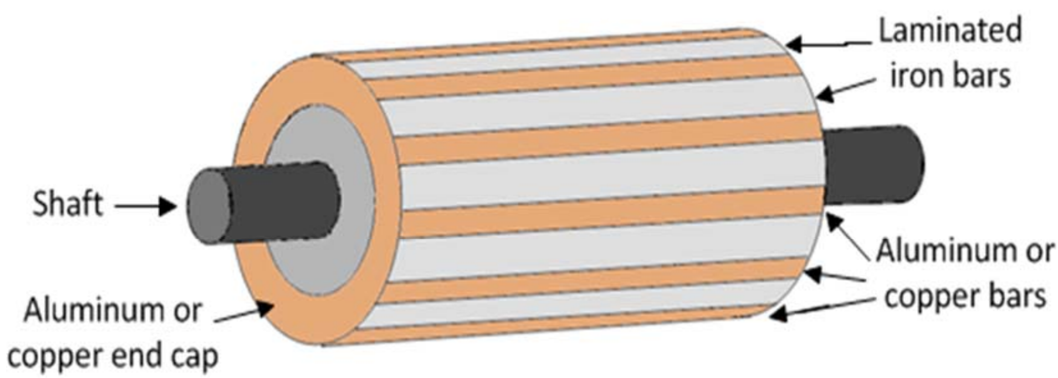
It is stationary part of the machine. It has hollow space in its center. The inner circumference of the stator core has alternate number of slots and teeth on which stator winding are placed. Generally, 3 phase windings are provided on these slots which are uniformly distributed and spaced 120^0 electrically apart. Stator core is protected by the outer covering called yoke made of cast iron. The stator core is to carry the alternating flux which produces hysteresis and eddy current losses. In order to reduce eddy currents and hysteresis loss in the stator core it is assembled of high grade, low0 electrical loss, and silicon steel punching. The thickness of punching varies from 0.35mm to 0.65mm. In smaller sizes, the stator plated form complete annular rings but for the larger machines they are prepared of segmental laminations to avoid wastage of steel.

b.Rotor

The rotor comprises a cylindrical laminated iron core/ with slots around the core, carrying the rotor conductors. In general, the same sheet steel laminations are employed for the rotor core as for the stator, but owing to the lower frequencies of the rotor flux, thicker laminations can be employed without excessive iron loss. It is rotating part of motor. It is cylindrical in shape with central shaft. The shaft is supported by bearing at both ends so that rotor rotates freely keeping an air gap of about 1mm to 4mm between rotor and stator. It is made of laminated silicon steel. There are two types of rotor. There are two types of rotor:

i. squirrel cage rotor
ii. phase wound rotor (slip ring rotor)

i. Squirrel cage rotor



Induction Motor Squirrel Cage Rotor

Squirrel cage rotor is made of laminated cylindrical core with parallel slots. These parallel slots carry rotor conductor. A squirrel cage rotor is the rotating part used in most common form of A.C induction motor. It consists of a cylinder of steel with aluminum or copper conductors embedded in its surface.

ii. Phase wound rotor:

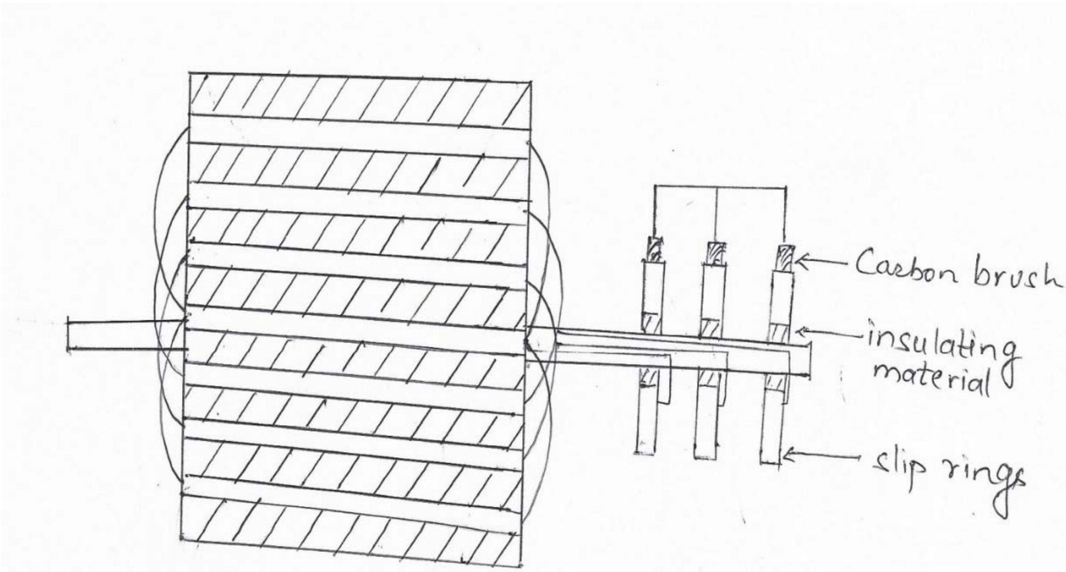


Figure: phase wound rotor

This type of rotor is also made of cylindrical laminated core. It has open slots along the outer circumference. Three ends of rotor winding are connected to three separated slip-rings and the slip rings are short circuited by the carbon brush. As the name implies, such a rotor is wound with an insulated windings similar to that of the stator except that the number of slots is smaller and fewer turns per phase of a heavier conductor are used. Since the connection of the wound secondary to the external terminals is made through slip rings and brushes, so wound secondary motors are often called slip-ring induction motors.

c.Yoke

It is the outermost frame of the machine. It covers the stator core and provides mechanical protection for the whole machine. The outer surface of the yoke has much number of fins to provide more contact area thus by giving effective way of cooling the machine.

3.3 Operation as motor

3.3.1 Concept on different terms:

a. Synchronous speed:

The speed at which machine rotates constantly is called synchronous speed. It is the speed of rotating magnetic field. It is given by:

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

Where; N_s = synchronous speed

f = frequency

p =no of pole

b. Slip:

The difference between the speed of rotating magnetic field (synchronous speed) with the actual speed of the rotor expressed as the fraction of synchronous speed. It is denoted by “s”. it is expressed in terms of percentage.

$$S = \frac{Ns - N}{Ns} \times 100\%$$

Where,

N= speed of rotor

N_s= synchronous speed

c. Rotating magnetic field

When three phase winding is energized from three phase supply, a rotating magnetic field is produce. The field is such that its pole does not remain in fixed position on stator but goes on shifting its position in stator. So it is called rotating magnetic field.

3.3.2 Operating Principle of three phase Induction machine as motor:

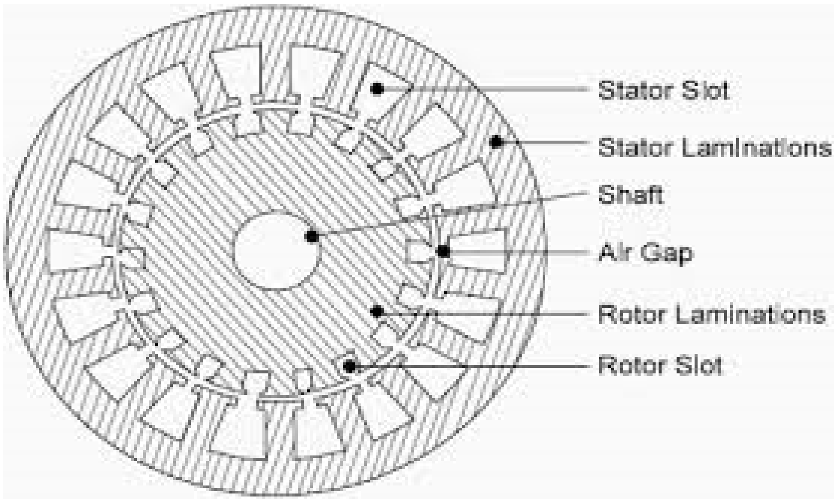


Figure 3.3.2 3-phase induction motor

When three phase supply is given to three phase stator winding, rotating magnetic field is develop on it. This field is passed through the air gap and cut the rotor conductor which is stationary. Due to relative speed between moving rotating magnetic field and stationary rotor, emf is develop in the rotor. Since the rotor conductor is short circuited the current flows through it.When it is placed in magnetic field, the rotor conductor experience force. Due to the combination of this force torque is developed which then rotates the rotor. Direction of motion of rotor and rotating magnetic field will be same.

Numerical:

1. An induction motor has a rated speed of 715rpm. How many poles have its rotating magnetic field?

   Sol^n;

   No of poles $= \frac{120f}{N}$

   $= \frac{120x50}{715}$

   $= 8$

2. A 60 Hz induction motor has 2 poles and runs at 3510rpm. Calculate

i. synchronous speed

ii. Percent slip

sol^{n};

Synchronous speed= $\frac{120f}{p}$

$= \frac{120x60}{2}$

= 3600 rpm

Percent slip = $\frac{N_S - N}{N_S}$x100

$= \frac{3600-3510}{3600}$x 100

= 2.5%

2. Calculate the speed of a 4 pole,50Hz, 400V, 3-phase induction motor when it is operating at a slip of 1.5 percent.

Sol$^{n:}$

Synchronous speed (N_s) = $\frac{120f}{p}$

$= \frac{120x50}{4}$

= 1500 rpm

Slip , s = 1.5% = 0.015

Operating speed, N = N_s (1-0.015)

= 1500((1-0.015) = 1477.5rpm

3.4 Equivalent circuit

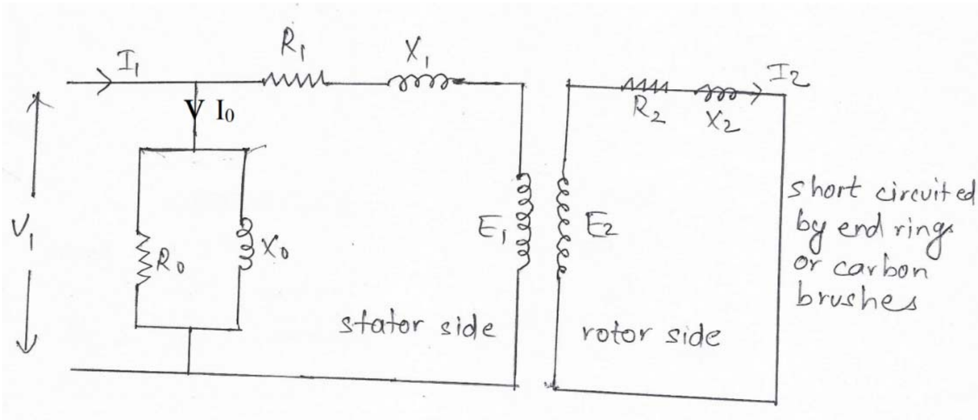


Figure 3.4 equivalent circuit of 3 phase induction machine

The above figure shows the equivalent circuit of induction motor. The equivalent circuit of transformer and induction motor is same at the stationary condition but at the running condition, slip plays important role.

V_1 = supply voltage to stator winding per phase

I_1 = stator current per phase

I_0 = no load stator current

E_1= stator emf per phase

E_2= rotor emf per phase

R_1= stator winding resistance

X_1 = stator reactance

R_2 = rotor winding resistance

X_2= rotor reactance

I_2= rotor circuit current

R_0 = no-load resistance

X_0 = no-load reactance

Stand still condition:

We know;

Rotor emf per phase induced is:

$$E2 = \frac{N2}{N1} \times E1$$

Then;

Rotor current " I2 ' = $\dfrac{E_2}{Z}$

$$= \frac{E_2}{\sqrt{(R_2)^2 + ((SX_2)^2)}}$$

$$= \frac{E_2}{\sqrt{(R_2)^2 + (X_2)^2}} \quad \text{as } s = 1;$$

Here, the rotor current "I2" lags "E2" by the angle of ϕ_2

$$\cos\phi_2 == \frac{R_2}{\sqrt{(R_2)^2 + (X_2)^2}}$$

The torque developed by the rotor at standstill condition is proportional to the product of flux per pole and active component of E_2.

$\therefore$ Starting torque;

$T \prec \phi I_2 \cos\phi_2$

$T = k\phi I_2 \cos\phi_2$ where k is the proportionality constant

Also;

The flux produced is directly proportional to applied voltage along with the stator emf and the rotor emf. i.e

$\phi \prec v_1 \prec E_1 \prec E_2$

Ts = k E_2 I_2 $\cos\phi_2$

$$Ts = k E_2 \frac{E_2}{\sqrt{(R_2)^2 + (X_2)^2}} \frac{R_2}{\sqrt{(R_2)^2 + (X_2)^2}}$$

$$Ts = \frac{KE_2{}^2 R_2}{(R_2)^2 + (X_2)^2}$$

Now,

Under running condition;

$N \neq 0$

So ;

Slip (s) = $\dfrac{N_S - N}{N_S} > 0$

Induced emf in rotor;

$E_r = sE_2$

And frequency of the rotor is; $f_r = sf$

Rotor current $I_r(2) = \dfrac{SE_2}{\sqrt{(R_2)^2 + (SX_2)^2}}$

I_r lags E_r by some angle ϕ_r

So;

$$\cos\phi_r = \frac{R_2}{\sqrt{(R_2)^2 + (SX_2)^2}}$$

The torque developed by the rotor at running condition is proportional to the product of the flux per pole and active component I_r ;

So;

Running torque;

$T_r \prec \phi (I_r \cos\phi_r)$

Since;

$\phi \prec v_1 \prec E_1 \prec E_2$

$Tr = k\, E_2\, I_2 \cos\phi_2$

$$T_r = k\, E_2 \frac{SE_2}{\sqrt{(R_2)^2 + (SX_2)^2}} \frac{R_2}{\sqrt{(R_2)^2 + (SX_2)^2}}$$

$$T_r = \frac{KE_2^{\,2} R_2}{(R_2)^2 + (SX_2)^2}$$

3.5 Torque-slip characteristics of three phase induction motor

3.5.1 Provide the concept of slip

The difference between the synchronous speed N_s of the rotating stator field and the actual rotor speed N is called slip. It is usually expressed as a percentage of synchronous speed.

$$\text{Slip(s)} = \frac{N_S - N}{N_S} \text{ x } 100$$

The above equation shows that the relative speed (N_s –N) of the rotor and the rotating magnetic field is directly proportional to the slip (s). The value of slip ranges between 0 to 1.

3.5.2 Relation of rotor torque in 3-phase induction motor

The torque " T " developed by the rotor is directly proportional to:

i. rotor current
ii. rotor emf
iii. power factor of the rotor circuit

Therefore;

$$T \prec E_2 I_2 \cos\phi_2$$

$$T = K E_2 I_2 \cos\phi_2$$

Where;

$I2$ = rotor current at standstill
$E2$ = rotor emf at standstill
$\cos\phi_2$ = rotor p.f at standstill

3.5.3 Characteristics of Torque and slip of 3 phase induction motor

Under the running condition, the motor torque is given by;

$$T_r = \frac{KE_2{}^2 R_2 s}{(R_2)^2 + (SX_2)^2}$$

So, when a curve is drawn between the torque and slip for the particular value of the rotor resistance " R_2 ", then the graph thus obtained is called torque-slip characteristics. Figure 3.5.3 shows the torque-slip characteristics for the slip range from s = 0 to s = 1 for the various values of the rotor resistance.

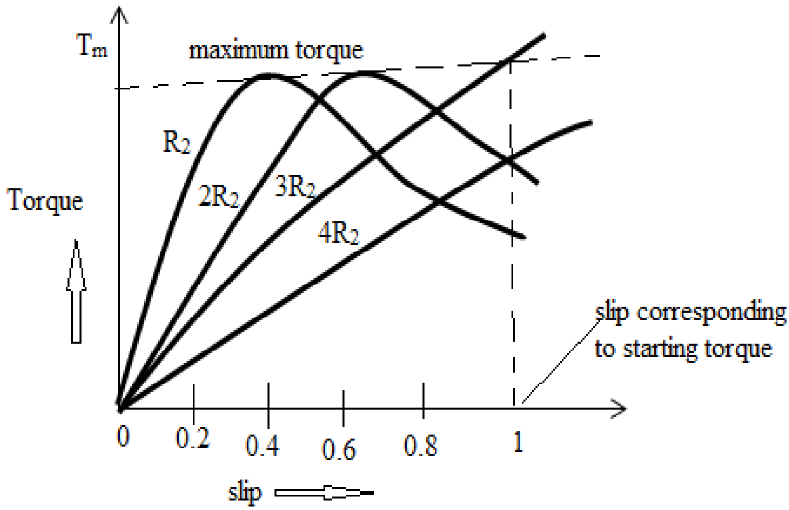


Figure 3.5.3 torque-slip characteristics

We should notice the following things carefully from the torque-slip characteristics;

i. At s = 0, T = 0 so that torque –slip curve starts from the origin.
ii. At normal speed, slip is small so that sX_2 is negligible as compared to R_2.

$$T \prec \frac{s}{R_2}$$

$T \prec s$ as R_2 is constant

Hence, torque-slip curve is a straight line from zero slip to a slip that corresponds to full – load.

i. As slip increases beyond the full-load slip, the torque increases and becomes maximum at $s = \frac{R_2}{X_2}$. This maximum torque in an induction motor is called pull-out torque or breakdown torque. Its value is at least twice the full – load value when the motor is operated at rated voltage and frequency.

ii. When slip increases beyond that corresponding to maximum torque, the term s^2X^2 increases very rapidly so that R_2^2, may be neglected as compared to $s^2X_2^2$.

$$T \prec {}^{s}\!/_{s^2 X_2^{\,2}}$$

$T \prec 1/s$ as the value of X_2 is constant

The torque is now inversely proportional to slip. Hence torque-slip curve is a rectangular hyperbola.

i. The maximum torque remains the same and is independent of the value of the rotor resistance. Therefore, the addition of resistance to the rotor circuit does not change the value of the maximum torque but it only changes the value of slip at which maximum torque occurs.

3.6 Induction motor starter

3.6.1 Introduction and requirement of 3 phase induction motor starter

With the normal voltage supply when given to the motor, it draws high current at the starting. At the starting the speed of the rotor is zero having the value of slip is unity. Hence, it results in the induction of maximum voltage in the rotor circuit and high current will flow through the rotor as well as stator circuits. Once, rotor starts rotating the value of slip will decrease and hence emf induced in the rotor circuit decreases and the value of stator current and rotor current will be normal. An induction motor, when directly switched on with full supply voltage draws around 4-7 times of their full load current and develops only 1.5 to 2.5 time f their full load torque. If the actual values depending upon the size and design of the motor. This high starting current objectionable because it will produce large line voltage drop that in turn will affect the operation of the other electrical equipment connected in the same line. Hence only small induction motors shall be started directly with full supply voltage. For large induction motors various starting methods are available to reduce starting current. They are as follows:

a) Primary resistors method
b) Auto transformer method
c) Star/delta starter method

3.6.2. Primary resistor method:

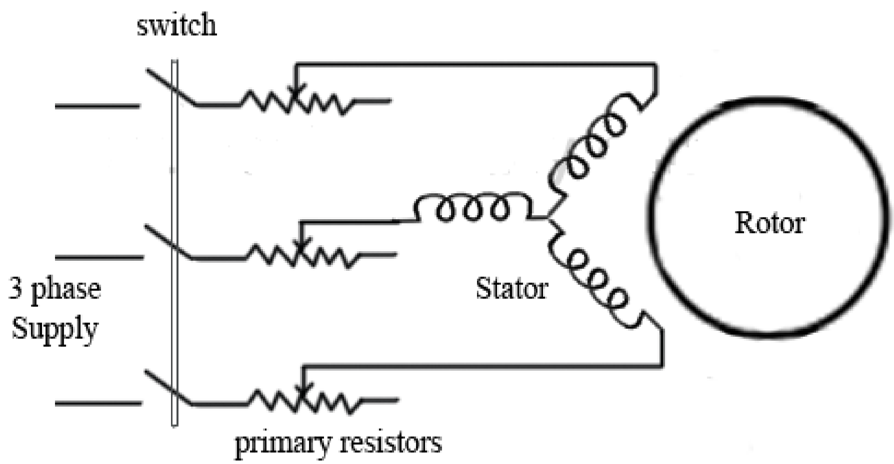


Figure 6.3.1 Primary resistance

In this method, external variable resistors are connected in series with each phase of stator winding as shown in figure 6.3.1. These external three resistors are used to drop some voltage and hence to reduce voltage applied across the stator winding. At starting whole resistance are connected in series with stator winding so that motor draws low starting current. As speed picks up, the resistance is gradually cut out and finally it is completely cut when motor runs with the normal speed. This method is applicable for the motor up-to 5 H.P.

This method has two drawbacks. At first, the reduced voltage during the starting time when applied to the motor lowers the starting torque and another one is, a lot of power is wasted in the starting resistance.

3.6.3. Auto-transformer method:

In auto-transformer method, there are three auto-transformers connected in star with double switch and three or four tapings as shown in figure 3.6.3. When the switch is in “OFF” position high voltage will developed across the winding. When the switch is in “ON” position, a reduced voltage is applied across the stator winding. When the motor runs up-to 80% of its normal speed the connections are changed so that full voltage appears across the stator winding without auto-transformer.

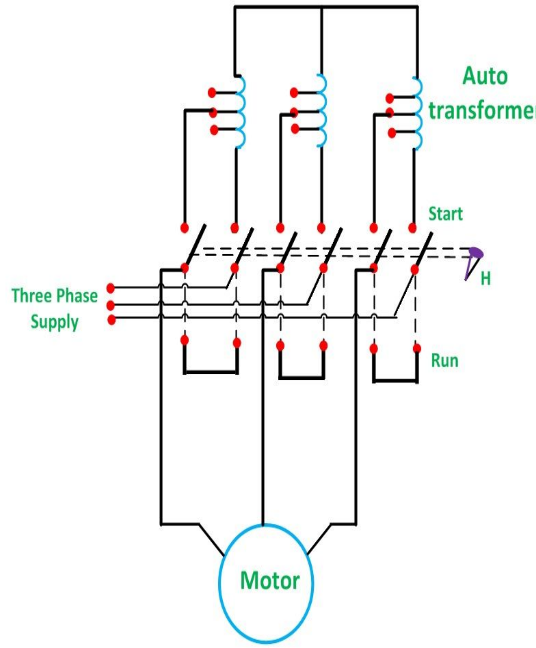


figure 3.6.3 Auto-transformer

This method is used for the large cage motors of output rating exceeding 20 KW.

3.6.4. Star/ delta transformer

This method uses a two way switch which connects the stator winding in “Star” for starting period and then in “Delta” for normal running period. Star-delta starter is a switch which is connected across the starter winding. During the starting time, the handle of the starter is moved from OFF to the STAR position, when windings get connected in star so that the applied voltage across the winding is reduced to $\frac{1}{\sqrt{3}}$ times the line voltage. Similarly, when the motor accelerates and gains speed, the handle of the switch is quickly thrown over to DELTA position, so that the voltage become equal

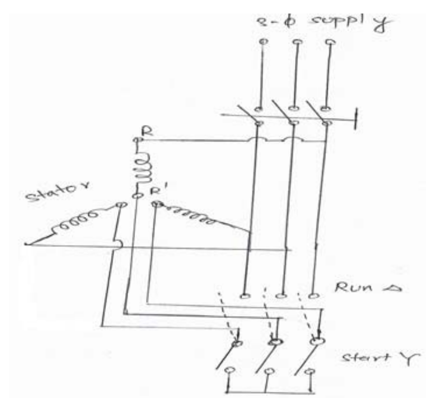


Figure: 3.6.4 Star/delta

to the line voltage and hence full-line voltage is supplied to the windings. Then, the motor runs at the normal speed. The connection is shown in above figure 6.3.4.

This method is normally used for the motors of rating between 4 and 20KW.

If the motor is started with delta connection

$$(I_d) = \frac{V}{Z}$$

If the motor is started with star connection:

$$(I_s) = \frac{\frac{V}{\sqrt{3}}}{Z}$$

$$= \frac{V}{\sqrt{3}Z}$$

3.7 Speed control of three – phase induction motor

3.7.1 Introduction of speed control of three-phase induction motor

Three phase induction motors are practically constant speed machines. From the view point of speed control characteristics, induction motors are inferior to dc motors. In induction motor, speed cannot be varied without losing efficiency and good speed regulation. DC shunt motor can be made to run at any speed within with good efficiency, simply by changing the field rheostat whereas the same is not possible in-case of induction motor.

3.7.2 Types of speed control of induction methods:

Some of the methods for controlling the speed of induction motors are as follows:

a) Stator voltage control method
b) Rotor rheostat method
c) Frequency control method

a. Stator voltage control method:

Since the speed of the motor is directly proportional to the magnitude of applied voltage, it can be increased or decreased by increasing or decreasing the magnitude of applied voltage. This method is cheaper and simple but rarely used because large change in voltage causes small change in speed. A large change in voltage will result large change in flux density, thereby seriously disturbing the magnetic condition of motor.

b. Rotor rheostat method:

In this method, the speed of motor is reduced by introducing an external resistance in rotor circuit. The change in speed is approximately inversely proportional to external resistance connected in rotor circuit. This method is applicable for only slip ring induction motor.

Since, we know the relation; Tr = $\frac{S}{R_2}$ so, for a given constant load torque, if R2 is increased, slip will increase and speed will decreased. This can be described with the figure shown in 3.7.2

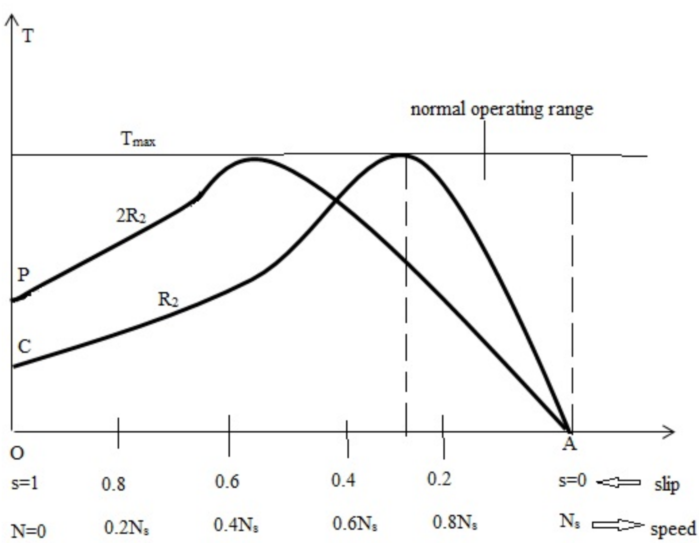


Figure 3.7.2 Speed control by changing rotor resistance

c. Frequency control method:

Speed is directly proportional to the supply frequency. The synchronous speed of rotating magnetic field is given by $N_s = \frac{(N_s - N)}{N_s}$. Therefore, speed can be controlled by changing the frequency of applied voltage. Usually, a variable frequency inverter is used for this purpose.

3.8 Application of three phase induction motor

It is used in different types of industries of small power where speed control is not required. Such as: printing machines, flour mills and other shaft drives of small power.

3.9 Basic idea of three phase induction generator and its uses

An induction generator is also called asynchronous generator that uses the principle of motor. When the shaft of the induction machine is run at speed more than synchronous speed then induction machine acts as induction generator. It has negative slip. Capacitor is required to give necessary reactive power. It is used in micro-hydropower, mini hydro power. An induction generator produces electrical power when the rotor of induction motor is to rotate above synchronous speed.

Teaching tips:

1. Visualization of different parts of three phase induction machine
2. Showing the video of working mechanism of the three phase induction machine

Reference and Resources:

3. S. Chand, “Principle of Electrical Machine”
4. Jain and Jain, “ABC of Electrical Engineering”
5. J.B Gupta, “Electrical Machines”

CHAPTER 4

Synchronous Machines

Learning outcomes:

After the completion of this chapter, the students will;

1) Know about the constructional detail about synchronous machine.
2) Working operation of synchronous machine
3) How paralleling operation synchronization of alternator is done

4.1 Definition and its function and applications

4.1.1 Synchronous machine:

A synchronous machine is an a.c machine. It can be used as generator as well as motor. The machine which rotates at a constant speed equal to the synchronous speed is called synchronous machine. In case of generator, the machine has to be driven at a constant speed equal to the synchronous speed. Most of the power generating station uses synchronous generator which is also known as alternator. Synchronous machine are generally constructed in larger sizes. Small size alternators are not economical. The modern trend is to build alternators of very large sizes capable of generating 500MVA or even more. The synchronous motor is rarely built in small size owing to superior performance characteristics and economical construction of the induction motors.

4.1.2 Function and application of synchronous machines:

The function of synchronous generator is to generate electricity where as that of synchronous motor is to develop torque.

Usually, it is used in power house and sub-station, factories etc.

4.2 Constructional detail

4.2.1 Constructional parts of synchronous machine:

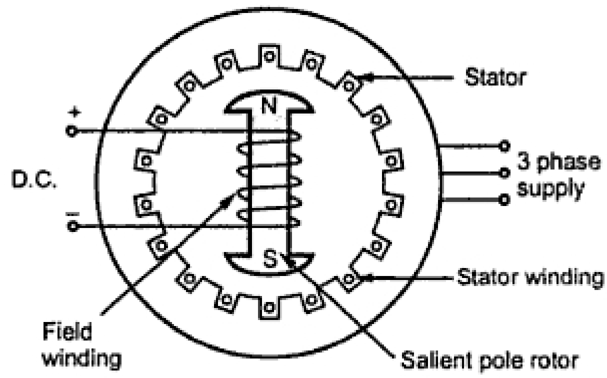


Figure 4.2 Synchronous machine

a. Stator

It is the stationary part of the synchronous machine. It has uniformly distributed three phase armature winding. It is an iron ring formed of laminations of special magnetic iron or steel alloy having slots on its periphery to accommodate armature conductors. The whole structure is held in the frame which may be of cast iron. Since the field rotates in between the stator, so that flux of the rotating field cuts the core of the stator continuously and causes eddy current loss in the stator core. To minimize the eddy current loss, the stator core is laminated.

b.Rotor

It is the rotating part of the synchronous machine. It has the number of magnetic poles excited by dc source. The roto are if two types:

i. Salient pole rotor
ii. Cylindrical type rotor

i. Salient pole rotor

This type of rotor has got projected magnetic pole. The construction of this of rotor is easier and cheaper than cylindrical rotor. This type of rotor is generally used in the generators driven by low speed prime movers such as water turbine. If driven at the high speed, the salient field poles would produce noise and it would cause the excessive windage loss. Some of the features of the salient pole rotor as follow:

1) They have large diameter and short axial length.
2) The pole shoes cover about 2/3 of pole pitch.
3) Poles are laminated in order to reduce eddy current losses.
4) These are employed with hydraulic turbines or diesel engines. The speed is 100 to 375 rpm.

ii. Cylindrical type rotor

This type of rotor has smooth magnetic poles in the form of closed cylinder. Construction of this type of rotor is more compact and robust with compare to salient pole rotor. This type of rotor is generally used in the generator driven by high speed prime movers like steam engine and gas turbine. It is also known as non-salient pole type rotor. Some of the features of this type of rotor are as follow:

1) They are of smaller diameter and of very long axial length.
2) Robust construction and noiseless operation
3) Less windage loss
4) Better in dynamic balancing
5) High operating speed(3000 rpm)

c. Exciter

The exciter is generally a dc shunt or compound generators. In the small synchronous generators exciter is mounted on the same shaft on the synchronous generators. This will provide dc current required to magnetize the magnetic poles of the rotor. The dc current generated by the exciter is fed to the field winding of the alternator through slip ring and carbon brush arrangement.

d. Stator winding

The winding which are kept in stator is known as stator winding.

e. Field winding

The winding which are kept in rotor is known as field winding.

4.3 Operation as generator

4.3.1 Operating principle of synchronous machine as generator

When the rotor is rotated by the prime mover, the stator winding are cut by the magnetic flux of rotor poles. Consequently, an emf is induced in the stator conductor. Since the magnetic poles in the rotors are alternatively ("N" and "S"), so they induced alternating emf and hence current in the stator, the frequency of which depends upon the number of "N" and "S" poles moving past a stator conductor per second. The frequency of generated a.c emf is given by;

$f = \frac{PN_s}{120}$ where; P= no of magnetic poles

N_s = synchronous speed

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.

4.3.2 Derivation of emf equation of synchronous generator

Let;

Z = no of conductors or coil sides in series per phase

Z = 2T (where T is the no of turns in series per phase)

ϕ = flux per pole in Weber

P = number of rotor poles

N = rotor speed in r.p.m

In one revolution (i.e 60/N second), each stator conductor is cut by Pϕ weber

i.e $d\phi = P\phi$ and dt=60/N

∴ Average emf induced in one stator conductor;

$$= \frac{d\phi}{dt}$$

$$= \frac{p\phi}{\frac{60}{N}}$$

$$= \frac{P\phi N}{60} \text{ volts}$$

Since there are Z conductors in series per phase;

∴ Average emf/phase = $\frac{P\phi N}{60} Z$

$$= \frac{P\phi N}{60} \times \frac{120 f}{P}$$

$$= 2 f \phi Z \text{ volts}$$

RMS value of emf/ phase = average value/phase x form factor

$$= 2f\phi Z \times 1.11$$

$$= 2.22 f \phi Z$$

$$= 2.22 \times 2T\phi f \ (Z = 2T)$$

$$= 4.44 T f\phi \text{ volts}$$

In case of synchronous generator distribution factor (k_d) and pitch factor (k_p) appears.

So;

Emf equation of synchronous generator = $4.44\, k_d K_s f \phi\, T$ volts……………..(i)

4.3.3 Factors affecting the magnitude of emf

The magnitude of emf generator depends upon the frequency, flux and no of turns which can be easily seen from the equation (i) above. Besides that, it also depends upon the pitch factor and distribution factor.

i. Pitch factor

The ratio of phasor sum of induced emfs per coil to the arithmetic sum of induced emfs per coil is known as pitch factor. In short-pitch winding the induced emfs in the two sides of the coil are not in phase.

When the two coil sides forming a complete coil of a winding are180 electrical space degrees apart then the winding is known as full-pitch winding, and emf generated in the two side coils are in phase with each other.

When the coil span of winding is less than 180 electrical space degrees, then the winding is known as fractional (or short pitch)

Pitch factor (k_p) (or coil span factor), which is defined as ;

$$k_p = \frac{= \text{ emf with short- pitched winding}}{\text{emf with full-pitches winding}}$$

$$= \frac{\text{vector sum of the induced emf/coil}}{arithemtic\ sum\ of\ the\ induced\ emf/coil}$$

ii. Distribution factor

In almost all armature windings of alternators, the conductors are placed in two or more slots under one pole. So the emf’s in the adjacent coils is out of phase with respect to another by a certain angle, and the resultant emf will be less than their algebraic sum. For example, in a three- phase alternator having three slots per phase per pole. There are nine slots distributed over one pitch. Consequently, there is a phase difference of $180^0/9 = 20^0$ in between the adjacent poles.

4.3.4 Relation between internal emf and terminal voltage

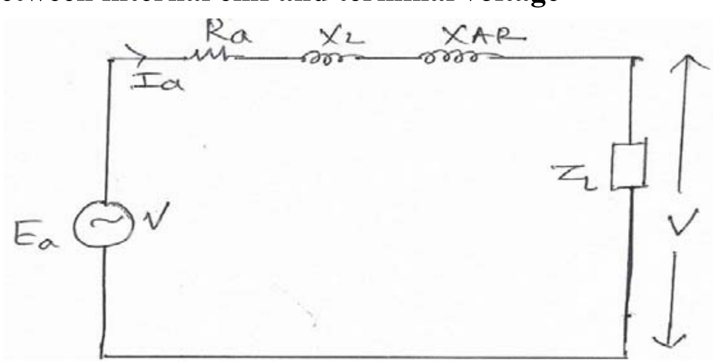


Figure 4.3.4 equivalent circuit diagram of alternator

The above figure 4.3.4 shows the equivalent circuit diagram of alternator for one phase. All the quantities are per phase. Here:

During the no-load condition, the current (I_a) will not flow through the circuit. Therefore, at that time, the terminal voltage (V) will be equal to that of load induced emf (E_a). i.e $V=E_a$

At the loaded condition, the current (I_a) will flow in the circuit. There will be certain voltage drop and hence, the terminal voltage will no more be equal to the load induced emf. The expression for the loaded condition is given below;

$$V = E_a - I_a(R_a + j(X_L + X_{AR})$$

4.4 Parallel operation and synchronization

4.1.4 Concept of parallel operation of machines:

Generally, in power system, there will be two or more alternators running in parallel. The required no of alternators are connected to fulfill the consumer's demand. The process of connecting the two alternators in parallel is known as "synchronization". In an interconnected power system, many no of alternators at various stations will be connected in parallel through bus bars at station and transmission lines. In such a system, an alternator will be synchronized to an infinite bus bar on which many number of alternators had been already connected. An infinite bus bar is the bus bar whose voltage and frequency is independent and constant with load.

When two or more than two generators are connected n parallel are called parallel operation of synchronous generator or synchronization. The synchronous generators which have been switched onto the bus bar for synchronized are incoming generator.

The advantages of parallel operation of alternators are:

i. continuity of service
ii. efficiency
iii. maintenance and repair
iv. load growth

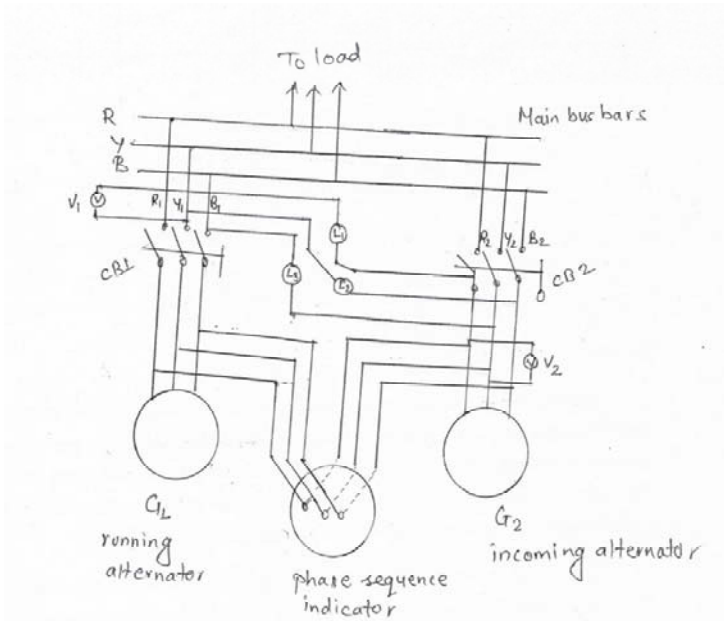


Figure : 4.1.4 (a) connection diagram for synchronization of two alternators

There are two methods of parallel operation of synchronous generator:

i. Dark lamp method
ii. Synchronous method

i. Dark lamp method:

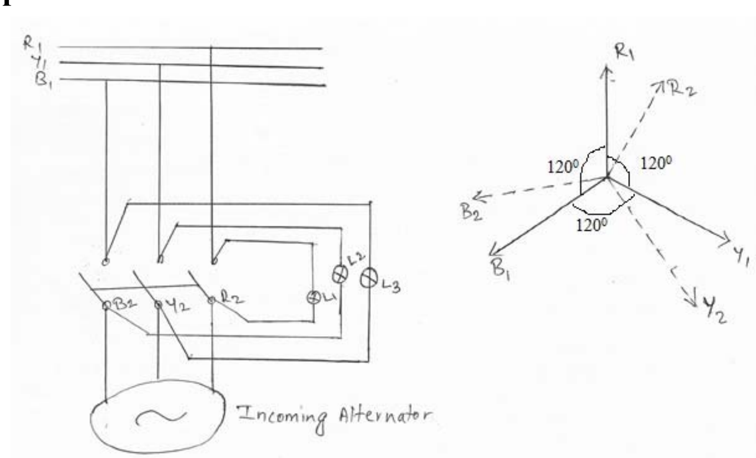


Figure 4.1.4 (i) dark lamp

In this method or parallel operation, three lamps L_1, L_2 and L_3 are connected as shown in figure above. The lamp "L_1" is direct connected between the phase R_1 and R_2 and the other two are cross connected between other two lamps.

When the frequency and phase of voltage of incoming generator is same as that of bus-bars the directly connected lamp "L_1" goes dark while cross- connected lamps "L_2" and "L_3" will be equally bright. At this instant, parallel operation is done and switch of incoming generator can be closed to connect it to the bus bar.

ii. Synchronous method

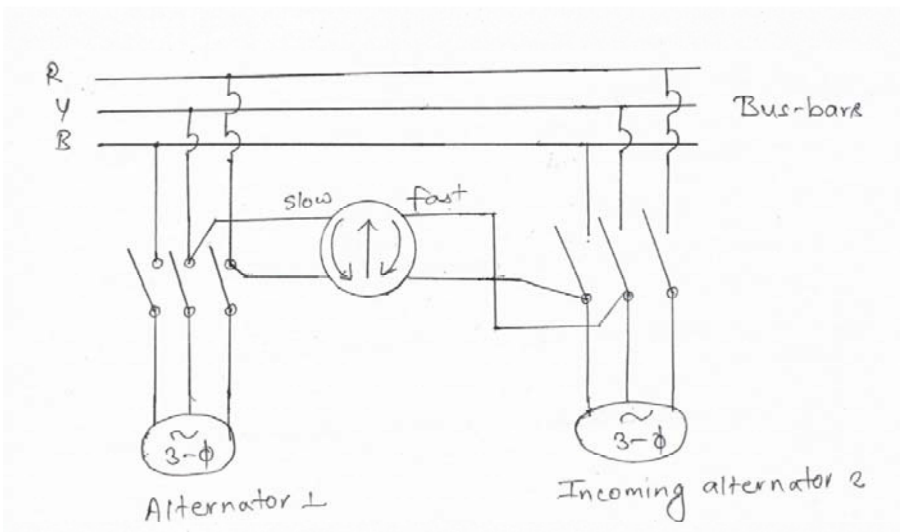


Figure 4.1.4 (ii) synchronous scope

A synchro scope consists of a rotor (moving coil) and a stator (fixed coil), one of which is connected to the bus bar. A pointer connected to the rotor rotates if there is a difference of frequencies.

- a. Clockwise rotation of pointer indicates that frequency of incoming alternator is higher.
- b. Anti-clock wise rotation of pointer indicates that the frequency of incoming alternator is lower.

- c. Zero (0') clock position of pointer indicates that the frequency of incoming alternator is equal to the bus bar frequency. Then, incoming alternator can be synchronized i.e connected to the bus bar.

4.4.2 Requirement of parallel operation of alternator

The proper method of connecting an alternator to the infinite bus bars is called synchronizing. A stationary alternator must not be connected to live bus-bars. It is because the induced e.m.f is zero at standstill and a short-circuit will result. For paralleling the alternator safely certain conditions are needed to be met up. Following are the conditions to be fulfilled for paralleling operation of alternators:

1) The terminal voltage (r.m.s value) of the incoming alternators must be the same as bus-bars voltage.
2) The frequency of the generated voltage of the incoming alternator must be equal to the bus-bars frequency.
3) The phase of the incoming alternator voltage must be identical with the phase of the bus-bars voltage. In other words, two voltages must be in phase with each other.
4) The phase sequence of the voltage of the incoming alternator should be same as that of the bus-bars.

4.5 Synchronous motor

4.5.1 Introduction to synchronous motor

Synchronous motor is doubly excited machine i.e two electrical inputs are provided to it. Three phase supply is given to stator winding whereas dc supply is given to rotor winding. They are the ac motor which always rotates at a constant speed equal to synchronous speed ($N_s = 120f/p$) i.e in synchronism with the revolving field produced by the 3-phase supply. The speed of rotation is therefore, tied to the frequency of the source. Since the frequency is fixed, the motor speed stays constant with the given load and voltage of three phase supply. The construction of synchronous motor and synchronous is almost similar.

Operating principle of synchronous motor

When three phase supply is given to the stator winding, rotating magnetic field is produced. The rotor carrying dc current also produces constant flux. At particular condition, rotor and stator poles might be at same polarity ($N_S – N_R$, $S_S – S_R$

causing the repulsive force on the rotor and other next second, it will be ($N_S – S_R$) causing attractive force. But due to the inertia of rotor, it is unable to rotate t any direction due to attractive and repulsive force and remains in the stand still condition. Hence, it is not self-started.

To overcome this inertia, rotor is initially fed with some mechanical input which rotates it in same direction as near to synchronous speed. After sometimes magnetic locking occurs and the motor rotates in synchronism with frequency.

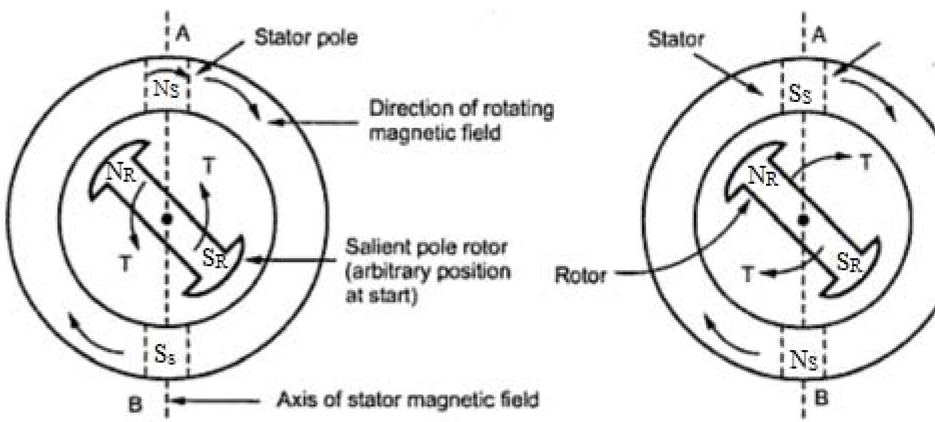


Figure 4.5.1

Characteristics of synchronous motor:

1) Synchronous motors are not self- starting. They require some external means to bring their speed close to synchronous speed to before they are synchronized.
2) It is used in power factor improvement.
3) This motor has unique characteristics of operating under any loading of electrical factor. So, this motor is used in the improvement of power factor.
4) It runs at either at synchronous speed or not at all. i.e while running it maintains a constant speed equal to the synchronous speed.

Starting method of synchronous motor

A synchronous motor is not self-starting, so its rotor is temporarily speeded up to or near synchronous speed. There are two methods of starting the synchronous motor which are as follows:

i. By using damper winding
ii. By using prime mover

i. By using damper winding

In this method, the field magnet of rotor is provided with additional winding known as damper winding. Damper is also known as squirrel cage winding. To start motor, three phase supply is given to the stator winding is left un-energized. The rotating magnetic field of the stator will induced current in the damper winding and the motor accelerates like a squirrel cage induction motor. When the motor reaches synchronous speed, then rotor field winding is energized. This result in the magnetic interlocking of rotor poles which stator and motor runs at the synchronous speed.

ii. By using prime mover

In this method, DC compound motor or three phase induction motor is used to start the motor. When the synchronous motor attains synchronous speed the rotor field is energized, thereby the rotor poles are magnetically interlocked with stator pole, and the motor continuous to run at the synchronous speed. At this condition the prime mover are disconnected.

4.5.2 Application of synchronous motor

The applications of the synchronous motor are listed below:

a. Synchronous motors are particularly attractive for low speeds (< 300 r.p.m) because the power factor can always be adjusted to unity and efficiency is high.
b. Over- excited synchronous motors can be used to improve the power factor of a plant while carrying their rated loads.
c. They are used to improve the voltage regulation of transmission lines.
d. High power electronic converters generating very low frequencies enable us to run synchronous motors at ultra – low speeds. Thus, huge motors in the 10MW range drive crushers, rotary kilns and variables speed ball mills

Teaching tips:

1. Visualization of different parts of synchronous machine
2. Showing the video of synchronization done between two alternators

Reference and Resources:

1. S. Chand, "Principle of Electrical Machine"
2. Jain and Jain, "ABC of Electrical Engineering"
3. J.B Gupta, "Electrical Machines"

CHAPTER-5
"Single phase fractional horse power motors"

Learning outcomes:

After the completion of this chapter, the students;

1) Will know the constructional detail of single types induction motor
2) Will know the constructional detail along with the advantage of universal and shaded pole motor.
3) Will know the operation of single phase induction motor
4) Will know how single phase induction motor can be made self-started

5.1 Single phase induction motor

5.1.1 Introduction of single phase induction motor

This type of motor is used on single-phase supply. It is most familiar motors that are used in our home, shop, office etc. The construction of single phase induction motor is similar to that of three phase induction motor, except that the stator is provided with a single phase supply between poles. It has stator with slots and the squirrel cage rotor with a small air-gap in between. Generally, the single phase induction motor is not self- starting and requires some starting means to get started.

5.1.2 Constructional detail of single phase induction motor

In single phase motors, there are mainly two parts one rotating and other is stationary part. 1) Stator 2) rotor

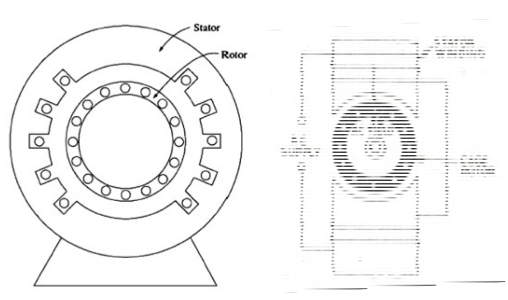


Figure 5.1.2 Construction of single phase induction motor

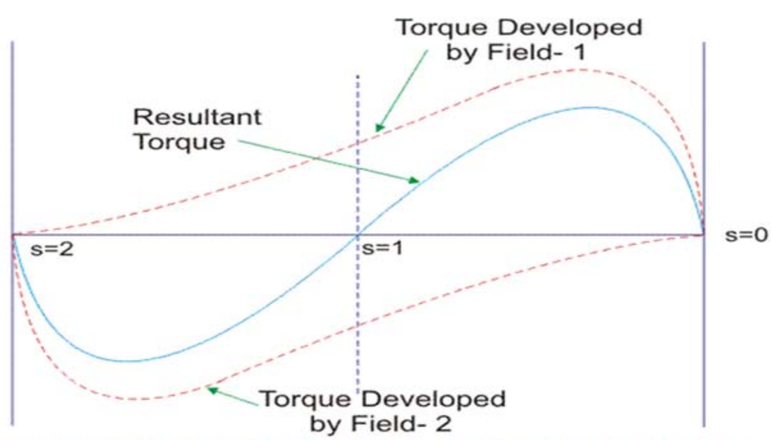
1. **Stator**: It is stationary part of the machine. It is made up of stampings. The stampings are slotted on its periphery to carry the winding called stator winding or min winding.
2. **Rotor:** Rotor is same as squirrel cage rotor. It consist of uninsulated copper or aluminum bars placed in the slots. The copper or aluminum bars are slotted by ring known as end ring.

5.1.3 Operating principle of single phase motor and zero starting torque characteristic

Operation of single phase induction motor

When single phase supply is given to stator winding of single phase induction motor, the alternating current starts flowing through the stator or main winding. This alternating current produces alternating flux called main flux. This main flux also link with the rotor conductors and hence cut the rotor conductor. According to Faraday's law of electromagnetic induction, emf will be induced in the rotor. As rotor circuit is closed ones o, the current starts flowing in the rotor. Then, this rotor current produces it own flux called rotor flux. Now there are two fluxes. These two fluxes produce the desired torque which is required by the motor to rotate.

Torque - slip characteristics of single phase induction motor



Torque Slip Characteristics of Single Phase Induction Motor

Figure: 5.1.3

From the figure 5.1.3, we see that at a slip of unity, both forward and backward field develops equal torque but the direction of which are opposite to each other so the net torque produced is zero hence the motor fails to start. From here we can say that these motors are not self -starting unlike the case of three phase induction motor. There must be some means to provide the starting torque. If by some means, we can increase the forward speed of the machine due to which the forward slip decreases the forward torque will increase and the reverse torque will decrease as a result of which motor will start.

From here we can conclude that for starting of single phase induction motor, there should be a production of difference of torque between the forward and backward field. If the forward field torque is larger than the backward field than the motor rotates in forward or anti clockwise direction. If the torque due to backward field is larger compared to other, then the motor rotates in backward or clockwise direction.

5.2 Method of making Single Phase Induction Motor self-starting

5.2.1 Principle of self – starting of single phase induction motor

The single phase induction motor is not self-starting. To make it self-started, we need to produce a revolving stator magnetic field. This may be achieved by converting a single – phase supply into two phase- supply through the use of an additional winding. As soon as the motor attains sufficient speed, the starting means (which is additional winding) can be removed depending upon the type of motor used. By the help of following methods, single phase induction motor is made self-started:

1) Split phase method
2) Capacitor start and induction run method
3) Capacitor start and run method

5.2.2 Methods of making single phase induction motor self-starting

1. Split Phase Induction Motor

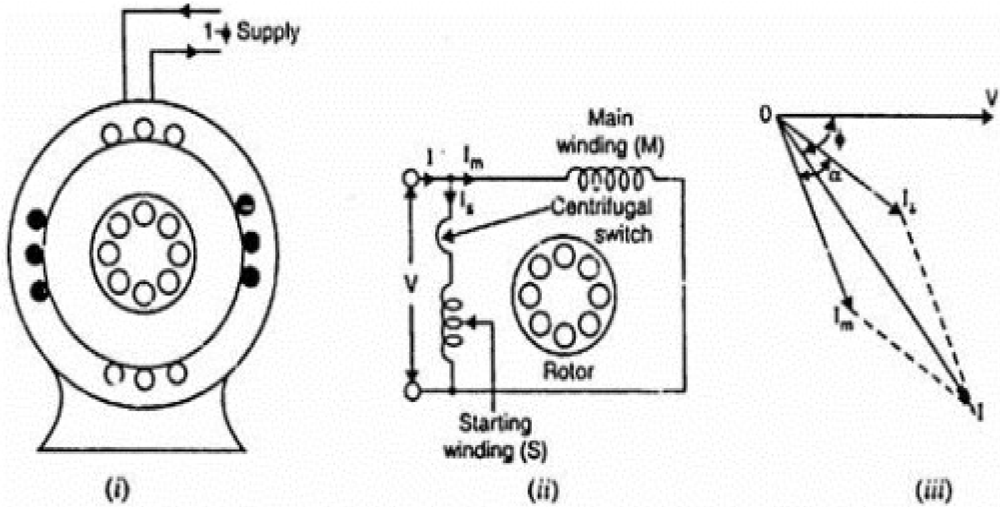


Figure 5.2.2(a) Split phase induction motor

- This motor is started by two phase motor action by using auxiliary or starting winding.
- The stator of split phase induction motor is provided with on auxiliary (main) or starting winding in addition to the main or running winding.
- The starting winding has high resistance and small reactance and in the main winding has low resistance and large reactance.

Operation:

- When single phase supply is given to the stator winding of single phase motor, then main winding carries current I_m and starting winding carries current Is.
- Since main winding is highly inductive and starting winding have highly resistive, the current I_m and Is have a phase difference (20^0 to 30^0). Due to this phase difference, the starting torque will be developed which expression is given below:

$T_s = k\ I_m I_s \sin\prec$ where;

k = constant value whose magnitude depends upon the design of th motor

I_m = current flowing to the main winding

I_s = current flowing to the starting winding

When the motor reaches about 75% of full speed, the centrifugal switch opens and circuit gets opened.

2. Capacitor Start Induction Motor

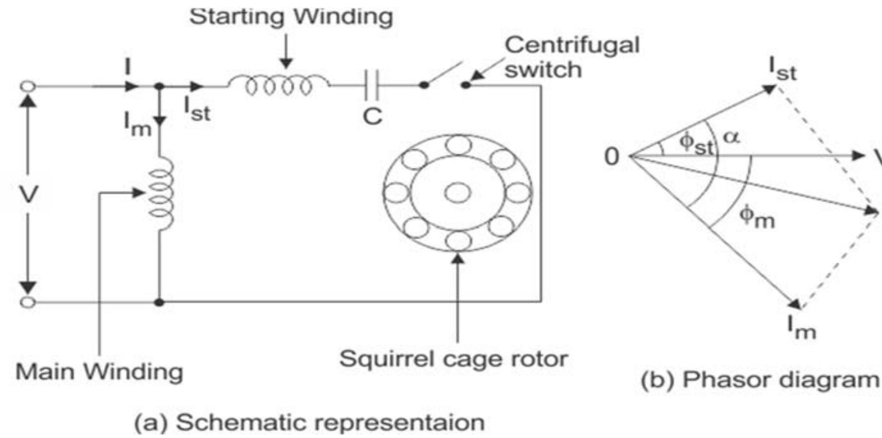


Figure: 5.2.2(b) Capacitor start induction motor

- This motor is same as split phase except that stator winding has many turns as the main winding. A capacitor 'C' is connected in series with the starting winding.
- The main winding has high reactance whereas the starting winding has high resistance
- When the single phase supply is given to the stator. Current "I_m" flows in the main winding and the current "I_s" flows on the starting winding.
- The value of capacitor is so choose that I_s lead I_m by about 80^0.). Due to this phase difference, the starting torque will be developed which expression is given below:

$T_s = k\ I_m I_s \sin \prec$ where;

k = constant value whose magnitude depends upon the design of th motor

I_m = current flowing to the main winding

I_s = current flowing to the starting winding

- The starting winding is opened by the centrifugal switch when the motor attains about 75% of synchronous speed.

3. Capacitor Start Capacitor Run Motor

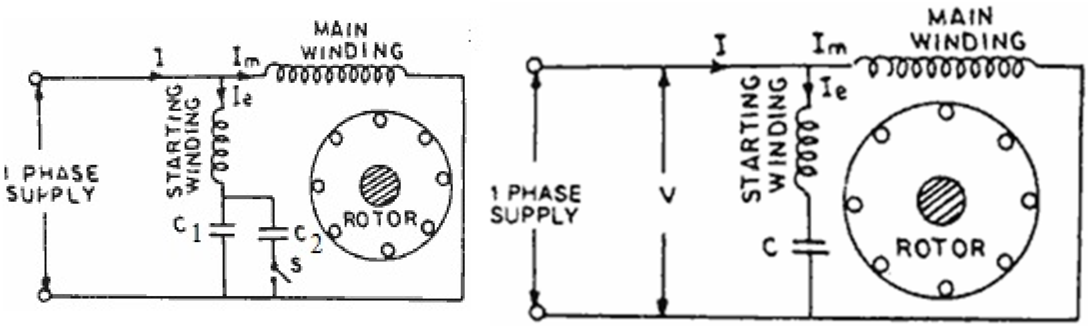


Figure 5.2.2© Capacitor start/capacitor run motor

The stator of this motor contains two winding i.e stating and main winding.

When single phase current "I" is given to the stator "I_s" flows in the starting winding and "I_m" flows in the main winding.

- In this type of starting of motor are described as the two methods.
- In fig 1) Single capacitor C is used for both starting and running. This design eliminates the need of a centrifuged switch and at the same time improves the power, factors and efficiency of motor.
- The capacitor used here produces the required amount of starting torque and also helps in self starting.
- In other design, two capacitors C_1 and C_2 are used in the starting winding. The smaller capacitor C_1 required for optimum running condition is permanently connected in parallel with C_2 for optimum starting required in the circuit during starting. The starting capacitor C_2 is disconnected when the motor approaches about 75% synchronous speed. Due to the presence of C_1 in the circuit, it helps to improve the power factor and the running conditions of the single phase induction motor. This type of motor has high starting torque.

5.3 Shaded Pole Motor

5.3.1 Introduction to shaded pole motor

The shaded pole motor is very popular motor for rating below 40W (nearly .05hp). This type of motor is very simple in construction. Shaded pole motor has salient poles on the stator excited by a single phase supply and a squirrel – cage rotor which is shown in figure 5.3.1

Construction and operation of shaded pole motor

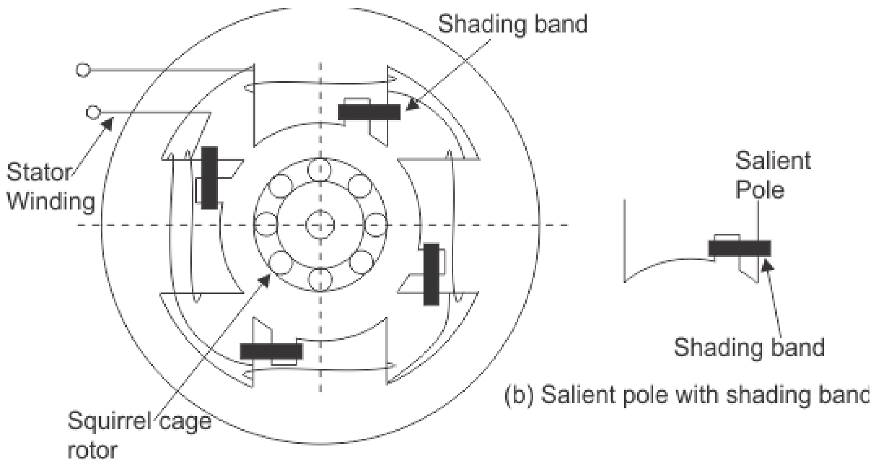


Figure 5.3.1 Shaded pole motor

Construction:

As shown in figure, this motor has both stator and a rotor. It has salient poles which are different from any other poles. Each pole has slot cut nearly one third distance from one edge. Around the smaller part of the pole is placed a short-circuited copper coil known as shading coil. This part of the pole is known as shaded pole and the other is unshaded ploe. The motor is of squirrel cage type.

Working Principle

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.

5.3.2 Advantages of application of shaded pole motor

Advantages:

The following are the advantages of the shaded pole motor:

- Such motors are built in very small size (5-50 kw) and are extremely rugged, reliable and cheap.
- They don't need any commutator, switches, brushes and slip rings etc.
- There is the absence of the centrifugal switch and are simple in construction

Disadvantages:

The followings are the disadvantages of the shaded pole motor:

- Low starting torque
- Very little overload capacity
- Very low efficiency
- Low Power factor

Applications:

The followings are the applications of the shaded pole motor:

- Small fans
- Toys
- Hair driers
- Desk fans

5.4 Single phase series motor and universal motor

5.4.1 Introduction to single phase series motor and universal motor

A universal motor is such a motor which works on both ac and dc supply at almost same speed and output. Since the performance remains same for the supply. Hence, the name universal is therefore given to it.In it, both armature and field winding ae in series. Since the armature current and flux reverse simultaneously, the torque always acts in the same direction regardless of the polarity of the supply.

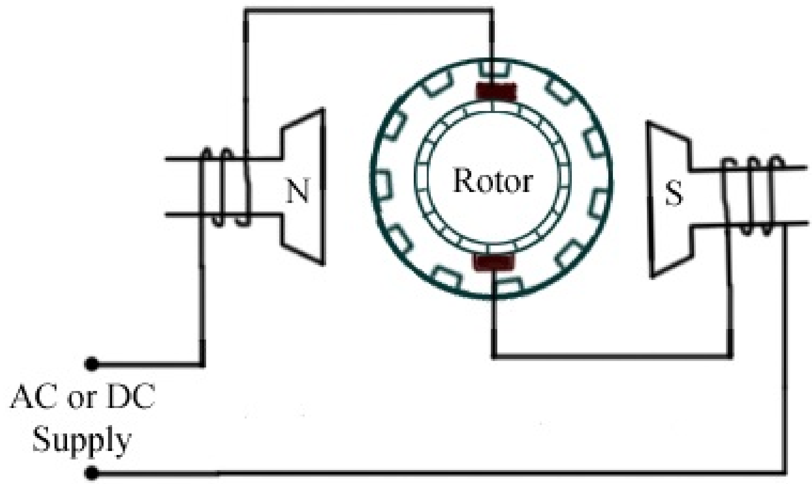


Figure 5.4.1 Universal motor

Operation:

Since field winding and armature winding are connected in series, the same current passes through both when motor is connected to either ac or dc supply. The field winding produces an alternating flux (ϕ) that reacts with current flowing in the armature to produce a torque. The magnetic flux of the series field and armature produces by this current reverses at the same time, the torque always acts in the same direction. Since universal motors are series wound, they have high starting torque and high speed.

It is noted that in this type of motor, no rotating flux is produced and the principle of operation is same as that of d.c series motor.

5.4.2 Advantages and application of single phase series and universal motor

Advantages of universal motor:

1) Universal motor has high starting torque so can run at high speed.
2) It has high weight and compact.
3) Universal motors are easy to control.

Application of universal motor:

1) Vacuum cleaner
2) Projectors

3) Sewing machine
4) Food mixture
5) hair dryer

Teachning tips:

1. Visualization of different types of single phase machine
2. Showing the video of working operation of different types of single phase motor

Reference and Resources:

1. S. Chand, “Principle of Electrical Machine”
2. Jain and Jain, “ ABC of Electrical Engineering”
3. J.B Gupta “Electrical Machines”

LAB MANUAL

EXPERIMENT NO. 1

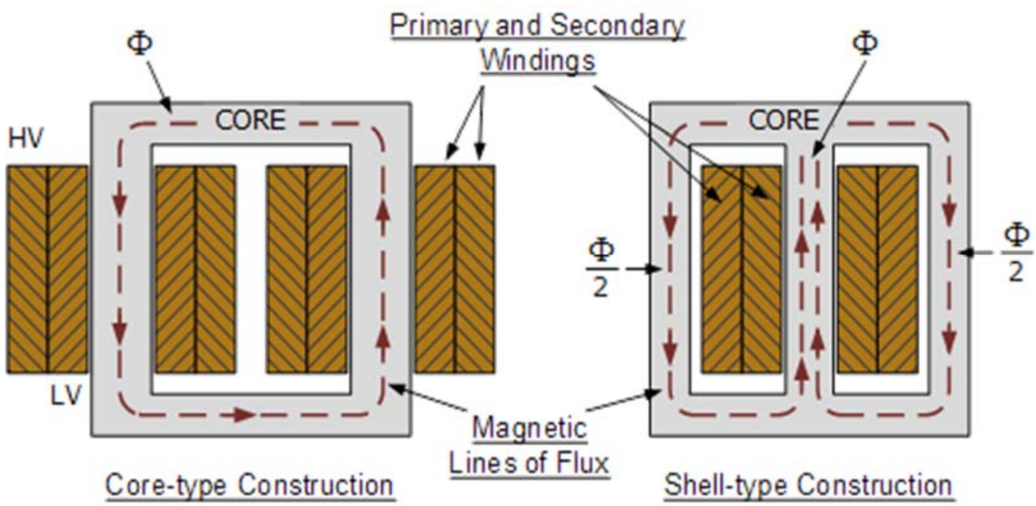
1. Familiarization with different core section and parts of the transformer.

Apparatus required:

Different types of transformer according to the core section, power transformer

Theory:

Transformer Core Construction:



In both types core design, the magnetic flux linking the primary and secondary windings travels entirely within the core with no loss of magnetic flux through air. In the core type transformer construction, one half of each winding is wrapped around each leg(or limb) of the transformers magnetic circuit as shown above.

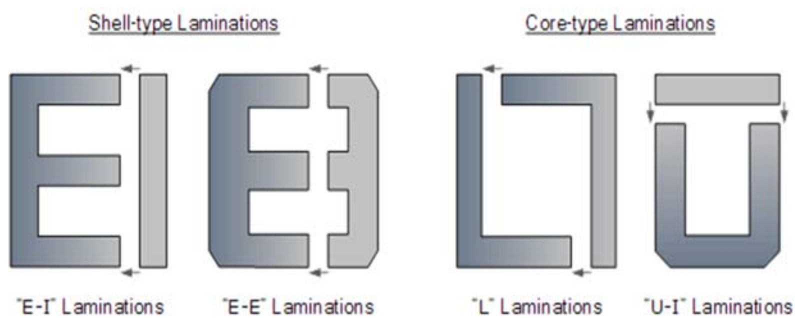
The coils are not arranged with the primary winding on one leg and the secondary on the other but instead half of the primary winding and half of the secondary winding are placed one over the other concentrically on each leg inn order to increase magnetic coupling allowing practically all of the magnetic lines of force go through both the primary and secondary windings at the same time. However, with this type of transformer construction, a small percentage of the magnetic lines of force flow outside of the core and this called “leakage flux.

Shell type transformer cores overcome this leakage flux as both primary and secondary windings are wound on the same center leg or limb which has twice the cross-sectional area of the two outer limbs. The advantage here is that the magnetic flux has two closed magnetic paths to flow around external to the coils on both left and right hand sides before returning back to the central coils

This means that the magnetic flux circulating around the outer limbs of this type of transformer construction is equal to $\frac{\phi}{2}$. As the magnetic flux has a closed path around the coils, this has the advantage of decreasing core losses and increasing overall efficiency.

But you may be wondering as to how the primary and secondary windings are wound around these laminated iron or steel cores for this types of transformer constructions. The coils are firstly wound on a former which has cylindrical, rectangular or oval type cross section to suit the construction of the laminated core. In both the shell and core type transformer constructions, in order to mount the coil windings, the individual laminations are stamped or punched out from larger steel sheets and formed into strips of thin steel resembling the letters “E’s”, “L’s”, “U’s” and “I’s” as shown below

Transformer Core Types:



These lamination stampings when connected altogether form the required core shape. For example two “E” stampings plus two end closing “I” stamping to give an E-I core forming one element of a standard shell-type transformer core. These individual laminations are tightly butted together during the transformers construction to reduce the reluctance of the air gap at the joints producing a highly saturated magnetic flux density.

Transformer core laminations are usually stacked alternately to each other to produce an overlapping joint with more lamination pairs being added to make up the correct core thickness. This alternate stacking of the laminations also gives the transformer the advantage of reduced flux leakage and iron losses. E-I laminated transformer the advantage of reduced flux leakage and iron losses. E-I core laminated transformer construction is mostly used in isolation transformers, step-up and step-down transformers as well as auto transformer.

Similarly, the various parts that we can see on the transformer are as follows:

1. **Transformer tank:** Tanks used for the housing of core and windings and for mounting various accessories required for the operation of transformer.
2. **Conservator tank:** It is small cylindrical tank mounted on the top of the oil transformer and connected to the main tank by a small pipe.
3. **Breather:** It is a device through which all the movement of the air from the transformer takes place.
4. **Buchholz relay:** It is a protective device that give alarm when the oil level is low or any fault occurs when the evolution of gases take place.
5. **Explosion vent:** It is a bent pipe with a glass cover at the end fitted on the top of the transformer tank. It provides protection against excessive pressure build up inside the transformer.
6. **Cooling tube:** They are the bent pipe kept on the outside of the transformer tank which is used to cool the transformer.
7. **Bushing:** It consists the current carrying element in the form of conducting rod and porcelain installed in the hole of the cover of the transformer and employed to isolate the current carry elements. Above 33kv, oil-filled or condenser type bushing are used.
8. **Windings:** In transformer, there are primary and secondary windings. Primary windings are connected to the source whereas secondary windings are connected to the load.

Conclusion:

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EXPERIMENT NO 2

Familiarization and design of simple transformer by winding in a core

Objective:

To fabricate and design a simple transformer.

APPARATUS REQUIRED:

1. Steel
2. Varnish
3. Scissor
4. Copper wire
5. Insulating paper
6. Rivet

THEORY:

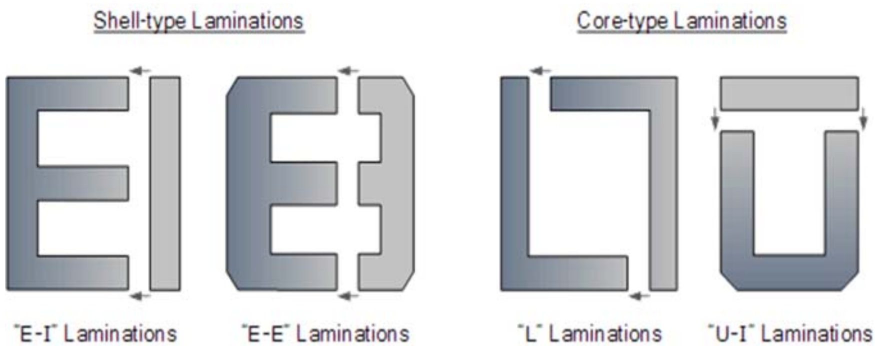
Transformer is an a.c static electrical device as its coil is not movable. It transfers the electrical energy from one circuit to another circuit keeping the frequency on both primary and secondary side. In it, the two circuits are electrically isolated but magnetically linked having the common flux. The energy transfer usually take place with a change of voltage (which is not necessary in all the cases).Generally when the transformer raises the voltage at the secondary side with respect to the primary then such a transformer is called as step-up transformer and if it lowers voltage at the secondary side then it is known as step-down transformer. Transformer is based on the principle of "Faraday's law of electromagnetic induction".

Functions of the transformer:

i. It can raise or lower the voltage and current in A.C circuits.
ii. It can increase or decrease the value of capacitance, inductance or resistance in an a.c circuits thus it can acts as impendence transferring device.
iii. It can isolate two circuits electrically.
iv. It can be used to prevent dc passing from one circuit to another.

PROCEDURE:

1. Take out the metal sheets.
2. For the shell type, cut down the metal plates in the form of “E and I” shape properly.
3. For the core type, cut down the metal plates in the form of “L,U,I”.
4. The samples for both core and shell type is shown below:



- Use the scissors while the metal plates.
- Join the plates to form the proper shape.
- Varnished each and every plate properly.
- Rivet them properly.
- Wound the wires on both sides (primary side and secondary side)
- Count the no. of turns carefully.

CONCLUSION:

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EXPERIMENT NO 3

TURN RATIO AND POLARITY TEST OF A TRANSFORMER

Objective:

To determine turn ratio and polarity test of a transformer

Apparatus Required;

S.No	Description	Range	Type	Quantity
1	Transformer		-	1 no.
2	AC Voltmeter	(0-500 V)	M.C	3 nos.
3	Variac		-	1 no.
4	Connecting leads		--	-

THEORY:

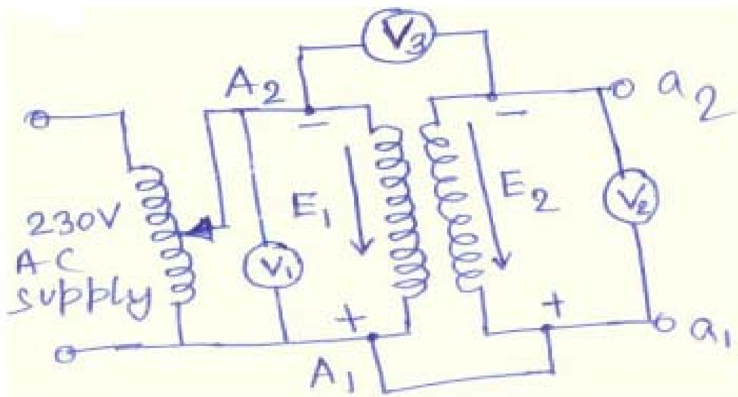
Polarity Test:

On the primary side of a two winding transformer, one terminal is positive with respect to the other one at any instant. At the same instant, one terminal of the secondary winding is positive with respect to the other one. Polarity test is performed to determine the terminals having the same instantaneous polarity. The relative polarities of the primary and secondary terminals at any instant must be known for connecting windings of the same transformer in parallel, or series, or for interconnecting two or more transformers in parallel, or for connecting single phase transformers for poly-phase transformation of voltages. In subtractive polarity, the voltage between A1 and a1 is reduced. The leads connected to these terminals and the two windings are, therefore, not subjected to high voltage stress. On the other hand in additive polarity the two windings and leads connected to A1, A2, a1 and a2 are subjected to high voltage stresses. This is the reason that subtractive polarity is preferred over additive polarity.

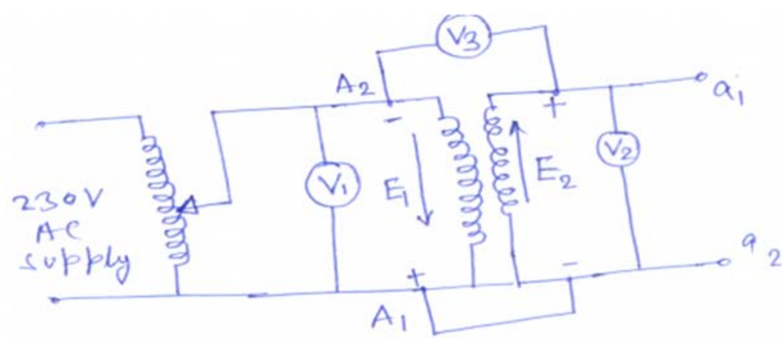
Voltage ratio Test:

The true ratio is based on turn-ratio. If the secondary and primary voltages are measured on no load, their ratio is very nearly equal to the true value. Measurement of primary and secondary currents in short –circuit test also gives fairly accurate result (voltage ratio=$\frac{V_2}{V_1}=\frac{I_1}{I_2}$), especially if the transformer has little leakage flux and low core reluctance.

Circuit diagram:



Subtractive Polarity



Additive Polarity

PROCEDURE:

Polarity Test:

1. As per circuit diagram, terminals A1 and A2 are marked plus and minus arbitrarily.
2. Now terminal A1 is connected to one end of secondary winding and a voltmeter is connected between A2 and other end of secondary winding.
3. A voltage V3 of suitable value is applied to the high voltage winding.

4. Measure E1 and E2 by connecting voltmeters V1 and V2 across two windings.
5. If the voltmeter V3 reading, measured in step 3 , is equal to E1 - E2 , then secondary terminal connected to A1 is +ve and another terminal –ve.
6. If the voltmeter V3 reading is equal to E1 + E2 , then secondary terminal connected to A1 is -ve and another terminal +ve.

PRECAUTION:

1. All connections should be tight.
2. All steps should be followed carefully.
3. Readings and calculation should be taken carefully.
4. Don't touch the live terminals.

OBSERVATION:

Subtractive polarity:

S.No	Reading for V_1	Reading for V_2	Reading for V_3	$V_3=V_2-V_1$

Additive polarity:

S.No	Reading for V_1	Reading for V_2	Reading for V_3	$V_3=V_2+V_1$

Voltage ratio:

Procedure:

1. Connect one voltmeter on the primary and the other on the secondary side, on open circuit.
2. Note down readings of both voltmeters.

Observation:

S.No	Reading for V_1	Reading for V_2	Voltage ratio: $\frac{V_2}{V_1}$

Calculation:

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RESULT AND DISCUSSIONS:

When the voltmeter reads the difference E1-E2 , the transformer is said to possess a subtractive polarity and when the voltmeter reads E1+E2 , the transformer is said to possess a additive polarity. The voltage ratio of a transformer is obtained from the readings of the two voltmeters one on the primary, and the other on the secondary side, on open circuit.

Voltage ratio= $\frac{V_2}{V_1}$

CONCLUSION:

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PRE EXPERIMENT QUESTIONS:

1. Define Transformer.
2. What do you understand by step-up and step-down transformer?
3. What are the properties of ideal transformer?

POST EXPERIMENT QUESTIONS:

1. What is the difference between ideal and practical transformer?
2. What happens when a transformer is connected with DC supply?
3. What is the need for performing polarity test on a transformer?
4. What is the need for performing voltage ratio test on a transformer?
5. How can we increase the value of voltage (required voltage greater than input voltage) by using single transformer?

EXPERIMENT NO: 4

TESTING OF TRANSFORMER FOR NO-LOAD AND LOAD OPERATION

I. FOR LOAD TEST:

OBJECTIVE:

To conduct load test on a single phase transformer

APPARATUS REQUIRED:

S.No.	Apparatus	Range	Type	Quantity
1	Ammeter	(0-10)A (0-5)A	MI MI	- -
2	Voltmeter	(0-150)V (0-300)V	MI MI	- -
3	Wattmeter	(300V,5A) (150V,5A)	Upf Upf	- -
4	Auto-transformer	1f,(0-260)V	-	- -
5	Resistive load	5KW,230V		1
6	Connecting wires	2.5sq.mm	Copper	Few

THOERY:

A transformer is a static device which transfers the electrical energy from one circuit to another circuit without any change in the frequency. The transformer works on the principle of electromagnetic induction between two windings placed on a common magnetic circuit. These two windings are electrically insulated from each other and also from the core. The losses in a transformer are (i) magnetic losses or core losses (ii) ohmic losses or copper losses.

This test is performed to determine the efficiency and regulation of a transformer at different load conditions. Usually, this test is performed for low, power, rating of transformers. This test gives accurate results as compared to the above tests. In this test, measurements are taken on HV side and LV side at different load conditions. W indicates the input power at LV side and W indicates the output power connected on secondary side (HV).

PRECAUTIONS:

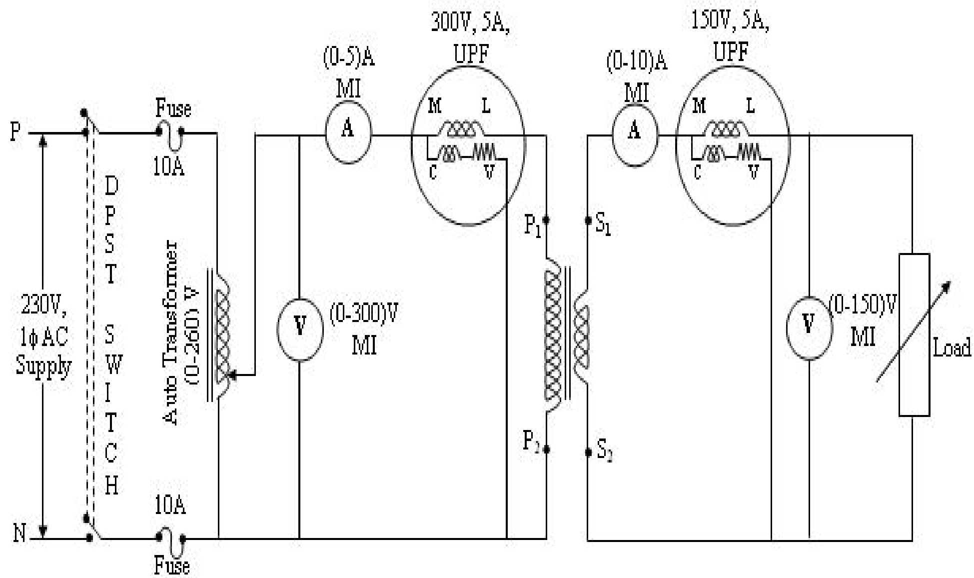
1. The field rheostat of the motor should be in the minimum position at the time of starting and stopping the machine.
2. The field rheostat of the generator should be in the maximum position at the time of starting and stopping the machine.
3. SPST switch should be kept open at the time of starting and stopping the machine

PROCEDURE:

1. Connections are made as per the circuit diagram.

2. After checking the minimum position of the field rheostat of the motor, maximum position of the field rheostat of the generator, opening of SPST switch, DPST switch is closed and starting resistance is gradually removed.
3. The motor is brought to its rated speed by adjusting the field rheostat of the motor.
4. The voltmeter V_1 is made to read zero by adjusting field rheostat of the generator and SPST switch is closed.
5. By adjusting field rheostats of motor and generator, various ammeter readings, voltmeter readings are noted.
6. The rheostats and SPST switch are brought to their original positions and DPST switch is opened.

CIRCUIT DIAGRAM:



FUSE RATING:

125% of rated current

$$\frac{125 \times 5}{100} = 6.25A$$

NAME PLATE DETAILS:

	Primary	Secondary
Rated Voltage :	230V	115V
Rated Current :	5A	10 A
Rated Power :	1KVA	1KVA

Tabular Column:

S.No.	Load	Primary			Secondary			Input Power W_1 x MF	Output Power W_2 x MF
		V_1 (Volts)	I_1 (Amps)	W_1 (Watts)	V_2 (Volts)	I_2 (Amps)	W_2 (Watts)		

FORMULAE:

Output power = W_2 x Multiplication factor

Input power = W_1 x Multiplication factor

CONCLUSION:

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VIVA QUESTIONS:

1. List the application of Transformer and types.
2. What is the function of Buchholz's Relay in transformer?
3. What do you understand by regulation of a transformer?
4. What are the other methods of testing transformers?
5. What is the disadvantage of testing a transformer using load test?
6. Is a high or low value of regulation preferred for a transformer? Give reasons.
7. What are the reasons for the drop in terminal voltage as the secondary current is increased?

II. FOR NO LOAD TEST:

OBJECTIVE:

To conduct no-load test on a single phase transformer

APPARATUS REQUIRED:

S.No.	Apparatus	Range	Type	Quantity
1	Ammeter	(0-2)A (0-5)A	MI MI	1 1
2	Voltmeter	(0-150)V	MI	2
3	Wattmeter	(150V,5A) (150V,5A)	LPF UPF	1 1
4	Connecting wires	2.5sq.mm	Copper	few

THEORY:

A transformer is a static device which transfers the electrical energy from one circuit to another circuit without any change in the frequency. The transformer works on the principle of electromagnetic induction between two windings placed on a common magnetic circuit. These two windings are electrically insulated from each other and also from the core. The losses in a transformer are (i) magnetic losses or core losses (ii) ohmic losses or copper losses.

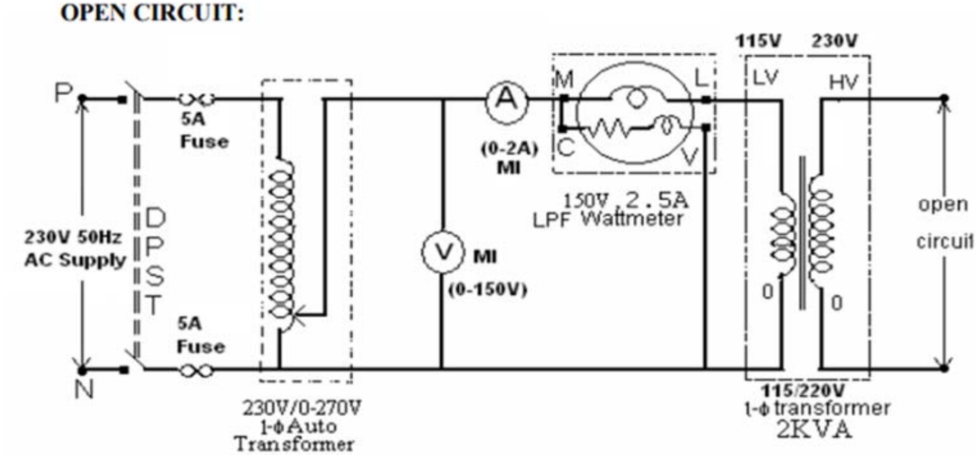
In this test the high voltage side of the transformer is left open. Primary side is connected across the normal rated voltage. Normal flux is hence set up in the core and the transformer has only iron loss and no copper loss as under no load current is negligible. Hence, power consumed during open circuit is only for feeding iron loss or core loss and it remains constant irrespective of load conditions. The voltmeter, ammeter and watt meter readings are noted down and the current I_u and I_w are calculated.

PROCEDURE:

1. Connections are made as per the circuit diagram.
2. Ensure that variac is set to zero output voltage position before starting the experiment.
3. Switch ON the supply. Now apply the rated voltage to the Primary winding by using Variac.
4. The readings of the Voltmeter, ammeter and wattmeter are noted down in Tabular form.
5. Then Variac is set to zero output position and switch OFF the supply.
6. Calculate Ro and Xo from the readings.

CIRCUIT DIAGRAM:

OPEN CIRCUIT:



MODEL CALCULATIONS:

Find the equivalent circuit parameters R0, X0, R01, R02, X01 and X02 from the O. C. test results and draw the equivalent circuit referred to L. V. side as well as H. V. side.

Let the transformer be the step-down transformer

Primary is H. V. side.

Secondary is L. V. side

$X_0 = \frac{V_1}{I_m}$ where $I_m = I_0 \sin\phi_0$

$R_0 = \frac{V_1}{I_w}$ where $I_w = I_0 \cos\phi_0$

TABULAR COLUMN:

V_0 (Volts)	I_0 (Amps)	W_0 (Watts)	R_0	X_0	$\cos\phi_0$

PRECAUTIONS:

I. Connections must be made tight

ii. Before making or breaking the circuit, supply must be switched off

CONCLUSION:

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VIVA QUESTIONS:

1. How are the meter ratings selected for no-load test?
2. Why is the no-load test conducted on the l.v side of the transformer?
3. What are the losses measured in an open-circuit test?
4. Write the emf equation of transformer.
5. What are two components of transformer no load current?
6. Draw no load phase diagram for the transformer.

EXPERIMENT NO: 5

FAMILIARIZATION WITH DIFFERENT PARTS OF DC MACHINE AND RUN IT AS MOTOR AND GENERATOR

Apparatus required:

DC machines

Theory:

Dc machines are the rotating electrical machines which can be used as either motors or generators. Dc machine is a device which converts mechanical energy into electrical energy and vice-versa. When the device acts as a generator (or dynamo), mechanical energy is converted into electrical energy. On the other hand, when the device acts as the motor, the electrical energy is converted into mechanical energy. The process of the interconversion is reversible. However, during the conversion process, a part of energy is transformed into heat, which is lost, and can't be reversible. therefore, this type of machine can work either as" motor" or "generator". Almost, generator and the motor are very much similar to each other in essential parts and construction. But slight modification is done for their operation.

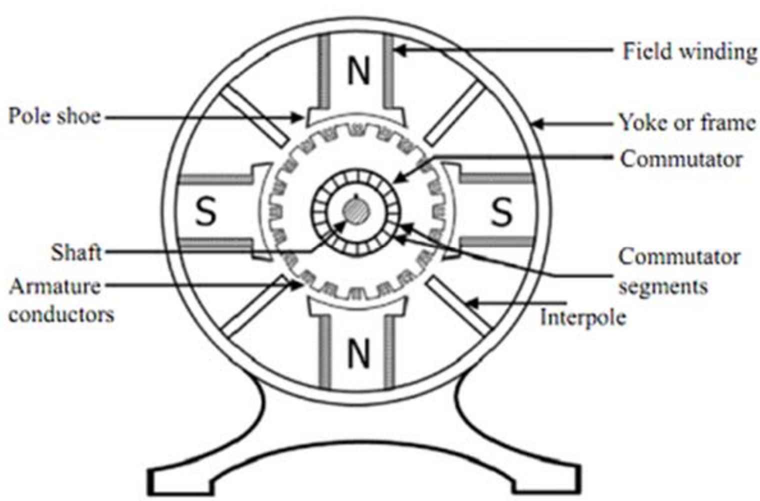

Figure: dc machine

The different parts of dc machines are as follows:

Yoke

It is the outermost frame of the machine. It provides mechanical support for the field pole and acts a protecting cover for the whole machine and also carries the magnetic flux produced by the field poles. In small machines, cast iron yokes are used, because of cheapness but yoke of large machine is invariably made of fabricated steel due to its high permeability.

i. Field poles

They are the iron core projected from yoke. The upper part of the pole, which is connected to the yoke, is known as pole -core. The lower and wider part is known as pole-shoe. The field poles are generally made from the laminated annealed steel sheet. The field poles are usually formed of laminations (thin sheet of steel) and are bolted to the frame or yoke to which are also fastened the end bells with their bearings and the brush rigging. The pole shoe serves two purposes:

- It spreads out the magnetic flux in the air gap and also being larger cross section reduces the reluctance of the magnetic path.
- It supports the field winding.

ii. Field winding

It is the copper wire or strip wound on the field pole. The windings are insulated from the pole core and each turns of windings are also insulated from each other to protect from turn to turn short circuit. When DC current is passed through these coils, they will magnetize the pole core and produce magnetic field in the central space of the machine.

iii. Armature

It is rotating part of the machine and is built up in a cylindrical or drum shape. The various parts of an armature are shaft, armature core, commutator and armature winding. The bearing holds the shaft on the central empty space of the machine in such way that there is a small air gap few mm between armature and the pole- shoes the armature core is made from laminated silicon steel sheet insulated with varnish. The purpose of armature is to rotate the conductors in the uniform magnetic field. It consists of coils of insulated wires wound around an iron and so arranged that electric currents are induced in these wires when the armature is rotated in a magnetic field. In addition, its most important function is to provide a path of very low reluctance to the magnetic flux. The armature core is made from high permeability silicon-steel stampings, each stamping, being separated from its neighboring one by thin paper or thin coating of varnish as insulation.

iv. Commutator

The commutator is a form of rotating switch placed between the armature and the external circuit and so arranged that it will reverse the connections to the external circuit at the instant of each reversal of current in the armature coil. It is made of number of copper segments insulated from each other and from the shaft. It is very important part of a dc machine and serves the following purposes:

1. It provides the electrical connections between the rotating armature coils and the stationary external circuit.
2. As the armature rotates, it performs a switching action reversing the electrical connections between the external circuit and each armature coil in turn so that the armature coil voltages add together and result in a dc output voltage.
3. It also keeps the rotor or armature mmf stationary in space.

v. Armature winding

Armature winding is an arrangement of conductors to develop desired emfs by relative motion in a magnetic field. In winding, conductor or group of conductors are distributed in different ways in slots all over the periphery of the armature. The conductors may be connected in series and parallel combinations depending upon the current and voltage rating of the machine. It is the enamel insulated copper wire wound on the slots of the armature core.

DC machine as generator:

An electric generator is based on the principle that whenever flux is cut by a conductor, an emf is induced which will cause the current to flow if the conductor circuit is closed.

The direction of induced emf (and hence current) is given by "Fleming's right hand rule"

When the armature of the dc generator is rotated with the help of prime mover (external force) and the field windings are excited then from the Faraday's law of electromagnetic induction, emf is induced in the armature conductors. This induced emf is taken out from the commutator and carbon brush arrangement.

DC machine as motor:

The operation of dc motor 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;

$F = BIL$ Newtons

When the dc source is applied to the carbon brush of the dc motor, the current flows through the positive brush, commutator, armature winding and finally goes out through the negative brush. The current flows through the field winding represents magnetic field while current flowing through the conductor of the armature winding represents mechanical force.

Conclusion:

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EXPERIMENT NO: 6

Assembling the dc starter and test it

Apparatus required:

1) DC motor
2) Starter
3) Ammeter

Theory:

Basically, a dc motor starter is a variable resistance connected in series with armature circuit at starting.

t starting; speed (N) = 0

We know,

$$E_b = \frac{Z\phi N}{60}\frac{P}{A}$$

So, $E_b = 0$

Also;

$$I = \frac{V - Eb}{Ra}$$

$$= \frac{V}{Ra} \uparrow$$

If motor is started directly, it will draw high current at starting for few seconds. Starting current could be 20 times greater than normal load current. It may produce sparking in the carbon brush and hence fuse may block out.

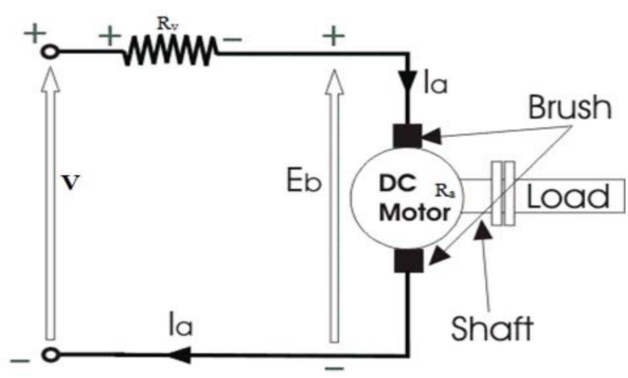
Therefore, we use control mechanism to reduce the magnetic of starting current i.e dc motor starter.

At starting;

When R_v is used

$$I_a = \frac{V - Eb}{Rv + Ra}$$

Thus, it is cleared that by using the dc motor stator initially high flowing of current in the motor is controlled thus prevent the machine from getting damaged.



PROCEDURE:

i. Connect the ammeter in series to the motor.
ii. Run the motor and note down the current through ammeter without connecting starter at first.
iii. Connect the ammeter in series to the variable resistor.
iv. Run the motor and note down the current after the connection of starter.
v. Compare the amount of current flowing through the motor with and without using the starter**.**

Measurement table:

S.N	Armature current (I_a) (without starter)	Armature current (I_a) (with starter)

CONCLUSION:

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Viva Questions:

1) What is starter?
2) What is the role of starter in the dc motor?
3) What happen when the motor is started without using the starter?

EXPERIMENT NO: 8

SPEED CONTROL OF DC SHUNT MOTOR BY ARMATURE CONTROL AND FLUX CONTROL METHOD

OBJECTIVE:

To control the speed of DC shunt motor by

a. Varying armature voltage with field current constant.
b. Varying field current with armature voltage constant

APPARATUS REQUIRED:

S.No	Apparatus	Range	Type	Quantity
1	Ammeter	(0-20)A	MC	1
2	Voltmeter	(0-300)V	MC	1
3	Rheostats	1250Ω,0.8A 50 Ω,3.5 A	Wire Wound	Each 1
4	Tachometer	(0-3000) rpm	Digital	1
5	Connecting wires	2.5 sq.mm	Copper	Few

THEORY:

Dc machines are the rotating electrical machines which can be used as either motors or generators. Dc machine is a device which converts mechanical energy into electrical energy and vice-versa. Any d.c motor can be made to have smooth and effective control of speed over a wide range. The shunt motor ruins at a speed defined by the expression which is shown below:

$$E_b = \frac{\phi ZNPA}{60A} \quad \text{and } E_b = V - I_a R_a$$

$$\text{i.e } N = \frac{V - I_a R_a}{K\phi} \quad \text{where } k = \frac{ZP}{60A}$$

Since, $I_a R_a$ drop is negligible ; $N \alpha V$

$$N \; \alpha \; \frac{1}{\phi}$$

$$\text{Or, } N \; \alpha \; \frac{1}{I_f}$$

Where,

N is the speed

V is the applied voltage

I_a is the armature current

R_a is the armature resistance

ϕ is the field flux

PRECAUTIONS:

1. Field Rheostat should be kept in the minimum resistance position at the time of starting and stopping the motor.
2. Armature Rheostat should be kept in the maximum resistance position at the time of starting and stopping the motor.

PROCEDURE:

1. Connections are made as per the circuit diagram.
2. After checking the maximum position of armature rheostat and minimum position of field rheostat, DPST switch is closed

(i) Armature Control:

3. Field current is fixed to various values and for each fixed value, by varying the armature rheostat, speed is noted for various voltages across the armature.

(ii) Field Control:

4. Armature voltage is fixed to various values and for each fixed value, by adjusting the field rheostat, speed is noted for various field currents.
5. Bringing field rheostat to minimum position and armature rheostat to maximum position DPST switch is opened

TABULAR COLUMN:

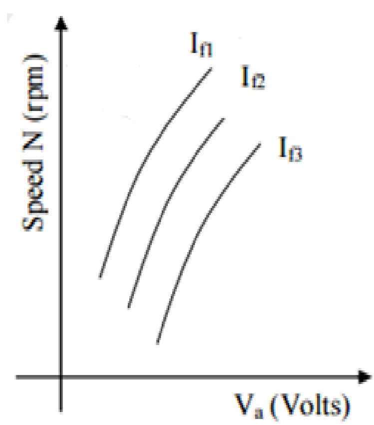
i. Armature voltage control:

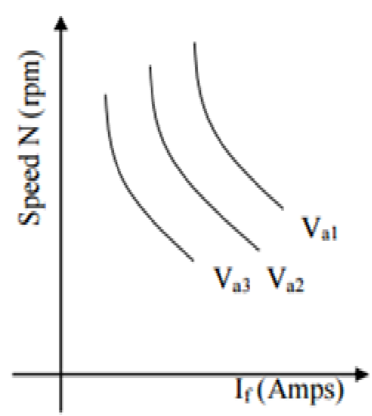
S.N0	I_{F1}=		I_{f2}=		I_{f3}=	
	Armature voltage V_a(Volts)	Speed N(rpm)	Armature voltage V_a(Volts)	Speed N(rpm)	Armature voltage V_a(Volts)	Speed N(rpm)

ii. Field control:

S.No	V_{a1}=		V_{a2}=		V_{a3}=	
	Field current I_f(A)	Speed N(rpm)	Field current I_f(A)	Speed N(rpm)	Field current I_f(A)	Speed N(rpm)

MODEL GRAPH:





CONCLUSION:

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VIVA QUESTIONS

1. Give the relation of speed with respect to emf and flux.
2. List the disadvantages of these methods.

EXPERIMENT NO: 9

SPEED CONTROL OF DC SERIES MOTOR BY ARMATURE CONTROL AND FLUX CONTROL METHOD

OBJECTIVE:

To control the speed of DC series motor by

1) armature divert method
2) field divert method

APPARATUS REQUIRED:

S.No	Apparatus	Range	Type	Quantity
1	Ammeter	(0-20)A	MC	1
2	Voltmeter	(0-300)V	MC	1
3	Rheostats	1250Ω,0.8A 50 Ω,3.5 A	Wire Wound	Each 1
4	Tachometer	(0-3000) rpm	Digital	1
5	Connecting wires	2.5 sq.mm	Copper	Few

THEORY:

Dc machines are the rotating electrical machines which can be used as either motors or generators. Dc machine is a device which converts mechanical energy into electrical energy and vice-versa. Any d.c motor can be made to have smooth and effective control of speed over a wide range.

We know;

$$E_b = \frac{\phi ZNPA}{60A} \text{ and } E_b = V - I_a R_a$$

$$\text{i.e } N = \frac{V - I_a R_a}{K\phi} \text{ where } k = \frac{ZP}{60A}$$

Since, $I_a R_a$ drop is negligible ; $N \alpha V$

$$N \alpha \frac{1}{\phi}$$

$$\text{Or, } N \alpha \frac{1}{I_f}$$

Where,

N is the speed
V is the applied voltage
I_a is the armature current
R_a is the armature resistance
ϕ is the field flux

a. Armature diverter method:

n this method, a variable resistance (R_v) is connected in parallel to the armature winding as shown in figure below. Due to this variable resistance (R_v), some of the armature current will get diverted and pass through diverter (Rv). For a constant load torque, if the armature current Ia is reduced due to diverter (Rv), then flux per pole must increase to produce constant torque ($\because T \prec \phi$ Ia). This results in an increase in main line current taken from the supply and a fall in speed ($\because N \prec \frac{1}{\phi}$). The variation speed can be controlled by varying the value of diverter resistance RV. This method is only suitable for controlling the speed below the normal rated speed.

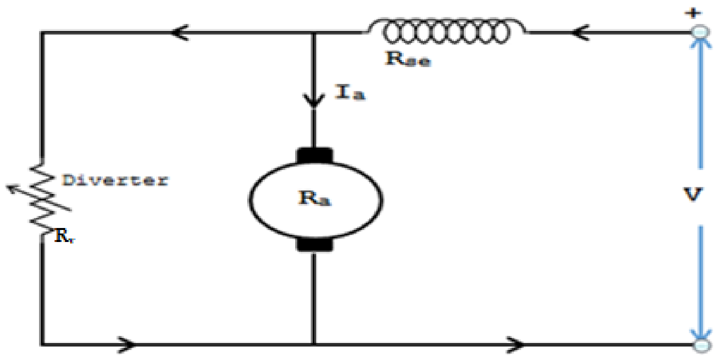

Figure 2.8 (d) : Armature diverter method

b. Field diverter method:

In this method, a variable resistance (R_v) is connected in parallel to the series field winding as shown in figure below. Any desired amount of current can be passed through the field winding by adjusting the value of diverter (R_v). Hence, flux can be decreased. Since, the speed is inversely proportional to the flux, the speed can be increased. This method gives speed above the normal value because flux is reduced by this method.

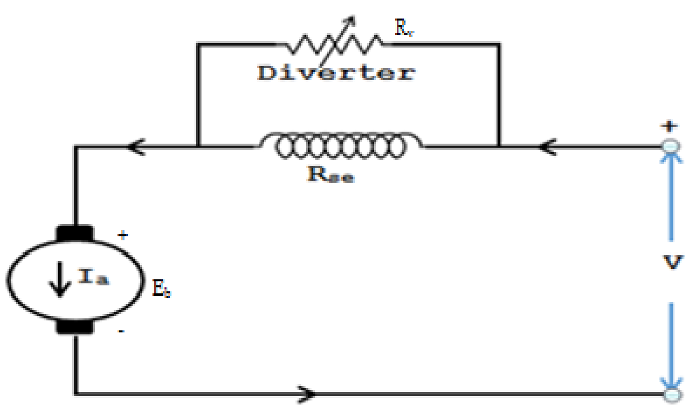

Figure Field diverter method

PRECAUTIONS:

1. Field Rheostat should be kept in the minimum resistance position at the time of starting and stopping the motor.

2. Armature Rheostat should be kept in the maximum resistance position at the time of starting and stopping the motor.

PROCEDURE:

1. Connections are made as per the circuit diagram.
2. After checking the maximum position of armature rheostat and minimum position of field rheostat, DPST switch is closed

MEASURMENT TABLE:

a. Armature divert

S.N	Armature Current I_a(Amp)	Speed N(rpm)

Field divert:

S.N	Field current I_f(A)	Speed N(rpm)

CONCLUSION:

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EXPERIMENT NO: 10

FAMILIARIZATION WITH DIFFERENT PARTS OF THREE PHASE INDUCTION MOTOR AND RUN IT AS MOTOR

Apparatus required:

Three phase induction machine

Diagram:

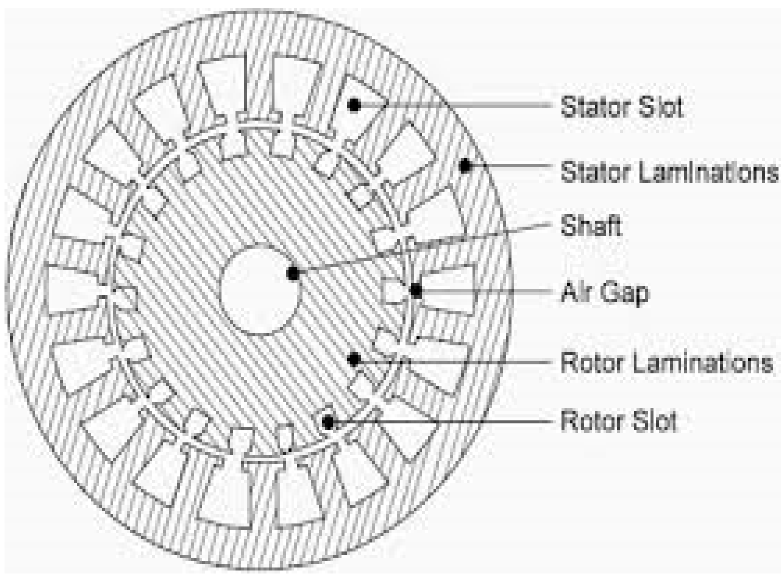


Figure: cross-sectional diagram of 3 phase induction machine

Theory:

Three phase Induction motors are the most widely used electric motor in the industry.

Normally, they run at constant speed from no load to full load. The speed is frequency dependent. The speed control of three phase induction machine is difficult. These motors are simple, low price, easy to maintain. Generally, three phase induction motors are self-started.

Regarding the construction, it is very simple. The essential features of induction motor are: laminated stator core carrying a polyphase winding, a laminate rotor core carrying either a cage or polyphase winding, the latter with mounted slip rings, a stiff shaft to preserve the very short air gap.

There are mainly 3 parts of induction machine:

a. Stator
b. Rotor
c. Yoke

a. Stator

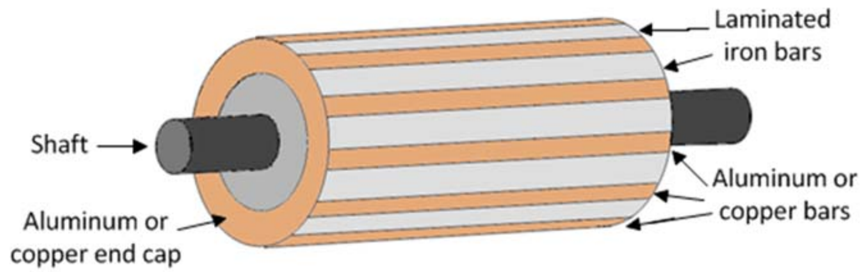
It is stationary part of the machine. It has hollow space in its center. The inner circumference of the stator core has alternate number of slots and teeth on which stator winding are placed. Generally, 3 phase windings are provided on these slots which are uniformly distributed and spaced 120^0 electrically apart. Stator core is protected by the outer covering called yoke made of cast iron. The stator core is to carry the alternating flux which produces hysteresis and eddy current losses. In order to reduce eddy currents and hysteresis loss in the stator core it is assembled of high grade, low0 electrical loss, and silicon steel punching. The thickness of punching varies from 0.35mm to 0.65mm. In smaller sizes, the stator plated form complete annular rings but for the larger machines they are prepared of segmental laminations to avoid wastage of steel.

b.Rotor

The rotor comprises a cylindrical laminated iron core/ with slots around the core, carrying the rotor conductors. In general, the same sheet steel laminations are employed for the rotor core as for the stator, but owing to the lower frequencies of the rotor flux, thicker laminations can be employed without excessive iron loss. It is rotating part of motor. It is cylindrical in shape with central shaft. The shaft is supported by bearing at both ends so that rotor rotates freely keeping an air gap of about 1mm to 4mm between rotor and stator. It is made of laminated silicon steel. There are two types of rotor. There are two types of rotor:

i. squirrel cage rotor
ii. phase wound rotor(slip ring rotor)

i. Squirrel cage rotor



Induction Motor Squirrel Cage Rotor

Squirrel cage rotor is made of laminated cylindrical core with parallel slots. These parallel slots carry rotor conductor. A squirrel cage rotor is the rotating part used in most common form of A.C induction motor. It consists of a cylinder of steel with aluminum or copper conductors embedded in its surface. Almost 90 percent of induction motors are provided with squirrel cage rotor because of its very simple, robust and almost instructible construction. In large motors the rotor bars, instead of being cast, are wedged into the rotor slots and are then welded securely to the end rings.

ii. Wound rotor

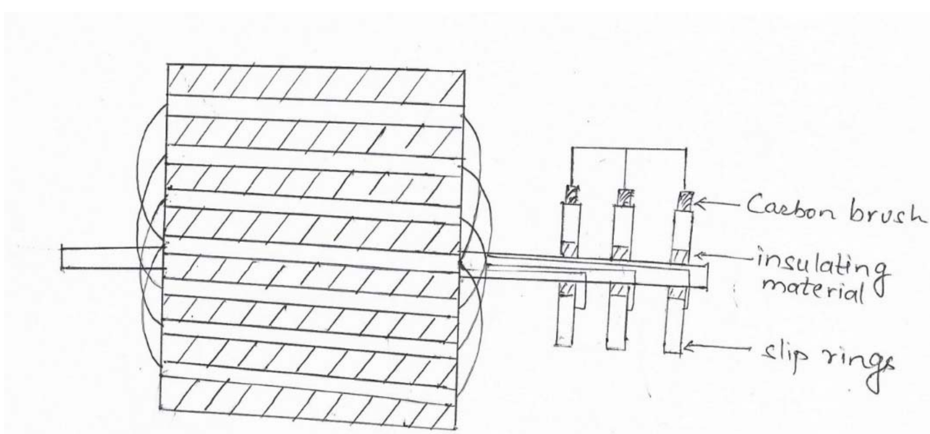


Figure: wound type rotor

This type of rotor is also made of cylindrical laminated core. It has open slots along the outer circumference. Three ends of rotor winding are connected to three separated slip-rings and the slip rings are short circuited by the carbon brush. As the name implies, such a rotor is wound with an insulated windings similar to that of the stator except that the number of slots is smaller and fewer turns per phase of a heavier conductor are used. Since the connection of the wound secondary to the external terminals is made through slip rings and brushes, so wound secondary motors are often called slip-ring induction motors.

c. Yoke

It is the outermost frame of the machine. It covers the stator core and provides mechanical protection for the whole machine. The outer surface of the yoke has much number of fins to provide more contact area thus by giving effective way of cooling the machine.

Three phase Induction machine as motor:

When three phase supply is given to three phase stator winding, rotating magnetic field is develop on it. This field is passed through the air gap and cut the rotor conductor which is stationary. Due to relative speed between moving rotating magnetic field and stationary rotor, emf is develop in the rotor. Since the rotor conductor is short circuited the current flows through it. When it is placed in magnetic field, the rotor conductor experience force. Due to the combination of this force torque is developed which then rotates the rotor. Direction of motion of rotor and rotating magnetic field will be same.

Conclusion:

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EXPERIMENT NO: 11

ASSEMBLING THE AUTO-TRASNFORMER STARTER AND TEST IT

APPARTUS REQUIRED:

1) Three phase induction motor
2) Voltmeter
3) Tachometer
4) Auto-transformer starter

THEORY:

In auto-transformer method, there are three auto-transformers connected in star with double switch and three or four tapings as shown in figure below. When the switch is in “OFF” position high voltage will developed across the winding. When the switch is in “ON” position, a reduced voltage is applied across the stator winding. When the motor runs up-to 80% of its normal speed the connections are changed so that full voltage appears across the stator winding without auto-transformer.

This method is used for the large cage motors of output rating exceeding 20 KW.

PROCEDURE:

1) Measure the speed of the motor at first with the help of tachometer
2) Connect the auto-transformer starter.
3) Again, measure the speed of the motor after connecting auto-transformer

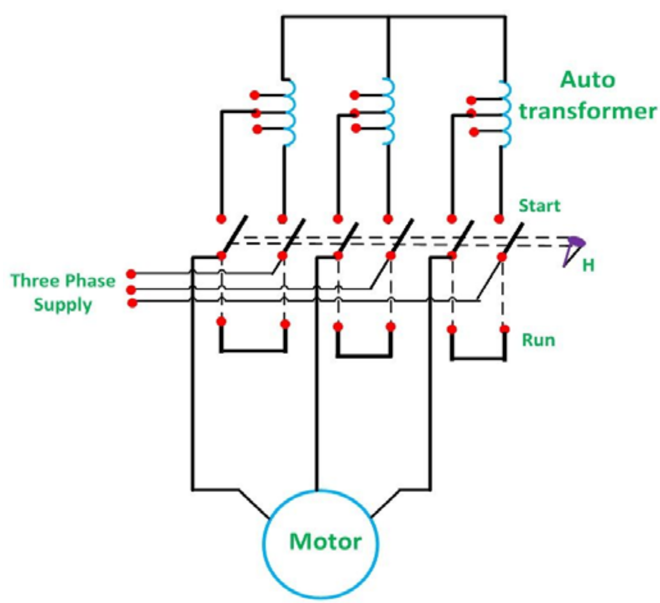

Figure: Auto-transformer

MEASUREMENT TABLE:

S.N	Speed in the absence of auto-transformer	Speed in the presence of auto-transformer

CONCLUSION:

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Viva question:

1) What is the importance of using auto-transformer starter in three phase induction motor?

EXPERIMENT NO: 12

ASSEMBLING THE STAR-DELTA STARTER AND TEST IT

APPARTUS REQUIRED:

2) Three phase induction motor
3) Voltmeter
4) Tachometer
5) Star-delta starter

THEORY:

This method uses a two way switch which connects the stator winding in "Star" for starting period and then in "Delta" for normal running period. Star-delta starter is a switch which is connected across the starter winding. During the starting time, the handle of the starter is moved from OFF to the STAR position, when windings get connected in star so that the applied voltage across the winding is reduced to $\frac{1}{\sqrt{3}}$ times the line voltage. Similarly, when the motor accelerates and gains speed, the handle of the switch is quickly thrown over to DELTA position, so that the voltage become equal to the line voltage and hence full-line voltage is supplied to the windings. Then, the motor runs at the normal speed. The connection is shown in figure below. This method is normally used for the motors of rating between 4 and 20KW.

If the motor is started with delta connection

$(I_d) = \frac{V}{Z}$

If the motor is started with star connection:

$$(I_s) = \frac{\frac{V}{\sqrt{3}}}{Z}$$

$$= \frac{V}{\sqrt{3}Z}$$

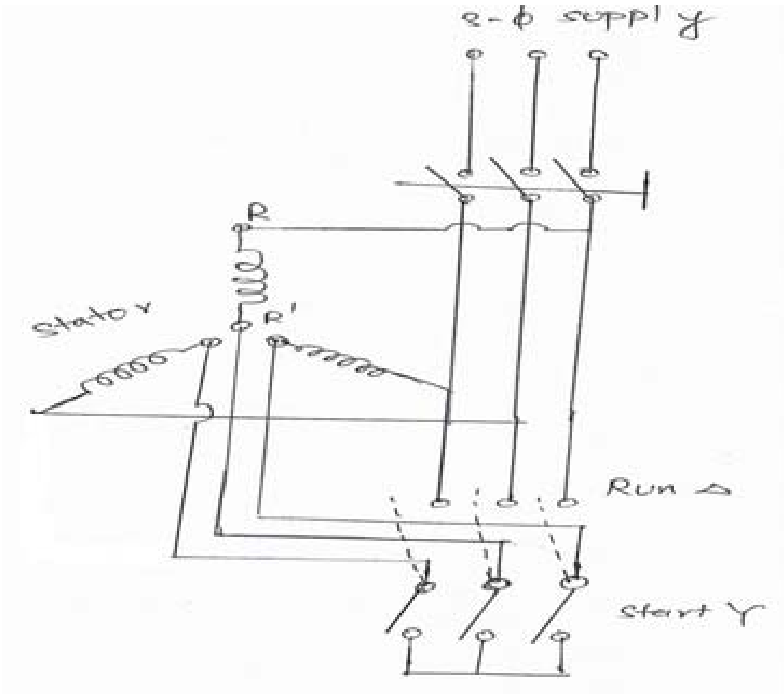

Figure: Star-delta

PROCEDURE:

1) Measure the speed of the motor at first with the help of tachometer.
2) Connect the star-delta starter.
3) Again, measure the speed of the motor after connecting auto-transformer

MEASUREMENT TABLE:

S.N	Speed in the absence of auto-transformer	Speed in the presence of auto-transformer

CONCLUSION:

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Viva question:

What is the importance of using star-delta starter in three phase induction motor?

EXPERIMENT NO: 13

SPEED CONTROL OF THREE PHASE (SLIP RING) INDUCTION MOTOR BY ROTOR RHEOSTAT METHOD

OBJECTIVE:

To Control the speed control of 3 phase slip ring induction motor by rotor resistance control.

APPARATUS REQUIRED

S.No	Name of apparatus	Type	Range	Quantity
1	Ammeter	MI	(0-10A)	1
2	Voltmeter	MI	(0-600V)	1
3	Rotor resistance starter	-	-	1
4	Auto transformer	3Phase	415/(0-470)V	1
5	Tachometer	Digital	-	1
6	Wattmeter	LPF	600V,10A	2
7	Connecting leads	-	-	Required

THEORY:

Rotor Rheostat Control:

In this method, which is applicable to slip ring induction motors alone, the motor speed is reduced by introducing an external resistance in the rotor circuit. For this purpose, the rotor starter may be used provided it is continuously rated. This method is in fact similar to the armature rheostat control method of d.c shunt motors.

NAME PLATE DETAILS:

3Φ Induction motor

Rated Voltage :

Rated Current :

Rated Speed :

Rated Power :

Rated Frequency

PRECAUTION:

The motor input current should not exceed its rated value.

PROCEDURE:

1) Connections are given as per the circuit diagram.
2) Keep the rotor resistance stator output as zero voltage & the external rotor resistance at Minimum resistance position.
3) Switch ON the supply & increase the input voltage to stator winding up to its rated value.
4) Measure the speed.
5) Now increase the rotor resistance in steps & note the corresponding values of speed.
6) Draw a graph of rotor resistance versus speed.

TABULAR COLUMN:

S.No	EXTERNAL ROTOR TESISTANCE IN OHMS	SPEED (RPM)

CIRCUIT DIAGRAM

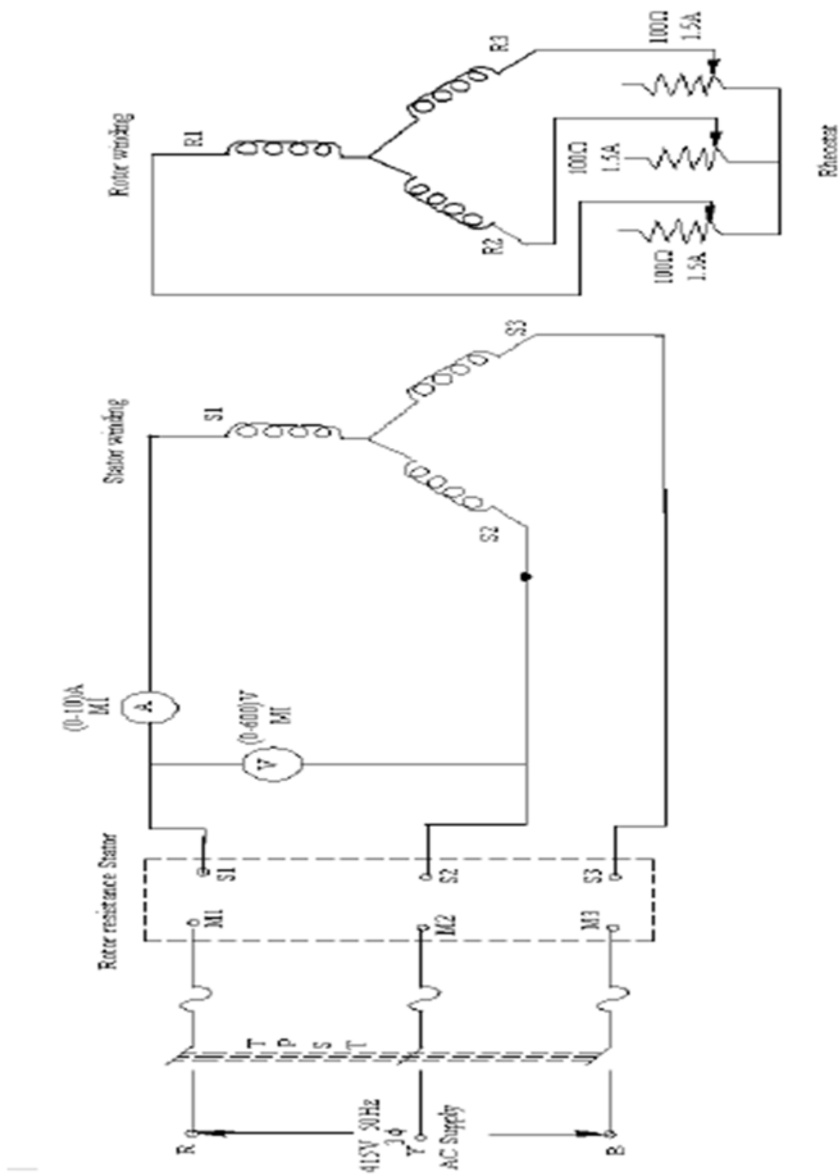

Figure Draw a graph of rotor external resistance versus speed.

CONCLUSION:

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EXPERIMENT NO: 14

SPEED CONTROL OF THREE PHASE INDUCTION MOTOR BY STATOR VOLTAGE CONTROL METHOD

APPARATUS REQUIRED:

1) Ammeter
2) Voltmeter
3) Tachometer
4) Varaic
5) Connecting leads

THEORY:

Stator voltage control method:

Since the speed of the motor is directly proportional to the magnitude of applied voltage, it can be increased or decreased by increasing or decreasing the magnitude of applied voltage. This method is cheaper and simple but rarely used because large change in voltage causes small change in speed. A large change in voltage will result large change in flux density, thereby seriously disturbing the magnetic condition of motor.

PROCEDURE:

1) Measure the speed of the motor at the beginning.
2) Connect the varaic across the supply.
3) Measure the speed of the motor on different applied voltage.

MEASUREMENT TABLE:

S.N	VARIABLE VOLTAGE	SPEED

CONCLUSION:

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EXPERIMENT NO: 15

FAMILIARIZATION OF DIFFERENT PARTS OF THREE PHASE SYNCHRONOUS MACHINE

APPARATUS REQUIRED:

Three phase synchronous machine

Diagram:

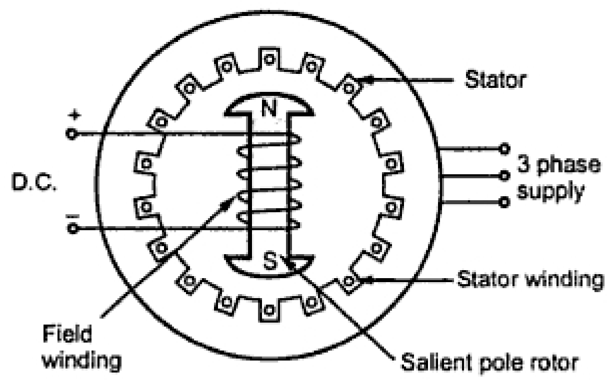

Figure: synchronous machine

Theory:

A synchronous machine is an a.c machine. It can be used as generator as well as motor. The machine which rotates at a constant speed equal to the synchronous speed is called synchronous speed. In case of generator, the machine has to be driven at a constant speed equal to the synchronous speed. Most of the power generating station uses synchronous generator which is also known as alternator. Synchronous machine are generally constructed in larger sizes. Small size alternators are not economical. The modern trend is to build alternators of very large sizes capable of generating 500MVA or even more. The synchronous motor is rarely built in small size owing to superior performance characteristics and economical construction of the induction motors.

The different parts of synchronous motors are as follows:

a. Stator

It is the stationary part of the synchronous machine. It has uniformly distributed three phase armature winding. It is an iron ring formed of laminations of special magnetic iron or steel alloy having slots on its periphery to accommodate armature conductors. The whole structure is held in the frame which may be of cast iron. Since the field rotates in between the stator, so that flux of the rotating field cuts the core of the stator continuously and causes eddy current loss in the stator core. To minimize the eddy current loss, the stator core is laminated.

b. Rotor

It is the rotating part of the synchronous machine. It has the number of magnetic poles excited by dc source. The roto are if two types:

i. Salient pole rotor
ii. Cylindrical type rotor

i. Salient pole rotor

This type of rotor has got projected magnetic pole. The construction of this of rotor is easier and cheaper than cylindrical rotor. This type of rotor is generally used in the generators driven by low speed prime movers such as water turbine. If driven at the high speed, the salient field poles would produce noise and it would cause the excessive windage loss. Some of the features of the salient pole rotor as follow:

1) They have large diameter and short axial length.
2) The pole shoes cover about 2/3 of pole pitch.
3) Poles are laminated in order to reduce eddy current losses.
4) These are employed with hydraulic turbines or diesel engines. The speed is 100 to 375 rpm.

ii. Cylindrical type rotor

This type of rotor has smooth magnetic poles in the form of closed cylinder. Construction of this type of rotor is more compact and robust with compare to salient pole rotor. This type of rotor is generally used in the generator driven by high speed prime movers like steam engine and gas turbine. It is also known as non-salient pole type rotor. Some of the features of this type of rotor are as follow:

1) They are of smaller diameter and of very long axial length.
2) Robust construction and noiseless operation

1. Less windage loss

1) Better in dynamic balancing
2) High operating speed(3000 rpm)

c. Exciter

The exciter is generally a dc shunt or compound generators. In the small synchronous generators exciter is mounted on the same shaft on the synchronous generators. This will provide dc current required to magnetize the magnetic poles of the rotor. The dc current generated by the exciter is fed to the field winding of the alternator through slip ring and carbon brush arrangement.

d. Stator winding

The winding which are kept in stator is known as stator winding.

e. Field winding

The winding which are kept in rotor is known as field winding.

Conclusion:

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EXPERIMENT NO:16

TO RUN A THREE-PHASE SYNCHRONOUS GENERATOR AND OBTAINS ITS LOAD AND NO-LOAD CHARACTERISTICS

OBJECTIVE:

To draw the V and Λ curves of a 3-phase synchronous motor at no-load and load conditions.

APPARATUS REQUIRED:

S.NO	Name of apparatus	Type	Quantity
1	Voltmeter	Dc (0-300)V	1
2	Voltmeter	Ac (0-300)V	1
3	Ammeter	0-10A dc	1
4	Ammeter	0-10A dc	1
5	Wattmeter	0-3KW	1
6	Frequency meter	-	1
7	Phase sequence meter	-	1

Motor Specifications:

S.NO	Dc motor	Synchronous motor
1	Voltage (220 V)	Voltage (220 V)
2	Current (9A)	Current (5A)
3	1500rpm	Speed 1500 rpm
4	-	Power (3.5kVA)

THEORY:

Normal Excitation:-

If the field current is equal to the rated excitation, which is called the normal field excitation. The p.f. of the motor is unity at this excitation.

Under Excitation:-

A field current below the normal excitation is called unclear excitation. Here I increases and operating p.f. of motor decrease. The power factor is lagging when it is under excited (equivalent to inductive load).

Over Excitation:-

Field current above the normal excitation is called over excitation. Here Ia again increases and operating p.f. decreases, but it is leading here. Hence the motor draws leading current.

If the armature current is plotted against the field current of a synchronous motor at constant load, the curve appears as V. Hence the curve is known as V curve. The current drawn by the motor will be minimum when the current I_a is in phase with the voltage or the power factor of the motor is unity.

It is observed from the experiment that whenever the field current changes, the no-load armature current raises sharply on each side, of the unity power factor point. It is also observed that at full load, large changes in field current or excitation make relatively less difference in the armature current.

The input power = 3 VI cosф. Thus, if the power factor for constant output is plotted against the field current, out a constant load it will be as inversion of V curve. The V and inverted V curves of a synchronous motor can be obtained by performing the synchronization test. The v-curves of synchronous machine motor show how armature current varies with If , when motor input is kept constant. These curves are obtained by plotting as armature current against dc field current while motor input is kept constant.

The inverted v-curves of synchronization machine motor shows how pf varies with If, when motor input is kept constant, such that they change with power factor change. The synchronization switch is closed when (1) frequency of voltage on both sides of the switch is same. (2) Line to neutral voltage on the supply side must be equal to corresponding line to neutral voltage on the synchronous machine side closing the synchronizing switch is called synchronization.

If the phase angle between V and I is less than 900 the power per phase delivered by ac supply source VIcosф is positive. Machine is acting as a synchronous generator if the phase angle lies between 900 and 1800, cosф is negative, then ac supply source actually now receives power. The synchronous machine acts as a generator.

Synchronous motor runs at a constant speed. If the load is kept constant the power output remains constant. As excitation varies its power factor varies whereas the input also remains constant.

Thus the current drawn decreases in magnitude which the phase angle (of lag) also decreases and power factor increases. At a certain Stage, pf = 1, further increase in excitation pf decreases thus angle increases.

Now on load condition, if line to neutral voltage of the machine coincide with those of the supply the voltages of the lamps become zero all times lamps are dark. This time the synchronization switch is closed, if not the phase move away from synchronization. At one point the voltage across each lamp becomes twice a phasor voltage and lights reach maximum intensity. .The limit of stability depends on the excitation. The stronger the excitation the more stable is the machine.

The input power is constant at a constant load on the motor. The armature current and power factor changes with the change in the excitation.

PROCEDURE:

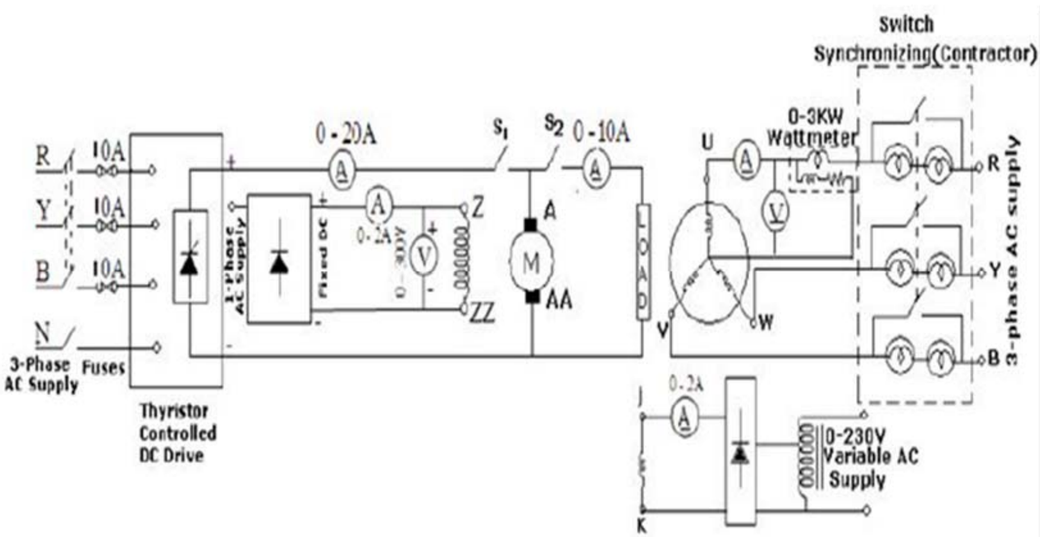
The following steps should be followed for starting practical:

1. Connect the circuit as shown in the circuit diagram.
2. Keep the dc motor (prime mover) potentiometers and synchronous machine field auto-transformer at zero position.
3. Switch on S, switch.
4. Push the start button and slowly increase the potentiometer till the motor attains the rated speed.

5. Check the phase voltage, frequency and phase sequence of the A.P.S.E.B. supply at the synchronizing switch (contactor).
6. Adjust the auto-transformer (to increase the excitation of the syn. machine) till the phase voltage of the synchronous machine is same as the A.PS.E.B. supply at the synchronizing switch.
7. Check the frequency and phase sequence of the A.P.S.E.B. supply and the synchronous machine are same on both sides of the synchronizing switch.(connect the frequency meter across the R-Phase, Neutral on the supply side and simultaneously check at the generate side. Adjust the prime mover (DC Motor) speed till the frequencies are equal.
8. Check the lamps connected across the synchronization switch.
9. If the lamps are not gradually becoming dark then adjust the dc motor speed very gently till the lamps become dark.
10. Push the synchronizing ON button when all the lamps are dark.
11. Now, the syn. machine is parallel to the power supply and starts working as a synchronous motor. Switch – off the S1 switch (to disconnect the supply to the DC motor.
12. Gradually, decrease the excitation of the synchronous motor by decreasing the auto- transformer position and record I. I_{no} and power per phase of the synchronous motor.
13. Similarly, increase the excitation of the syn. Motor by increasing the auto - transformer position and record If, I_{ph} and power per phase of the synchronous motor. Do not exceed the field current more than 1.2 amps (rating of the field current).
14. Switch - off the power supply contactor and set the auto – transformer and dc drive potentiometer to zero position. Synchronous machine contactor is also becomes off.

    (Note : Do not touch the Synchronization switch OFF button)

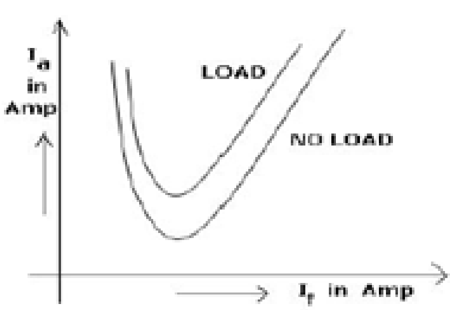
CIRCUIT DIAGRAM:

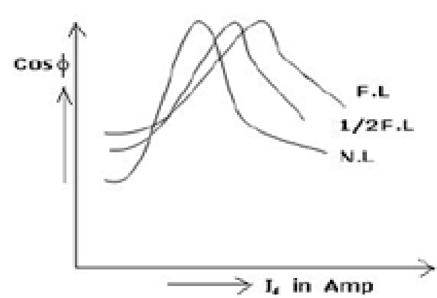


PRACTICAL OBERSERVATION TABLE:

I_f	I_a	W	V	Pf

MODEL GRAPH:





RESULT AND CONCLUSION:

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Viva questions:

1) Define synchronous machine.
2) What are the elements for generating emf in alternators?
3) What type of rotor is adopted for high speed alternators?
4) What is the maximum speed of a 50Hz alternators?

EXPERIMENT NO: 17

ASSEMBLING AND DE-ASSEMBLING OF SPLIT-PHASE INDUCTION MOTOR AND RUN IT

APPARATUS REQUIRED:

Single phase split type induction motor

THEORY:

1. Split Phase Induction Motor

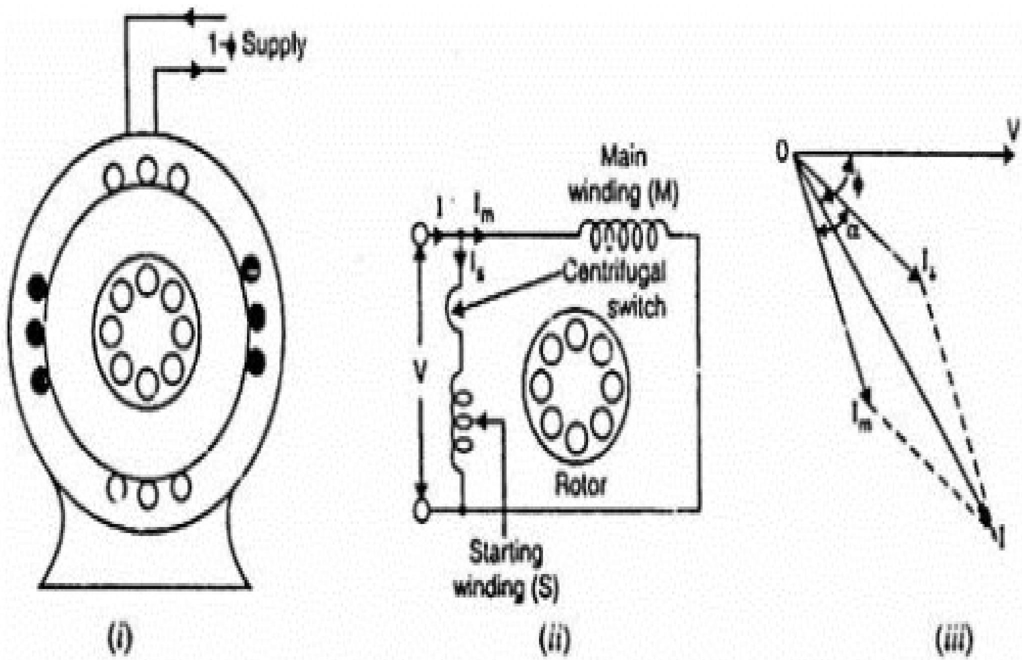

Figure Split phase induction motor

This motor is started by two phase motor action by using auxiliary or starting winding. The stator of split phase induction motor is provided with on auxiliary (main) or starting winding in addition to the main or running winding. The starting winding has high resistance and small reactance and in the main winding has low resistance and large reactance. When single phase supply is given to the stator winding of single phase motor, then main winding carries current I_m and starting winding carries current Is. Since main winding is highly inductive and starting winding have highly resistive, the current I_m and Is have a phase difference (20^0 to 30^0). Due to this phase difference, the starting torque will be developed which expression is given below:

$T_s = k\ I_m I_s \sin \prec$ where;

k = constant value whose magnitude depends upon the design of th motor

I_m = current flowing to the main winding

I_s = current flowing to the starting winding

When the motor reaches about 75% of full speed, the centrifugal switch opens and circuit gets opened.

PROCEDURE AND DISSCUSSION:

In-case of de-assembling the motor, un-tie all the screw and remove all the rotating parts and see all its internal parts. In-case of assembling, tie-on all the screw properly. Then, it can be run.

CONCLUSION:

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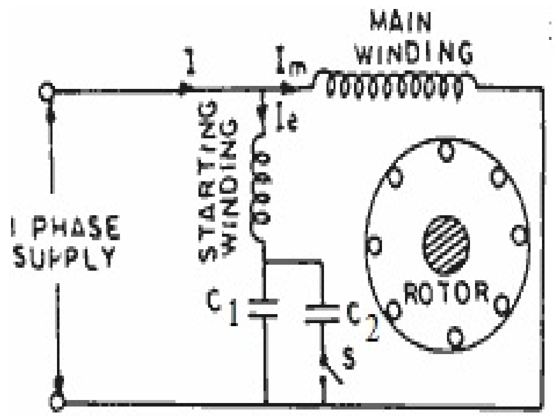
EXPERIMENT NO: 18

ASSEMBLING AND DE-ASSEMBLING OF CAPACITOR START AND INDUCTION MOTOR AND RUN IT

APPARATUS REQUIRED:

Capacitor start and run induction motor

THEORY:



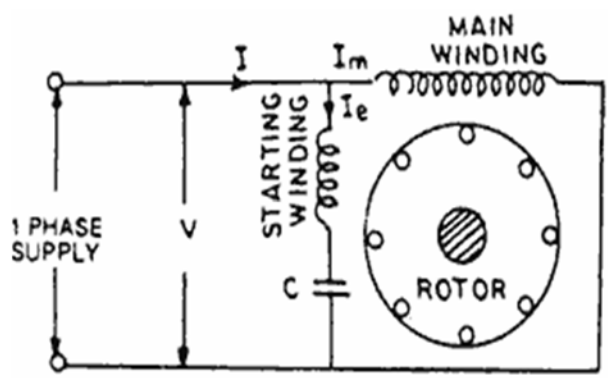


Figure Capacitor start/capacitor run motor

The stator of this motor contains two winding i.e stating and main winding.When single phase current “I” is given to the stator “I_s” flows in the starting winding and “I_m” flows in the main winding. In this type of starting of motor are described as the two methods. In fig 1) Single capacitor C is used for both starting and running. This design eliminates the need of a centrifuged switch and at the same time improves the power, factors and efficiency of motor. The capacitor used here produces the required amount of starting torque and also helps in self starting.

In other design, two capacitors C_1 and C_2 are used in the starting winding. The smaller capacitor C_1 required for optimum running condition is permanently connected in parallel with C_2 for optimum starting required in the circuit during starting. The starting capacitor C_2 is disconnected when the motor approaches about 75% synchronous speed. Due to the presence of C_1 in the circuit, it helps to improve the power factor and the running conditions of the single phase induction motor. This type of motor has high starting torque.

PROCEDURE AND DISSCUSSION:

In-case of de-assembling the motor, un-tie all the screw and remove all the rotating parts and see all its internal parts. In-case of assembling, tie-on all the screw properly. Then, it can be run.

CONCLUSION:

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