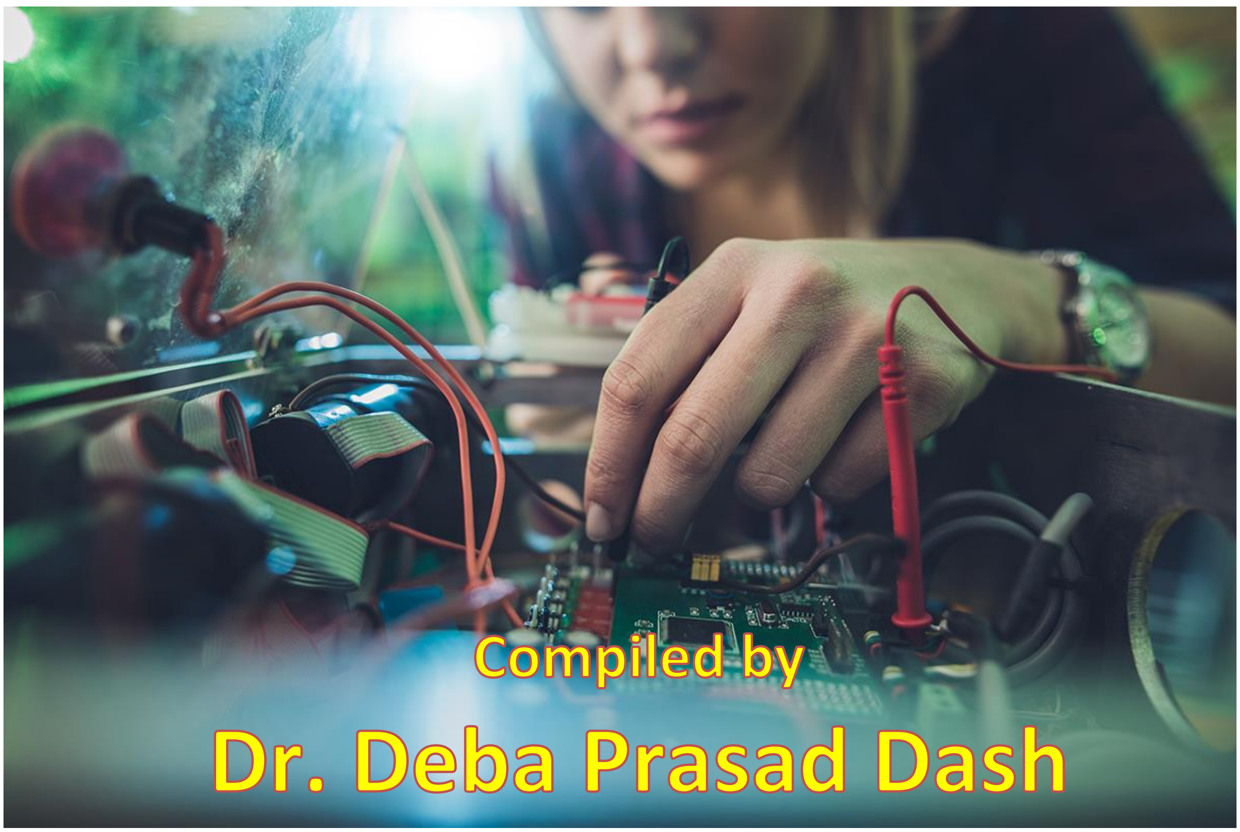
GOVERNMENT COLLEGE OF ENGINEERING, KALAHANDI

Lecture notes

on

BASIC ELECTRICAL ENGINEERING
(Module IV)



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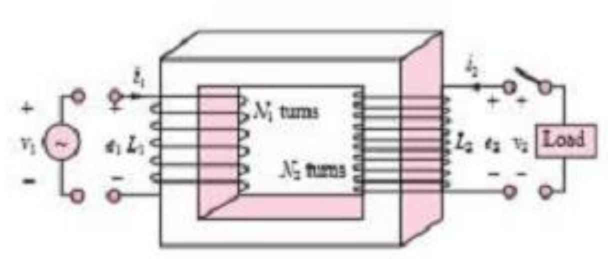
MODULE-IV

TRANSFORMER: One of the more common magnetic structures in everyday applications is the transformer. An ideal transformer is a device that can step an AC voltage up or down by a fixed ratio, with a corresponding decrease and increase in current. A simple magnetic transformer is shown as below



Here coil L_1 represents the input side of the transformer or primary winding of it, where as the coil L_2 is the output coil or secondary winding ; both winding are wound around the same magnetic structure. The operation of a transformer requires a time-varying current; if a time-varying voltage is applied to the primary side of the transformer, a corresponding current will flow in L_1 ;this current acts as an mmf and causes a (time-varying) flux in the structure.

Thus, a transformer operates by converting electric energy to magnetic, and then back to electric energy.

$$e_1 = N_1 \frac{d\phi}{dt} = v_1$$

Due to flux an emf induced across the secondary coil is

$$e_2 = N_2 \frac{d\phi}{dt} = v_2$$

So the relation between the input and output voltage is $\frac{v_2}{v_1} = \frac{N_2}{N_1}$

As mmf in transformer remains same though out the core i.e.

$$i_1 N_1 = i_2 N_2$$

$$\frac{i_2}{i_1} = \frac{N_1}{N_2}$$

Here N_1 and N_2 are the primary and secondary turns, respectively. As the ideal transformer does not dissipate any power, since

$$v_1 i_1 = v_2 i_2$$

Power efficiency η = Output power/ Input power

PRINCIPLE OF OPERATION:

It is based on the principle of mutual induction i.e. whenever the amount of magnetic flux linked with the coil charges, and emf is induced in the coil. Whenever alternating voltage V_1 is applied to the primary winding, I_0 (exciting current) flows which sets up Ø in magnetic core. This flux links with both windings and E_1& E_2 are induced.

IDEAL TRANSFORMER:

1-Primary and secondary winding resistance are negligible, hence no resistive voltage drop.

2- leakage flux and leakage inductance are zero. There is no reactive voltage drop in the windings.

3- power transformer efficiency is 100% i.e. there are no hysteresis loss, eddy current loss or heat loss due to resistance.

4- permeability of the core is infinite so that it requires zero mmf to create flux in the core.

Power In the primary= power in the secondary .

$E_1 I_1 = E_2 I_2$

$I_1 / I_2 = E_2 / E_1 = N_2 / N_1 = K = V_2 / V_1$

EMF Equation:

$$\varphi = \varphi_m \sin wt$$

$$e_1 = -N_1 \frac{d\varphi}{dt} = -N_1 \frac{d}{dt}(\varphi_m \sin wt)$$

$$e_1 = -N_1 w \varphi_m \cos wt = -N_1 \times 2\pi f \varphi_m \cos wt$$

$$e_1 = N_1 2\pi f \varphi_m \sin\left(wt - 90^o\right) \qquad [E_{m1} = 2\pi f N_1 \varphi_m]$$

$$\text{R.M.S value of } E_1 \text{ is:} E_1 = \frac{E_{m1}}{\sqrt{2}} = \frac{2\pi f N_1 \varphi_m}{\sqrt{2}} = 4.44 f N_1 \varphi_m$$

$$E_2 = 4.44 f N_2 \varphi_m$$

Voltage Transformation Ratio:

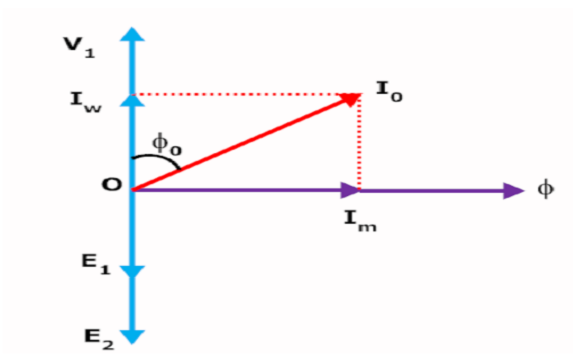
$$\frac{E_2}{E_1} = \frac{N_2}{N_1}$$

- N_2/N_1 is known as voltage transformation ratio and represented by K.

- If $N_2>N_1$ or $K>1$ then step up transformer

- If $N_1>N_2$ or $K<1$ then step down transformer

Practical Transformer on no load:



A transformer is said to be on no load if its primary winding is connected to AC supply and secondary is open. i.e secondary current is zero

- When an A.C voltage is applied to primary, a small current I0 flows in primary.

- I_0 = N0-load current

Im = magnetizing current. It magnetizes the core and sets flux. So, in phase with it.

Im is called the reactive or wattless component of no load current

- Iw produces eddy current and hysteresis losses in the core and very small copper loss in primary. It is called active or wattful component of no load current.

- Iw is in phase with the applied voltage (V_1) at the primary.

- No load current I_0 is small. So drops in R_1 and X_1 on primary side are very

small. At no load $V_1 = E_1$.

No load primary copper loss is very small. So, no load primary input power is equal to iron loss

$I_w = I_0 \cos\varphi_0$, $I_m = I_0 \sin\varphi_0$, $I_0 = \sqrt{I_m^2 + I_w^2}$

No load power factor, $\cos\varphi_0 = \frac{I_w}{I_0}$

No load input power (active power) $= V_1 I_0 \cos\varphi_0$,

No load reactive power $= V_1 I_0 \sin\varphi_0$

INTRODUCTION TO ELECTRIC MACHINES

The operation of the three major classes of electric machines—DC, synchronous, and induction—first is described as intuitively as possible. The second part of the chapter is devoted to a discussion of the applications and selection criteria for the different classes of machines. The emphasis of this chapter is on explaining the properties of each type of machine, with its advantages and disadvantages with regard to other types; and on classifying these machines in terms of their performance characteristics and preferred field of application.

ROTATING ELECTRIC MACHINES:

The range of sizes and power ratings and the different physical features of rotating machines are such that the task of explaining the operation of rotating machines in a single chapter may appear formidable at first. Some features of rotating machines, however, are common to all such devices. This introductory section is aimed at explaining the common properties of all rotating electric machines. We begin our discussion with reference to Figure 14.1, in which a hypothetical rotating machine is depicted in a cross-sectional view. In the figure, a box with a cross inscribed in it indicates current flowing into the page, while a dot represents current out of the plane of the page.

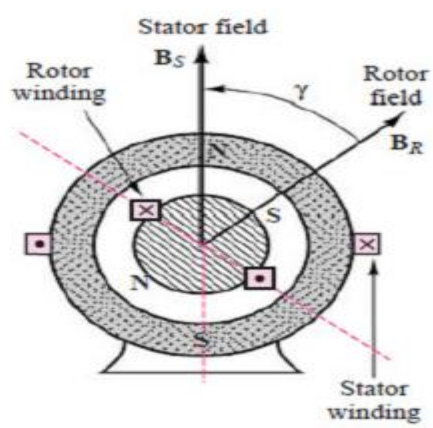


Figure 14.1 A rotating electric machine

In Figure 14.1, we identify a stator, of cylindrical shape, and a rotor, which, as the name indicates, rotates inside the stator, separated from the latter by means of an air gap. The rotor and stator each consist of a magnetic core, some electrical insulation, and the windings necessary to establish a magnetic flux (unless this is created by a permanent magnet). The rotor is mounted on a bearing-supported shaft, which can be connected to mechanical loads (if the machine is a motor) or to a prime mover (if the machine is a generator) by means of belts, pulleys, chains, or other mechanical couplings. The windings carry the electric currents that generate the magnetic fields and flow to the electrical loads, and also provide the closed loops in which voltages will be induced.

DC MACHINE

Emf induced in coil $e = -N\, d\Phi/dt$ volt

Emf induced in a conductor $e = Blv$ volt

Force developed in a conductor $F = BIL$ N

Electrical energy $E_n = VIt$ Whour

Electrical power (Active) $P=VI$ Watt

Resistance of conductor $R=\rho l/a$ Ohm

Eqn. of current by Ohm's law, $I=V/R$ A

Magnetizing force, $H=NI/L$ AT/m

Flux density, $B=\Phi/A$

Electrical field intensity, $E=V/d$ V/m

Current density, $J=I/a$ A/m^2

INTRODUCTION: 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.

ESSENTIAL FEATURES:

There is no real difference between a dc. motor and dc generator either from the point of view of the essential components or of the fundamental principles involved. In the generator there is a conversion of mechanical to electrical energy while in the motor there is the reverse conversion of electrical to mechanical energy. The structure difference is merely one of the enclosure. Most generators work in sheltered situations e.g. in power stations and an open type of construction is thus possible, the advantage being that all the parts are in consequence, easily accessible.

<u>CONSTRUCTION</u>:

<u>STATOR</u>	<u>ROTOR</u>
Yoke/Frame	Armature core
Field magnet (pole core &pole shoe)	Armature winding/ conductor
Main field winding	Commutator & Brushes
Interpoles/commutating poles	Shaft
Interpoles winding	Bearings

STATOR & ROTOR

All conventional electrical machines consist of a stationary member called the stator separated by an air gap from a rotating member called rotor. In d.c machines the stator usually consists of salient poles with coils wound round them so as to produce a magnetic field.

The rotor is familiarly called the armature and consists of a series of coils located in slots around its periphery and connected to a commutator.

Yoke/Frame :

Yoke is the outer frame dc m/c. It carries the magnetic flux provided by the pole and acts as a protecting shield for the entire machine. In small generators yokes are made of cast iron whereas in large machine cast sheet is used.

Field magnet :

It is a strong permanent magnet (in case of a small dynamo) or an electromagnet (in case of large dynamo) of intense magnetic field.

Pole core & Pole shoe : The field magnet has two parts

Pole core

Pole shoes.

Pole core is made of cast steel or cast iron with laminated.

pole shoes screwed on to the holes in the yoke.

ARMATURE CORE:

- It houses armature coils in the slots. It is cylindrical or drum shaped.
- Armature is placed in between the two poles of field magnet and is rotated about its central axis mechanically (by a prime mover)
- Thickness of laminations is of the order of 0.5mm. Perforations exist in these laminations to provide axial flow of air through the armature for cooling purposes.
- Armature core is keyed to the shaft.
- During rotation it cuts the magnetic flux of the field magnets.
- It also provides a path of very low reluctance to the flux from north pole to south pole.

ARMATURE WINDING:

- It is made up of copper.
- It consists of large no. of insulated coils, each coil having one or more turns.
- Armature conductor are placed in armature slots.

Commutator:

- It converts the alternating current produced in the armature conductors into direct current.
- It consists of wedge shaped copper segments (Insulated from either side to form a ring. The number of segments of commutator equals the no. of armature coils.
- It facilitates the collection of current from the armature conductors.

<u>Brushes</u>

- They are fixed on the commutator by pressure springs.
- They are usually made of a high grade carbon or graphite and are in the shape of rectangular block.

- These are housed in a brush holder.
- They collect the current from the commutator and finally they pass on the EMF generated to load.

Types of Armature Winding

These are of two types : Lap winding

Wave winding

Pole Pitch

- It is defined as the no of armature conductors per pole.
- If there are 80 conductors and 8 poles, pole pitch is 80/8 = 10.

Lap winding:

To get these type foe dg following rules are commonly used: winding must be full pitched i.e.

$$Y_B + Y_F = \text{Pole Pitch}$$

1. To place the coil properly on the armatures, the front pitch as well as back pitch must be odd.
2. No. of commutator segment = no. of coils.
3. winding must close upon itself.
4. $Y_c = \pm 1$

   For Progressive or right handed winding

   $Y_F = Z/P - 1$ and $Y_B = Z/P + 1$

   For Retrogressive or left handed winding

   $Y_F = Z/P + 1$ and $Y_B = Z/P - 1$

Wave Winding:

1. Y_B & Y_F are odd and of opposite sign.
2. Y_B & Y_F are nearly equal to the pole pitch and differ by 2.
3. Y_C = (No. of commutator bars ± 1) / No. of pairs of pole

Comparison:

Lap winding	Wave winding
No. of parallel paths = no. of poles	No of parallel path = 2
No. of brushes sets = no. of poles	No. of brushes sets = 2
Used for high current & low voltage	Used for low current & high voltage

PRINCIPLE OF OPERATION OF DC GENERATOR:

Principle:

Faradays law of electromagnetic induction according to which emf is induced in the conductors which drives the current through the conductor.

Fig below shows a single turn generator.

The coil is rotated in anticlockwise direction with the help of prime mover.

Fig. shows the different instants of the induced emf due to different positions of the coil.

Magnetic field is produced either by a permanent magnet or an electromagnet energised by the DC supply.

The flux linked with the coil is maximum but the rate of change of flux is minimum. Hence, emf cannot be generated . Therefore current flows through the conductors.

Types of DC Machines

Both the armature and field circuits carry direct current in the case of a DC machine.

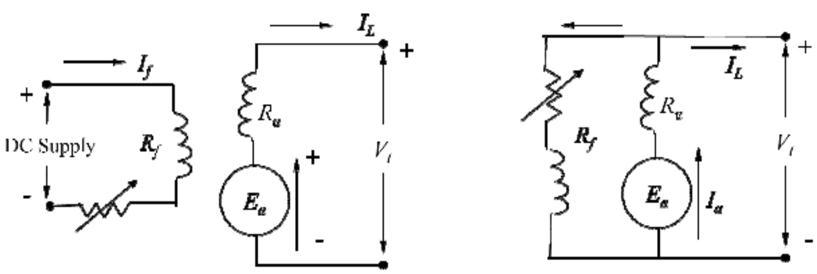
Self-excited DC machine: when a machine supplies its own excitation of the field windings. In this machine, residual magnetism must be present in the ferromagnetic circuit of the machine in order to start the self-excitation process.

Separately-excited DC machine: The field windings may be separately excited from an eternal DC source.

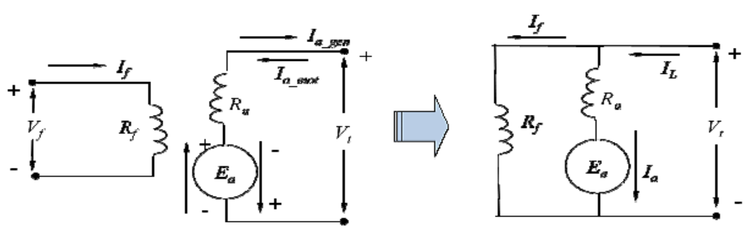
Shunt Machine: armature and field circuits are connected in parallel. Shunt generator can be separately-excited or self-excited.

Series Machine: armature and field circuits are connected in series.

Separately-Excited and Self-Excited DC Generators



Equivalent circuit of a DC Machine



$$V_f = I_f R_f$$
$$V_t = E_a \pm I_a R_a$$

Generated EMF and Electromagnetic Torque

$$V_f = I_f R_f$$
$$V_t = E_a \pm I_a R_a$$

Three phase Induction Motor:

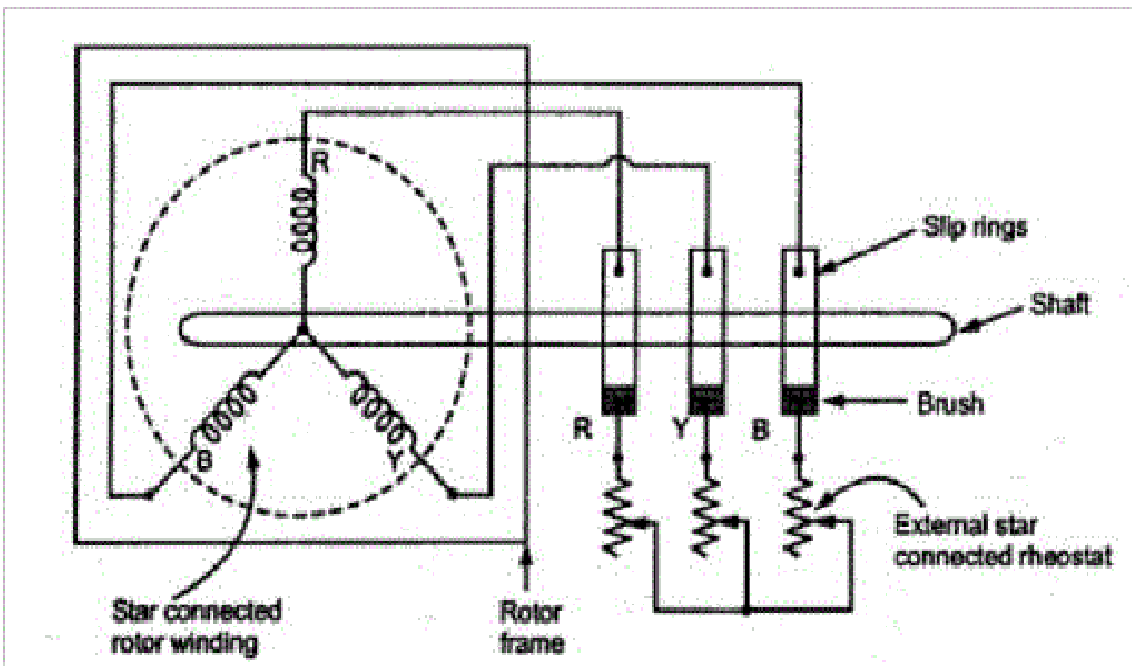
Three-phase induction motors are the most common and frequently encountered machines in industry.

- simple design, rugged, low-price, easy maintenance
- wide range of power ratings: fractional horsepower to 10 MW
- run essentially as constant speed from no-load to full load

Its speed depends on the frequency of the power source

Stator :- three phase winding in star or delta

Rotor :- Squirrel cage rotor, Slip ring or phase wound rotor



Rotating Magnetic Field: Balanced three phase windings, i.e. mechanically displaced 120 degrees form each other, fed by balanced three phase source

A rotating magnetic field with constant magnitude is produced, rotating with a speed.

$$n_{sync} = \frac{120 f_e}{P} \quad rpm$$

P is the no. of poles and nsync is called the synchronous speed in rpm (revolutions per minute).

Principle of operation:

This rotating magnetic field cuts the rotor windings and produces an induced

voltage in the rotor windings.

- Due to the fact that the rotor windings are short circuited, for both squirrel

cage and wound-rotor, and induced current flows in the rotor windings

- The rotor current produces another magnetic field A torque is produced as a result of the interaction of those two magnetic fields

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Slip: The difference between synchronous speed Ns and actual speed N of the rotor is known as slip.

$$\% \text{ Slip} = \frac{N_s - N}{N_s} \times 100\%$$

Sometimes, Ns- N is called slip speed

Frequency of rotor (f′) :

$$N_s - N = \frac{120 f'}{P}$$

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

$$\frac{N_s - N}{N_s} = \frac{f'}{f}$$

$$f' = sf$$

Torque Equation:

$$T_{EM} = \frac{60}{2\pi N_s} * rotor\ .input$$

Unit- synchronous watt

TORQUE- SLIP OR TORQUE-SPEED CHARACTERISTICS

$$T_{EM} = \frac{180}{2\pi N_s} * \frac{SE_2^2 R_2}{R_2^2 + (SX_2)^2}$$

For a constant supply voltage, E2 is also constant. So we can write torque equation as:-

$$T \alpha \frac{SR_2}{R_2^2 + (SX_2)^2}$$

As R2 is constant.

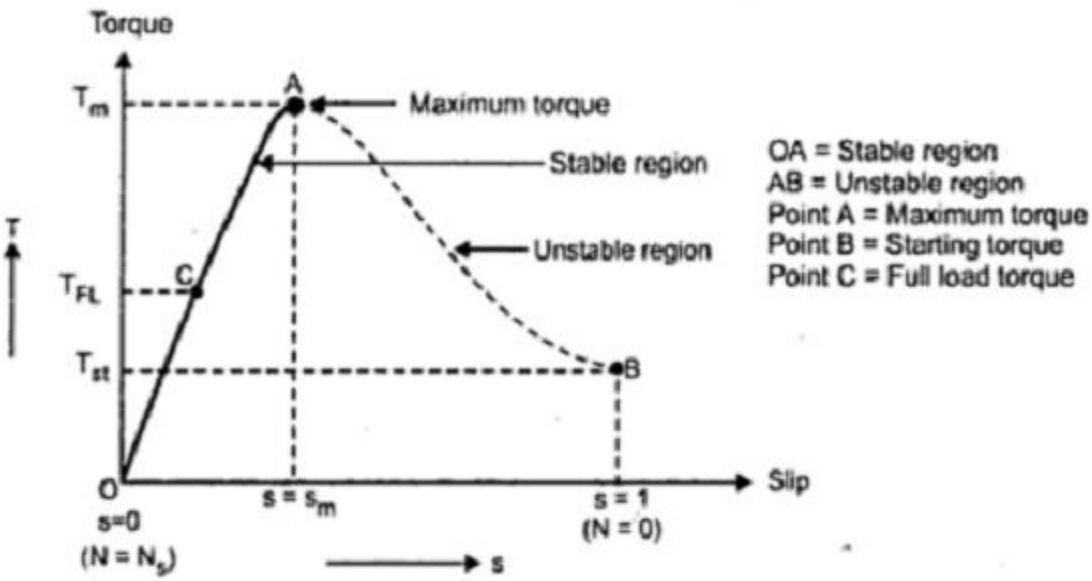
1) HIGH SLIP REGION –
   Here S is high

So,

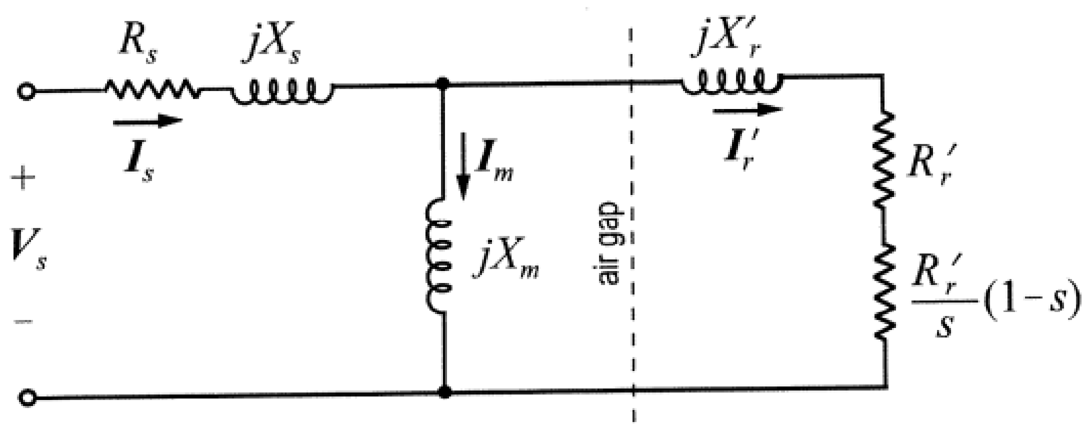
$$T \alpha \frac{SR_2}{(SX_2)^2} \alpha \frac{1}{S}$$

As R2 and X2 are constants

$$T_{Full\ Load} < T_M$$



EQUIVALENT CIRCUIT



Introduction to 1-phase induction motor:

- Used for domestic application
- 1-phase IM are fractional KW motors
  - Rotor – squirrel cage
  - Stator – distributed

Types of 1-phase IM:

- Resistance split phase IM
- Capacitor split phase IM
  - Capacitor start IM

Synchronous Machine Construction:

- Field :- carrying a DC excited winding
- Armature : three phase winding in which emf is generated
- Armature stationary and rotating field structure
- Armature winding is built of sheet-steel laminations having slots on its inner periphery
- Three phase winding is placed in these slots and serves as armature winding.
- connected in star
- Field is connected to an external source through slip rings and brushes or else receives excitation from rotating bodies
- Damper bars on the rotor :- damps the oscillations due to transients
- Depending on rotor construction:-

➢ Round rotor type

- High speed machine such as turbine generators

➢ Salient pole type

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Frequency of output voltage:

Let P = no of rotor poles

N= Speed of the rotor in rpm

Number of cycles generated in one revolution = P/2

Time taken for one revolution = 60/N seconds

In 60/ N sec, no. of cycles = P/2

In 1 sec, no. of cycles generated = P/2/60/N = PN/120

So, frequency (f) = PN/120 Hz

Emf equation:

Let P = no of poles

N= speed in rpm

T_{ph} = no of concentric turns

K_d = distribution factor

Φ = flux produced per pole in weber

In one revolution flux cut by one armature conductor = ΦP=dΦ

Time taken for one revolution = 60/N sec = dt

Therefore average emf induced in the conductor is given by

e= dΦ/dt= Φp/60/N=ΦPN/60 = 2ΦPN/120

e = 2Φf volts

therefore, f = PN/120

For a sinusoidal ac voltage,

rms value = average value x form factor

The value of form factor is 1.11 in case of sinusoidal a.c

Rms value of induced emf per conductor = 1.11 x e

= (1.11) x(2Φf)

=2.22 Φf volts

End