Unit-V : Electrical Machines

Part: A - Single Phase Transformer

Syllabus

- Single Phase Transformer Construction
- Working (No load & On load)
- EMF Equation
- Losses, Efficiency, Regulation
- Phasor diagram.

What is a Transformer?

A ***transformer*** is *a static piece of equipment used either for raising or lowering the voltage of an AC supply with a corresponding decrease or increase in current*.

The use of transformers in transmission system is shown in the Figure below.

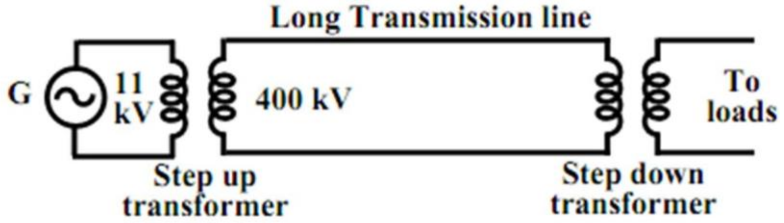


Fig.3-1 A simple single phase power system.

Principle of Operation

A transformer in its simplest form will consist of a rectangular laminated magnetic structure on which two coils of different number of turns are wound as shown in Figure 3.2a.

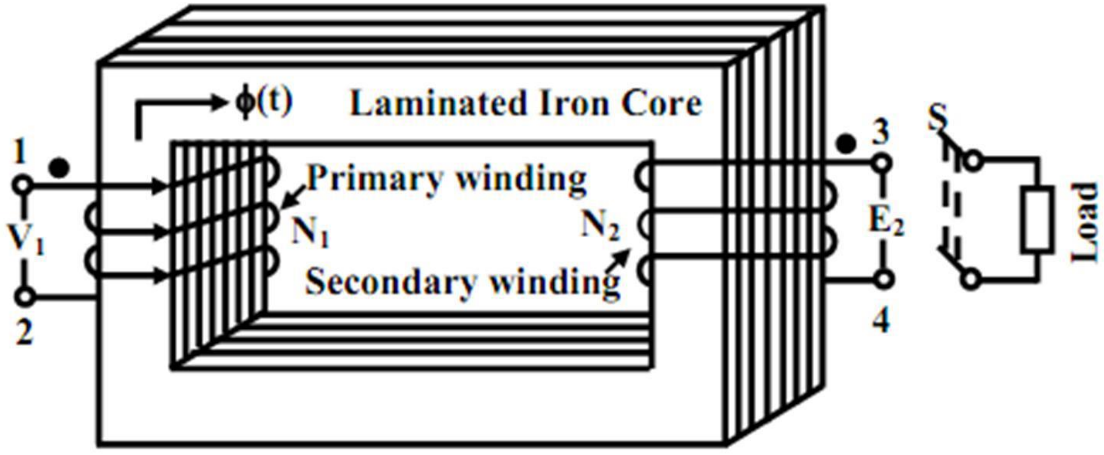


Figure 23.2: A typical transformer.

The winding to which AC voltage is impressed is called the primary of the transformer and the winding across which the load is connected is called the secondary of the transformer.

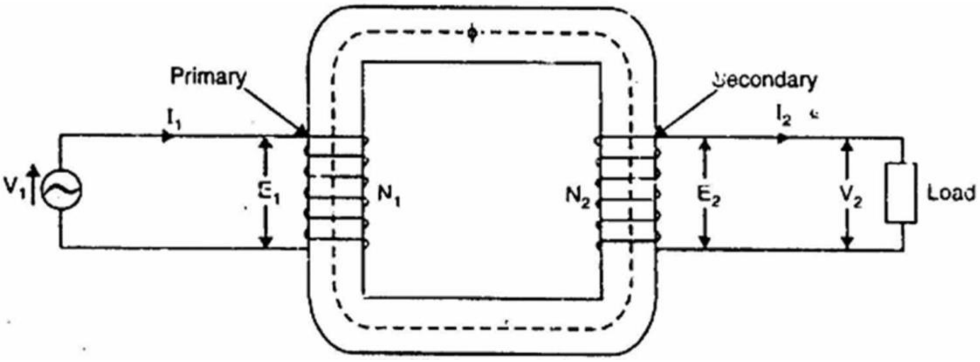


Fig.3-2b

Depending upon the number of turns of the primary (N_1) and secondary (N_2), an alternating emf (E_2) is induced in the secondary. This induced emf (E2) in the secondary causes a secondary current I_2. Consequently, terminal voltage V_2 will appear across the load. If $V_2 > V_1$, it is called a ***step up-transformer***. On the other hand, if $V_2 < V_1$, it is called a ***step-down transformer***.

When an alternating voltage V_1 is applied to the primary, an alternating flux Φ is set up in the core. This alternating flux links both the windings and induces emfs E1 and E2 in them according to ***Faraday's laws of electromagnetic induction***. The emf E1 is termed as primary emf and emf E2 is termed as Secondary emf.

Clearly, $$E_1 = -N_1 \frac{d\phi}{dt}$$

and $$E_2 = -N_2 \frac{d\phi}{dt}$$

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

Note that magnitudes of E_2 and E_1 depend upon the number of turns on the secondary and primary respectively. If $N_2 > N_1$, then $E_2 > E_1$ (or $V_2 > V_1$) and we get a step-up transformer. On the other hand, if $N_2 < N_1$, then $E_2 < E_1$ (or $V_2 < V_1$) and we get a step-down transformer. If load is connected across the secondary winding, the secondary e.m.f. E_2 will cause a current I_2 to flow through the load. Thus, a transformer enables us to transfer a.c. power from one circuit to another with a change in voltage level.

The following points may be noted carefully:

(i) The transformer action is based on the laws of ***electromagneticinduction***.

(ii) There is no electrical connection between the primary and secondary.

(iii) There is no change in frequency i.e., output power has the samefrequency as the input power.

Can DC Supply be used for Transformers?

The DC supply cannot be used for the transformers. This is because the transformer works on the principle of ***mutual induction***, for which current in one coil must change uniformly.If DC supply is given, the current will not change due to constant supply and transformer will not work

There can be saturation of the core due to which transformer draws very largecurrent from the supply when connected to DC.

Thus DC supply should not be connected to the transformers.

Construction

We usually design a power transformer so that it approaches the characteristics of an ideal transformer. To achieve this, following design features are incorporated:

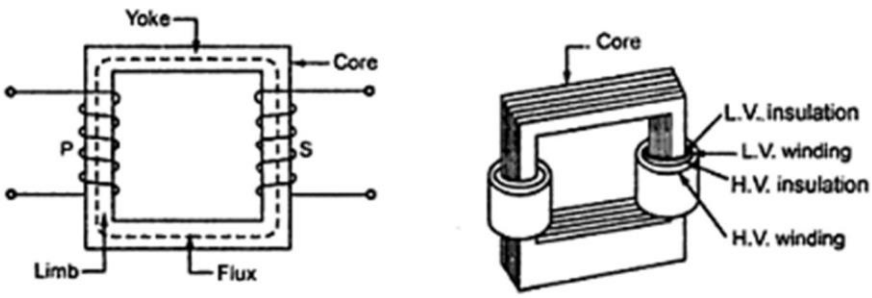
(i) The core is made of silicon steel which has low hysteresis loss and high permeability. Further, core is laminated in order to reduce eddy current loss. These features considerably reduce the iron losses and theno-load current.

(ii) Instead of placing primary on one limb and secondary on the other, it is a usual practice to wind one-half of each winding on one limb. This ensures tight coupling between the two windings. Consequently, leakage flux is considerably reduced.

(iii) The winding resistances are minimized to reduce Copper loss and resulting rise in temperature and to ensure high efficiency.

Transformers are of two types: (i) core-type transformer (see Fig.3-3) and (ii) shell-type transformer (see Fig.3-4).

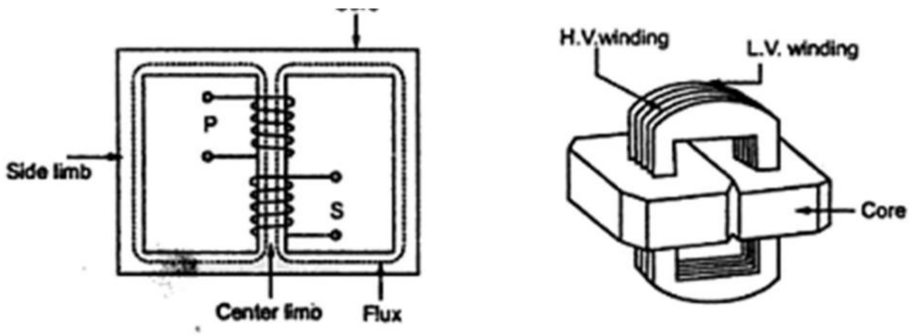
Core-Type Transformer: In a core-type transformer, half of the primary winding and half of the secondary winding are placed round each limb to reduce the leakage flux.



(a) Representation (b) Construction

Fig.3-3 **Core type transformer**

Shell-Type Transformer: This method of construction involves the use of a double magnetic circuit. Both the windings are placed round the central limb to ensure a low-reluctance flux path.



(a) Representation (b) Construction

Fig.3-4 **Shell type transformer**

Comparison of Core and Shell Type Transforms

Core Type	Shell Type
The winding encircles the core.	The core encircles most part of the windin
It has single magnetic circuit	It has double magnetic circuit
The core has two limbs	The core has three limbs
The cylindrical coils are used.	The multilayer disc or sandwich type coils are used.
The winding are uniformly distributed on two limbs hence natural cooling is effective	The natural cooling does not exist as the windings are surrounded by the core.
Preferred for low voltage transformers.	Preferred for high voltage transformers.

Cooling of Transformers

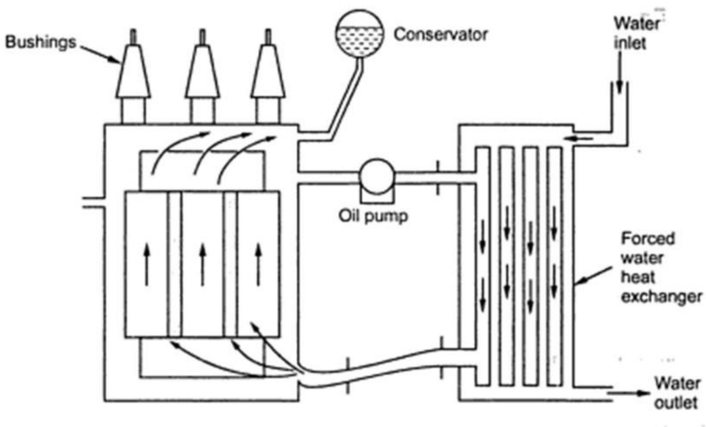
When transformer supplies a load, two types of losses occur inside the transformer. The iron losses occur in the core while copper losses occur in the windings. The power lost due to these losses appears in the form of heat. This heat increases the temperature of the transformer. ***To keep the temperature rise of the transformer within limits, a suitable coolant and cooling method is necessary.***

The various cooling methods are designated witch depended upon: A: cooling

medium used and B: type of circulation employed.

The various coolant used such as Air, Gas, Mineral oil, and water.

One of cooling method system is shown in figure below which is called ***Oil Forced Water Forced cooling system***;



Oil forced water forced cooling method

EMF Equation of a Transformer

Consider that an alternating voltage V_1 of frequency f is applied to the primary as shown in Fig. 3-2b. The sinusoidal flux Φ produced by the primary can be represented as:

$$\phi = \phi_m \sin\omega t$$

The instantaneous e.m.f. e_1 induced in the primary is

$$e_1 = -N_1 \frac{d\phi}{dt} = -N_1 \frac{d}{dt}(\phi_m \sin\omega t)$$

$$= -\omega N_1 \phi_m \cos\omega t = -2\pi f N_1 \phi_m \cos\omega t$$

$$= 2\pi f N_1 \phi_m \sin(\omega t - 90°) \qquad \text{(i)}$$

It is clear from the above equation that maximum value of induced e.m.f. in the primary is

$$E_{m1} = 2\pi f N_1 \phi_m$$

The r.m.s. value E^ of the primary e.m.f. is

$$E_1 = \frac{E_{m1}}{\sqrt{2}} = \frac{2\pi f N_1 \phi_m}{\sqrt{2}}$$

or $\quad E_1 = 4.44 f N_1 \phi_m$

Similarly $\quad E_2 = 4.44 f N_2 \phi_m$

In an ideal transformer, $E_1 = V_1$ and $E_2 = V_2$.

Note. It is clear from exp. (i) above that e.m.f. E_1 induced in the primary lags behind the flux ϕ by 90°. Likewise, e.m.f. E_2 induced in the secondary lags behind flux ϕ by 90°.

Voltage Transformation Ratio (K)

From the above equations of induced emf, we have,

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

The constant K is called voltage transformation ratio. Thus if K = 5 (i.e.N2/N1 = 5),

then E2 = 5 E1.

Concept of Ideal Transformer

A transformer is said to be ideal if it satisfies following properties:

i) It has no losses.
ii) Its windings have zero resistance.
iii) Leakage flux is zero i.e. 100 % flux produced by primary links withthe secondary.
iv) Permeabitity of core is so high that negilgiblc current is required toestablish the flux in it.

NOTE:

For an ideal transformer, the primary applied voltage V1 is same as theprimary induced emf E1 as there are no voltage drops.

For ideal transformer:

(i) $E_1 = V_1$ and $E_2 = V_2$ as there is no voltage drop in the windings.

$$\therefore \quad \frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{N_2}{N_1} = K$$

(ii) there are no losses. Therefore, volt-amperes input to the primary are equal to the output volt-amperes i.e.

$$V_1 I_1 = V_2 I_2$$

$$\text{or} \quad \frac{I_2}{I_1} = \frac{V_1}{V_2} = \frac{1}{K}$$

Hence, currents are in the inverse ratio of voltage transformation ratio. This simply means that if we raise the voltage, there is a corresponding decrease of current.

Volt-Ampere Rating

Transformer rating is specified as the product of voltage and current and called **KVA rating**.

$$\text{kVA rating of a transformer} = \frac{V_1 I_1}{1000} = \frac{V_2 I_2}{1000}$$

The full load primaty and secondary currents which indicate the safe maximum values of currents which transformer windings can carry can be given as:

$$I_1 \text{ full load } = \frac{\text{kVA rating} \times 1000}{V_1} \quad \text{... (1000 to convert kVA to VA)}$$

$$I_2 \text{ full load } = \frac{\text{kVA rating} \times 1000}{V_2}$$

Ideal Transformer on No Load

Consider an ideal transformer in Fig. 3-5. For no load I_2 =0. I_1 is just necessary to produce flux in the core, which is called ***magnetising*** currentdenoted as I_m. I_m is very small and lags V_1 by 90^0 as the winding is purely inductive.

According to Lenz's law, the induced e.m.f opposes the cause producing it which is supply voltage V_1. Hence E_1 and E_2 are in antiphase with V_1 but equalin magnitude and E_1 and E_2 are in phase.

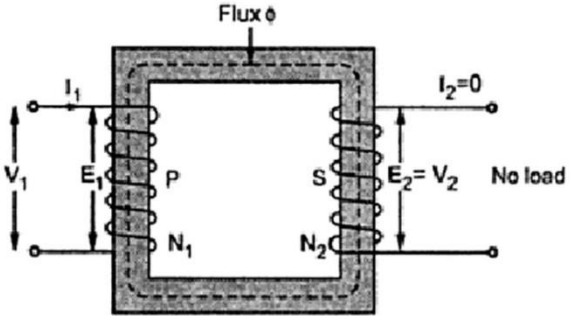
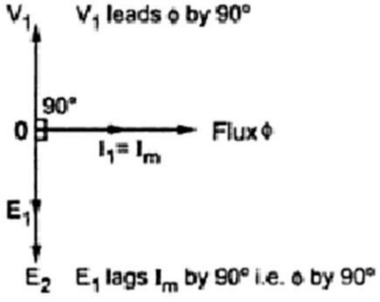


Fig.3-5

This can be illustrated in the phase diagram as shown below:

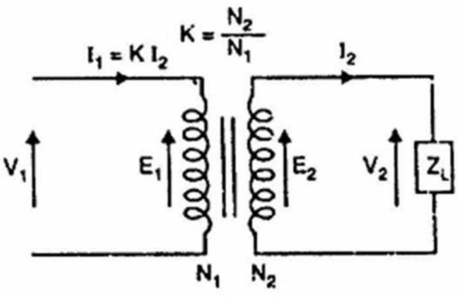


Phasor diagram for ideal transformer on no load

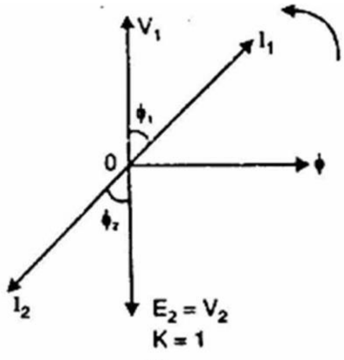
Ideal Transformer on Load

Let us connect a load Z_L across the secondary of an ideal transformer as shownin Figure below:

The secondary emf E2 will cause a current I_2 to flow through the load:



(i)



(ii)

$$I_2 = \frac{E_2}{Z_L} = \frac{V_2}{Z_L}$$

The angle at which I_2 leads or lags V_2 (or E_2) depends upon the resistance and reactance of the load. In the present case, we have considered inductive load so that current I_2 lags behind V_2 (or E_2) by ϕ_2.

The secondary current I_2 sets up an m.m.f. N_2I_2 which produces a flux in the opposite direction to the flux ϕ originally set up in the primary by the magnetizing current. This will change the flux in the core from the original value. However, the flux in the core should not change from the original value. Thus when a transformer is loaded and carries a secondary current I_2, then a current I_1, (= K I_2) must flow in the primary to maintain the m.m.f. balance. In other words, the primary must draw enough current to neutralize the demagnetizing effect of secondary current so that mutual flux ϕ remains constant. Thus as the secondary current increases, the primary current I_1 (= KI_2) increases in unison and keeps the mutual flux ϕ constant. The power input, therefore, automatically increases with the output. For example if K = 2 and I_2 = 2A, then primary will draw a current $I_1 = KI_2 = 2 \times 2 = 4A$. If secondary current is increased to 4A, then primary current will become $I_1 = KI_2 = 2 \times 4 = 8A$.

The Phasor diagram for the ideal transformer on load is shown in Figure (ii)above. The secondary current I_2 lags behind V_2 (or E_2) by Φ_2. It causes a primary current $\boxed{I_1 = KI_2 = I2}$ (for K=1) which is in antiphase with it.

(i) $\phi_1 = \phi_2$

or $\cos \phi_1 = \cos \phi_2$

Thus, power factor on the primary side is equal to the power factor on the secondary side.

(ii) Since there are no losses in an ideal transformer, input primary power is equal to the secondary output power i.e.,

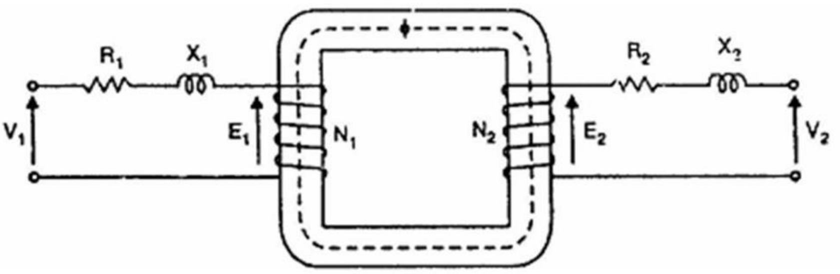
$$V_1 I_1 \cos\phi_1 = V_2 I_2 \cos\phi_2$$

Practical Transformer

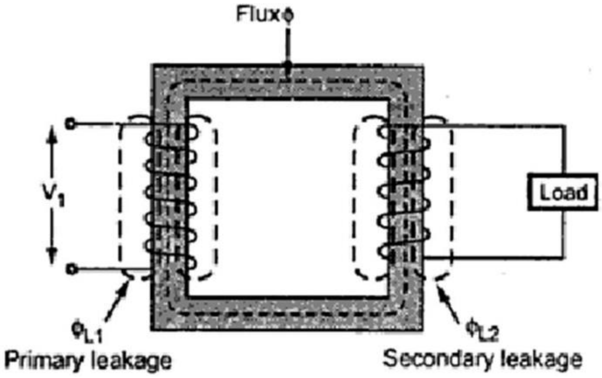
A practical transformer differs from the ideal transformer in many respects. The practical transformer has (i) ***iron losses*** (ii) ***winding resistances*** and (iii) ***magnetic leakage***, giving rise to leakage reactance.

(i) ***Iron losses***. Since the iron core is subjected to alternating flux, there occurs eddy current and hysteresis loss in it.

(ii) ***Winding resistances***. Since the windings consist of copper conductors, it immediately follows that both primary and secondary will have winding resistance. The primary resistance R1 and secondary resistance R2 act in series with the respective windings as shown below:

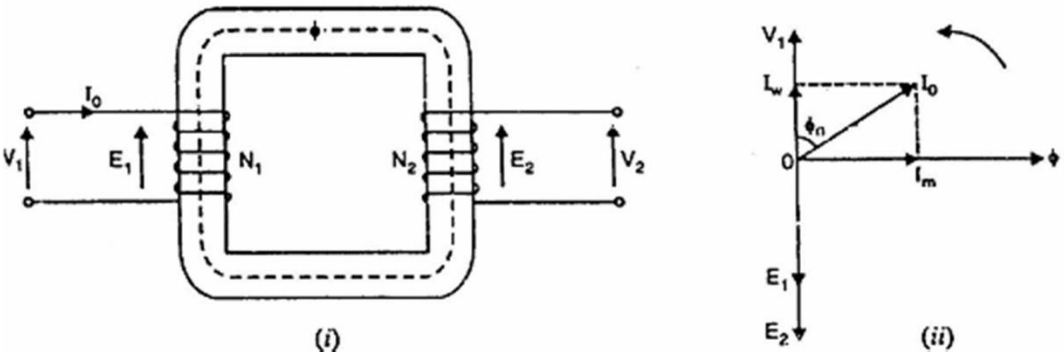


(iii) ***Leakage reactance***. Both primary and secondary currents produce flux. The flux Φ which links both the windings is the useful flux However, primary current would produce some flux Φ which would not link the secondary winding and is called ***mutual flux*** (***for more information review Lecture Note 2***) (See Fig. below).



Practical Transformer on No Load

Consider the figure below:



The primary will draw a small current I_0 to supply (i) the iron losses and (ii) a very small amount of copper loss in the primary. Hence the primary no load current I_0 is not 90° behind the applied voltage V_1 but lags it by an angle $\Phi_0 < 90°$ as shown in the phasor diagram.

The no-load primary current I_0 can be resolved into two rectangularcomponents:

(i) The component I_W in phase with the applied voltage V_1. This is known as active or working or iron loss component and supplies the iron loss and a very small primary copper loss.

$$\boxed{I_W = I_0 \cos \phi_0}$$

ii)

The component I_m lagging behind V_1 by 90° and is known as magnetizing component. It is this component which produces the mutual flux ϕ in the core.

$$\boxed{I_m = I_0 \sin \phi_0}$$

Clearly, I_0 is phasor sum of I_m and I_W,

$$\therefore \quad I_0 = \sqrt{I_m^2 + I_W^2}$$

No load p.f., $\cos\phi_0 = \dfrac{I_W}{I_0}$

It is emphasized here that no load primary copper loss (i.e. $I_0^2 R_1$) is very small and may be neglected. Therefore, the no load primary input power is practically equal to the iron loss in the transformer i.e.,

No load input power, W_0 = Iron loss

Note. At no load, there is no current in the secondary so that $V_2 = E_2$. On the primary side, the drops in R_1 and X_1, due to I_0 are also very small because of the smallness of I_0. Hence, we can say that at no load, $V_1 = E_1$.

Practical Transformer on Load

We shall consider two cases (i) when such a transformer is assumed to have no winding resistance and leakage flux (ii) when the transformer has winding resistance and leakage flux.

No winding resistance and leakage flux

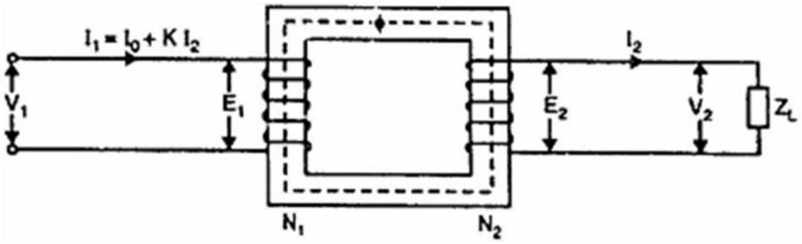


Fig. above shows a practical transformer with the assumption that resistancesand leakage reactances of the windings are negligible. With this assumption, V_2

$= E_2$ and $V_1 = E_1$.

Let us take the usual case of inductive load which causes the I_2 to lag V_2 by Φ_2.The total primary current I_1 must meet two requirements:

(a) It must supply the no-load current I_0 to meet the iron losses in the transformer and to provide flux in the core.

(b) It must supply a current I'_0 to counteract the demagnetizing effect of secondary currently I_2. The magnitude of I'_2 will be such that:

$$N_1 I'_2 = N_2 I_2$$

or
$$I'_2 = \frac{N_2}{N_1} I_2 = K I_2$$

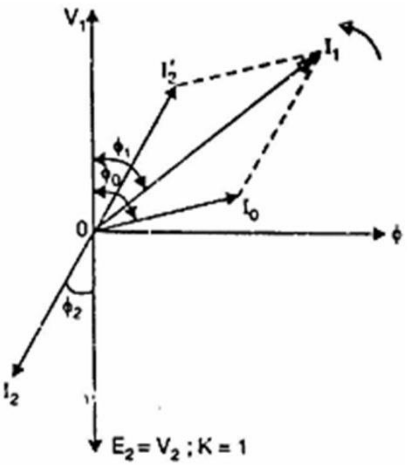
The total primary current I_1 is the phasor sum of I'_2 and I_0 i.e.,

$$I_1 = I'_2 + I_0$$

ϕ where
$$I'_2 = -K I_2$$

Note that I'_2 is 180° out of phase with I_2.

Phasor Diagram: Both E_1 and E_2 lag behind the mutual flux f by 90°. The current I'_2 represents the primary current ~~to neutralize~~ the demagnetizing effect of secondary current I_2. Now $I'_2 = K\ I_2$ and is antiphase with I_2. I_0 is the no-load current of the transformer. The phasor sum of I'_2 and I_0 gives the total primary current I_1. Note that in drawing the phasor diagram, the value of K is assumed to be unity so that primary phasors are equal to secondary phasors.



Transformer with resistance and leakage reactance

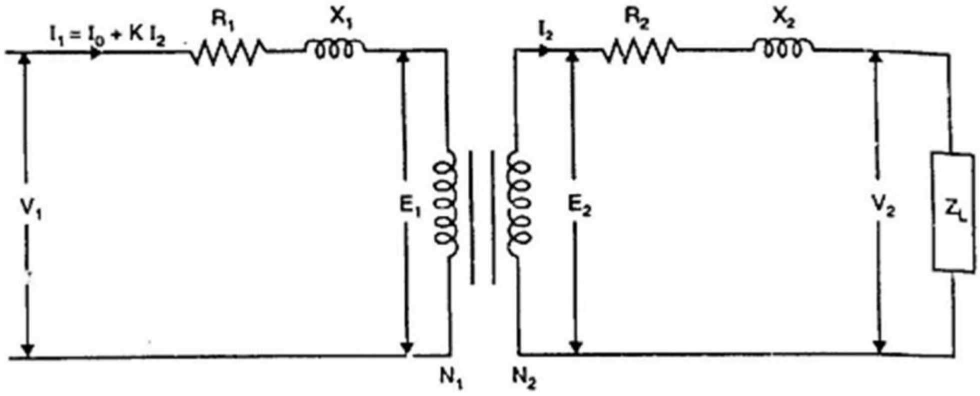
(a) It must supply the no-load current I_0 to meet the iron losses in the transformer and to provide flux in the core.

(b) It must supply a current I'_2 to counteract the demagnetizing effect of secondary current I_2. The magnitude of I'_2 will be such that:

The total primary current I_1 must meet **two requirements:**

$$N_1 I'_2 = N_2 I_2$$

or $$I'_2 = \frac{N_2}{N_1} I_2 = K I_2$$



The total primary current I_1 will be the phasor sum of I'_2 and I_0 i.e.,

$$I_1 = I'_2 + I_0 \quad \text{where} \quad I'_2 = -KI_2$$

$$V_1 = -E_1 + I_1(R_1 + jX_1) \quad \text{where} \quad I_1 = I_0 + (-KI_2)$$

$$= -E_1 + I_1 Z_1$$

$$V_2 = E_2 - I_2(R_2 + jX_2)$$

$$= E_2 - I_2 Z_2$$

Phasor Diagram:

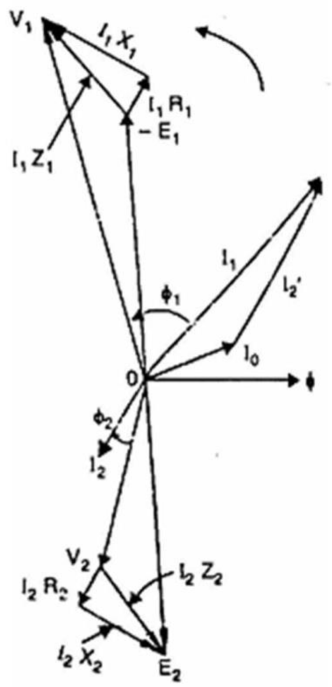
Note that counter emf that opposes the applied voltage V_1 is $-E_1$. Therefore, if we add I_1R_1 (in phase with I_1) and $I_1 X_1$ (90° ahead of I_1) to $-E_1$, we get the applied primary voltage V_1. The phasor E_2 represents the induced emf in the secondary by the mutual flux. The secondary terminal voltage V_2 will be what is left over after subtracting I_2R_2 and I_2X_2 from E_2.

Load power factor = $\cos \phi_2$

Primary power factor = $\cos \phi_1$

Input power to transformer, $P_1 = V_1 I_1 \cos \phi_1$

Output power of transformer, $P_2 = V_2 I_2 \cos \phi_2$



Assignment 5 A)

1. Explain the construction and working of single phase transformer. Also mention various types of single phase transformers. (W-2018)
2. Draw and explain phasor diagram of single phase transformer for inductive load. (W-2019)
3. Derive an EMF equation of transformer. (S-2019)
4. Explain the Ideal transformer on No load and On load with neat phasor diagram (S-2019)
5. Explain the Practical transformer on No load and On load with neat phasor diagram (S-2018)
6. What is efficiency and regulation in transformer?

Part: B – DC Motor

Syllabus

- Electromechanical Energy Conversion
- Working principle
- Construction of D.C. Motors
- Types of dc motor
- Characteristics and applications of D.C. Motors

Electromechanical Energy Conversion Principles

An electromechanical energy conversion device is the device that converts electrical energy into mechanical energy or, mechanical energy into electrical energy. Electromechanical energy conversion takes place via the medium of a magnetic field or an electric field, but most practical converters use magnetic field as the coupling medium between electrical and mechanical systems, this is because the electric storing capacity of the magnetic field is much higher than that of the electric field. Electromechanical energy converters are either gross-motion devices such as microphones, loudspeakers, electromagnetic relays, and certain electrical measuring instruments, etc.

DC, induction and synchronous machines are used extensively for electromechanical energy conversion. When the conversion takes place from electrical to mechanical form, the device is called the motor, and when the mechanical energy is converted to electrical energy, the device is called a generator. In these machines, conversion of energy from electrical to mechanical form or from mechanical to electrical from results from the following two electromagnetic phenomena:

1. When a conductor is allowed to move in a magnetic field, a voltage is induced in the conductor.
2. When a current-carrying conductor is placed in a magnetic field, then a mechanical force is experienced by the conductor.

In monitoring action, current flows through the conductors placed in a magnetic field. A force is produced on each conductor. The conductors are placed on the rotor which is free to move. An electromagnetic torque produced on the rotor is transferred to the shaft of the rotor and can be utilized to drive a mechanical load. Since the conductors rotate in the magnetic field, a voltage is induced in each conductor. In generating action, the rotor is driven by a prime mover. A voltage is induced in the rotor conductors. If an electrical load is connected to the winding formed by these conductors, a current will flow, delivering electric power to the load. Moreover, the current flowing through the conductors will interact with the magnetic field to produce a reaction torque, which will tend to oppose the torque developed by the prime mover.

Conservation of energy

According to the principle of conservation of energy, energy can neither be created nor be destroyed it can only be transformed from one state to another.

In an energy conversion device, the total input energy is equal to the sum of the following three components:

Thus, with an electromechanical conversion device, the energy balance equation can be written as

$$\begin{bmatrix}\text{Electrical}\\ \text{energy}\\ \text{input}\end{bmatrix} = \begin{bmatrix}\text{Energy to}\\ \text{electrical}\\ \text{losses}\end{bmatrix} = \begin{bmatrix}\text{Energy to field}\\ \text{storage in the}\\ \text{electrical system}\end{bmatrix} = \begin{bmatrix}\text{Mechanical}\\ \text{energy}\\ \text{output}\end{bmatrix}$$

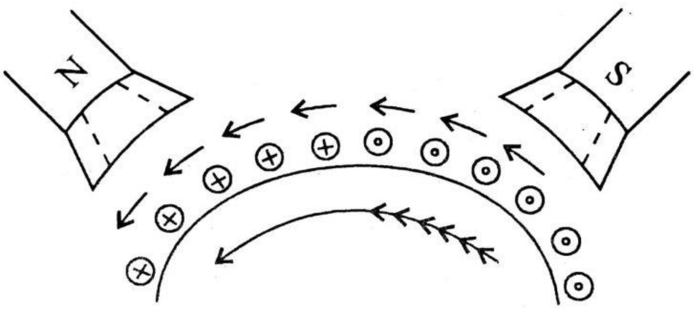
The above equation is for motor action. For generator action, the energy balance equation is written as

$$\begin{bmatrix}\text{Total mechanical}\\ \text{energy input}\end{bmatrix} = \begin{bmatrix}\text{Electrical energy}\\ \text{output}\end{bmatrix} + \begin{bmatrix}\text{Total energy}\\ \text{stored}\end{bmatrix} + \begin{bmatrix}\text{Total energy}\\ \text{dissipated}\end{bmatrix}$$

Working of DC Motor
How does DC Motor Works?

Consider a part of a multipolar DC motor as shown in the figure. When the main supply is applied to the armature conductors and field magnets are excited, the conductors experience a force that tends to rotate the armature.

Armature conductors under N-pole are assumed to carry current downwards and the S-poles carry upwards. Now by applying Fleming's Left-hand rule, the direction of the force on each conductor can be found. This is shown by small arrow marks in the figure in each conductor.



Part of Multipolar D.C. Motor

The force 'F' experienced by each conductor tends to rotate the armature in the anti-clockwise direction. The continuous and unidirectional torque is developed by a commutator which reverses the current in each conductor as it passes from one pole to another.

Working Principle of DC Motor

The operation of D.C. The motor is based on the working principle that when a current-carrying conductor is located in a magnetic field, it undergoes a mechanical force, guided by Fleming's left-hand rule and whose magnitude is given by:

$$F = BIl \text{ newtons.}$$

Where,

- B = Flux density in cub/m²
- I = Current through the conductor in amperes.
- l = Length of the conductor in meters.

Constructional and Parts of DC Motor

The construction of the D.C. motor is the same as D.C. Generator.

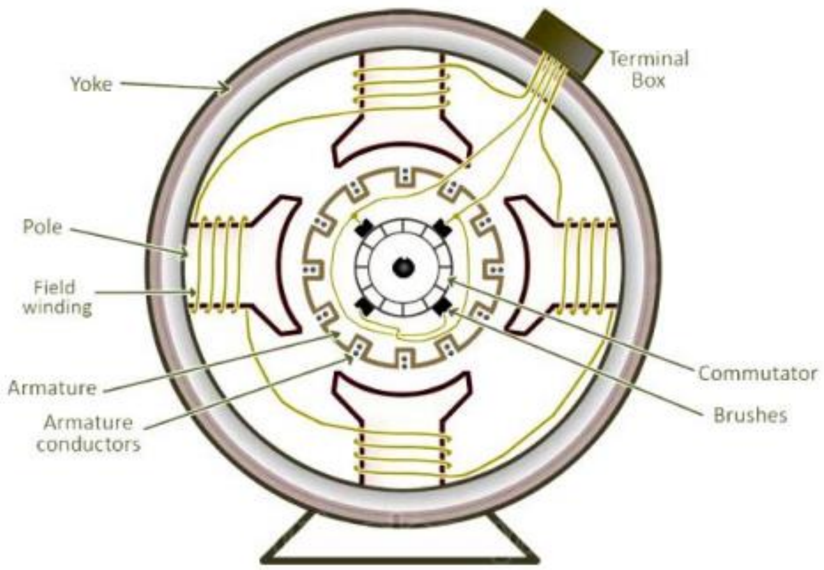


Figure 1: constructional details of a simple 4-pole DC machine

Following are the **parts of a DC motor:**

1. Yoke or frame
2. Field poles
3. Field winding
4. Brushes
5. End shields
6. Armature core
7. Armature winding
8. Commutator
9. Shaft

1) Yoke or Frame: It is a stationary part called a starter. The functions of Yoke are:

- It supports the field poles and field winding.

- Provides a magnetic path to the main field flux.
- Provides protection to armature from mechanical injury.

2) Field Poles: The main functions of poles are :

- Provides support to the field winding.
- Provide slow reactance path to the main field flux.
- Distributes the main field flux uniformly all around the periphery of the armature.

3) Field Windings: They produce a magnetic field when D.C. is passed through them.
4) Brushes: They receive D.C. from the main and supply it to the armature winding through a commutator.
5) End Shields: The main functions are:

- Supports the bearings in which armature rotates.
- Covers the armature and protects it.

6) Armature Core: It houses the windings in the slot and provides a low reactance path to the main field flux and the armature flux.
7) Armature Windings: It produces armature flux when current is passed through them. This flux reacts with the main field flux and produces rotation or torque.
8) Commutator: It collects D.C. from brushes, converts it into A.C., and supplies it to the armature windings.
Shaft: The main functions are :

- It provides support to the armature, windings and commutator.
- It helps the armature to rotate.

Torque equation of DC motor

Torque is the turning moment of a force about an axis and is measured by the product of force (F) and radius (r) at right angle to which the force acts i.e. D.C. Motors

$$T = F \times r$$

In a D.C. motor, each conductor is acted upon by a circumferential force F at a distance r, the radius of the armature. Therefore, each conductor exerts a torque, tending to rotate the armature. The sum of the torques due to all armature conductors is known as gross or armature torque (T_a).

Let in a D.C. motor
r = average radius of armature in m
L = effective length of each conductor in m
Z = total number of armature conductors
A = number of parallel paths
I = current in each conductor = I_a/A
B = average flux density in Wb/m2
ϕ *= flux per pole in Wb*
P = number of poles Force on each conductor,
F = BIL newtons

Torque due to one conductor = F ´x r newton- metre

Total armature torque, T_a *= Z F r newton-metre*
= Z B I L r
Now I = Ia/A,

B = ϕ /a where a is the x-sectional area of flux path per pole at radius r.
Clearly, a = 2Πr L/P.

$$Ta = Z\ x \left(\frac{\emptyset}{a}\right) x \left(\frac{Ia}{A}\right) x\ L\ r$$

$$Ta = Z\ x \left(\frac{\emptyset}{2\pi r\ L/P}\right) x \left(\frac{Ia}{A}\right) x\ L\ r$$

$$Ta = \left(\frac{Z\ \emptyset P Ia}{2\pi A}\right) \text{N – m}$$

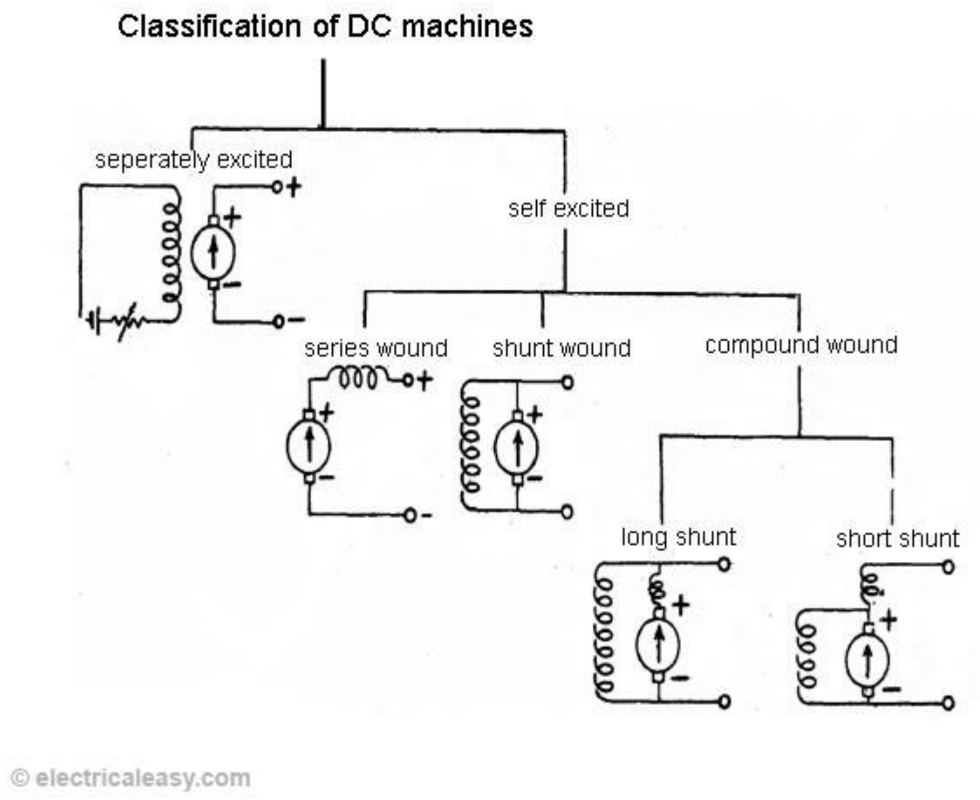
$$Ta = 0.159 \left(\frac{Z\ \emptyset P Ia}{A}\right) \text{N – m}$$

Since Z, P and A are fixed for a given machine

$$\therefore Ta\ \alpha\ \emptyset Ia$$

Hence torque in a D.C. motor is directly proportional to flux per pole and armature current.

Types of DC Motors



Following are the **three main types of DC motors:**

1. Separately excited dc motor
2. Permanent magnet dc motor
3. Self excited dc motor
4. Shunt-wound dc motors
5. Series wound dc motors

6. Compound wound dc motors0
7. Cumulative compound DC motor
8. Differential compound DC motor
9. Short shunt DC motor
10. Long shunt DC motor

Characteristics Of DC Motors

Characteristics Of DC Series Motors

Torque Vs. Armature Current (T_a-I_a)

This characteristic is also known as **electrical characteristic**. We know that torque is directly proportional to the product of armature current and field flux, $T_a \propto \phi.I_a$. In DC series motors, field winding is connected in series with the armature, i.e. $I_a = I_f$. Therefore, before magnetic saturation of the field, flux ϕ is directly proportional to Ia. Hence, before magnetic saturation Ta α Ia^2. Therefore, the Ta-Ia curve is parabola for smaller values of Ia. After magnetic saturation of the field poles, flux ϕ is independent of armature current Ia. Therefore, the torque varies proportionally to Ia only, T ∝ Ia.Therefore, after magnetic saturation, Ta-Ia curve becomes a straight line. The shaft torque (Tsh) is less than armature torque (Ta) due to stray losses. Hence, the curve Tsh vs Ia lies slightly lower. In DC series motors, (prior to magnetic saturation) torque increases as the square of armature current, these motors are used where high starting torque is required.

Speed Vs. Armature Current (N-Ia)

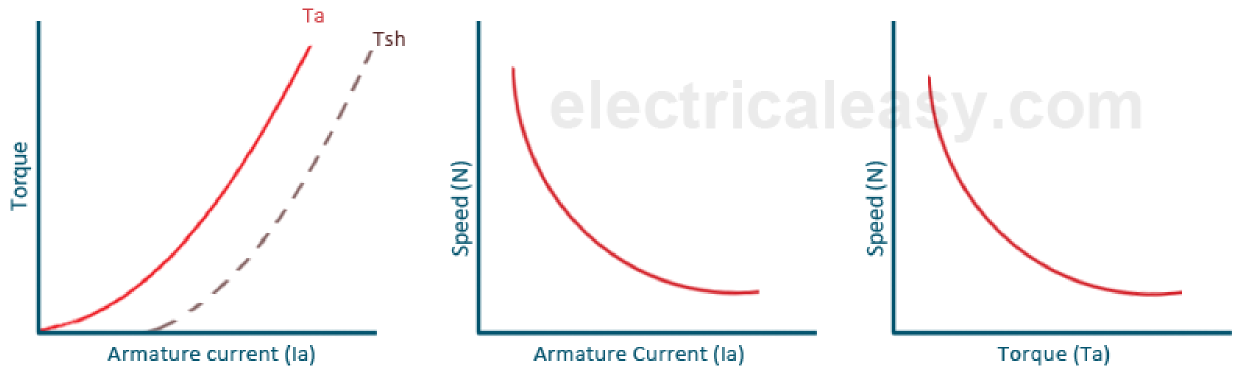
We know the relation, $N \propto E_b/\phi$

For small load current (and hence for small armature current) change in back emf Eb is small and it may be neglected. Hence, for small currents speed is inversely proportional to ϕ. As we know, flux is directly proportional to Ia, speed is inversely proportional to Ia. Therefore, when armature current is very small the speed becomes dangerously high. That is **why a series motor should never be started without some mechanical load**.

But, at heavy loads, armature current Ia is large. And hence, speed is low which results in decreased back emf Eb. Due to decreased Eb, more armature current is allowed.

Speed Vs. Torque (N-Ta)

This characteristic is also called as **mechanical characteristic**. From the above two **characteristics of DC series motor**, it can be found that when speed is high, torque is low and vice versa.



Characteristics of DC series motor

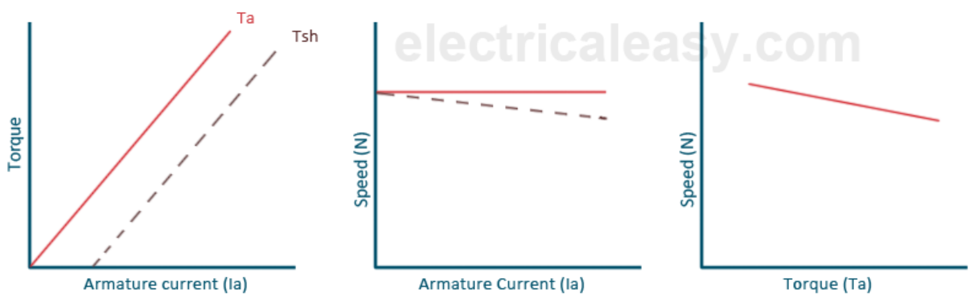
Characteristics of DC Shunt Motors

Torque Vs. Armature Current (Ta-Ia)

In case of DC shunt motors, we can assume the field flux ϕ to be constant. Though at heavy loads, ϕ decreases in a small amount due to increased armature reaction. As we are neglecting the change in the flux ϕ, we can say that torque is proportional to armature current. Hence, the Ta-Ia characteristic for a dc shunt motor will be a straight line through the origin.
Since heavy starting load needs heavy starting current, **shunt motor should never be started on a heavy load**.

Speed Vs. Armature Current (N-Ia)

As flux ϕ is assumed to be constant, we can say N ∝ Eb. But, as back emf is also almost constant, the speed should remain constant. But practically, ϕ as well as Eb decreases with increase in load. Back emf Eb decreases slightly more than ϕ, therefore, the speed decreases slightly. Generally, the speed decreases only by 5 to 15% of full load speed. Therefore, **a shunt motor can be assumed as a constant speed motor**. In speed vs. armature current characteristic in the following figure, the straight horizontal line represents the ideal characteristic and the actual characteristic is shown by the dotted line.



Characteristics of DC shunt motor

Characteristics of DC Compound Motor

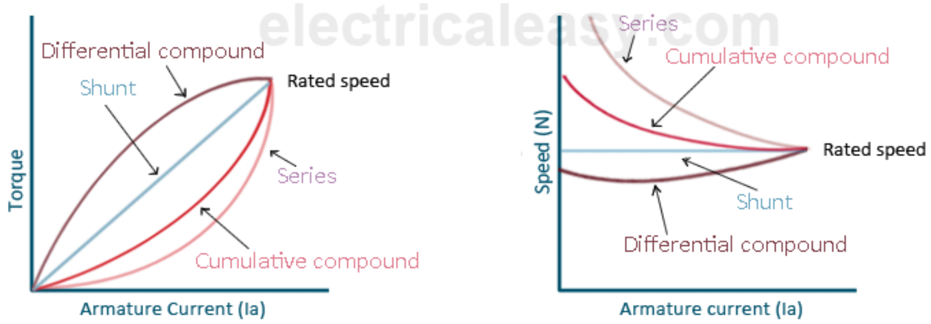
DC compound motors have both series as well as shunt winding. In a compound motor, if series and shunt windings are connected such that series flux is in direction as that of the shunt flux then the motor is said to be cumulatively compounded. And if the series flux is opposite to the direction of the shunt flux, then the motor is said to be differentially compounded. Characteristics of both these compound motors are explained below.

(a) Cumulative compound motor

Cumulative compound motors are used where series characteristics are required but the load is likely to be removed completely. Series winding takes care of the heavy load, whereas the shunt winding prevents the motor from running at dangerously high speed when the load is suddenly removed. These motors have generally employed a flywheel, where sudden and temporary loads are applied like in rolling mills.

(b) Differential compound motor

Since in differential field motors, series flux opposes shunt flux, the total flux decreases with increase in load. Due to this, the speed remains almost constant or even it may increase slightly with increase in load ($N \propto E_b/\phi$). Differential compound motors are not commonly used, but they find limited applications in experimental and research work.



Characteristics of DC compound motor

Applications of DC Motors:

1. **Series motor:** It is used where very high starting torque and variable speed is required, such as electrical fraction work, electric locomotives, trolleys, cranes, hoists, conveyors. air compressors, vacuum cleaners, hair driers, sewing machines etc.
2. **Shunt motors:** It is where constant speed is required with low starting torque such as for lathes, centrifugal pumps, fans, reciprocating pumps, drilling machines, boring machines. Spinning and weaving machines etc.
3. **Compound motor:** It is used where sudden loads are applied or removed such as for shears, punches, coal cutting machines, elevators, conveyors, heavy planners, rolling mills, ice machines, printing presses, air compressors etc.

Assignment 5 B)

7. Draw and explain characteristics of DC motors.(W-2019)
8. Explain the construction of DC machines in detail. (W-2019)
9. State & explain the applications of different types of D. C. motor. (W-20218)
10. Explain different types of DC motors.
11. Explain the concept of electromechanical energy conversion.
12. Derive torque equation of DC motor.