UNIT-2

Dc and Ac machines

Dc Generator:-

* A DC Generator is an Electromechanical Energy conversion device that converts mechanical power into DC electrical power through the process of electromagnetic induction.
* A Dc Generator operates on the principle of "Electromagnetic induction" ie, when the magnetic flux linking a conductor changes, an Emf is induced in that conductor.
* A Dc generator has a field winding and an armature winding.
* The EMF induced in the armature winding of a Dc generator is alternating one and is converted into direct voltage using a commutator mounted on the shaft of the generator.
* The armature winding of Dc Generator is placed on the rotor where as the field winding is placed on the stator.

Parts of a DC Generator:-

A DC Generator consists of six main parts,

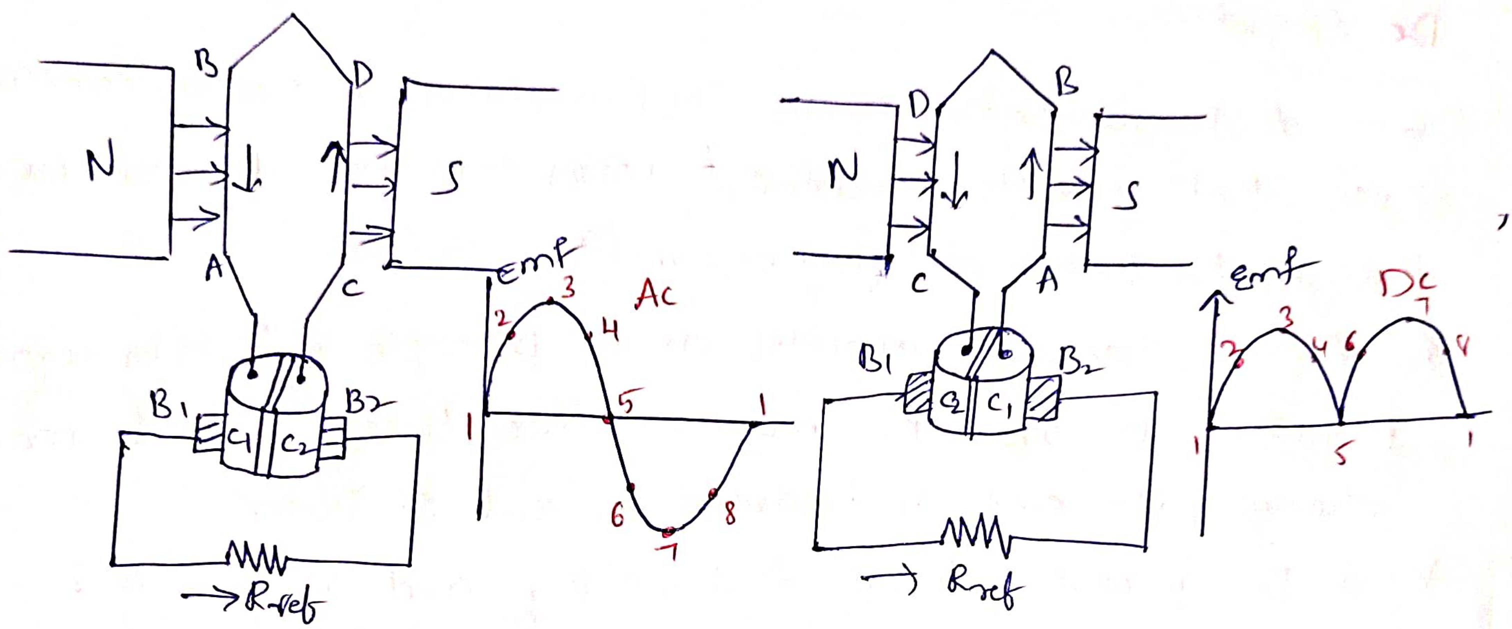
1. Yoke, 2. Armature core, 3. Armature winding, 4. commutator, 5. Brushes, 6. Magnetic field system.

Principle of Dc generator:-

It works on the principle of "Electromagnetic Induction" ie, "when ever conductor cut the magnetic flux lines, the emf is induced in that conductor".

Operation of a DC Generator:-

* Consider a single loop DC generator as shown in the fig.



* In this a single turn loop 'ABCD' is rotating clockwise in a uniform magnetic field with a constant speed.
* When the loop rotates, the magnetic flux linking the coil sides 'AB' and 'CD' changes continuously.
* This change in flux linkage induces an EMF in coil sides and the induced EMF in one coil side adds the induced EMF in the other.
* The EMF induced in a DC Generator can be explained as follows.

a) When the loop is in position-1, the generated EMF is zero because, the movement of coil sides is parallel to the magnetic flux.

b) When the loop is in position-2, the coil sides are moving at an angle to the magnetic flux and hence, a small EMF is generated.

c) When the loop is in position-3, the coil sides are moving at right angle to the magnetic flux, therefore the generated EMF is maximum.

d) when the loop is in position – 4, the coil sides are cutting the magnetic flux at an angle, thus a reduced EMF is generated in the coil sides.

e) when the loop is in position – 5, no flux linkage with the coil side and are moving parallel to the magnetic flux. Therefore, no EMF is generated in the coil.

f) At the position – 6, the coil sides move under a pole of opposite polarity and hence the polarity of generated EMF is reversed.

g) The maximum EMF will generate in this direction at position – 7 and zero when at position – 1.

This cycle repeats with revolution of the coil.

* It is clear that the generated EMF in the loop is alternating one.
* It is because any coil side (say AB) has EMF in one direction when under the influence of N-pole and in the other direction when under the influence of S-pole.
* Hence, when a load is connected across the terminals of the generator, an alternating current will flow through it.
* Now, by using a commutator, this alternating emf generated in the loop can be converted into direct voltage.

This is DC Generator.

EMF equation of DC Generator:-

when the armature of a DC generator rotates in magnetic field, an Emf is induced in the armature winding, this induced Emf is known as generated Emf. It is denoted by E_g.

Derivation of EMF Equation of DC generator:-

let

ϕ = Magnetic flux per pole in Wb.

Z = Total number of armature conductors.

The magnetic flux cut by one conductor in one revolution of the armature being,

ϕ = Magnetic flux per pole in wb

$d\phi = P \times \phi$ Wb

Time taken in completing one revolution is given by,

$$dt = \frac{60}{N} \text{ seconds.}$$

Hence, according to law of electromagnetic induction, the Emf generated per conductor is,

$$E_g / \text{conductor} = \frac{d\phi}{dt} = \frac{P\phi}{60/N} = \frac{P\phi N}{60}$$

Since, the number of conductors in series per parallel path is,

No. of conductors / parallel path = Z/A

Therefore,

Total generated EMF, E_g = EMF per parallel path.

$$E_g = (E_g / \text{conductor}) \times \frac{\text{No. of conductors}}{\text{parallel paths}}$$

$$E_g = \left(\frac{P\phi N}{60}\right)\left(\frac{Z}{A}\right)$$

The emf equation of a DC generator, $\boxed{E_g = \frac{\phi Z N}{60} \times \frac{P}{A}}$

where P = number of poles in the machine.

A = number of parallel paths.

N = speed of armature in RPM.

$A = P \rightarrow$ for LAP winding.

$A = 2 \rightarrow$ for wave winding.

For any dc generator, Z, P and A are constant.

So, $E_g \propto N\phi$

* In a DC generator, the induced EMF in the armature is directly proportional to the flux per pole and speed of rotation.

Case 1:- For lap winding, $A=P$, $\boxed{E_g = \frac{\phi Z N}{60}}$

Case 2:- For wave winding, $A=2$,

$$\boxed{E_g = \frac{\phi Z N P}{120}}$$

OCC characteristics of DC generator:-

* The open circuit characteristics (O.C.C) or magnetization characteristic's is the curve that shows the relationship between the generated EMF at No-load (E_0) and the field current (I_f) at constant speed.

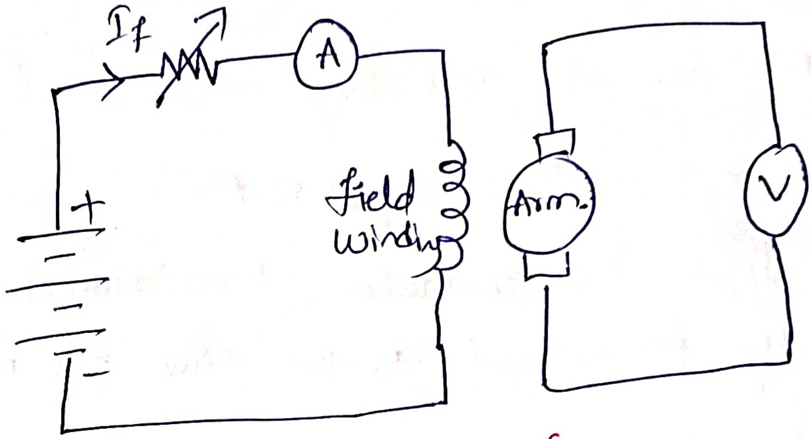
* It is also known as no-load saturation curve.

* Its shape practically the same for all types of DC generator whether separately excited or self excited.

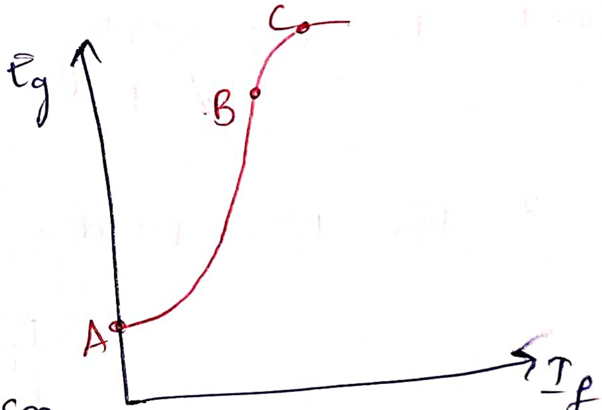
* In order to determine the open circuit characteristics of a DC generator, the field winding is excited by an external

DC source.

* The generator is run at its normal speed.
* The field current (I_f) is increased gradually from zero and the corresponding values of generated EMF at no-load (E_0) is noted from a voltmeter connected across the armature terminals.



* On plotting the relation between the E_0 and I_f, we obtain the open circuit char's as shown in the figure.
* Following points can be observed from the OCC curve–



a) Initially the field current is zero, there being some generated emf OA, which is due to the residual magnetism.

b) From point A to B, the curve is linear. It is because in this range, the reluctance of iron core is negligible as compared to the air gap. The reluctance of air gap is constant and hence it has linear relationship.

c) After point B, the reluctance of iron also comes into picture. Since, at higher flux densities, the relative permeability (μ_r) of the iron decreases and hence the reluctance of iron is no longer negligible. This results in the deviation of the curve from the linear relationship.

d) After point C, the pole cores begins to saturate magnetically and the generated emf (E_0) at no-load tends to level off.

Principle and operation of Dc motor:-

A Dc motor is an Electromechanical Energy conversion device, which converts Electrical Energy input into the mechanical Energy output.

* A Dc motor operates on the principle of "Electromagnetic induction", ie, whenever current carrying conductor cut the magnetic field lines, it experience a force.
* The magnitude of force is given by,

$$\boxed{F = BIL \text{ Newtons}}$$

B → magnetic flux density
I → current
L → Length of the conductor.

* The direction of this force is given by "Flemings left hand Rule".
* A Dc motor has a field winding and an armature winding.

Flemings left hand Rule:-

Middle finger: Direction of current.
Thumb finger: Direction of force
Fore finger: Direction of magnetic field lines.

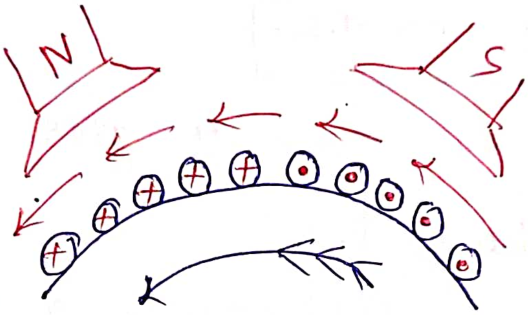
Parts of a Dc motor:-

A Dc motor consists of six main parts.

1. Yoke, 2. Armature core, 3. Armature winding
4. Commutator, 5. Brushes, 6. magnetic field system.

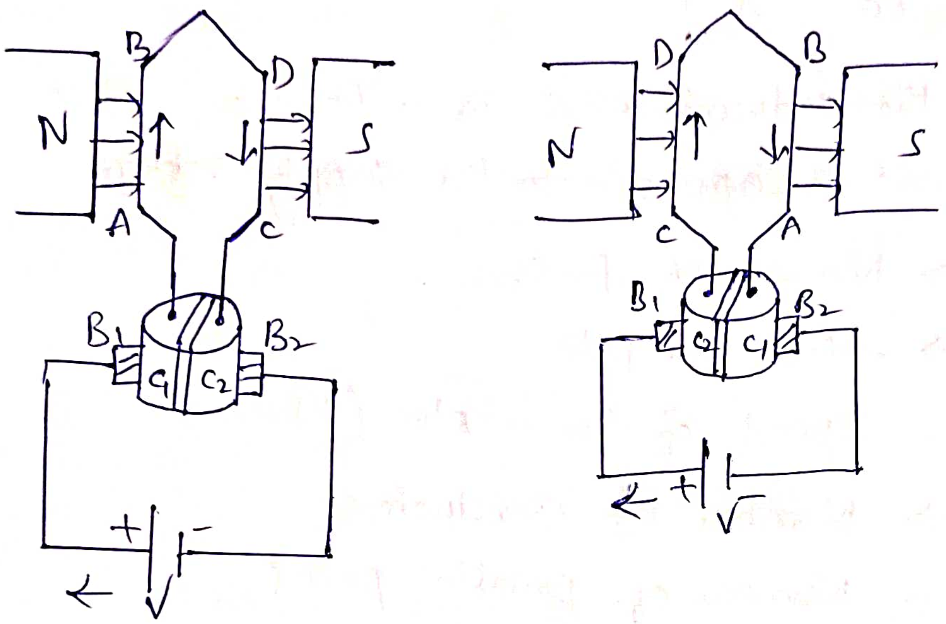
Working of DC motor:-

* Consider a part of a multipolar DC motor as shown in the figure below.
* When the terminals of the motor are connected to an external source of DC supply.
  - The field magnets are excited developing alternate North and south poles.
  - The armature conductors carry currents.



* All conductors under North-pole carry currents in one direction while all the ~~~~ conductors under south-pole carry currents in the opposite direction.
* The armature conductors under N-pole carry currents into the plane of the paper (denoted as ⊗ in the figure). A
* And the conductors under S-pole carry currents out of the plane of the paper (denoted as ⊙ in the figure).
* Since each armature conductor is carrying current and is placed in the magnetic field, a mechanical force acts on it.
* On applying "Fleming's left-hand rule", it is clear that force on each conductor is tending to rotate the armature in the anticlockwise direction.
* All these forces add together to produce a 'driving torque' which sets the armature rotates.

Principle of operation of DC motor:-



* When the motor armature rotates, the conductors also rotate and hence cut the flux.
* In accordance with the laws of Electromagnetic Induction, Emf is induced in the conductors, and it is found by "flemings Right hand rule", is in opposite direction to the applied voltage.
* Because of its opposing direction, it is referred to as "counter Emf" or "back emf" E_b.
* The Rotating armature generating the back emf. E_b is like a battery of emf E_b put across a supply mains of 'V' volts.
* As the armature rotates, a voltage is generated in its coils. In the case of a generator, the emf of rotation is called "the Generated emf" or "Armature Emf" and it is denoted by "E_g".

* In the case of a motor, the emf of rotation is known as "Back emf" or "Counter Emf", and it is represented by "E_b".

$$\boxed{E_b = \frac{\phi Z N}{60} \times \frac{P}{A}} \text{ volts.}$$

In a motor, the induced emf is called as "Back emf E_b," because it acts as opposite to the supply voltage.

where $P \rightarrow$ Number of poles

$\phi \rightarrow$ flux per pole

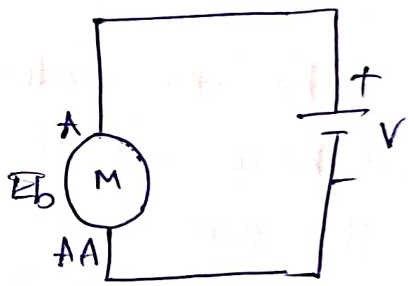
$N \rightarrow$ speed of the motor (RPM)

$Z \rightarrow$ Number of conductors

$A \rightarrow$ Number of parallel paths.

$$E_b \propto \phi N$$

$$\boxed{E_b = K\phi N}$$



$$V = E_b + I_a R_a$$

Back emf, $\boxed{E_b = V - I_a R_a}$

$V \rightarrow$ supply voltage

$I_a \rightarrow$ Armature current

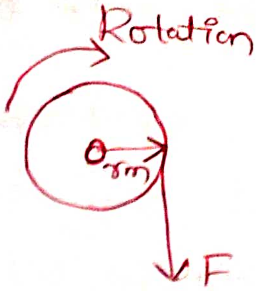
$R_a \rightarrow$ Armature Resistance

$$K\phi N = V - I_a R_a$$

$$* \boxed{N = \frac{V - I_a R_a}{K\phi}}$$

The above relation shows that the speed of a DC motor can be controlled through change in voltage, flux and armature Resistance.

Torque equation of DC motor :-



$$\omega = \frac{2\pi N}{60} \text{ rad/sec}$$

Torque, $\tau = F \times r$, N-m

$= F \times$ distance moved

$= F \times 2\pi r$ joules.

$2\pi r \rightarrow$ perimeter of the circle

$$\text{power, } P = \frac{\text{work done}}{\text{time}}$$

$$= \frac{2\pi r \times F}{\text{time for 1 rev}} = \frac{F \times 2\pi r}{(60/N)}$$

$\left(\because \text{rpm} = 60,\ \text{rps} = \frac{N}{60},\ \text{time for 1 revolution} = \frac{60}{N} \right)$

$$P = (F \times r) \cdot \frac{2\pi N}{60}$$

$$P = \tau \times \frac{2\pi N}{60} \text{ watts}$$

power in armature = Power at o/p ($E_b I_a$)

$$E_b I_a = \tau \times \frac{2\pi N}{60}$$

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

$$\frac{\phi Z \cancel{N} P}{\cancel{60} A} \times I_a = \tau \times \frac{2\pi \cancel{N}}{\cancel{60}}$$

$$\boxed{\tau = \frac{1}{2\pi} \phi I_a \cdot \frac{PZ}{A}} \text{ N-m}$$

$$\tau = 0.159\, \phi I_a Z \left(\frac{P}{A} \right) \text{ N-m}$$

$$\boxed{\tau \propto \phi I_a}$$

Speed control of Dc motor:-

Back emf 'E_b' of a Dc motor is nothing but the induced emf in armature conductors due to rotation of the armature in magnetic field.

Thus, the magnitude of E_b can be given by "Emf equation of a Dc Generator".

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

E_b can also be given as, $E_b = V - I_a R_a$

thus, From the above equations,

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

but, for a Dc motor A, P and Z are constants.

Therefore, $N \propto \frac{E_b}{\phi}$ [where $k \rightarrow$ constant]

This shows the speed of a Dc motor is directly proportional to the back emf (E_b) and inversly proportional to the flux per pole.

$$N \propto \frac{V - I_a R_a}{\phi}$$

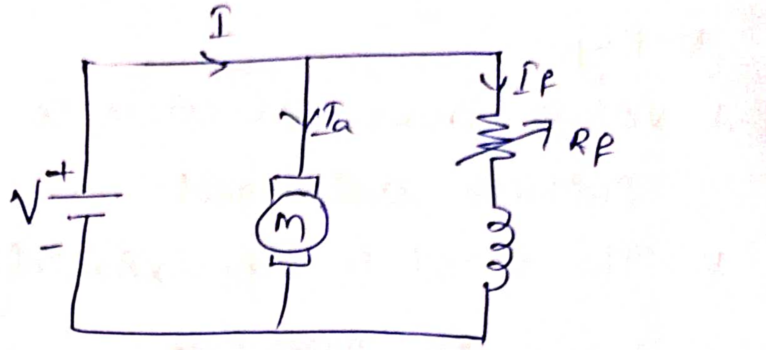
Speed controlling methods are 3 types.

1) Voltage control method
2) Armature control method
3) flux control method.

Speed control methods of DC motor:-

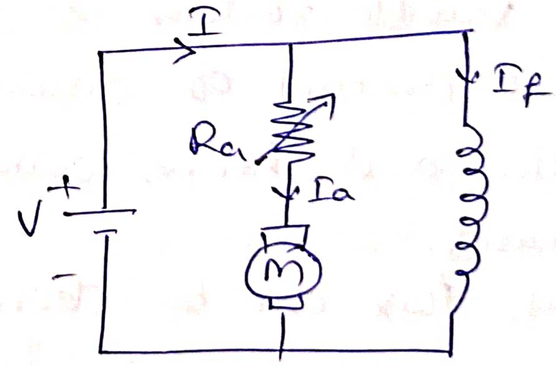
Speed control of shunt motor:-

1) flux control method:-



* It is already that the speed of a dc motor is inversely proportional to the flux per pole.
* By decreasing the flux, speed can be increased and viceversa
* To control the flux, a rheostat is added in series with the field winding as shown.
* Adding more resistance in series with the field winding will increase the speed as it decreases the flux.
* In shunt motors, as field current is relatively very small, $I_{sh}^2 R_{sh}$ loss is small.
* This method is quite efficient.

2. Armature control method:-



* Speed of a dc motor is directly proportional to the back emf, Eb and $E_b = V - I_a R_a$
* When the supply voltage 'V' and the armature resistance 'Ra' are kept constant, then the speed is directly proportional to arm. current Ia.
* If, we add resistance in series with the armature, Ia decreases and, hence, the speed also decreases.
* Greater the resistance in series with the armature, greater the decrease in speed.

3. Voltage control method:-

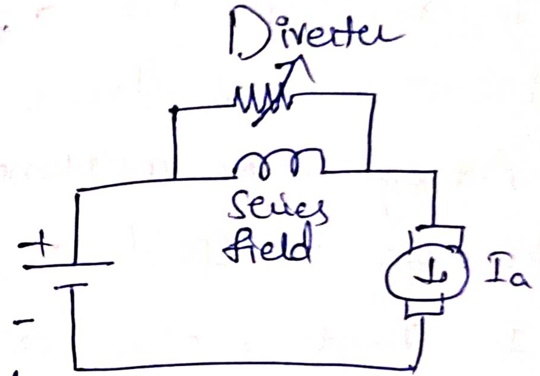
In this method, the shunt field is connected to a fixed exciting voltage and armature is supplied with different voltages.

* Voltage across armature is changed with the help of suitable switchgear.
* The speed is approximately proportional to the voltage across the armature.

Speed control of series motor:-

1) Flux control method:-

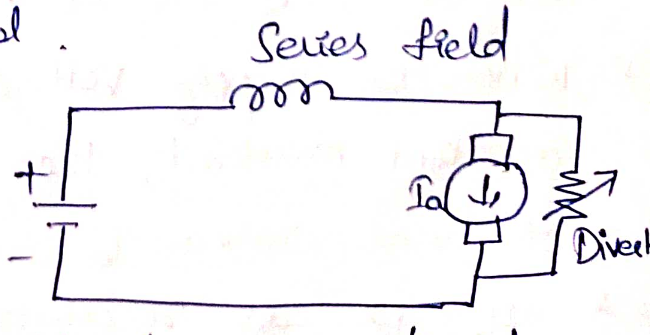
a) field diverter:-



(a) field diverter

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

b) Armature diverter:-



(b) Armature diverter

* Diverter is connected across the armature as shown in fig.
* For a given constant load torque, if armature current is ~~redu~~ reduced then the flux must increase, as $T_a \propto \phi I_a$.

Performance characteristics of Dc motors:-

Three characteristic curves are considered important for Dc motors which are,

(i) Torque Vs. Armature current (T Vs I_a)
(ii) Speed Vs. Armature current (N Vs I_a)
(iii) Speed Vs. Torque (N Vs. T).

These are explained below for each type off of Dc motor.

These characteristics are determined by keeping the following two relations in ~~we~~ mind.

$$T_a \propto \phi . I_a \quad \text{and} \quad N \propto \frac{E_b}{\phi}$$

Then above equations can be studied at emf and torque equation of dc machine.

* For a Dc motor, magnitude of the back emf is given by the same emf equation of a dc generator ie.,

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

For a machine P, Z and A are constant,

$$\therefore \boxed{N \propto \frac{E_b}{\phi}}$$

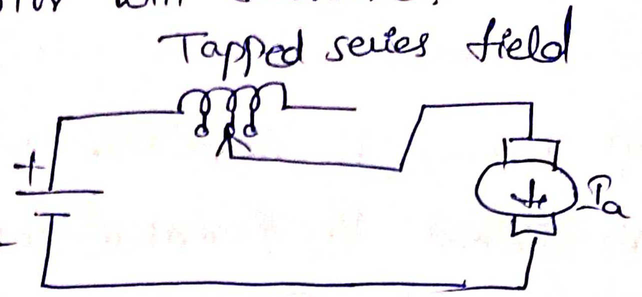
characteristics of DC Series motor:-

1) T Vs I_a:-

* This char's is also known as "Electrical characteristics".
* The torque is directly proportional to the product of arm. current and field flux. $\boxed{T_a \propto \phi . I_a}$

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

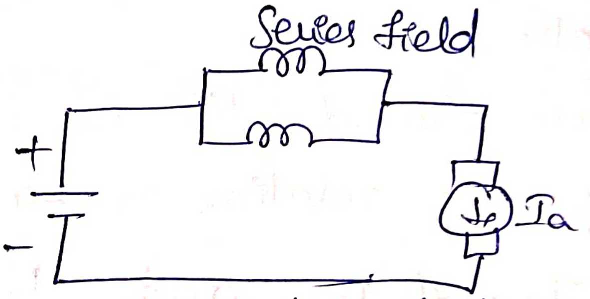
(c) Tapped field control:-



(c) Tapped field

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

(d) Parallel field coils:-



(d) paralleling field coils.

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

2. Variable Resistance in series with armature:-

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

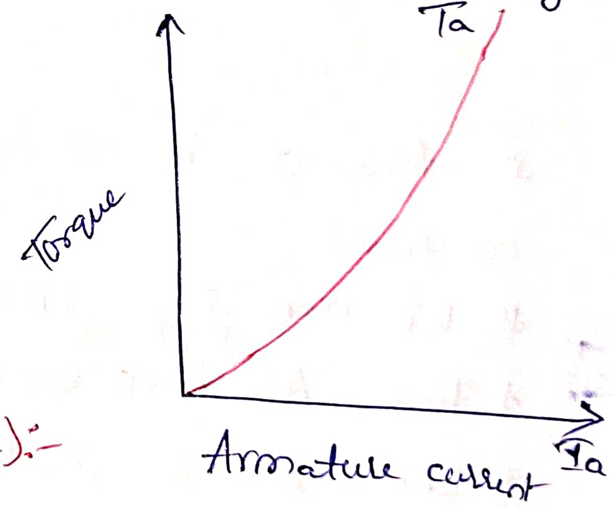
3. Series - parallel control:-

* This system is widely used in electric traction, where two or more mechanically coupled series motors are employed.
* For low speeds, the motors are connected in series, and for higher speeds, the motors are connected in parallel.
* When in series, the motors have the same current passing through them, although voltage across each motor is divided.
* When in parallel, the voltage across each motor is same although the current gets divided.

* In DC series motors, field winding is connected in series with the armature. i.e., $I_a = I_f$ 9
* Therefore, before magnetic saturation of the field, flux ϕ is directly proportional to I_a.
* Hence, before magnetic saturation $T_a \propto I_a^2$.

The $T_a - I_a$ curve is parabola for smaller values of I_a.

* After magnetic saturation of the field poles, flux ϕ is independent of armature current 'I_a'.
* Therefore, the torque varies proportionally to I_a only, $T \propto I_a$. Therefore, after saturation, $T_a - I_a$ curve becomes straight line.
* In DC series motors, torque increases as the square of armature current, these motors are used where high starting torque is required.



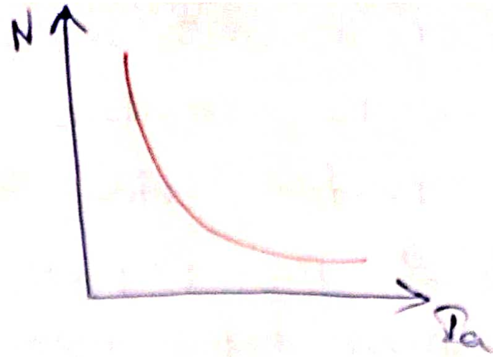
(2) Speed Vs. Armature current (N-Ia):-

We know the relation, $\boxed{N \propto \frac{E_b}{\phi}}$

* For small load current change in back emf 'E_b' is small and it may be neglected.
* Hence, for small currents speed is inversely proportional to ϕ. we know $\phi \propto I_a$. So $N \propto \frac{1}{\phi \propto I_a} \Rightarrow N \propto \frac{1}{I_a}$
* when 'I_a' is very small the speed becomes dangerously high.
* That is why a series motor should never be started

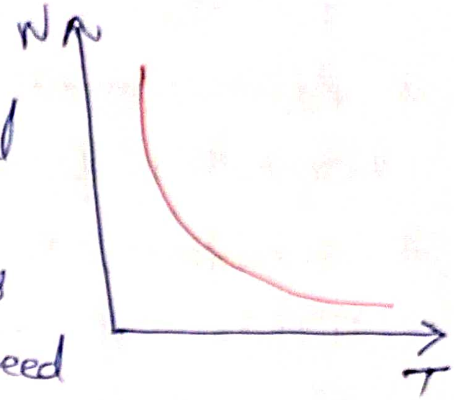
without some mechanical load.

* But, at heavy loads, I_a is large. And hence, speed is low which results in decreased back emf 'E_b'.
* Due to decreased E_b, more arm. current is allowed.



3) N-Ta char's:-

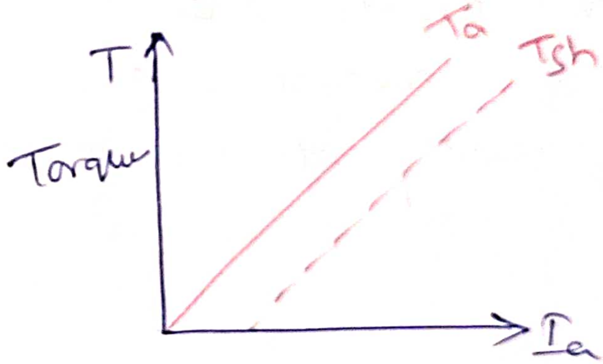
* This char's is also called as "mechanical char's".
* From the above two char's of DC series motor, it can be found that when speed is high, torque is low and vice versa.



char's of DC shunt motors:-

1) T- Ia char's:-

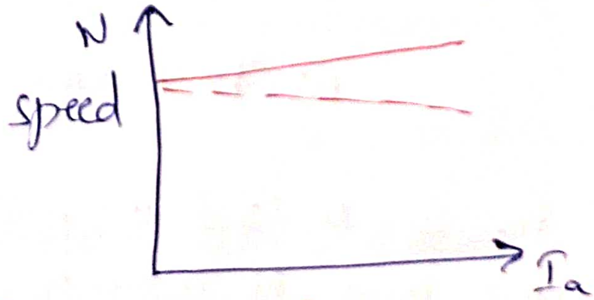
* flux ϕ, is assumed to be constant.
* We can say $N \propto E_b$.
* But, As back Emf is also almost constant.
* Shunt motors should never be started on a heavy load.



2) N- Ia char's:-

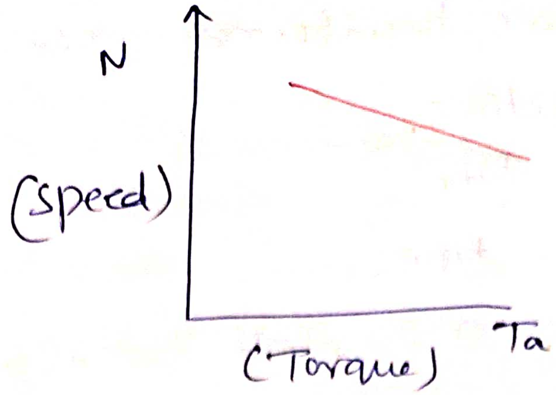
$\phi \rightarrow$ constant

$N \propto E_b$, E_b almost constant

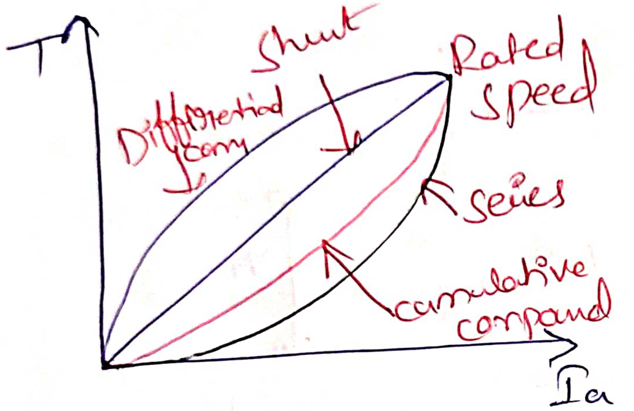


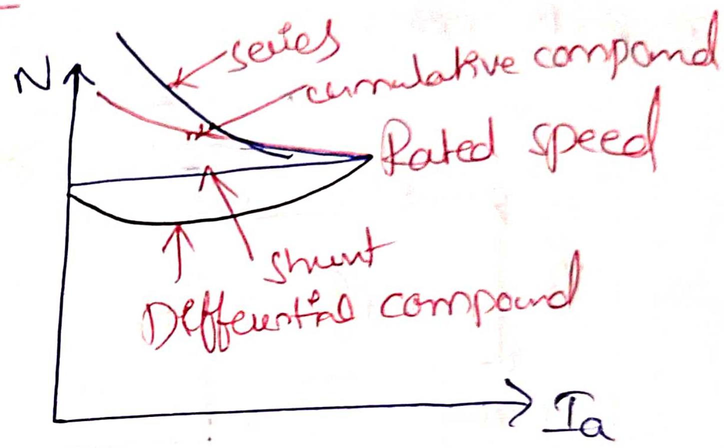
* But practically, ϕ as well as E_b decreases with increase in load.
* E_b decreases slightly more than ϕ, the 'N' decreases slightly.
* The straight horizontal line represents the ideal char's & actual char's is shown by dotted line.

3) T–N char's:-



Char's of DC compound motor:-





The above char's represents the char's of DC compound motor.

Principle and operation of 1-Ø Transformer:-

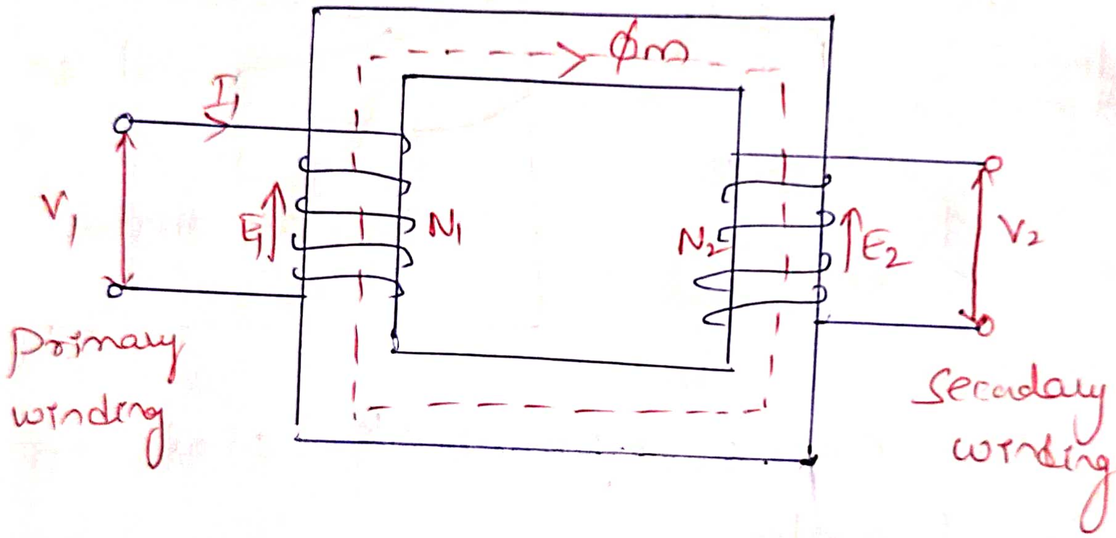
* A single phase transformer consists of two windings
  1) primary winding
  2) secondary winding put on a magnetic core.
* The magnetic core is made from thin sheets (called laminations) of high graded silicon steel and provides a definite path to the magnetic flux.
* These laminations reduce the eddy-current losses while the silicon steel reduces the hysteresis losses.

* For a single phase transformer, there are two types of transformer constructions.

1) core type
2) Shell type.

Working principle of single phase transformer:-

* The working of the transformer is based on the principle of mutual inductance between two coils wound on the same magnetic core.



* When an alternating voltage (V_1) is applied to the primary winding, an alternating magnetic flux (ϕ_m) sets up in the core and links with the secondary winding.
* i.e., the magnetic flux links both the windings of the transformer magnetically
* This magnetic flux induces EMF E_1 in the primary winding and E_2 in the secondary winding according to "Faraday's law of Electromagnetic Induction".

According to Lenz' law,

$$E_1 = -N_1 \frac{d\phi_m}{dt} \rightarrow (1)$$

Secondary Emf, $E_2 = -N_2 \frac{d\phi_m}{dt} \rightarrow (2)$

From eq → ① & eq → ②

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} \rightarrow ③$$

* From the above equations, it is clear that the induced Emfs in the primary and secondary windings depends upon the number of turn of the winding.
* If $N_1 > N_2$, then $E_2 > E_1$ ie., the primary Emf is greater than the secondary Emf, the transformer is called as "step ~~up~~ down transformer".
* If $N_1 < N_2$, then $E_1 < E_2$ ie., the primary Emf is less than the secondary EMF, the transformer is called as "step up transformer".
* If a load is connected across the terminals of the secondary winding, the secondary EMF causes a current I_2 to flow through the load.
* In this way, a transformer transfers AC power from one circuit to another circuit with a change in voltage level without any electrical connection between both the circuits ie., the power from input circuit to output circuit transfers magnetically.
* During this transfer of electrical power, the frequency does not change.

OC and SC Test on transformer:-

Open and short circuit tests are performed on a transformer to determine the,

1) Equivalent circuit of transformer
2) Voltage Regulation of transformer
3) Efficiency of transformer.

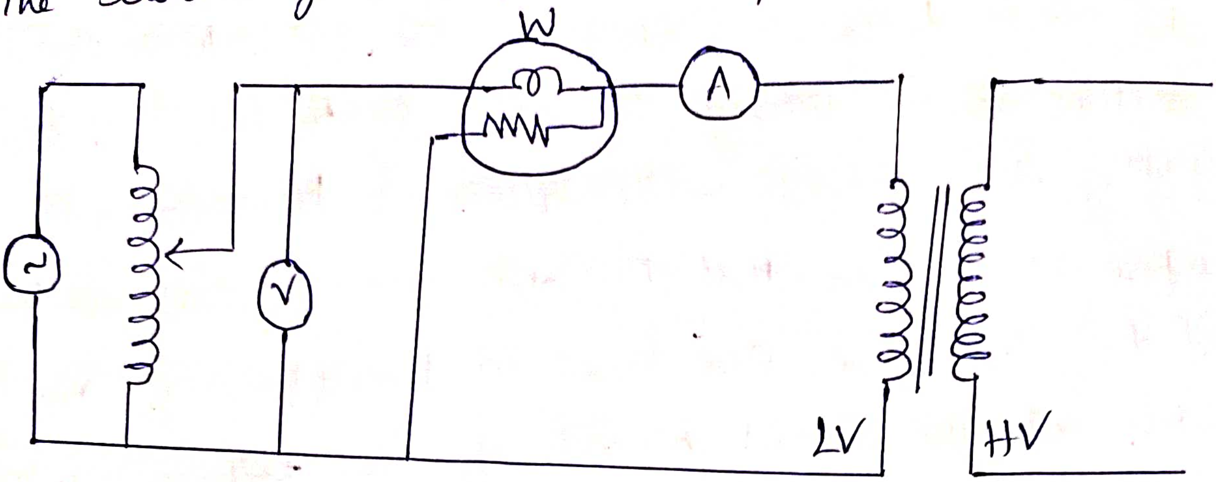
The power required for open circuit tests and short circuit tests on a transformer is equal to the power loss occuring in the transformer.

Open circuit test on Transformer:-

The connection diagram for open circuit test on transformer is shown in figure.

* A voltmeter, wattmeter and an ammeter are connected in LV side of the transformer as shown.
* The voltage at rated frequency is applied to that LV side with the help of a variac of variable ratio auto transformer.
* The HV side of the transformer is kept open. Now with the help of variac, applied voltage gets slowly increased ~~until~~ until the voltmeter gives reading equal to the rated voltage of the LV side.
* After reaching rated LV side voltage, we record all the three instruments reading. (Voltmeter, Ammeter & wattmeter)
* The ammeter reading gives the no load current I_e. As no load current I_e is quite small compared to rated current of the transformer, the voltage drops due to this current negligible

The below figure shows the open circuit test on Transformer,



* Since voltmeter reading V_1 can be considered equal to the secondary induced voltage of the transformer, wattmeter reading indicates the input power during the test.

* As the transformer is open circuited, there is no output, hence the input power here consists of core losses in transformer during no load condition.

* But as said earlier, the no-load current in the transformer is quite small compared to the full load current so, we can neglect the copper loss due to the no-load current.

* Hence, can take the wattmeter reading as equal to the core losses in the transformer.

Let us consider wattmeter reading is P_o.

$$\boxed{P_o = \frac{V_1^2}{R_m}}$$

$R_m \rightarrow$ Shunt branch resistance of transformer.

If, Z_m is shunt branch impedance of transformer

then, $\boxed{Z_m = \frac{V_1}{I_e}}$

Therefore, if shunt branch reactance of transformer is X_m,

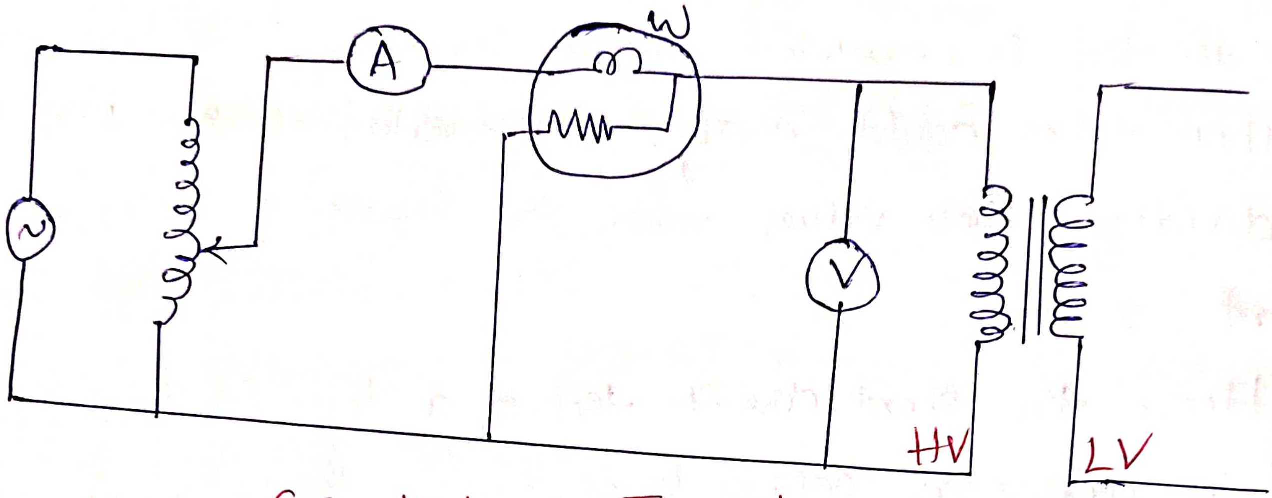
Then, $\left(\frac{1}{X_m}\right)^2 = \left(\frac{1}{Z_m}\right)^2 - \left(\frac{1}{R_m}\right)^2$

* These values are referred to the LV side of the transformer due to the tests being conducted on the LV side of transformer.
* These values could easily be referred to HV side by multiplying these values with square of transformation ratio.
* Therefore it is seen that the open circuit test on transformer is used to determine core losses in transformer and parameters of the shunt branch of the equivalent circuit of the transformer.

Short circuit test on Transformer:-

* The connection diagram for the short circuit test on the transformer is shown in figure below.
* A voltmeter, wattmeter, and an ammeter are connected in HV side of the transformer as shown.
* A low voltage of around 5-10% is applied to that HV side with help of a variac (ie., a variable ratio auto transformer).
* We short circuit the LV side of the transformer.
* Now with the help of variac applied voltage is slowly increased until the wattmeter, and an ammeter gives reading equal to the rated current of the HV side.
* After reaching the rated current of the HV side, we record all the three instrument readings (voltmeter, ammeter & wattmeter readings).
* The ammeter reading gives the primary equivalent of full load current.
* As the voltage applied for full load current in a

short circuit test on the transformer is quite small compared to the rated primary voltage of the transformer, the core losses in the transformer can be taken as neglected.



SC test on Transformer

* Let's say, Voltmeter reading is V_{sc}.
* The wattmeter reading indicates the input power during the test.
* As we have short-circuited the transformer, there is no output; hence the input power here consists of copper losses in the transformer.
* Since the applied voltage V_{sc} is short circuit voltage in the transformer and hence it is quite small compared to the rated voltage.
* So, we can neglect the core loss due to the small applied voltage.
* Hence, the wattmeter reading can be taken as equal to copper losses in the transformer.

Let us consider wattmeter reading is P_{sc}.

$$\boxed{P_{sc} = R_e I_L^2}$$

where, R_e is equivalent resistance of transformer.

If, Z_e is equivalent Impedance of transformer, $\boxed{Z_e = \frac{V_{sc}}{I_L}}$

Therefore, if equivalent reactance of transformer is X_e.

Then, $\boxed{X_e^2 = Z_e^2 - R_e^2}$

* These values are referred to the HV side of the transformer as the test is conducted on the HV side of the transformer.
* These values could easily be converted to the LV side by dividing these values with the square of transformation ~~and~~ ratio.
* Hence the short circuit test of a transformer is used to determine copper losses in the transformer at full load.
* It is also used to obtain the parameters to approximate the equivalent circuit of a transformer.