EEP 225 : Electric Machines

Lecture 2
DC Machines II

1 EMF Generated In An Armature Winding

let :

Z = Number of armature conductors.
ϕ = Useful flux per pole, in Webers (Wb)
P = Number of poles
N = Armature speed in rpm (revolution per minute)
a = Number of armature parallel paths.(either 2 or P)
Z/a = Number of conductor per path

So how can we find the volt generated by the armature?
the volt generated by the armature equals the volt generated by one of the parallel paths

- Remember: Faraday's law:

$$\text{emf} = -N\frac{\Delta\phi}{\Delta t}$$

emf = inducted voltage
N = number of turns
$\Delta\phi$ = change in magnetic flux
Δt = change in time

How to find change in magnetic flux ?

we find the flux cut by one conductor per one revolution:

which equals $P \times \phi$ (Weber).

therefore the flux cut by one conductor per second, we substitute in Faraday's law :

$$\begin{aligned}\text{emf}_{\text{conductor}} &= -N\frac{\Delta\phi}{\Delta t} \\ &= N\frac{P \times \phi}{60} \quad \text{(Weber/sec)}\end{aligned}$$

this is the emf generated by one conductor (which is pretty small), so the total emf between brushes equals (emf per conductor)×(number of conductors in series per path)

$$E_a = N\,\frac{P \times \phi}{60} \times \frac{Z}{a}$$

Rearranging:

$$\boxed{E_a = \frac{P}{a} \times \phi \times Z \times \frac{N}{60} \quad \text{(volt)}}$$

$\boxed{\text{1. Q}}$ — As an engineer, how to increase (control) the emf of a manufactured machine

A — Since number of Number of armature conductors (Z), Number of poles (P) and number of armature parallel paths (a) uncontrollable. we can only only control the flux (ϕ) by increasing the current I_f in the electro-magnet, and the armature speed (N)

$$E_a \propto \phi \; N$$

$$\boxed{E_a = K \; \phi \; N}$$

Note[1]:

$$\underbrace{E_a}_{\text{electrical term}} = K \underbrace{\phi}_{\text{magnetic term}} \underbrace{N}_{\text{mechanical term}}$$

What if I want to have a pure electro-mechanical equation?
We Know that :

$$\phi \; \propto \; I_f$$

$$\therefore E_a \propto I_f \; N$$

$$\boxed{\frac{E_2}{E_1} = \frac{I_{f\,2}}{I_{f\,1}} \times \frac{N_2}{N_1}}$$

We can use angular speed (ω [rad/ sec]) instead of (N [revolution/min])

[1] • Remember : Magnetic fields are the fundamental mechanism by which energy is converted from one form to another in motors, generators, and transformers. Note how magnetic field is necessary in the process of electro-mechanical conversion

- Remember :

$$\omega = 2\,\pi \times \frac{N}{60}$$

therefore:

$$\begin{aligned} E_a &= K\frac{60}{2\pi} \times \ \phi\, N \\ &= K_a\, \phi\, N \end{aligned}$$

$$K_a = \frac{P\,Z}{2\,\pi\,a} \quad \text{(V/Wb-rad/sec)}$$

K_a : Armature voltage constant

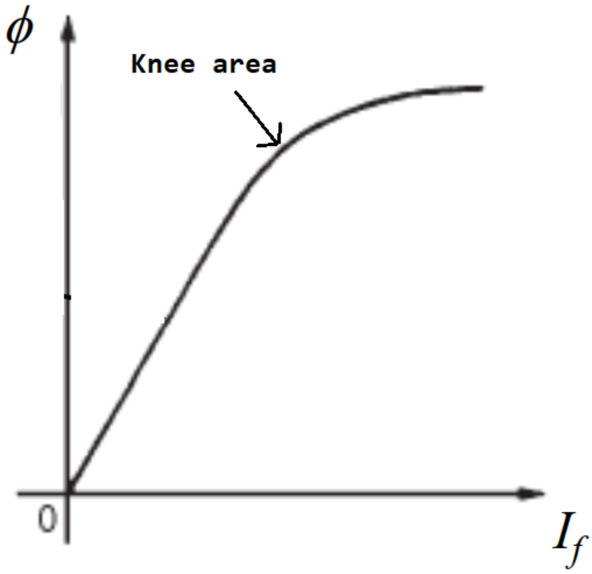

Figure 1: Relation between I_f and ϕ, the relation starts linear, as I_f increases till a point, ϕ saturates, we operate machines in the linear region to avoid saturation, as it is harder to control non linear machines

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$\boxed{\text{2. Q}}$ — A 4-pole generator has a total of 1440 conductors and a flux per pole of 4.6 mWb. When it is driven at 1200 rpm, the generated voltage is 265V.
Is the armature wound lap or wave?

A —

$$E_a = \frac{P}{a} \times \phi \times Z \times \frac{N}{60}$$
$$256 = \frac{4}{a} \times 4.6 \times 10^{-3} \times 1400 \times \frac{1200}{60}$$
$$\therefore a = 2$$

$\therefore$ Armature is wave wound[2]

$\boxed{3.\ \text{Q}}$ — A DC generator is found to develop an armature voltage of 200 V. If the flux is reduced by 25% and speed is increased by 40%. Find the new generated armature voltage.

A —

$$\frac{E_2}{E_1} = \frac{I_{f2}}{I_{f1}} \times \frac{N_2}{N_1}$$

$$\frac{E_2}{200} = \frac{0.75\, I_{f1}}{I_{f1}} \times \frac{1.4\, N_1}{N_1}$$

$$\therefore E_2 = 210\ V$$

2 Magnetization Curve of a DC Machine

$\boxed{4.\ \text{Q}}$ — How to measure the magnetization curve experimentally ?

A — It is hard to measure the flux, but because $E_a \propto \phi$ at constant speeds, it is easier to measure the open-circuit armature terminal voltage

- we rotate the DC machine at a given speed

[2]If $a = 4 = P$, then armature is lab wound

- then measure the open-circuit armature terminal voltage as the current in the field winding I_f is changed.

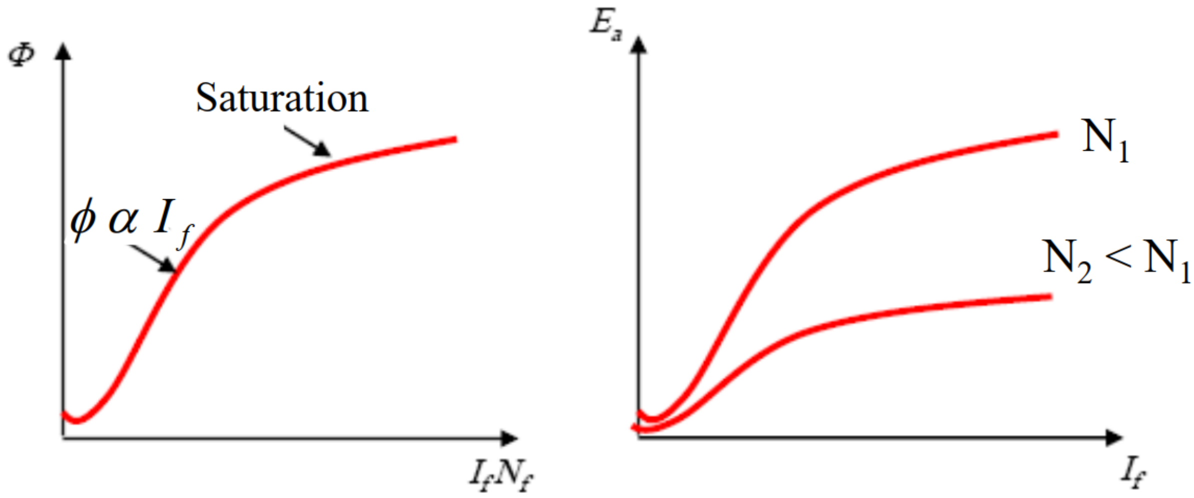

Figure 2: Magnetization curve

Note that the flux ϕ doesn't start at zero, because of the **Residual flux**.

$\boxed{\text{5. Q}}$ — What is Residual flux ?

A —

- Residual Magnetism or Residual flux: The magnetic flux density that remains in a material when the magnetic field is zero (switched off).
- This produces a small voltage which is called Residual Voltage.
- Iron can easily produce flux (be magnetized), but it is hard to loss magnetization.
- Residual flux is important in self excited generator as it will be shown later.

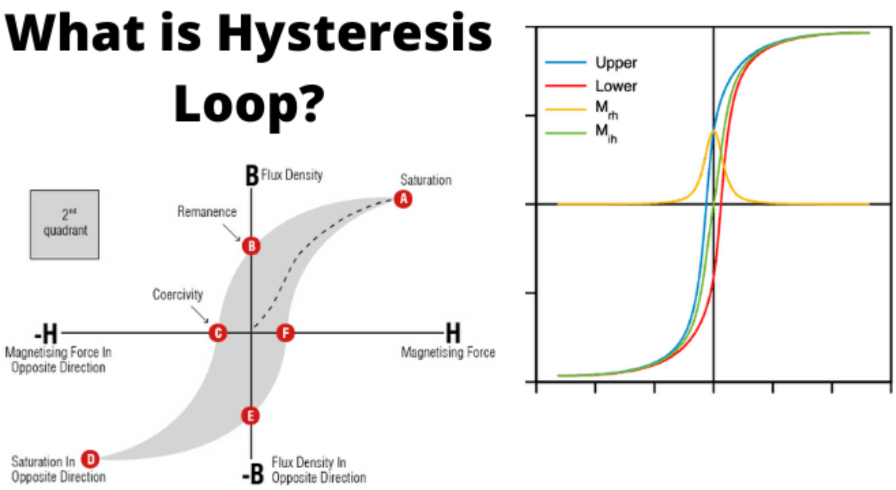

Figure 3: Magnetic hysteresis loop

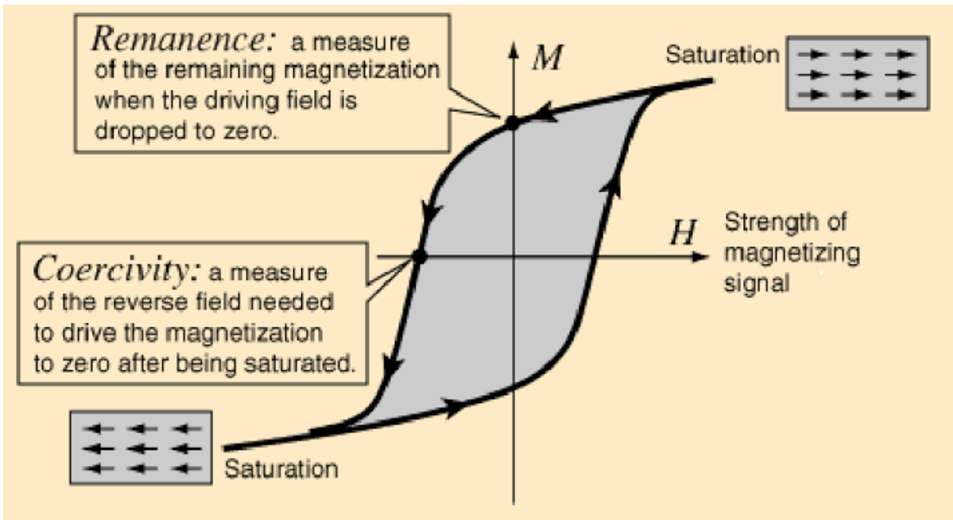

Figure 4: Magnetic hysteresis loop

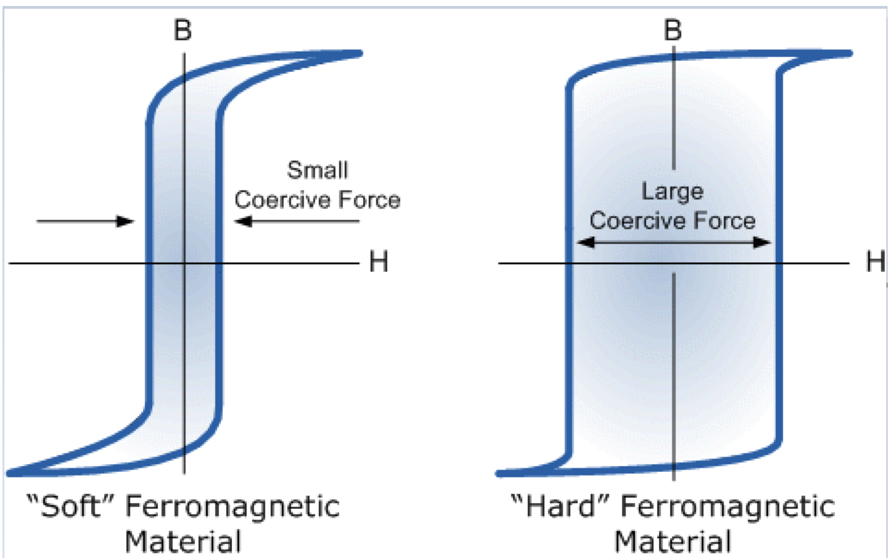

Figure 5: Magnetic hysteresis loop

Magnetic hysteresis loop area is lost, the thinner this area, the better the material is

3 Armature Reaction

Armature reaction is the effect of the armature field on the main field

In the machine, there are two sources of magnetic field, the first is from the coils in the stator (main field), the second in from the coils in the rotor (armature field).

At no load, there are no armature field, only main field exists (straight lines).

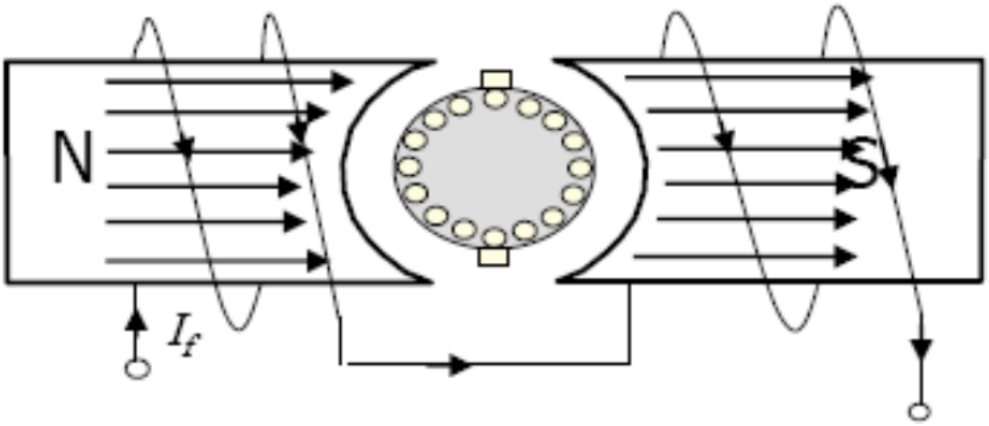

Figure 6: At no load, note the axis of the brushes is perpendicular to main field lines

in case of the existence of load, armature field exist because of current through the armature field (remeber right hand rule).

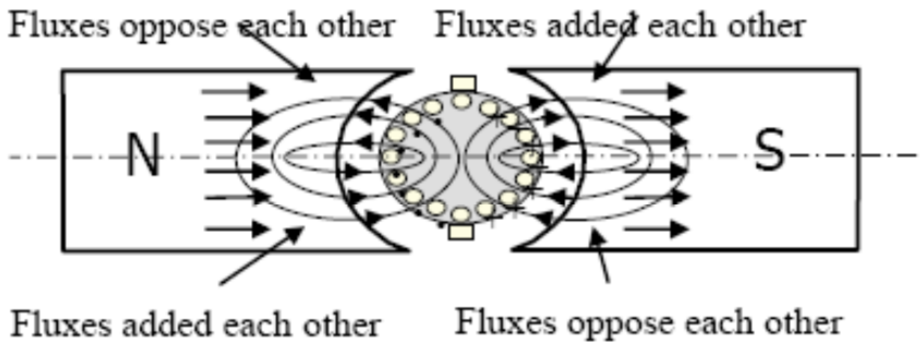

Figure 7: At load

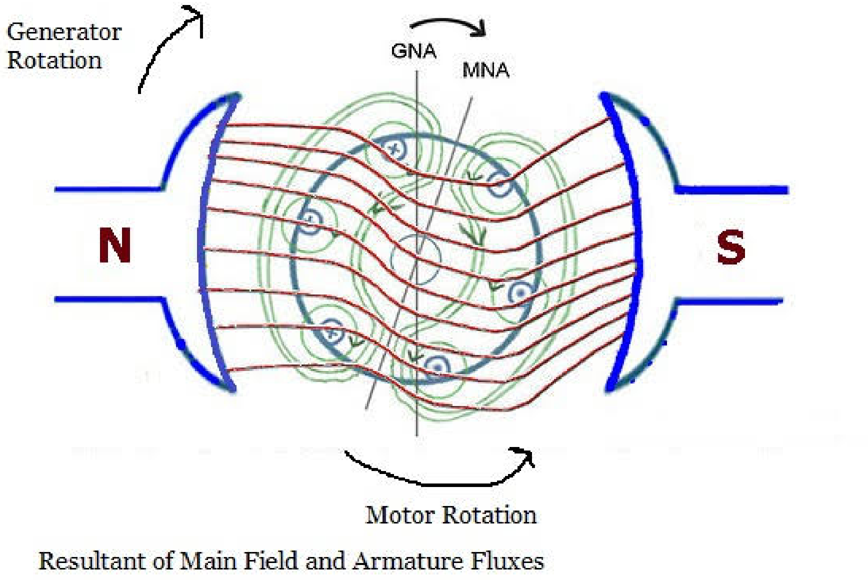

Figure 8: Armature Reaction

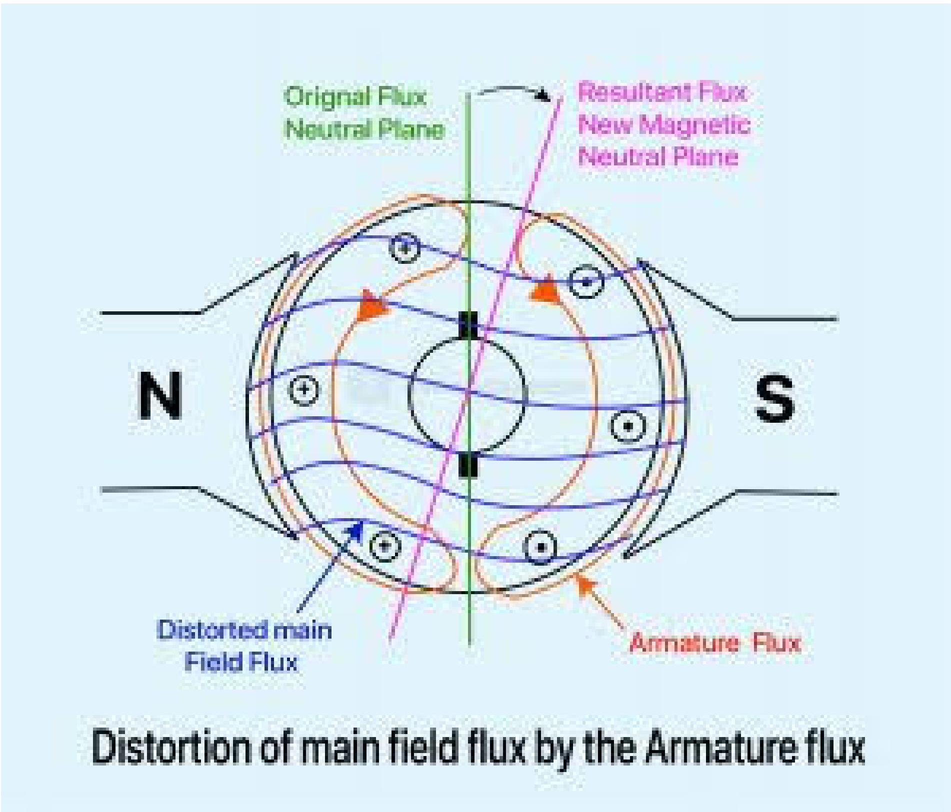

Figure 9: Armature Reaction

note that at 1st and 3rd quadrants fluxes added each other resulting in higher field, and at 2nd and 4th quadrants fluxes opposes each other resulting in lower field.

$\boxed{\text{6. Q}}$ — Disadvantages of Armature Reaction:

A —

- Demagnetizing effect (lower field)
- Cross magnetizing effect (distorted field)

$\boxed{\text{7. Q}}$ — How to compensate armature reaction?

A —

- Remember from the 1st lecture: usage of inter poles compensates the armature reaction
- we can move the brushes slightly to keep the brushes main axis perpendicular to the main field, but this method is not used anymore

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$\boxed{\text{8. Q}}$ — What is the goal of a machine designer engineer?

A — To establish a very strong magnetic field

4 Classification of DC Machines

There are four major types of dc generators, classified according to the manner in which their field flux is produced (i.e. according to the connection of the field winding with armature).

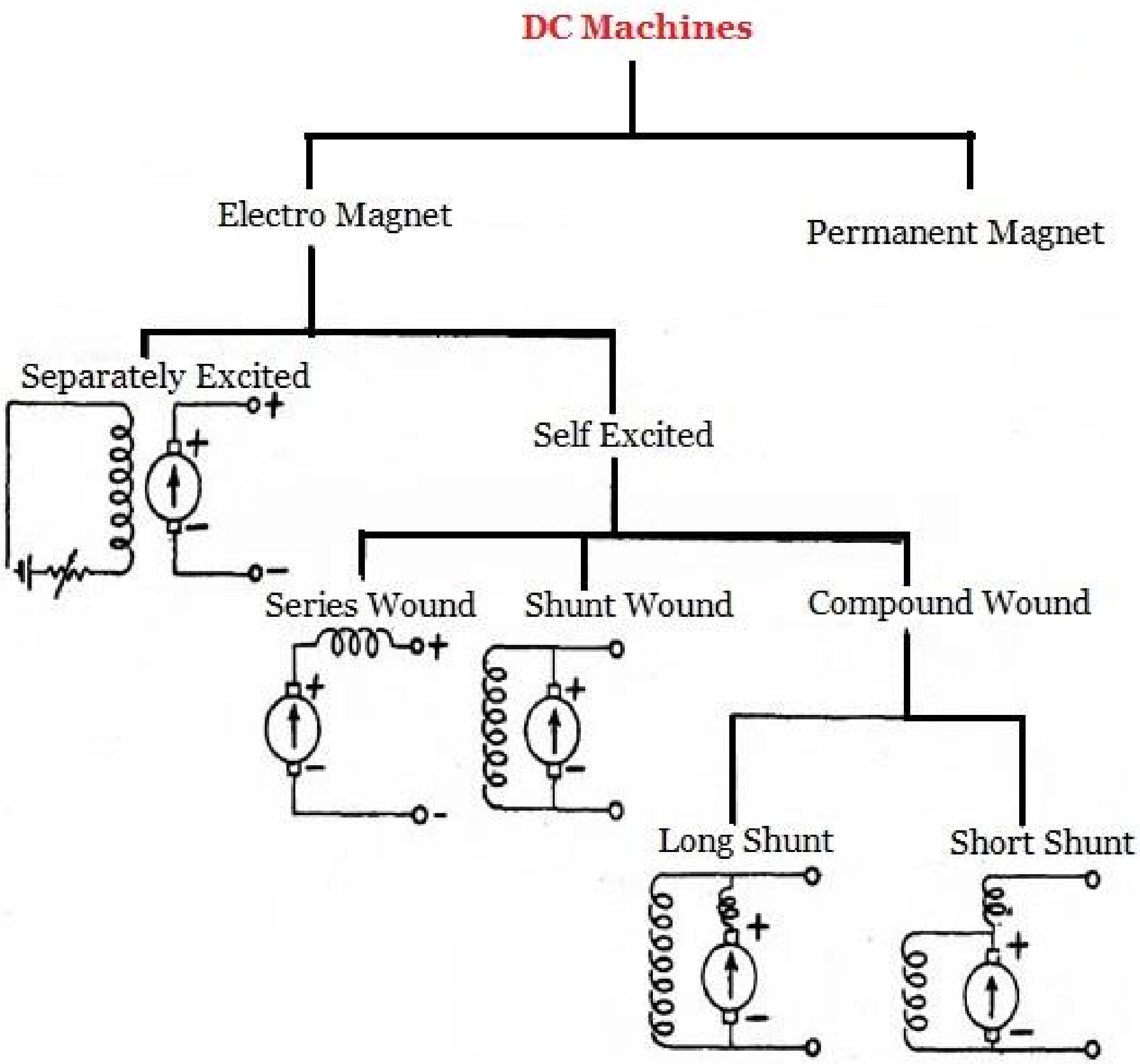

Figure 10: Classification of DC Machines

$\boxed{9.\ Q}$ — Describe the advantages an disadvantages of permanent magnet and electro magnet machine

A —

- Permanent magnets are uncontrollable, unlike electro magnets where you can control the flux by changing the current I_f
- Electro magnets are bigger and more expensive, unlike permanent magnets.That is because of existence of coils
- Therefore, there are no permanent magnet generators, because permanent magnets are smaller in size.

4.1 Separately Excited DC Generator

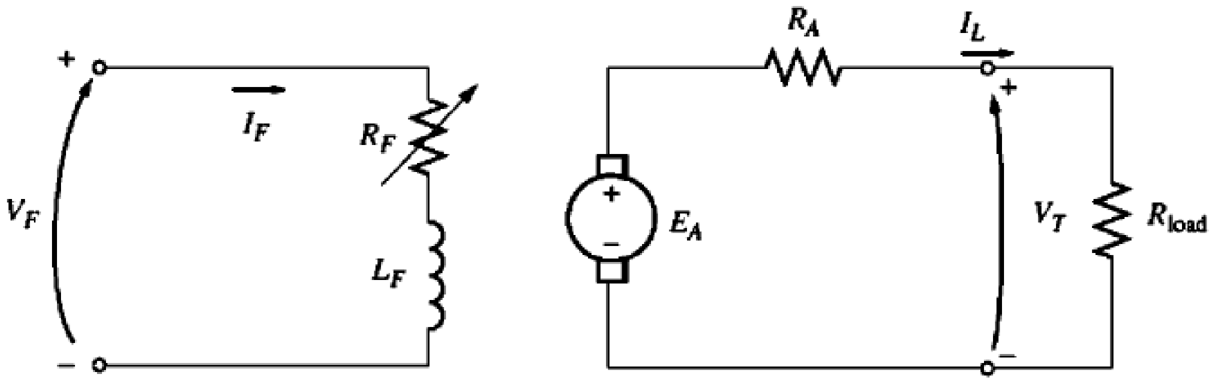

Figure 11: Separately excited DC generator model

Apply KVL

$$V_t = E_a - I_a\, R_a$$

$$V_f = R_f\, I_f \qquad I_a = I_l \qquad V_t = I_l\, R_l \qquad E_a = k_a\, \phi\, \omega_m$$

I_f, V_f, R_f	= field current, voltage and resistance.
I_l, R_l	= load current and resistance
V_t	= terminal voltage or load voltage.
I_a, R_a	= armature current and resistance.
E_a	is also known as back emf[3], induced emf or generated emf.
$I_a \times R_a$	= armature voltage drop.

Note the less the armature voltage drop, the better the machine is

4.1.1 Terminal Characteristics of a Separately Excited DC Generator

[4]

[4]When we the characteristics, we draw the output characteristics. For generators, we draw the voltage-current characteristics at the load. For Motors, we draw the torque-speed characteristics

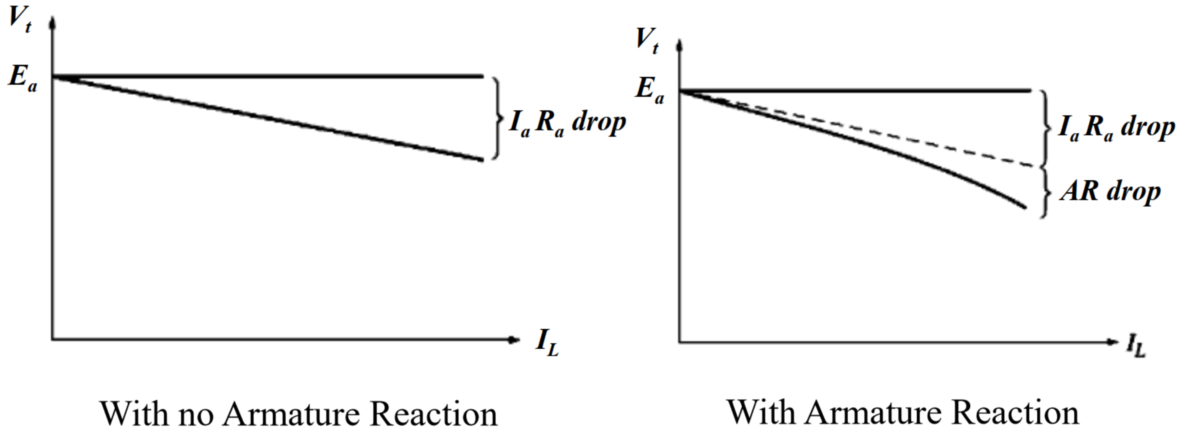

Figure 12: Terminal characteristics of a separately excited DC generator

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10. Q — How to overcome armature voltage drop?

A — The solution is not about the design of the machine, decreasing the armature voltage drop can be achieved by a control unit with feedback, whenever terminal voltage decreases, the control unit increases I_f.

4.2 Self Excited DC Generator

4.2.1 Shunt Generator

In a shunt generator, the field flux is derived by connecting the field circuit directly across the terminals of the generator.

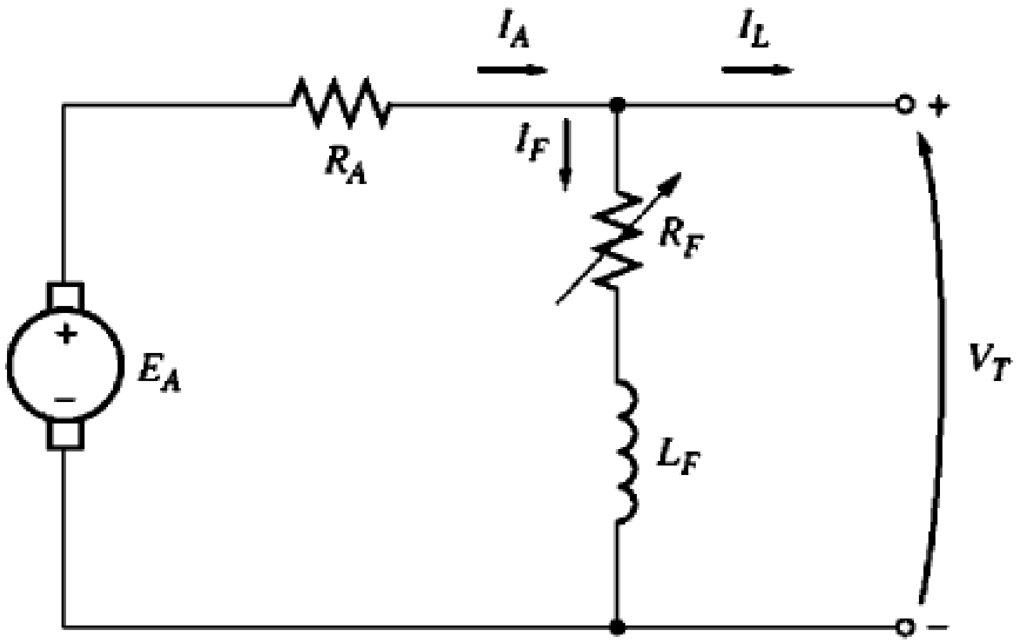

Figure 13: Self excited DC generator model

Apply KVL

$$V_t = E_a - I_a\, R_a$$

$$V_t = V_f = R_f\, I_f \qquad I_a = I_l + I_f \qquad E_a = k_a\, \phi\, \omega_m$$

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11. Q — If the generator supplies its own field current, how does it get the initial field flux to start when it is first turned on?

A — Residual flux

Because of presence of small residual flux in the field poles, DC shunt generator will have a small voltage at its terminal, a small current will start flowing through the field circuit of DC generator which produces magnetic flux increases the residual flux, , the voltage **build-up** till the point of intersection of field resistance line and magnetization curve / open circuit characteristic. [5]

[5] This is a positive feedback operation

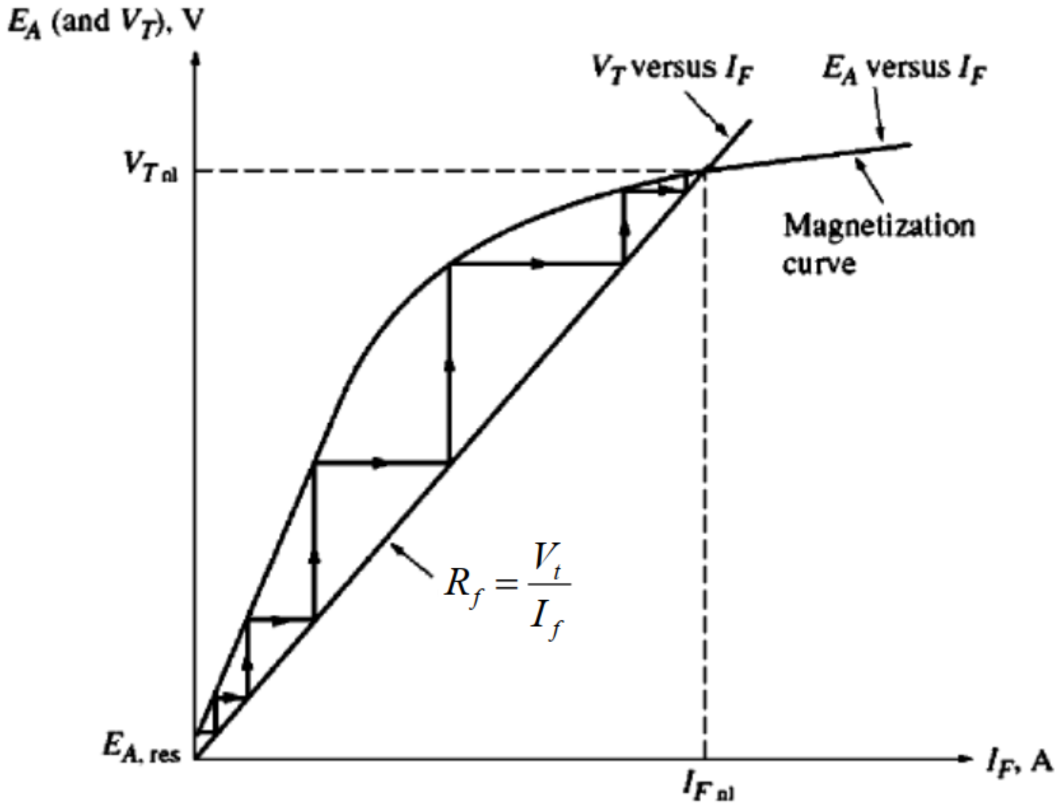


Figure 14: Voltage build-up

$\boxed{\text{12. Q}}$ — If the Voltage build-up fails, what could be the reasons?
What if a shunt generator is started and no voltage builds up? What could be wrong?

A —

- There are no residual flux (Very low probable to happen)
  The solution, shut down the generator, then connect the field circuit to a DC voltage for a short time to build residual flux, then reconnect the generator.

- Residual flux opposite to the field circuit flux.

  Residual flux and field flux must be in the same direction, if they are in opposite directions, there will no be a cumulative increase in in field current and no voltage build-up.[6]
  The solution : Reverse the connection of field circuit

[6] Note that the residual flux > field circuit flux

- Critical Field Resistance:

  It is the field circuit resistance above which the generator fails to excite. i.e. there will be no build up of the voltage.

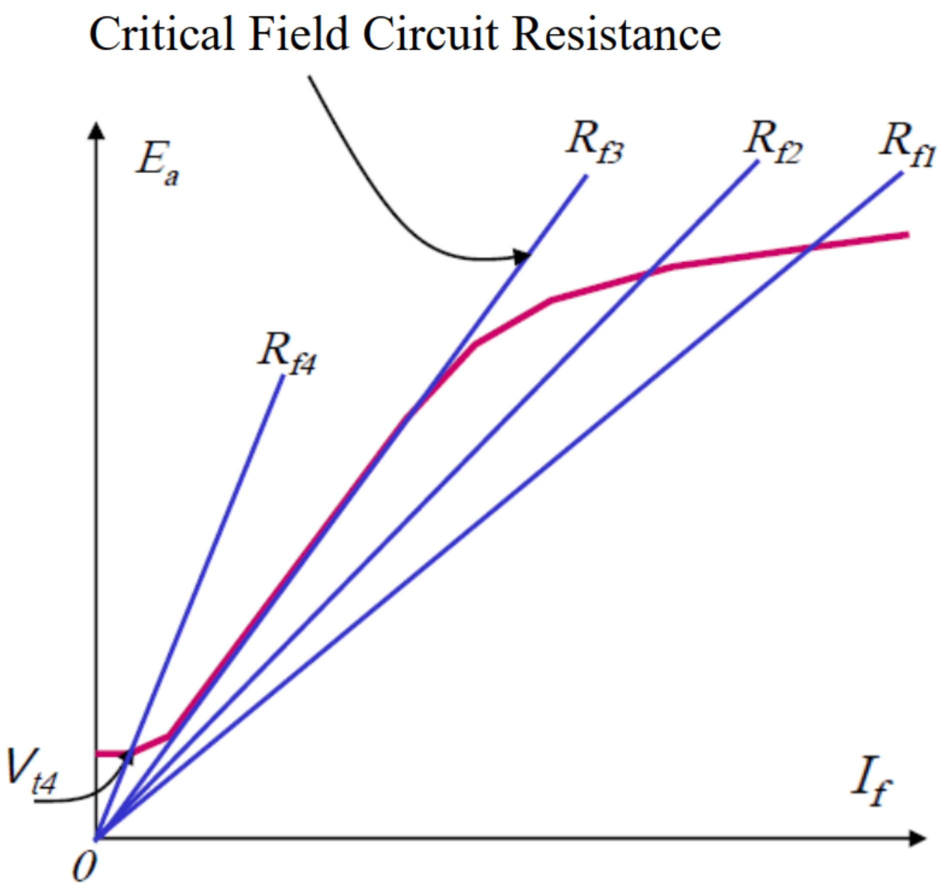


Figure 15: Critical Field Resistance

  if the resistance is higher than critical field resistance, no point of intersection exists between the line and the magnetization field, so the generator fails to build-up.

- Critical Speed:

  It is the speed below which the generator fails to excite. i.e. there will be no build up of the voltage.

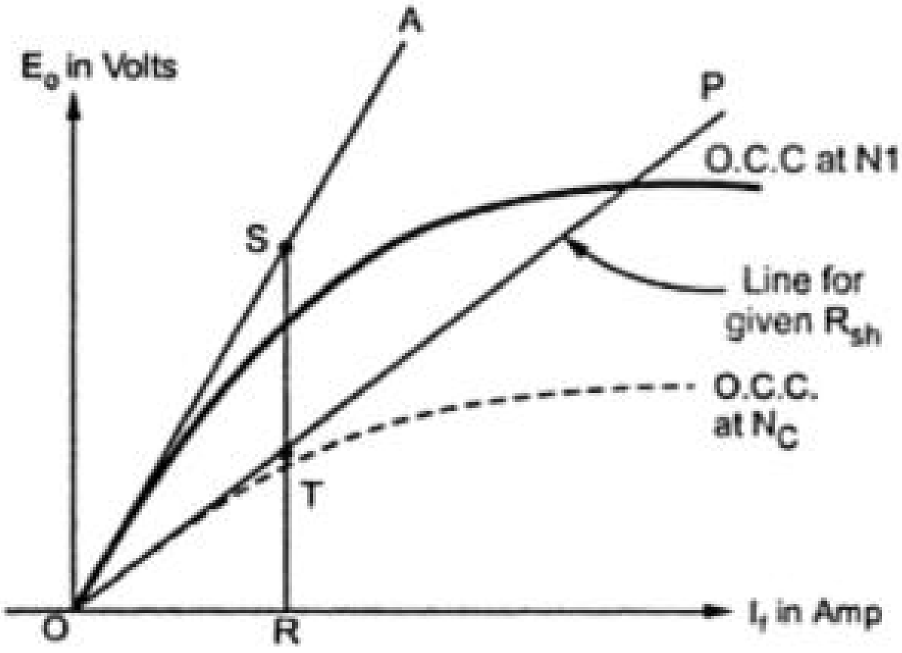


Figure 16: Critical speed

if the speed is lower than critical speed ,no point of intersection exists between the line and the magnetization field, so the generator fails to build-up.

4.2.2 Terminal Characteristics of a Shunt DC Generator

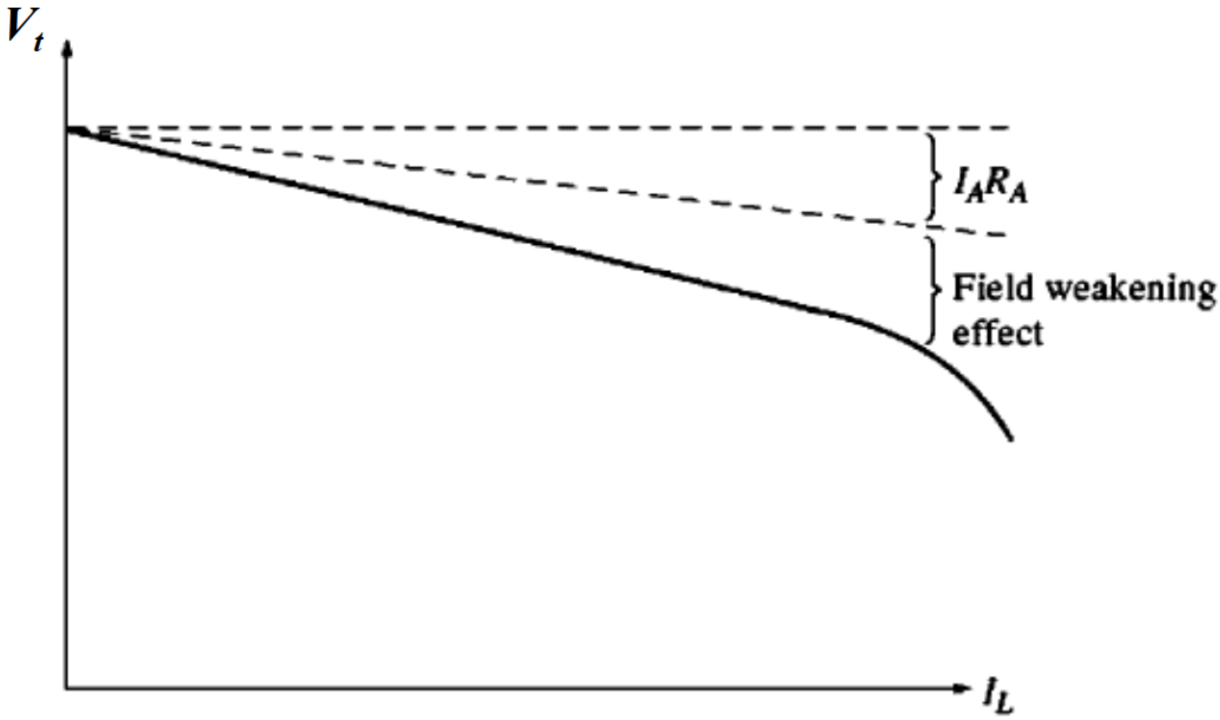


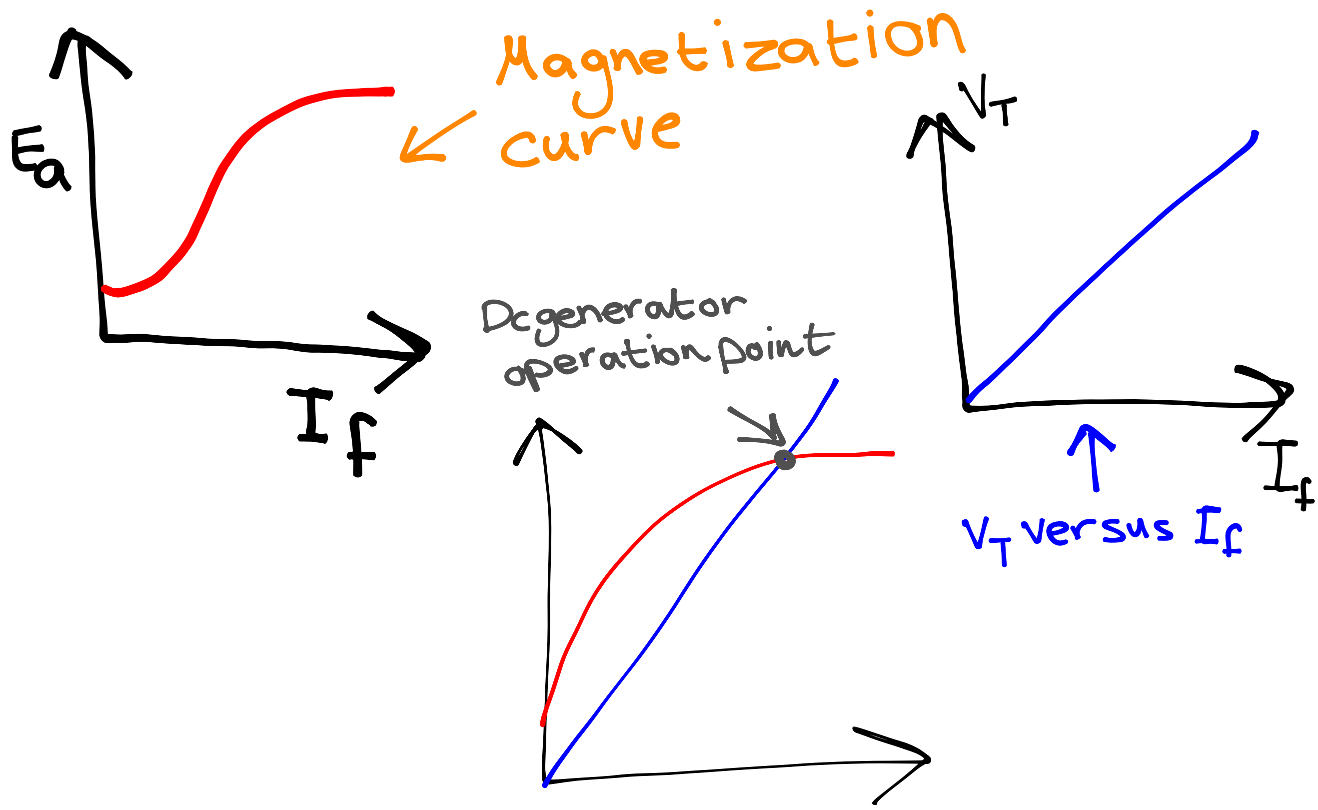
Figure 17: Terminal characteristics of a shunt DC generator

$\boxed{\text{13. Q}}$ — At the same speed, is terminal characteristics of the separately excited DC generator curve **higher than** terminal characteristics of the shunt DC generator curve ?

A — True, since in separately excited DC generator the field is generated from a separate circuit, emf is constant, on the other hand, in shunt DC generator the armature supplies the field current therefore emf is not constant due to armature reaction, when E_a decreases, I_f decreases

[7]

[7] In LaTeX by Taha Ahmed



If I don't want the generator to operate??