(12 marks)

Why dc shunt generator shall not be started at load? Explain the voltage build up process in dc generator. [8]

Explain the functions of commutator and carbon brushes in d.c. generator. Explain why dc shunt generator should be started without load. [8]

Explain voltage build up process in DC shunt generator. Why DC series generator is not started at no load? [8]

[8]

Explain the functions of commutator and carbon brushes in d.c generator with neat sketch. [8]

A 230V. shunt motor takes

a) Using circuit diagram and graphical representation, explain the characteristics of DC series generator and DC shunt generator. Also mention their applications. [8]

Make a detail comparison of dc shunt generator and dc series generator with their diagrams, equations and characteristics curve. [8]

Describe the construction and working principle of a dc generator with neat diagram. Also derive the emf equation of a dc generator. [8]

a) Derive an emf equation for a dc generator. [4]

b) DC shunt generator shall be started keeping its output terminal open. Justify the statement. [4]

What are different types of losses in DC generator? Derive the expression for the efficiency of DC generator.

Construction of DC Machine (Motor and Generator)

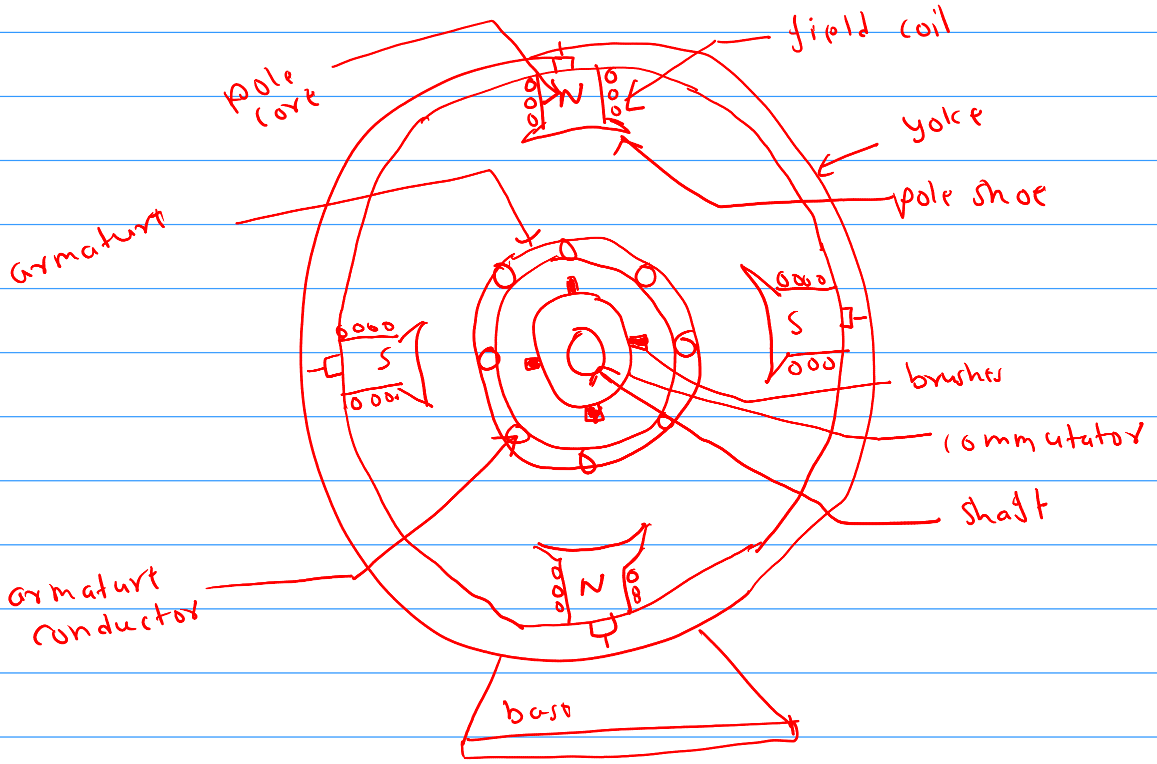


fig: DC machine

The DC machine consists of two primary sections :-

① Stator → Stationary part, which generates the magnetic field

② Rotor → the rotating part, which interacts with the mag field to produce mechanical or electrical energy.

Components of the DC Machine

① Yoke (Frame)

→ The outer cylindrical casting that provides mechanical support and protection for the internal parts of the machine.

→ Usually made with cast iron or steel to carry the magnetic flux produced by the poles.

② Poles (Pole Core and Pole Shoe)

→ Pole Core : the portion to which the field windings (field coils) are attached.

→ Pole shoe : The widened part of the pole that faces the armature. It spreads the magnetic flux over a larger area of the armature surface.

③ Field Coils (Field Windings)

→ Coils of insulated wire wound around each pole core.

→ when energized by DC current, they produce magnetic flux in the air gap between poles and the armature.

④ Armature (Rotor)

→ rotating part of the machine.

→ has slots on its outer surface to hold the armature conductor (wires)

→ For generator, rotation of the armature in the field induces a voltage in these conductors

→ For motor, current flows through these armature conductors and interacts with the magnetic field producing troque.

⑤ Armature Conductors

→ they connect to the commutator segments that provides the means to collect or supply current

→ They are coils or windings.

⑥ Shaft

→ Central axis on which the armature is mounted

→ It transmits mechanical power either out of the machine or into the machine.

⑦ Base

→ The supporting structure on which the machine is mounted.

⑧ Commutator and Brushes :

→ Commutator collects current from the armature conductor in dc generator while on dc motor, it supplies current to them.

→ Brushes are made of carbon or graphite, they rest on the commutator segments and slide over them as commutator rotates, maintaining physical contact to either collect or supply current.

Working of a DC Generator (IOE)

→ A DC Generator is an electrical machine that converts mechanical energy into direct current (DC) electrical energy. It's operation is based on Faraday's law of EMI.

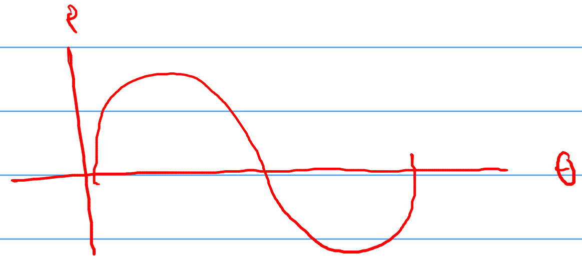
→ The shaft of the dc generator is rotated by some mechanical engine or turbine

→ magnetic field is established by field coils.

→ as the armature rotates, it's conductor cut through the magnetic field lines.

→ According to Faraday's law of EMI, emf will be induced across the conductor.

$$e = Blv \sin\theta$$



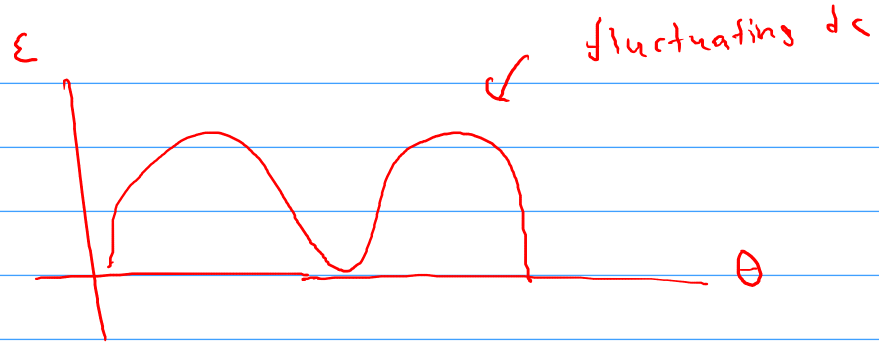
→ The nature of emf induced in the conductor will be alternating in nature.

→ To convert this ac voltage into dc voltage a commutator segment and carbon brush arrangement is used.

→ as the armature rotates, the commutator switches the connection of the conductor to the external ckt at the precise moment when the induced EMF changes direction. This rectifies the alternating emf, ensuring that the current in the external ckt flows in one direction only – producing direct current.

→ The brushes maintain constant contact with the rotating commutator, collecting the rectified current and transferring it to the external ckt.

→ The result is a steady dc current, though in practice there may be slight ripples.



→ the ripples can be minimized by multiple windings and commutator segments.

Emf of a DC Generator (EOE)

Let ϕ = mag flux per pole,

Z = total no of armature conductor

N = Speed of armature

A = No of parallel path in armature winding

Now,

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

Avg value of emf generated per conductor $(N=1)$

$$\varepsilon = \frac{d\phi}{dt} \quad \text{—(i)}$$

Magnetic flux cut by a conductor in one revolution

$d\phi = P \times \phi$ $\left(\begin{array}{l} P \rightarrow \text{no of mag poles} \\ \phi \rightarrow \text{flux per pole} \end{array} \right)$

Time for N revolution = 60s
Time for 1 revolution = $\left(\frac{60}{N}\right)s = dt$

From (i)

$$\varepsilon = \frac{d\phi}{dt} = \frac{P \times \phi}{\left(\frac{60}{N}\right)} \quad \therefore \boxed{E = \frac{NP\phi}{60}} \quad \text{— (ii)}$$

We know,

number of conductor in series = $\frac{Z}{A}$

So,

$$E = \text{emf per conductor} \times \frac{Z}{A}$$

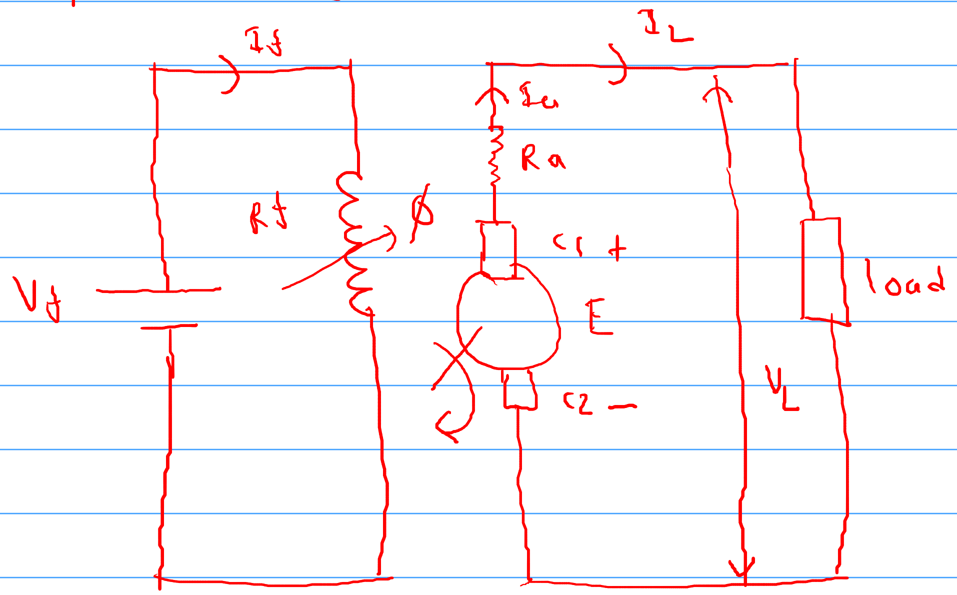
or $$\boxed{E = \frac{Z\phi N}{60} \times \frac{P}{A}}$$

For lap winding A = P
For wave winding = 2 for wave winding

Methods of Excitation (EOE)

① Sepperately excited DC generator.

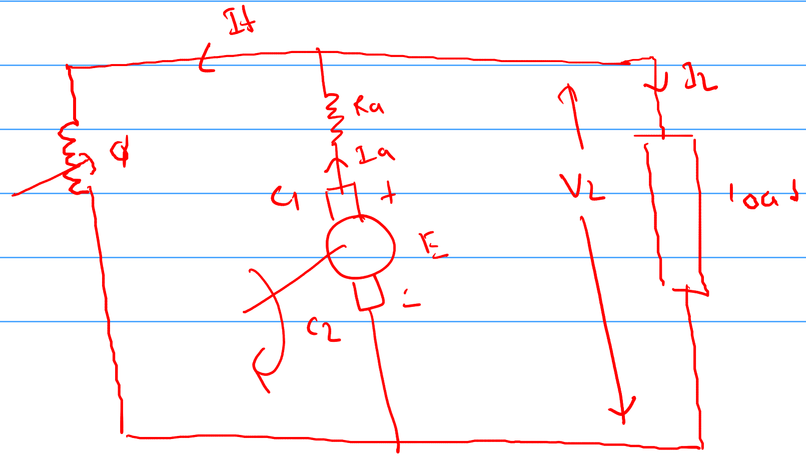
→ Here field winding current (I_f) is supplied by the seprrate dc source.



I_f → field winding current, R_f = resistance of field winding, E = emf generated by dc generator, I_a → armature current, R_a → resistance of armature winding.

② Self excited dc generator

→ Here the field winding current I_f is supplied by armature itself.

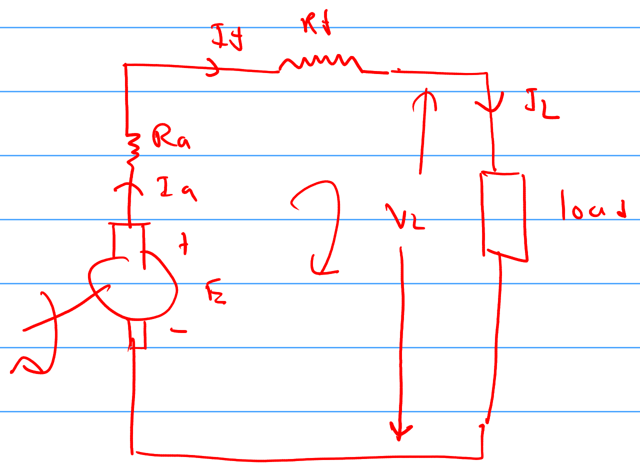


Self excited dc generators are classified into :-
(Types of dc generators)

1. DC series generator
2. DC shunt generator
3. DC compound generator
   (i) long shunt dc compound generator
   (ii) short shunt dc compound generator

(a) DC series generator

→ armature winding and field windings are connected in series



$$\boxed{I_a = I_f = I_L} \quad \text{— (i)}$$

KVL

$$\boxed{E = I_a R_a + I_f R_f + V_L} \quad \text{— (ii)}$$

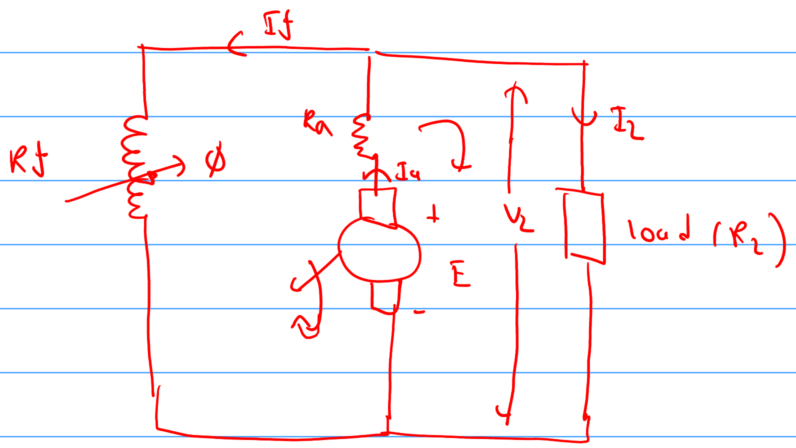
DC series generator not started at no load

→ field winding has to carry full load current, it is made of thick wire with few turns so that voltage drop in field winding is very small and load will get significant amount of voltage.

→ At no load, external ckt is open ($I_a = 0$), so no current flows through field winding ($I_f = 0$)

(2) DC Shunt generator

→ armature and field winding are connected in parallel



$$\boxed{I_a = I_f + I_L} \quad \text{— (i) (KCL)}$$

KVL

$$\boxed{E = I_a R_a + V_L}$$

$$\boxed{I_L = \frac{V_L}{R_L}} \qquad \boxed{I_f = \frac{V_L}{R_f}}$$

Why DC shunt generator should not be started with a load

→ when load is connected at startup, it draws current weakening the field winding and preventing proper voltage buildup. This can slow down or stop the generator from reaching it's full voltage. so, always start it without load and connect the load after it reaches full voltage.

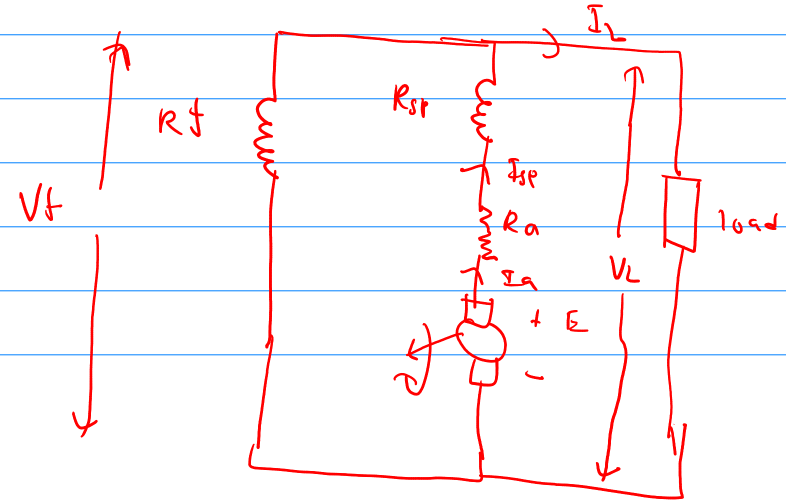
③ DC compound Generator

→ have two sets of field windings. The two sets may be connected in series with armature winding or load.

ⓐ long shunt DC compound generator

R_f → shunt field winding
R_{se} → series field winding

R_{se} is connected in series with armature and parallel with field winding.



$I_{se} = I_a$ — (i)

$I_{se} = I_f + I_L$ — (ii)

Using KVL in right loop

$E = I_a R_a + I_{se} R_{se} + V_L$ — (iii)

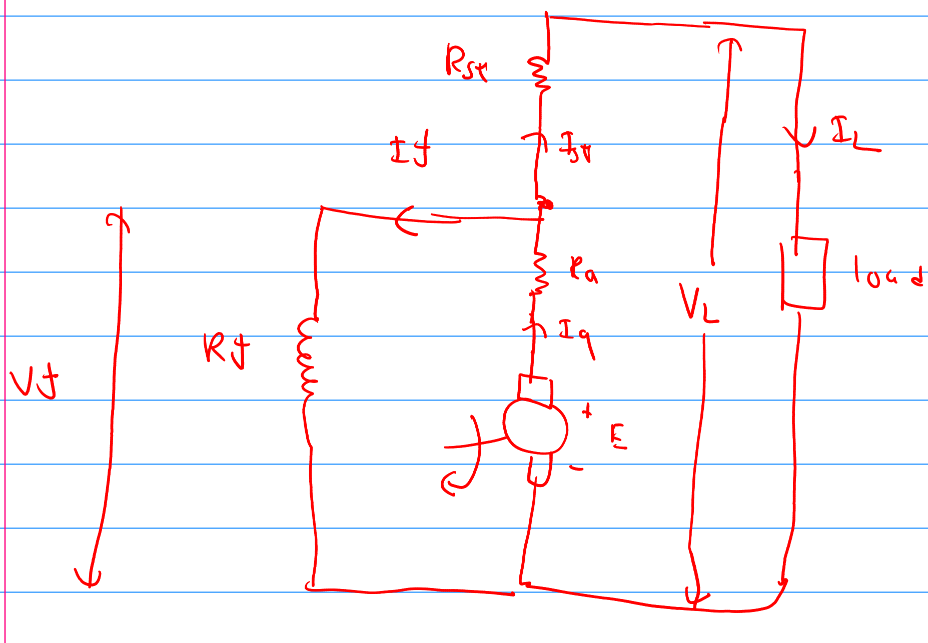
KVL in left loop

$E = I_a R_a + I_{se} R_{se} + I_f R_f$ — (iv)

$I_f = \frac{V_f}{R_f} = \frac{V_L}{R_f}$ — (v)

(b) Short Shunt dc compound generator

→ R_{se} is connected in series with load



$(V_L \neq V_f)$

$I_a = I_f + I_{se}$ | $I_{se} = I_L$

KVL in right loop

$E = I_a R_a + I_{se} R_{se} + V_L$

KVL in left loop

$E = I_a R_a + I_f R_f$

$$I_f = \frac{V_f}{R_f}$$

Voltage build up in a self excited DC generator (IOE)

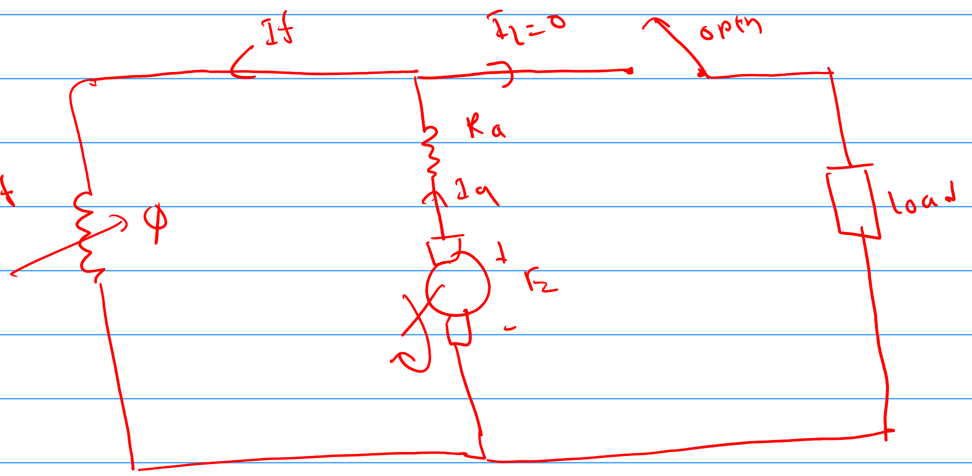


fig: DC-Shunt generator

→ A DC shunt generator builds voltage through a self-excitation process.

→ The load switch is opened during the voltage build up process as shown in figure.

→ even when the generator is off, it's field poles retain a tiny amount of magnetism called residual magnetism.

→ When the shaft of the machine is rotated at it's rated speed, a small amount of voltage will generated across the armature due to residual magnetic flux. There fore small amount of current will circulate in the field winding and is given by :-

$$E_{residual} = I_f R_a + I_f R_f \qquad (I_f = I_a)$$

$$I_f = \frac{E_{residual}}{(R_a + R_f)}$$

→ The current again produces some more magnetic flux therefore generated emf will increases.

→ again due to the increased emf, field current (I_f) will increase.

→ In this way emf induced in the armature goes on increasing. This process is known as the voltage build up process.

→ The voltage build up process stops after some time and generates a constant voltage.

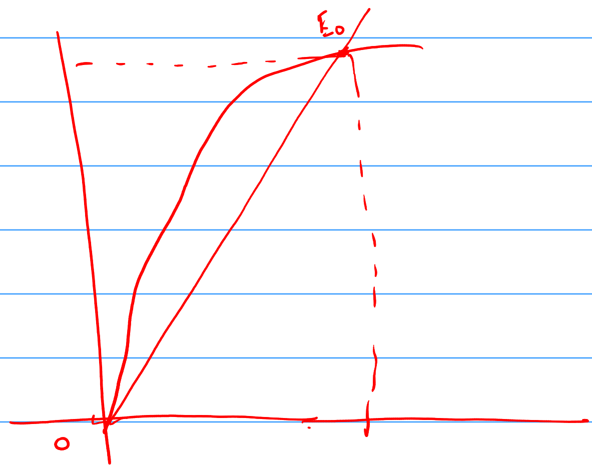


Fig: voltage buildup of a DC shunt generator

Critical resistance → maximum value of R_f for which the voltage build up process will be just successful.

Critical speed → minimum possible value of speed at which the voltage build up process will be just successful.

→ Armature reaction in a DC generator is the effect of the current in the armature coils on the main magnetic field.

→ The current flowing in the armature produces its own magnetic field. This field interferes with the main magnetic field created by field windings.

→ It distorts main magnetic field, reduces the generated voltage, shifts the neutral plane (the ideal brush contact point) which can cause sparking.

→ Compensating windings or interpoles are used to counteract these effects and maintain proper generator performance.

Losses in DC generators (Imp)

① Copper loss

→ armature windings ($I_a^2 R_a$)

→ field windings ($I_f^2 R_f$ and $I_{se}^2 R_{se}$)

(2) Iron loss or core loss (constant)

→ hysteresis loss

→ eddy current loss

③ mechanical loss

→ friction loss at bearings and commutator

→ air-friction (windage) loss of rotating armature

$\eta = \dfrac{\text{electrical p/w o/p}}{\text{mechanical p/w i/p}}$

1 HP / BHP = 745 W #

Characteristics of DC Generators (EOE)

① No-load (open ckt)

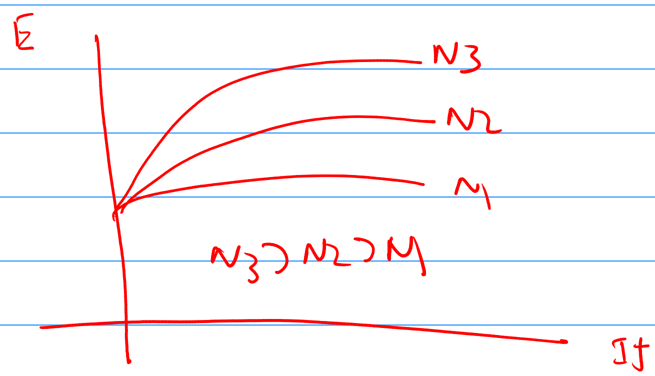
→ plot of induced emf (E) vs If at constant speed with no load

$$E = \frac{2\phi N}{60} \times \frac{P}{A} \qquad \text{Also,} \quad \phi \propto I_f$$

$E \propto N\phi$

$E \propto N I_f$

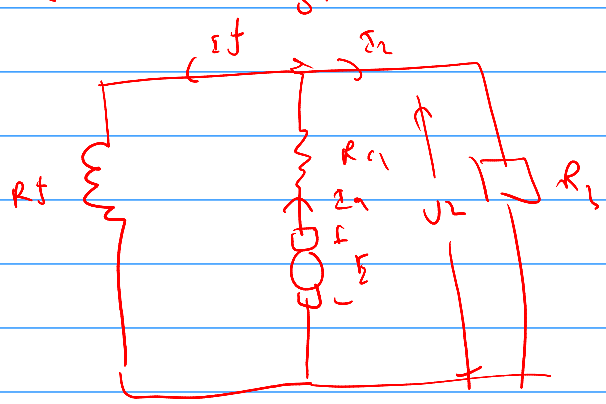
$E \propto I_f$



(no-load characteristics at different speed)

② load characteristics

ⓐ For DC shunt generator



Initially for no load, $I_L = 0$

$$E = V_L + I_a R_a$$

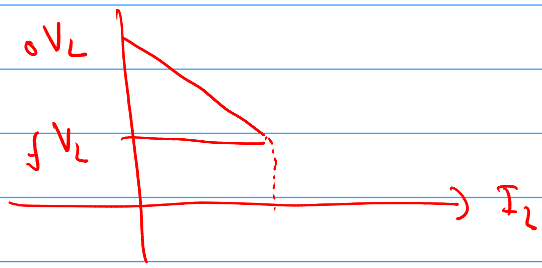
or $V_L = E - I_a R_a \approx E$ $\quad$ $I_a R_a$ is negligible

When loaded

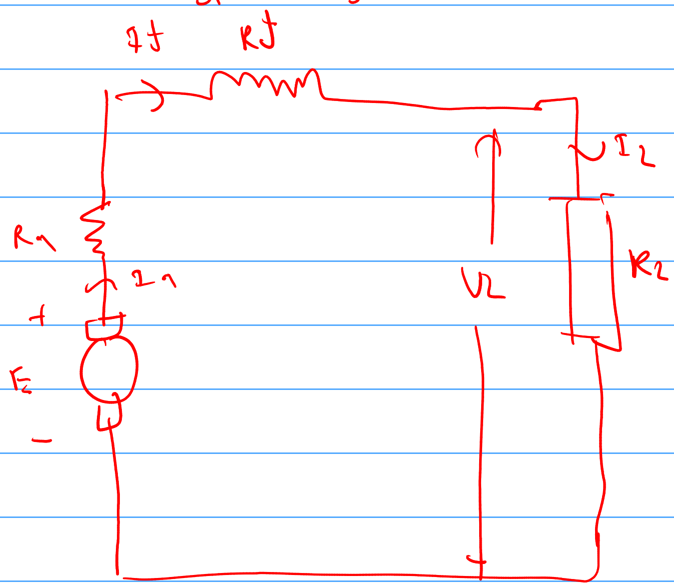
$(I_a = I_L + I_f)\uparrow$ $\quad$ (I_L and I_a increase, $I_a R_a$ is not negligible)

$$V = E - I_a R_a$$

Here $I_a I_a \uparrow\uparrow$ so $V \downarrow\downarrow$



(b) For DC series generator



initial at no-load

$I_L = 0$ so, $I_f = 0$, E is very small, V is negligible

When loaded

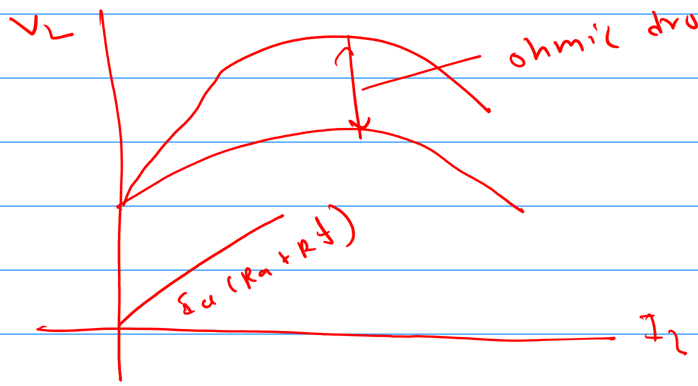
$$E = I_a R_a + I_f R_f + V$$

→ As $I_L \uparrow$, $I_f \uparrow$ because $I_L = I_f$

→ flux (ϕ) increases, leading to increase in E ($E \propto \phi$)

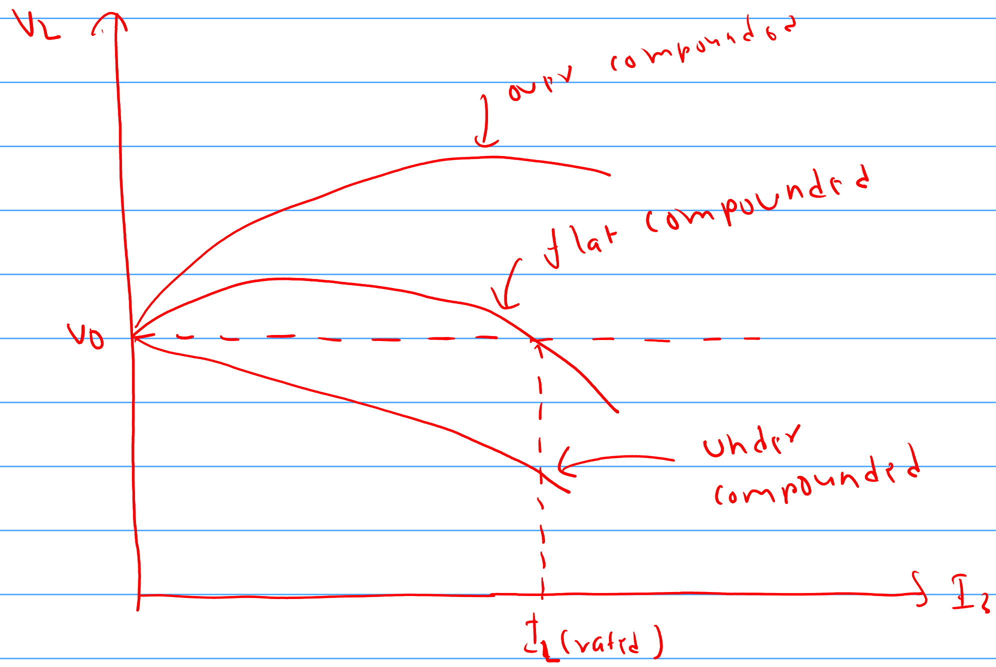
→ V increased with I_L

→ After magnetic saturation E stops increasing and V starts to drop due to the increasing voltage drop across armature resistance ($I_a R_a$)



(i) For DC compound generator

p.7.6



(i) Flat-compounded → same terminal voltage at no-load and full load

(ii) over-compounded → terminal voltage at full load is greater than no-load terminal voltage.

(iii) under-compounded → terminal voltage at ful load is less than no-load terminal voltage.

By adjusting the number of turns in the series field winding of DC compound generator the terminal voltage 'V' can be controlled in various ways.