Synchronous Generator

Armeture current in the stator will induc a magnetic field which is a noise (Armeture Reaction)

2 windings: field , Armeture

main B → field; induced B → Armeture

Rotor and Stator

Electrical magnet in the Stator → fixed B → Rotor moves → inducti-

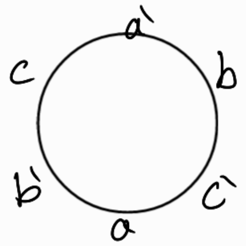
خطوط المجال تتقطع

Battery + Brushes + Slip rings

or

Small DC source or a Pilot exciter → AC source with permenant magnet

3-phase

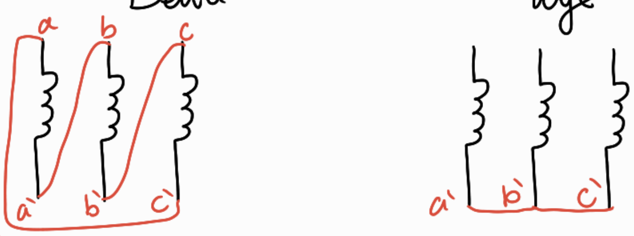


Poles of Rotor

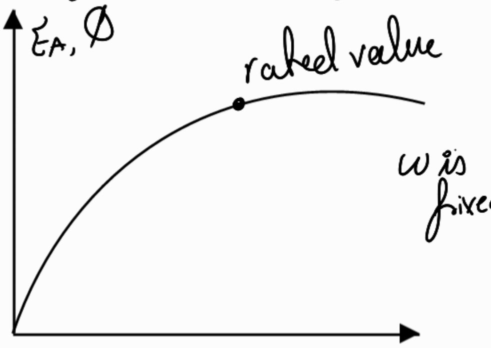
- Salient
- non-Salient

Connections

- Delta
- Wye



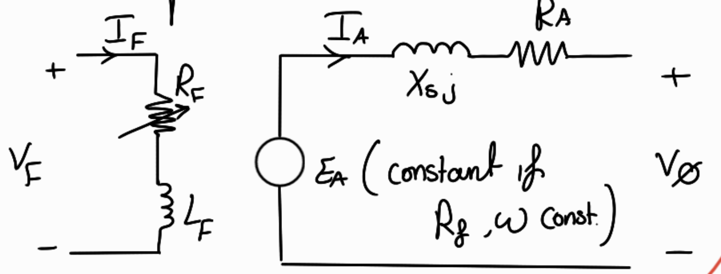
Magnetization curve for Synchronous generator



$E_A = K \phi \omega$

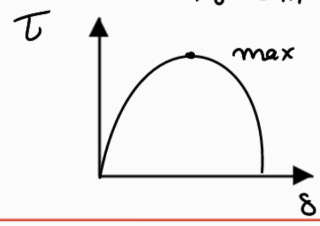
steel laminations to reduce eddy current

Single phase representation



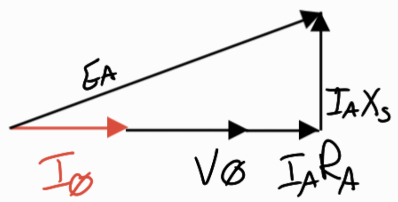
Induced torque

$$\tau_{ind} = \frac{3V_\phi E_A}{X_s \omega_m} \sin\delta$$

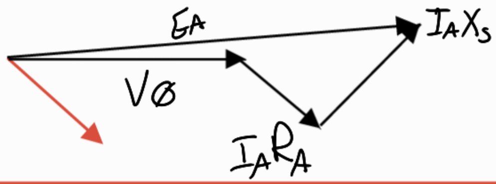


loads

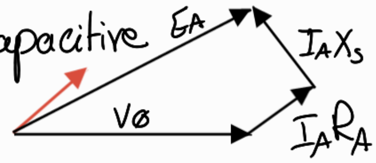
Resistive



Inductive



Capacitive

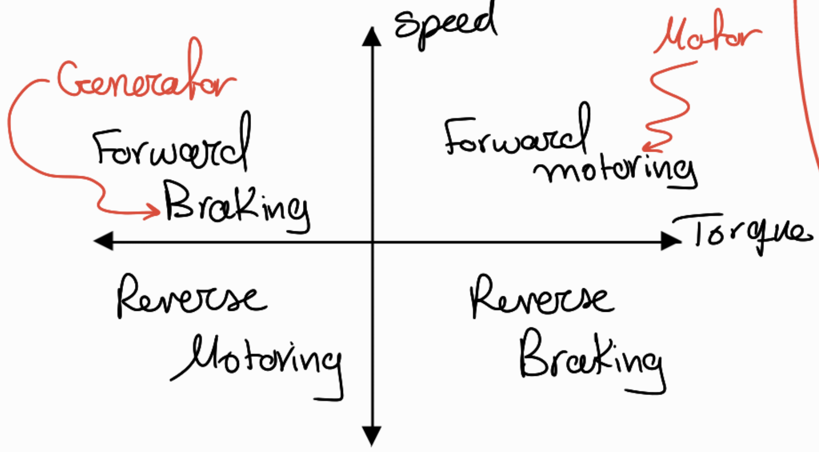


Voltage Regulation

ind	Resi	cap
$V_R \gg 0$	$V_R > 0$	$V_R < 0$

$$V_R = \frac{V_{nl} - V_{fl}}{V_{fl}} \times 100\%$$

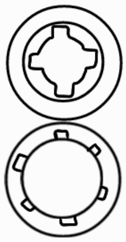
To keep V_T constant R_f is controlled until



Generators Parallel connections

1. Equal rms voltages
2. Same phase sequences
3. Same phase Angles
4. f_2 should be higher

Rotor can be →
Salient poles
non salient



Synchronous Motors

Rotor
fixed B

Coupling ⟷
at

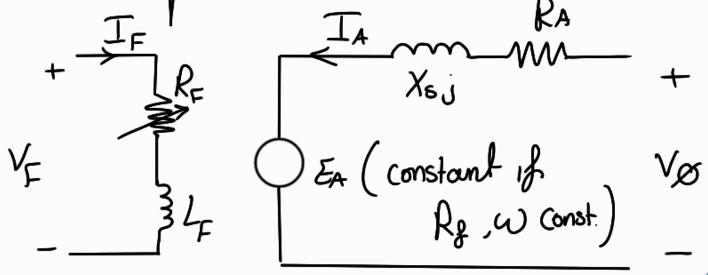
$$n_m = \frac{120 f_e}{P}$$

Stator
Rotating B from 3-Phase current source

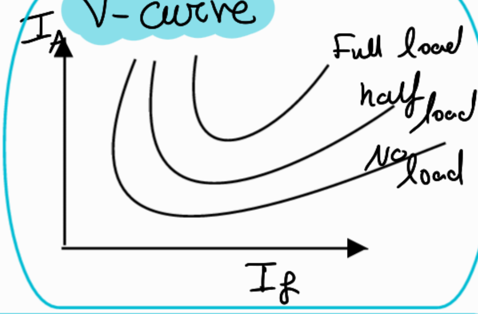
Squirrel cage → current passes in the bar
→ induced Force

Not self started
Needs a pushing force (Squirrel Cage)

Single phase representation

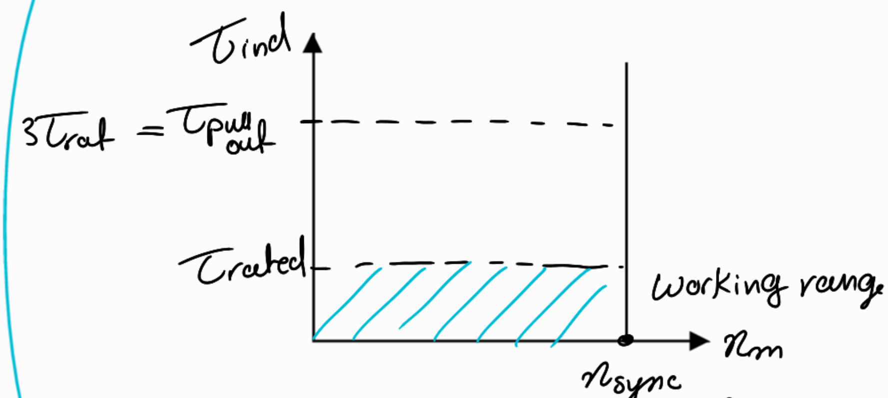


V-curve



Increasing the load
E_A is constant but
I_A increases, δ ↑

Torque Speed characteristics



$$n_{sync} = \frac{f_e\,120}{P}$$

$$\tau_{ind} = \frac{3 E_A V_\phi \sin\delta}{\omega X_s}$$

Slipping poles phenomena

Induction Motors

Squirrel cage needed to give a pushing force

Self starting Motor
No external DC source needed in the field

Difference between Rotor speed and electrical frequency speed is the **Slip**

$n_{slip} = n_{sync} - n_m$

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

$S = \frac{n_{sync} - n_m}{n_{sync}} \times 100\%$

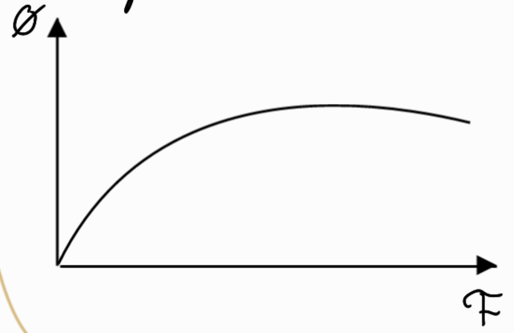
$n_m = (1 - S) n_{sync}$

$f_r = S f_e$ → constant

Rotor
- wound : 3-phase windings, Y connected, ends connected via slip rings on Rotor shaft (Resistance is controlled)
- Squirrel cage : Shorted ends Bars

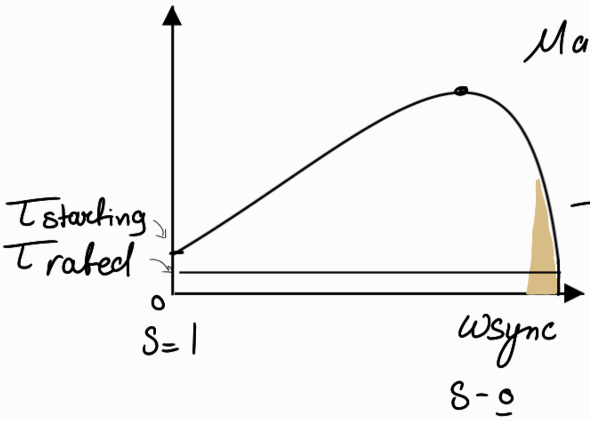
Max speed is the synchronous speed at which Rotor will slow down since No eind, No I_R, No B_R, No τ

Magnetization curve



- for wound Rotor
  $a = \frac{N_1}{N_2}$
- for squirrel cage
  a_{eff}

Torque – Speed characterestics



$\tau_{ind} = K \vec{B}_{net} \times \vec{B}_r$

At no load $n_{sync} = n_m$ → Small Slip → Small I_R → small B_R → small τ_{ind}

- At heavy load slip increases → n_m ↓ → δ ↑ → B_R ↓
  τ_{ind} ↑

Curve Regions

- Small Slip region $0.0 < S < 0.07$ (Normal operating Region)
- Moderate Slip region (pullout torque region)
- high slip region τ_{ind} ↓ → as load ↑ (starting torque region)
  ↳ Since PF is never zero

Extended curve

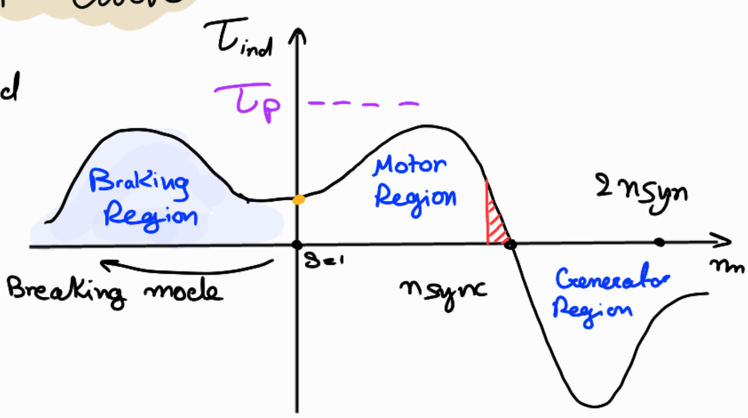
At n_{sync} : $\tau_{ind} = 0$

* curve is linear between full load and no load

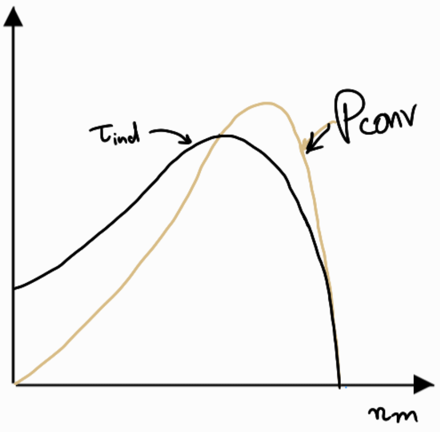
* $\tau_{max} = \tau_{pullout} = 2\text{-}3\ \tau_{rated}$

* starting $\tau = 1.5\ \tau_{rated}$

τ_{ind} depends on: ✓ $(\text{Voltage app})^2$
✓ n_{syn}

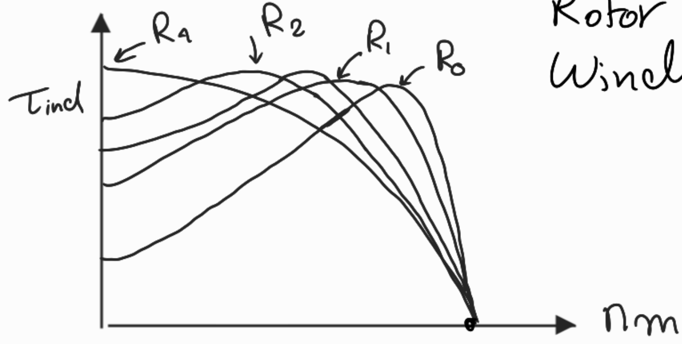


Converted power



Adding resistance to the machine

↳ Rotor Windings



To reduce starting current of the induction motor

1. Star to delta starting → $\frac{V}{\sqrt{3}} \to V$
2. Add Resistance
3. Start up transformer

- Separate windings are used to change the the speed by changing pole numbers

DC Machines

$SR = \frac{\omega_{m,nl} - \omega_{m,fl}}{\omega_{m,fl}}$ → if $SR < 0$ → motor is in Runaway (Stator hits the Rotor)

Back Emf

reduces current

EMF ∝ Speed
Back   Rotor

$e_{ind} = K \Phi \omega$

$\tau_{ind} = K \Phi I_A$

Types of DC motors

1. permanent magnet
2. Separately excited
3. Shunt → $V_f = V_T$
4. Series
5. Compound

Armature voltage change → Resistor in armature circuit or changing excitation current

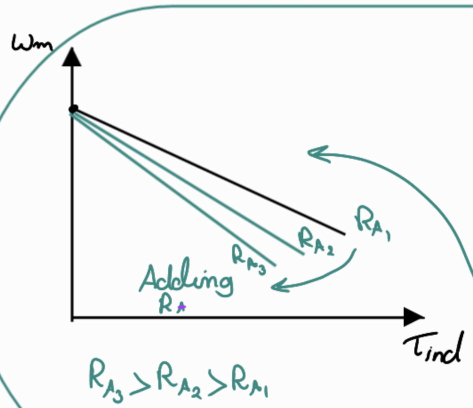
Shunt DC motor

* How does a shunt DC motor respond to a load?

→ If load increased

$\tau_{load} > \tau_{ind}$ → motor slows down $\omega \downarrow$ → $E_A \downarrow$ since $\omega \downarrow$ → Armature current $I_A \uparrow$, $I_A \uparrow = \frac{(V_T - E_A \downarrow)}{R_A}$

$\tau_{ind} \uparrow$ $(= K \Phi I_A \uparrow)$ → $\tau_{ind} = \tau_{load}$ at lower ω



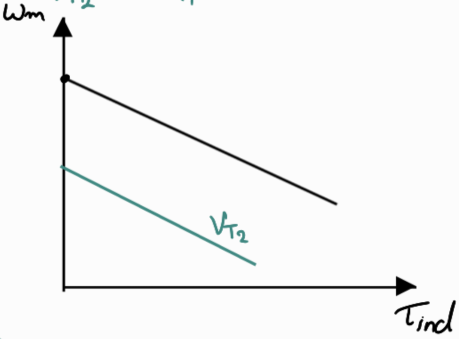
$R_{A_3} > R_{A_2} > R_{A_1}$

<u>Parameter that controls the DC motor speed</u> (shunt & separately excited)

- Terminal voltage of Armature
- Flux by adjusting R_F
- R_A by adding External resistance (R_{adj} is connected on series) meaning that Electrical losses are increased and energy is loss so less common method

Decreasing V_T

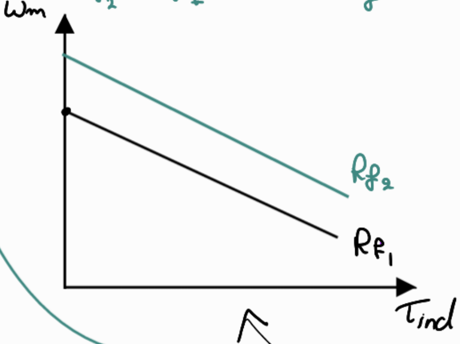
$V_{T_2} < V_{T_1}$



Changing $\phi \rightarrow R_f$

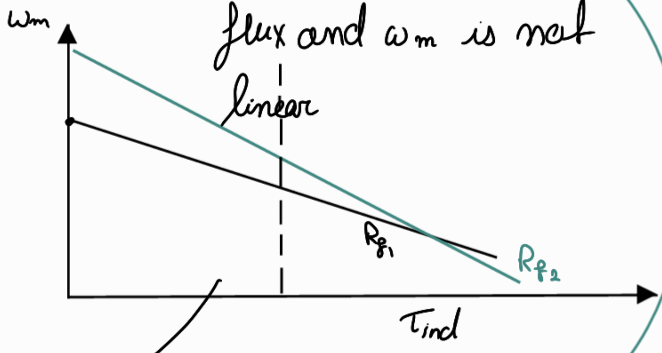
$R_{f_2} > R_{f_1}$

$I_f \downarrow \rightarrow \omega_m \uparrow$



$\rightarrow$ for ∞

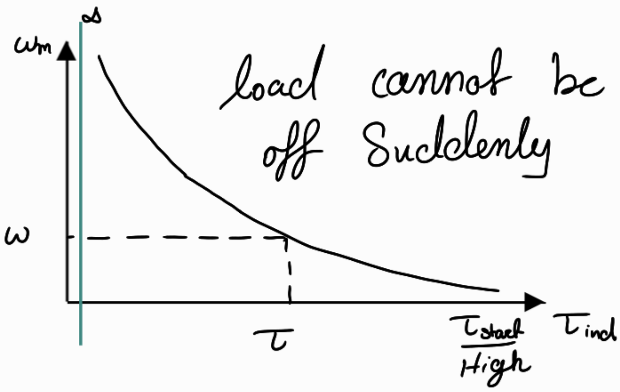
Note: Relation between flux and ω_m is not linear



Armature Reaction

Compensating windings are introduced to reverse the Armature windings

Series DC motor

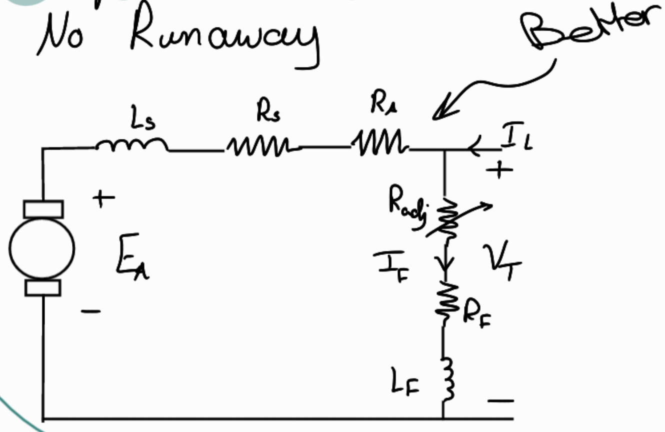


load cannot be taken off Suddenly

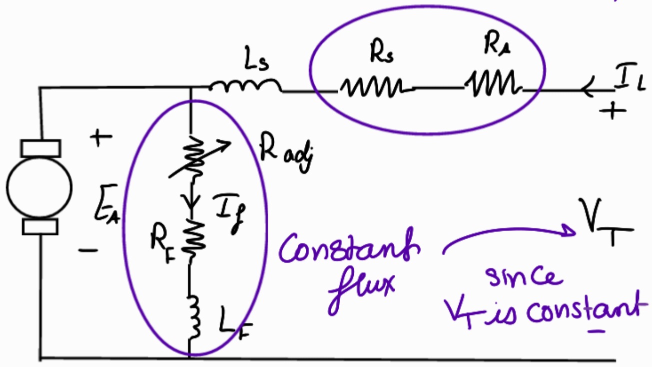
- Speed is controlled by changing terminal voltage → series Resistor

Compounded DC motor

No Runaway



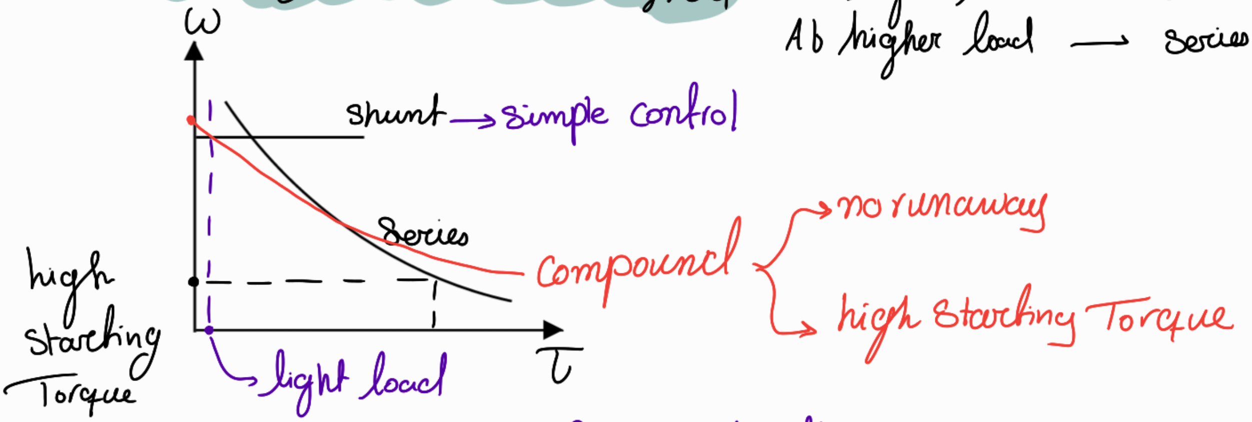
Speed Control is Same as shunt



Comulatively → Stronger magnetic field

At light load → shunt اقرب لل

At higher load → Series اقرب لل



runaway occurs for series (Bad)

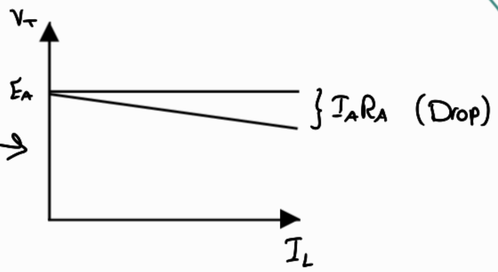
DC Generators

$E_A = K \phi \omega$

$= V_T + I_A R_A$

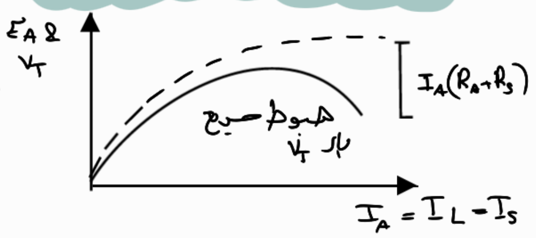
Best type

→ Separately excited



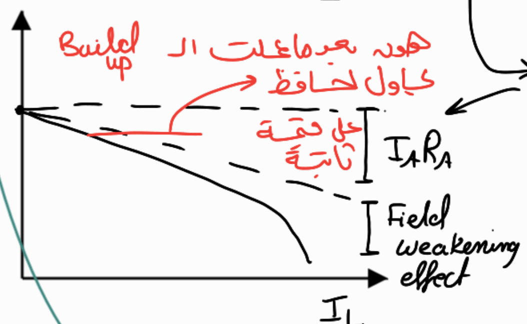
→ Series

Characterestics are Bad



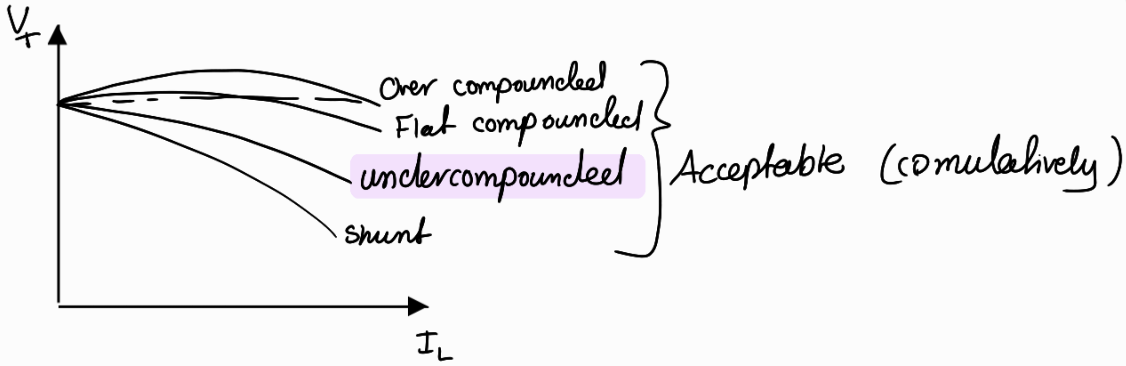
→ Shunt : ϕ_{res} which exists in the material itself or : 1. Flash the field (Battery connection)

2. Turn the direction of rotation

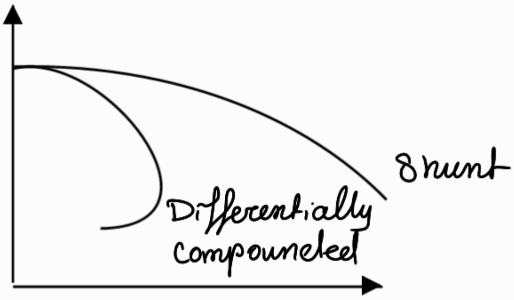


Compounded

- Comulatively



- Differentialy : Bad → Unacceptable



Universal motor

- operated either AC or DC
- It has a series motor characterestics
- Done by physical modifications