chapter 8

Speed Regulation

مش مربوط على ال shaft أي شي — Higher

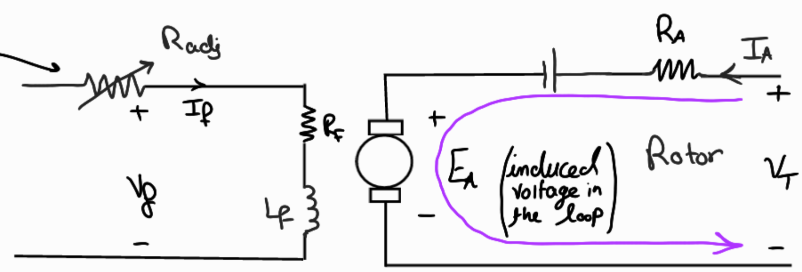
$$SR = \frac{\omega_{m,nl} - \omega_{m,fl}}{\omega_{m,fl}} \times 100\%$$

$$SR = \frac{n_{m,nl} - n_{m,fl}}{n_{m,fl}} \times 100\%$$

- SR should be + but can be negative in Runaway : فقدان التحكم بال motor
- In this case vibration causes stator to hit Rotor since air gap is small or (see lecture)

Types of DC motors

1. Permanent magnet
2. Separately excited
3. Shunt
4. Series
5. Compound



$$I_L = I_A$$

$$I_F = \frac{V_F}{R_F + R_{adj}}$$

- I_f can be controlled

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

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

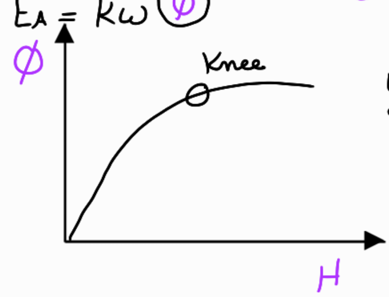
$V_T + I_A R_A + E_A = 0$

} Equations needed for Analysis

Magnetization Curve

→ we find rated value from if

$E_A = K\omega\phi$ → نفس الرسمة بس مضروبة بـ factor



$\omega_m = \omega_0$

$n_m = n_0$ → constant

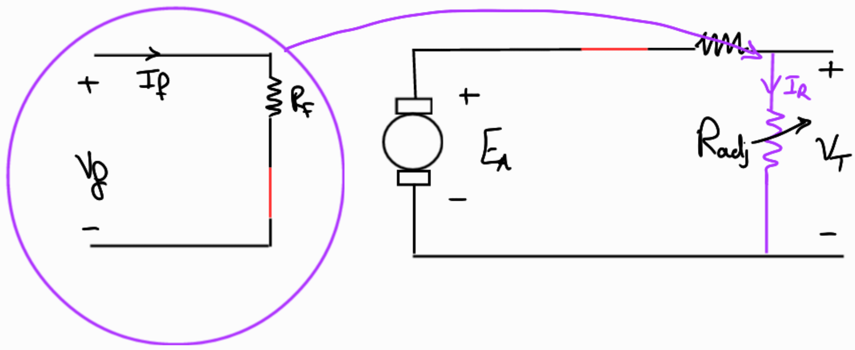
$I_F = \frac{V_F}{R_F}$

Shunt DC motor

- At: $V_f = V_T$

  يعني يعتبر حالة خاصة من

  separately excited الـ



- $I_L = I_A + I_F$

* 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

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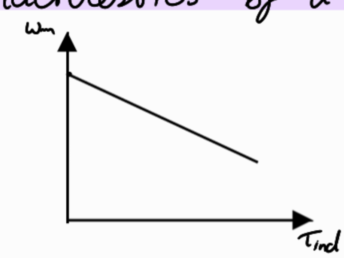
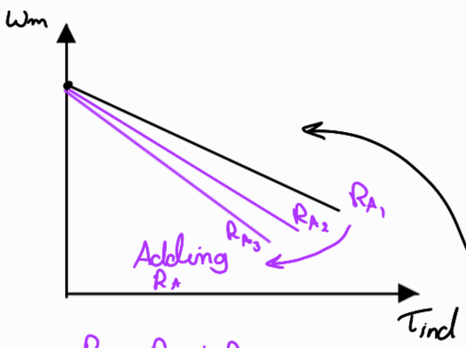
The terminal characteristics of a shunt DC motor & separately excited motor

$$\omega = \frac{V_T}{K\phi} - \frac{R_A \tau_{ind}}{(K\phi)^2}$$





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

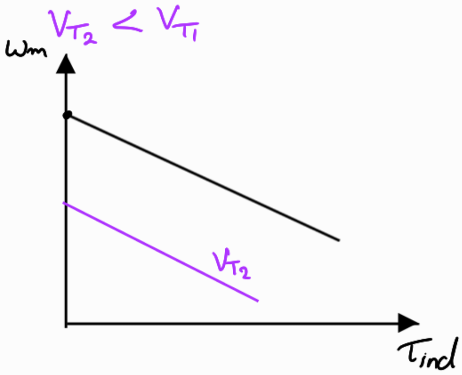
Parameter that controls the DC motor speed

- 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

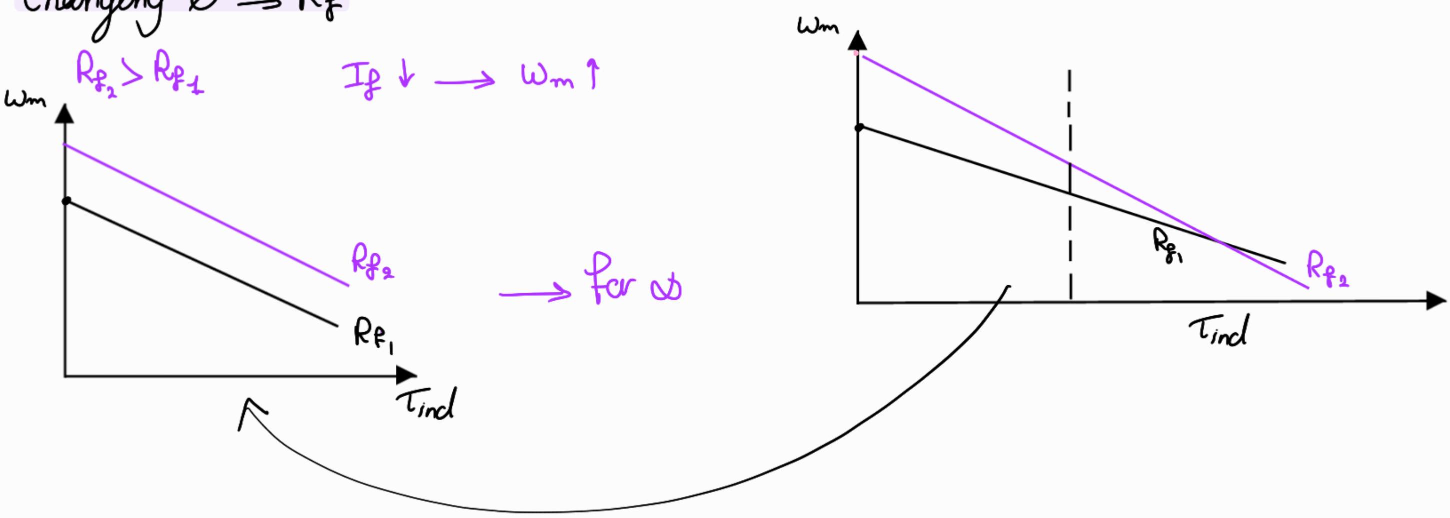
$V_{T_2} < V_{T_1}$



Note: Relation between flux and ω_m is not linear

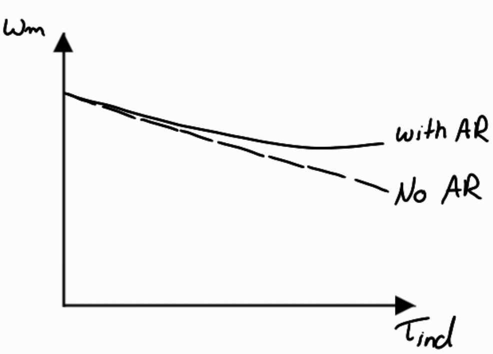
Changing $\phi \rightarrow R_f$

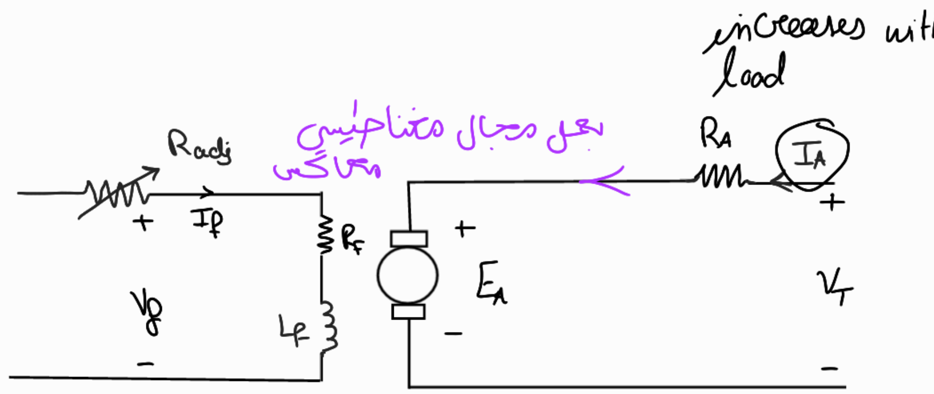
$R_{f_2} > R_{f_1}$ $I_f \downarrow \rightarrow \omega_m \uparrow$



Armature Reaction

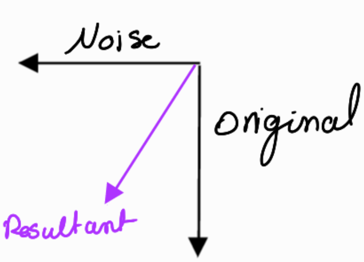
Noise Magnetic field





• : out

x : in



• A compensating windings are introduced to reverse the Armature windings and so it is neglected

Changing R_F or (flux)

1.	**Increasing R_F** causes **I_F to decrease.**	$I_F \downarrow = V_T / R_F \uparrow$
2.	Decreasing I_F, ⟹ **decreases ϕ**	-
3.	Decreasing ϕ **lowers E_A** instantaneously.	$E_A \downarrow = K\phi \downarrow \omega$
4.	Decreasing E_A causes **I_A to increase.**	$I_A \uparrow = (V_T - E_A \downarrow)/R_A$
5.	Increasing I_A, ⟹ **increases τ_{ind}** Note: $I_A \uparrow$ **predominates** over $\phi\downarrow$.	$\tau_{ind} \Uparrow = K\phi \downarrow I_A \Uparrow$
6.	Increasing τ_{ind} causes $\tau_{ind} > \tau_{load}$, hence **motor speeds up** $(\omega\uparrow)$.	-
7.	Since $\omega\uparrow$, **E_A increases again.**	$E_A \uparrow = K\phi\omega \uparrow$
8.	Increasing E_A causes **I_A to decrease**.	$I_A \downarrow = (V_T - E_A \uparrow / R_A)$
9.	Decreasing I_A causes τ_{ind} to **decrease** until $\tau_{ind} = \tau_{load}$ **at a higher speed ω**	$\tau_{ind} \downarrow = K\phi I_A \downarrow$

بعد قيمة معينة بحيراد flux يأثر أكثر

Example 8-1

input current $= I_L$

$P_{conv} = E_A I_A = \tau_{ind}\, \omega_m$

$E_{A_0} = K\phi\omega_0$, $E_{A_1} = K\phi\omega_1$

No load

At no load $E_{A_0} = V_T$

Changing terminal voltage

1.	**Increasing V_A** causes **I_A to increase.**	$I_A \uparrow = (V_A \uparrow - E_A)/R_A$
2.	Increasing I_A, ⟹ **increases τ_{ind}**	$\tau_{ind} = K\phi I_A \uparrow$
3.	Increasing τ_{ind} causes $\tau_{ind} > \tau_{load}$, hence **motor speeds up** $(\omega\uparrow)$.	-
4.	Since $\omega\uparrow$, **E_A increases.**	$E_A \uparrow = K\phi\omega\uparrow$
5.	Increasing E_A causes **I_A to decrease**.	$I_A \downarrow = (V_T - E_A \uparrow / R_A)$
6.	Decreasing I_A causes τ_{ind} to **decrease** until $\tau_{ind} = \tau_{load}$ **at a higher speed ω.**	$\tau_{ind} \downarrow = K\phi I_A \downarrow$

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Examples solving

Example 8-3

Rated power = 100 hp

compensating windings → Armature reaction is ignored

line current = 126 A = I_L

if load is changed : I_A stays constant Special Case → If not use →

Note:

$$n_2 = \frac{E_{A2}}{E_{A1}} n_1$$

1. $I_{A_1} = I_L - I_F$

$= 126 - \frac{250}{41.67} = 120\,A$ ($\frac{250}{41.67}$ → I_{f_1})

$E_{A_1} = -(R_A)(I_A) + 250$

$= 250 - (120)(0.03)$

$E_{A_1} = 246\,V$

} at speed 1103

For a Motor

$P_{out} = P_{Given}$ if

- At Full load conditions

$P_{out} = P_{conv} - P_{core} - P_{losses}$

if other conditions

if $R_F = 50$

Since I_A is constant → $E_{A_1} = E_{A_2} = 246.4$

$$\frac{E_{A_1}}{E_{A_2}} = \frac{K \phi_1 n_1}{K \phi_2 n_2} \longrightarrow 1 = \frac{\phi_1}{\phi_2} \frac{n_1}{n_2} \longrightarrow n_2 = \frac{\phi_1}{\phi_2} n_1$$

($\frac{\phi_1}{\phi_2}$ → we need this)

In Magnetization curve

At $I_{f_1} = 6A$ → $E_{A_1} = 268\,A$

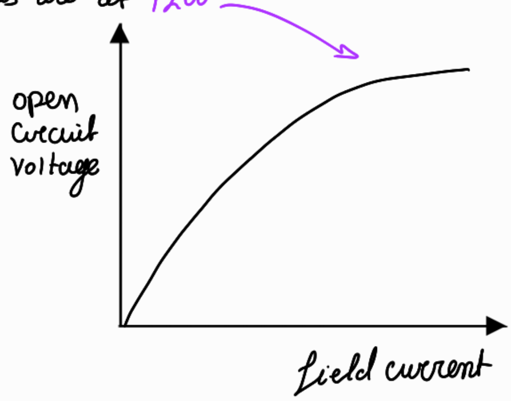
At $I_{f_2} = 5A$ → $E_{A_2} = 250\,A$

} Curve values are at 1200

$$\frac{\phi_1}{\phi_2} = \frac{268}{250} = 1.076$$

} → neglect 1200 RPM

$n_2 = 1.076\,(1103) = 1187$ RPM



<u>Example 5-1</u>

$V_A = 250V$

$I_A = 120A$

$n = 1103$

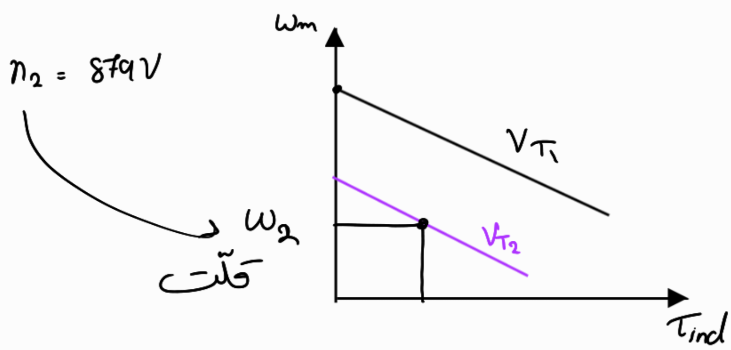
Speed if V_A is reduced to 200A?

$E_{A_1} = 246.4V$ at

$E_{A_2} = 200 - (120)(0.03) = 196.4V$

$n_2 = \frac{E_{A2}}{E_{A1}} n_1$

$n_2 = 879V$



The permanent Magnet DC motor

Disadvantage : I can't control the flux
Natural magnet losses it's properties with time

Advantages: 1. No external field circuit is required → no field circuit copper losses

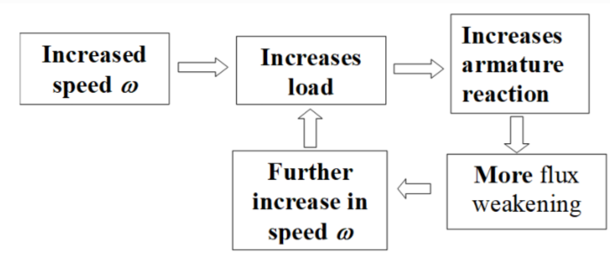
2. Smaller because no field circuit

To control speed for this motor:

1. Armature voltage control
2. Armature resistance control

Open field circuit

- If field circuit is disconnected → motor speed increases and becomes uncontrolable → Runaway Condition



This **continues until motor overspeeds**. This condition is known as **runaway**.

<u>To stop this:</u>

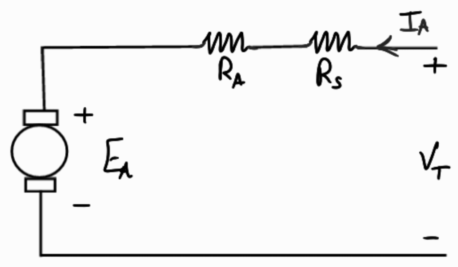
V_T is shut downed or else the motor will be damaged from high current or vibration

Torque Speed characteristics of series DC motor

Note

$P_M = V_T I_L$

$V_T = E_A + I_A (R_A + R_S)$



$\tau \propto \omega$

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

$\phi = C I_A$

$\tau_{ind} = K C I_A^2$ Non-linear Relationship

$I_A = \frac{\sqrt{\tau_{ind}}}{\sqrt{K}\sqrt{C}}$

اي تغيير في ال current بعطيني تيار عالي

اول ما أشغله بعطيني High starting current

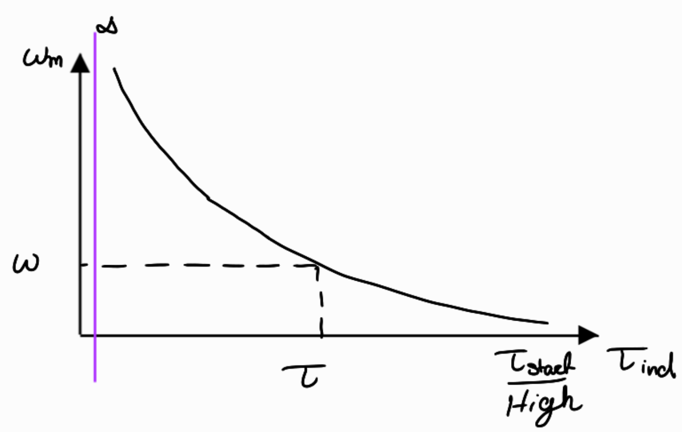
$V_T = K\phi\omega + \frac{\sqrt{\tau_{ind}}}{\sqrt{K}\sqrt{C}} (R_A + R_S)$

$\phi = \frac{\sqrt{C}\, \cancel{C} \sqrt{\tau_{ind}}}{\sqrt{K}\, \cancel{\sqrt{C}}}$

$V_T = \frac{\sqrt{K}\, \cancel{K} \sqrt{C}\sqrt{\tau_{ind}}}{\cancel{\sqrt{K}}} \omega + \frac{\sqrt{\tau_{ind}}}{\sqrt{KC}} (R_A + R_S)$

$\frac{\cancel{\sqrt{\tau_{ind}}\sqrt{KC}}}{\cancel{\sqrt{\tau_{ind}}\sqrt{KC}}} \omega = \frac{V_T - \frac{\sqrt{\tau_{ind}}}{\sqrt{KC}} (R_A + R_S)}{\sqrt{\tau}\sqrt{KC}}$

$$\boxed{\omega = \frac{V_T}{\sqrt{\tau_{ind} KC}} - \frac{R_A + R_S}{KC}}$$



Disadvantage of this motor

At light load (no load) speed goes to ∞

So we cannot start the motor with no load + can't take load off suddenly

See slide 44 (from lecture)

We control it by changing terminal voltage

Example 8-5

$E_A = V_T - I_A(R_A + R_S)$

$= 250 - 50(0.08) = 246\ V$

$n_2 = \frac{E_{A2}}{E_{A1}} n_1$

Magnetomotive force $= 25 \times 50 = 1250$

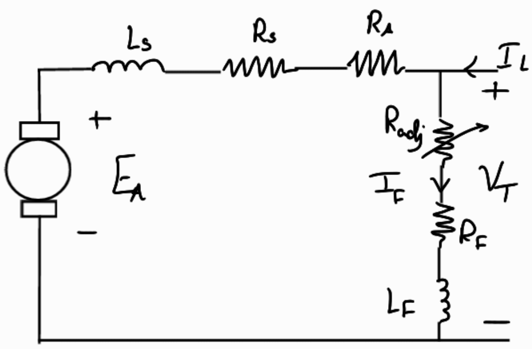
So $E_{A2} \simeq 80$

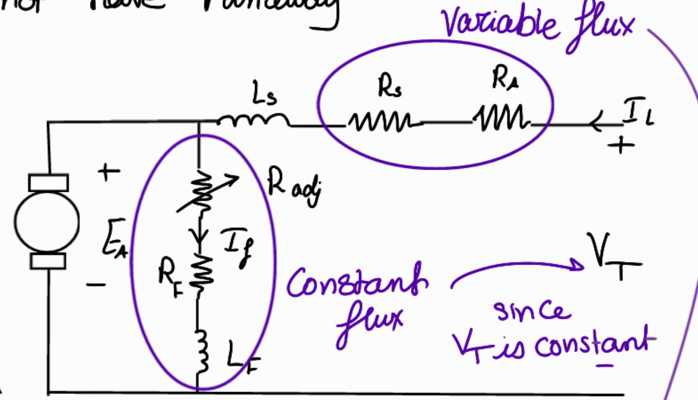
$n_2 = \left(\frac{246}{80}\right)(1200) = 3690\ RPM$

$\tau_{ind} = \frac{P}{\omega} = \frac{E_A I_A}{\omega} = \frac{(246)(50)}{\frac{3690 \times 2\pi}{60}} = 31.85\ N.m$

The compounded DC motor

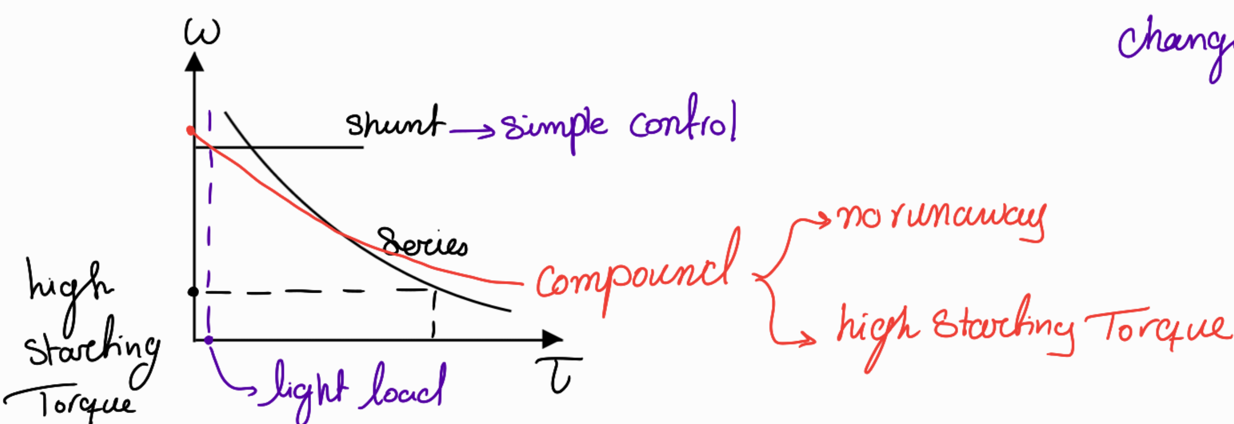
- It has a shunt and a series field and it compounds best features of both shunt & series motors and does not have runaway





Better connection than this
Since V_T is related to field resistanc
and so relation between V_T, I_F is simple
In the second, I_F depends on I_L

since R_A is variable
That depends on load
R_A changes → I_A
changes → Ø changes

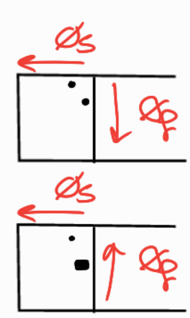


runaway occurs for series (Bad)

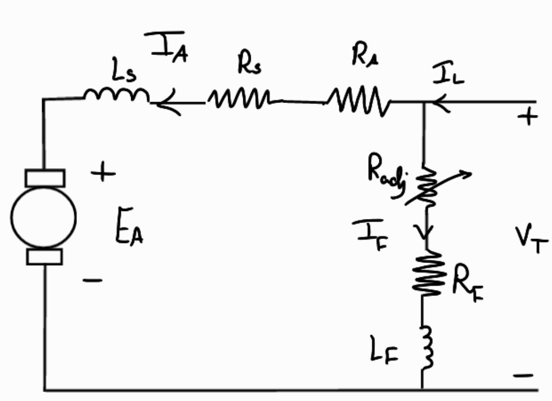
$$\phi_{net} = \phi_s + \phi_f \quad \text{Comulatively compound}$$

$$\phi_{net} = \phi_s - \phi_f \quad \text{Differentially Compound}$$

(series, shunt)



→ Ø↑ to prevent runaway
التيار داخل على • من الجهتين
unstable



$I_f = \frac{V_T}{R_f}$ constant

I_A is variable that depends on the load

At light load → shunt اقرب لل
At higher load → series اقرب لل

Speed control is done by controlling:-

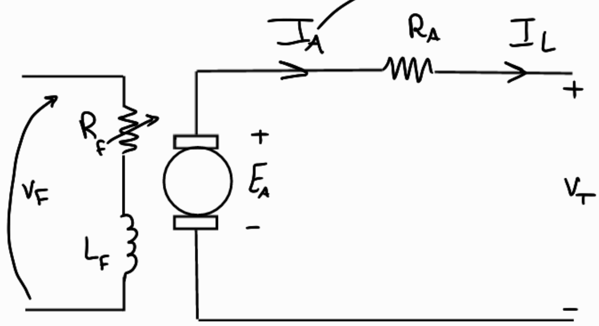
field resistance

Voltage V_A

Armature Resistance R_A

DC Generator

- Same Structure as motor → S.E / Shunt / Compound



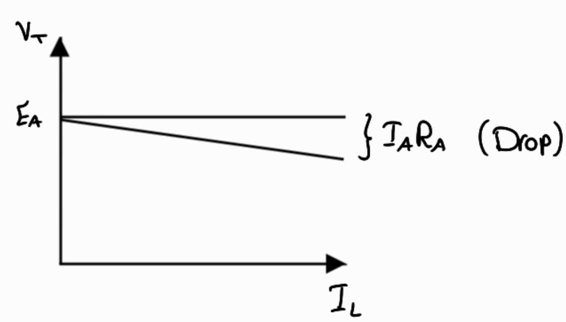
Separately excited DC Generator

$V_T = E_A - I_A R_A$

E_A needs to be increased to decrease drop

$E_A = K\varnothing\omega$ → **field current**

So: $\varnothing$ or ω are increased to increase E_A

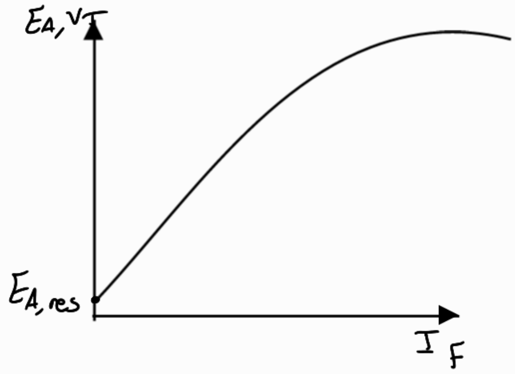


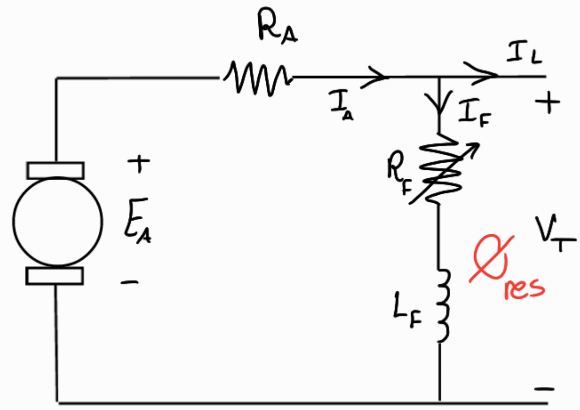
Best type of generator:

Terminal voltage is constant while changing load

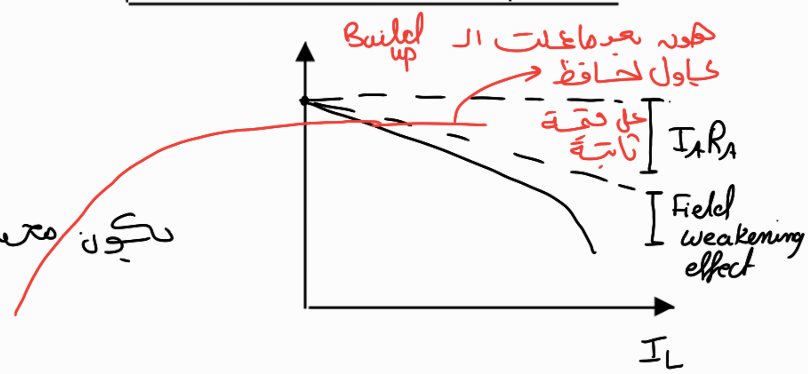
Shunt DC Generator

$\emptyset_{residual}$ gives mechanical energy $\rightarrow E_A = K\emptyset_{res}\omega_m$



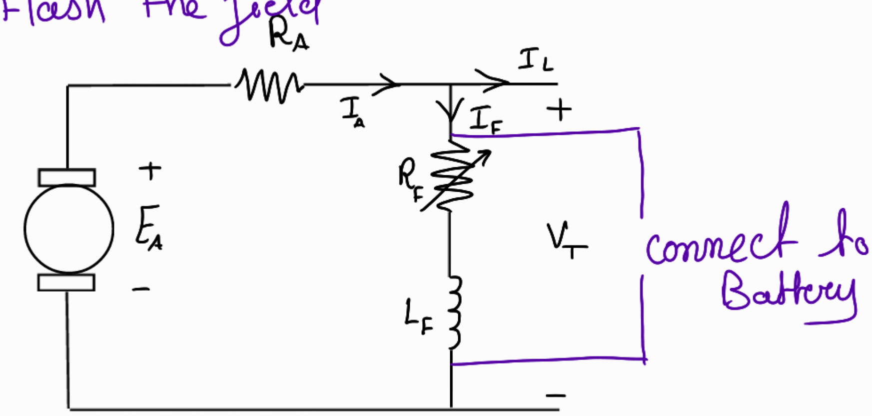


$\emptyset_{res}$ exists in material بكون محشور



If there was no $\emptyset_{res}$

1. Flash the field

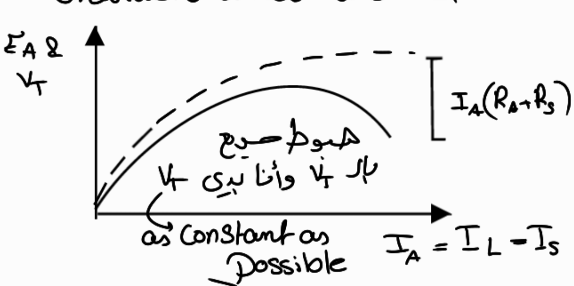


2. to turn the direction of rotation of generator

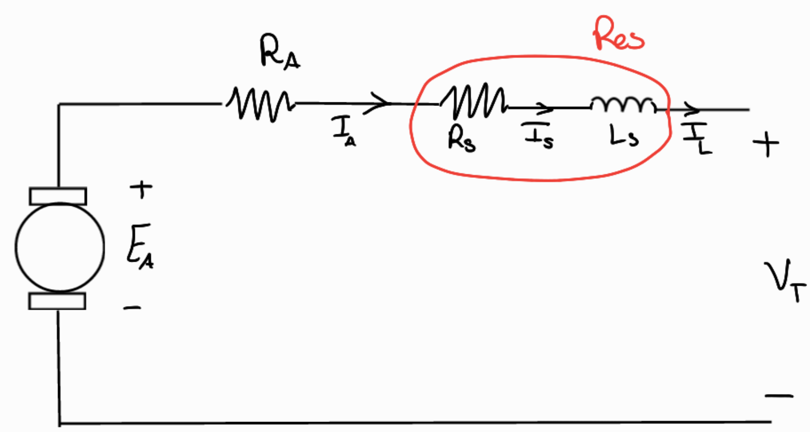
Series DC Generator

$V_T = E_A - (R_A + R_S)I_A$

Characteristics are Bad

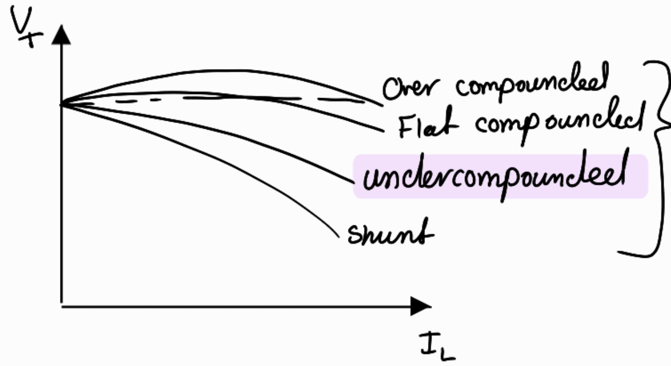


$I_A = I_L - I_S$



Compound DC Generators → to control it { ω_m, I_F }

Comulatively



} Acceptable (comulatively)

Differentialy : Bad → Unacceptable