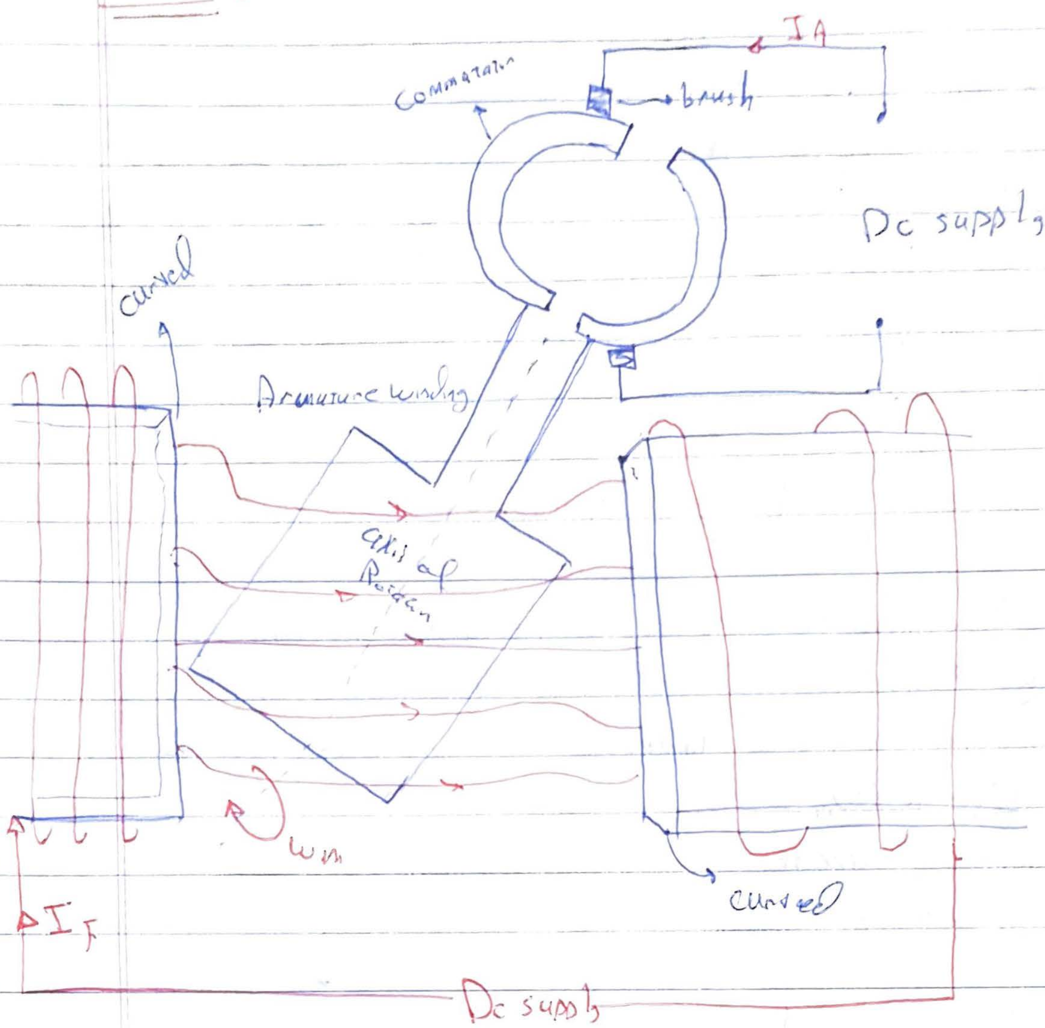
CH2: Dc Motors & Generators



Ⓐ الزمن طلك واحد.
حالك اكون ملك عدد كبر
لانه High Torque &

Armature → Rotor
Field → stator
I_A: Armature current
I_F: Field current

Ac عكس ⊗

⊗ operating principle of Dc machine (Motors Mode)

⊗ an electric current is supplied through the commutator & brushes
⊗ The current (I_A) passes through the armature windings, in the precense of magnetic field, and produces a magnetic force ($F_{ind} = I_A \vec{L} \times \vec{B}$)
⊗ The magnetic force will produces a torque which is able to rotate the Dc motor. ($T_{ind} = \vec{r} \times F_{ind}$)

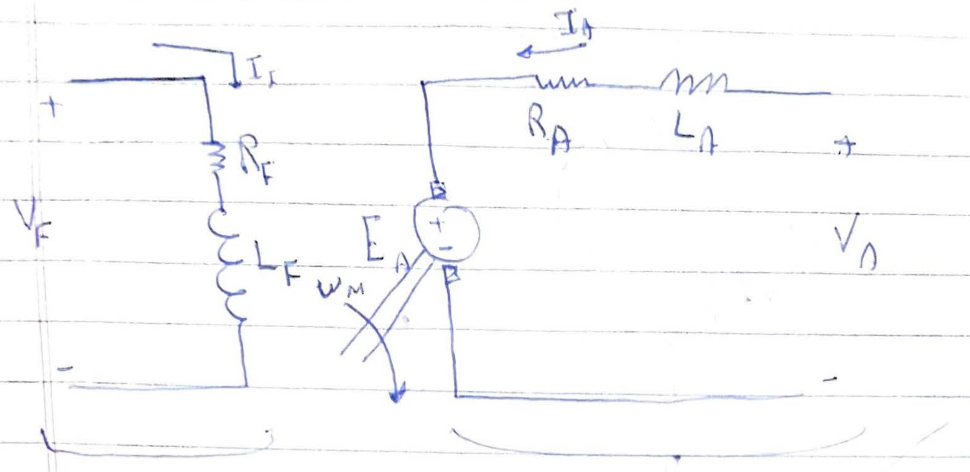
⊗ Types of Dc motors

(parallel)

① separately excited Dc motors ② shunt Dc motor
③ series Dc motor ④ componant Dc motors ⑤ permanent magnet Dc motor

⊗ نستخدم Dc Motor للأشياء التي تتطلب
• low power
• Drive is easiest than Ac induction ...

General equivalent circuit



Field circuit — Armature circuit.

R_F & L_F :- Resistance and inductance of field winding

R_A , L_A :- Resistance and inductance of armature winding

E_A :- internal voltage or induced or back emf voltage

$$E_A = K\phi\omega_m$$

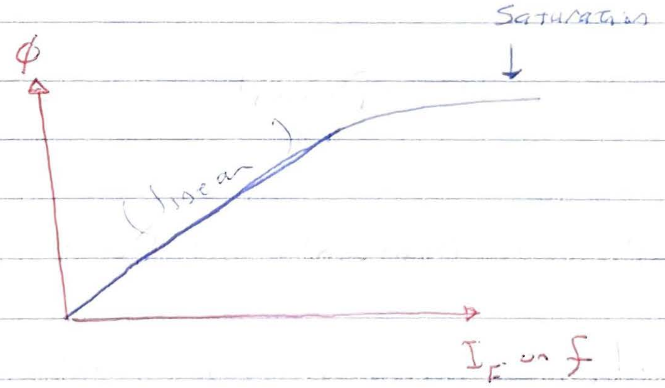
I_A :- Armature current

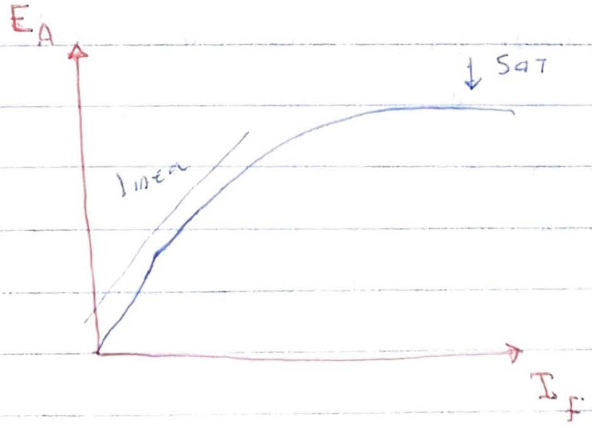
I_F :- Field current

$\phi = C I_F$

$E_A = K\phi\omega_m$, when ω_m is constant

$E_A = K'\phi$

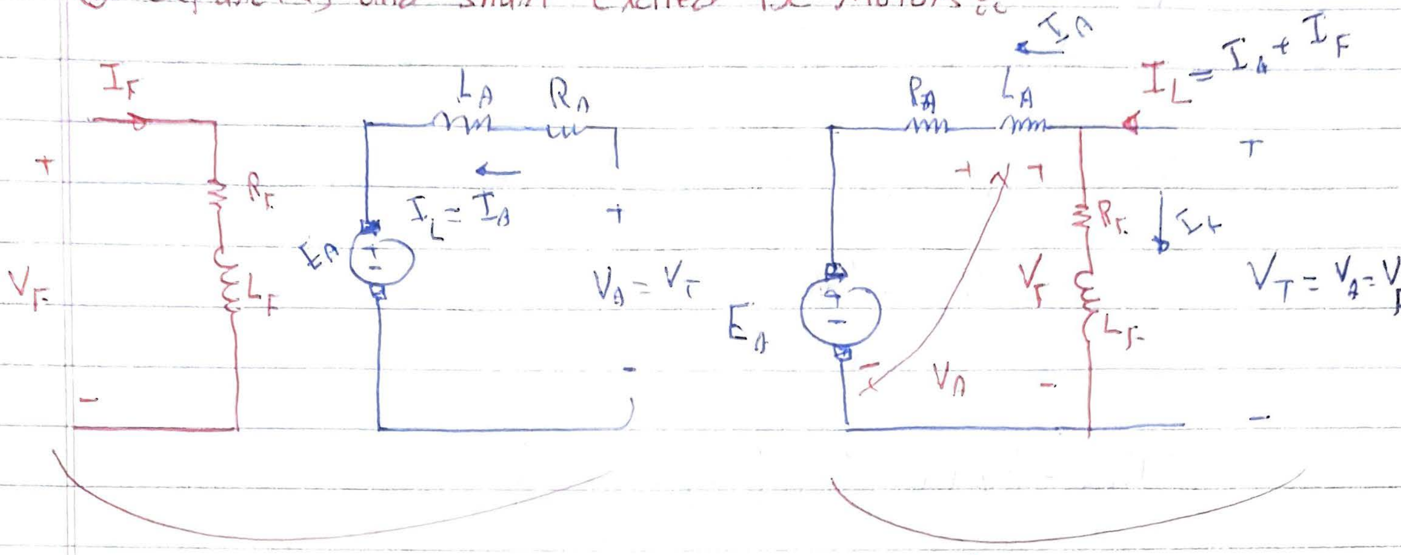




V_A :- Armature voltage

V_F :- Field voltage

① Separately and shunt excited DC Motors :-



seperately excited — shunt excited

V_T :- Terminal or motor voltage

I_L :- Motor or line current

⊛ equation of Dc machine " seperately & shunt excitation "

KVL in the armature circuit

- $V_T = R_A I_A + L_A \frac{dI_A}{dt} + E_A$
- Back emf voltage
  $E_A = K\phi\omega_m$
- Induced Torque
  $T_{ind} = K\phi I_A$
- Newton second law
  $T_{ind} - T_{Load} = J\frac{d\omega_m}{dT} + \underbrace{B\omega_m}_{\text{Friction factor}}$

⊛ Torque speed characteristics

under steady state condition, the motor voltage is given by:

$$V_T = R_A I_A + \cancel{L_A \frac{dI_A}{dt}}^{\,0} + E_A$$

$$V_T = R_A I_A + E_A = R_A I_A + K\phi\omega_m \, , \quad \text{solve for } I_A$$

$$I_A = \frac{V_T - K\phi\omega_m}{R_A}$$

$$T_{ind} = K\phi I_A = K\phi\left(\frac{V_T - K\phi\omega_m}{R_A}\right)$$

$$T_{ind} = \frac{K\phi}{R_A}\left(V_T - K\phi\omega_m\right)$$

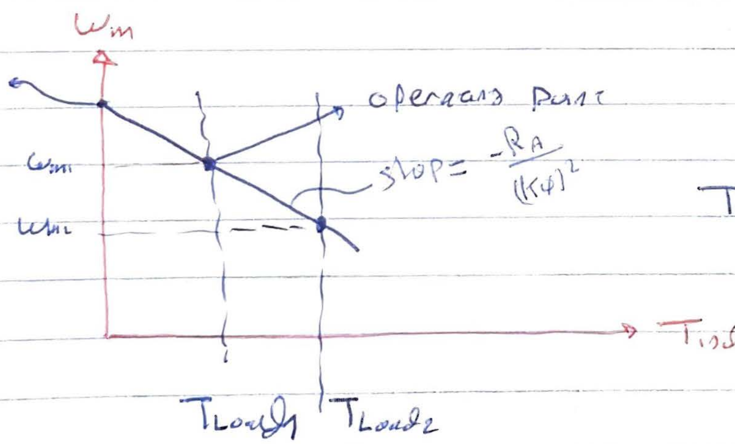
$$\frac{R_A}{K\phi} T_{ind} = V_T - K\phi\,\omega_m \Rightarrow \frac{R_A}{(K\phi)^2} T_{ind} = \frac{V_T}{K\phi} - \omega_m$$

مهم

$$\boxed{\omega_m = \frac{V_T}{K\phi} - \frac{R_A}{(K\phi)^2} T_{ind}}$$

No Load speed

shunt & seperatly



$T_{Load2} > T_{Load1} \Rightarrow \omega_{m2} < \omega_{m1} < \omega_{m,No\,Load}$

$$\omega_{m,NL}\Big|_{I_A = 0} = \frac{V_T}{K\phi}$$

OR $V_T = E_A$

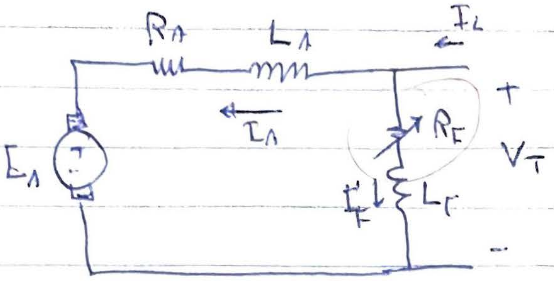
$T_{Load} \uparrow \Rightarrow \omega_m \downarrow \Rightarrow [E_A = K\phi\omega_m \downarrow]$

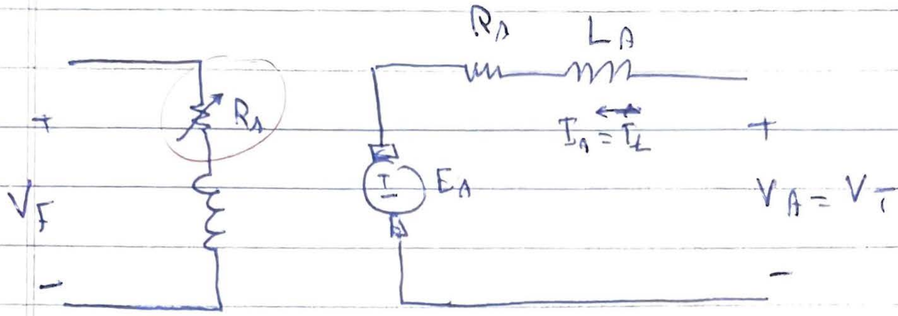
$\Rightarrow \left(I_A = \frac{V_T - E_A\downarrow}{R_A}\right)\uparrow \Rightarrow (T_{ind} = K\phi I_A)\uparrow$ until equals T_{Load}

لحد ما تصير
$T_{ind} = T_{Load}$

Method to control the speed

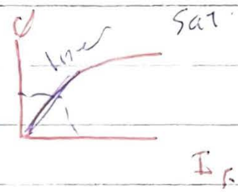
① Adjusting The Field resistor :



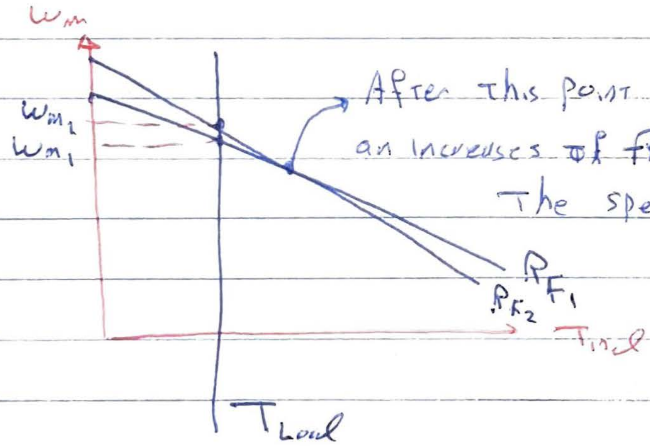


$R_A \uparrow \Rightarrow I_F \downarrow \Rightarrow \phi \downarrow$

$I_F = c\phi$



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



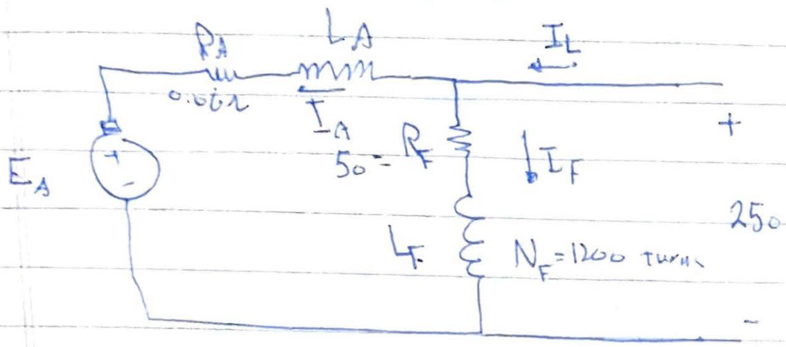
because $\frac{-1}{(K\phi)^2}$ slop decrease more.

After this point an increases of R_F decreases The speed and No load ω increased

⊗ بعد نقطة التقاطع المرن رح يصير العكس
أي تقل لذلك منطقة العمل دائماً
بكون قبل هذه النقطة.

$R_{F_2} > R_{F_1} \Rightarrow \omega_{m_2} > \omega_{m_1}$ (Field weakning)

Example: A 50 hp, 250 V, 1200 rpm DC shunt motor has armature resistance of 0.06 Ω. Its field circuit has a total resistance of 50 Ω which produces a no-load speed of 1200 rpm. There are 1200 turns per pole on the shunt field winding.



a) Find the speed of this motor when its ~~field~~ input current is 100 A?

وذلك
لأنه عند NL
وكمان I_A
تساوي صفر
so $E_A = V_T$

$V_L = R_A I_A + E_A$

$I_A = I_L - I_F \quad \rightarrow \quad I_A = 100 - \frac{250}{50} = 95\,A$

$E_A' = 250 - 0.06(95) = 244.3\ V$

$E_A = 250\ V$ (at No Load)

$E_A = K\phi\omega_m$

$250 = K\phi\,1200$

$244.3 = (K\phi)(\omega_m')$

ϕ is Not changed since V = 250 constant of field circuit

$\boxed{\omega_m' = 1173}$

b) Find the speed of this motor when its input current is 300 A?

$V_L = R_A I_A + E_A$

$250 = (0.06)(I_A) + E_A$

$\boxed{I_A = 295\,A}$, $\boxed{E_A = 232.3}$

$E_A = K\phi\omega_m \quad \Rightarrow \quad 250 = (K\phi)(1200)$ — ①

$232.3 = K\phi\,\omega_m'$ — ② $\Rightarrow \boxed{\omega_m' = 1115\ rpm}$

Converted power in ~~shunt~~ separately excited Dc motors

$V_L = R_A I_A + E_A$, Multiply the eq by I_A

$$V_L I_A = R_A I_A^2 + E_A I_A$$

$V_L I_A$ → input power

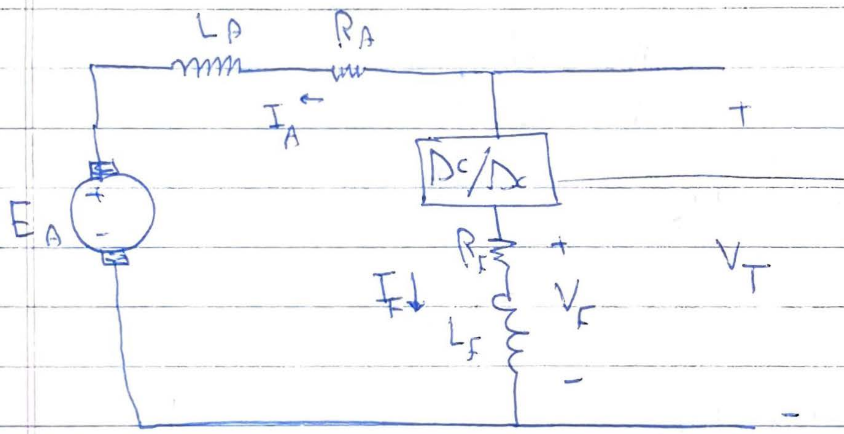
$R_A I_A^2$ → Copper losses in R_A

$E_A I_A$ → Converted power

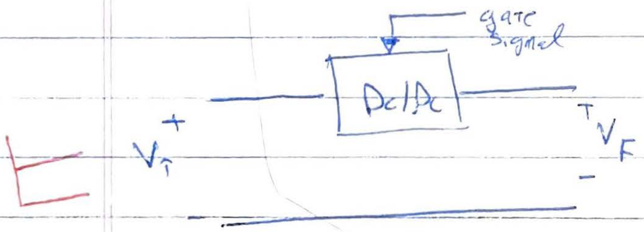
$$P_{conv} = E_A I_A = T_{ind}\,\omega_m \Rightarrow \boxed{T_{ind} = \frac{P_{conv}}{\omega_m}}$$

✱ Method to Control the speed (Repeated)

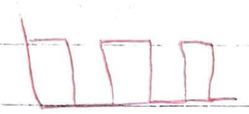
① adjusting the field resistor or adjust the field voltage:



تقلل V_F بيقلل
بقل I_F بيقل ϕ



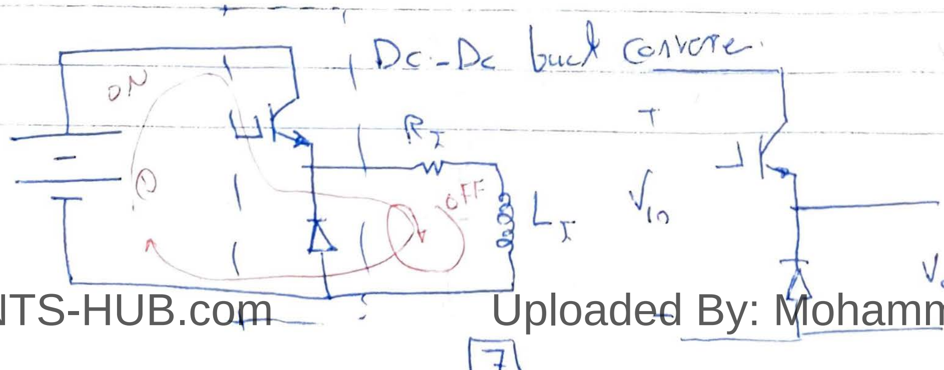
$V_F = \delta V_T$



كل ما زادت δ بتزيد V_F
من V_T وبقل فترة opp

where δ is called the duty cycle $0 \le \delta \le 1$

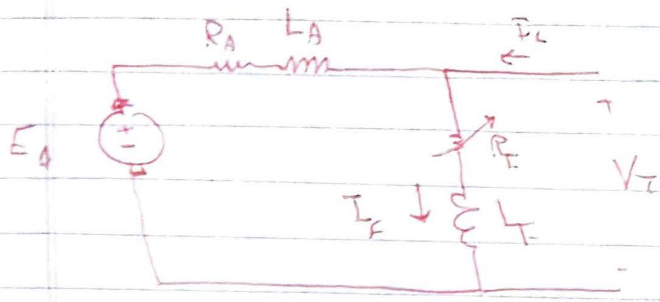
Dc-Dc buck converter



$V_{out} = \delta V_{in}$

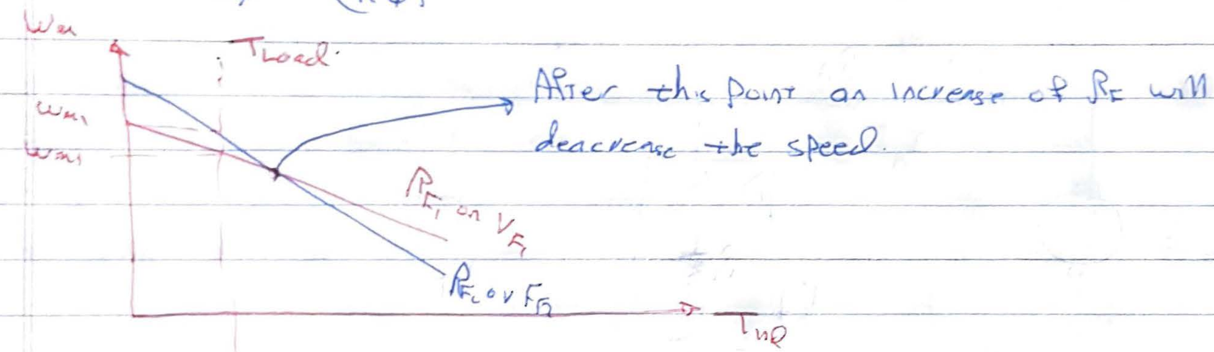
$$V_F \downarrow \Rightarrow \left(I_F = \frac{V_F}{R_F}\right)\downarrow \Rightarrow (\phi = C I_F)\downarrow \Rightarrow \omega \uparrow$$

② adjusting the field Resistor



$$R_F \uparrow \Rightarrow \left(I_F = \frac{V_F}{R_F}\right)\downarrow \Rightarrow (\phi = C I_F)\downarrow$$

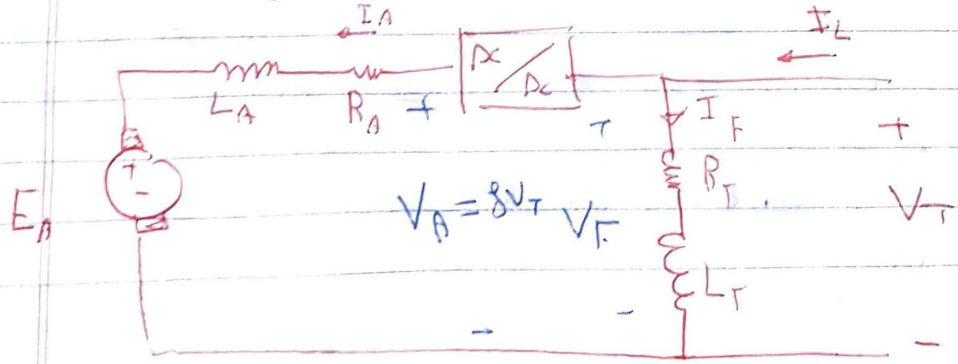
$$\omega_m = \frac{V_T}{K\phi} - \frac{R_A}{(K\phi)^2} T_{ind}$$



$R_{F_1} < R_{F_2} \Rightarrow \omega_{m_1} < \omega_{m_2}$

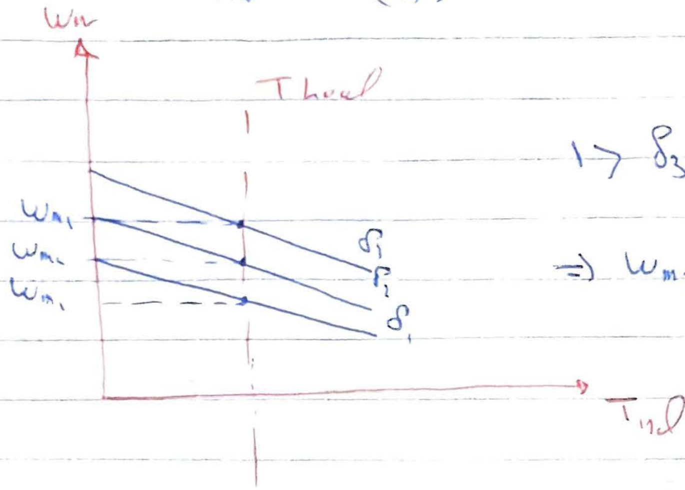
$V_{F_1} > V_{F_2} \Rightarrow \omega_{m_1} < \omega_{m_2}$

③ adjusting the armature Voltage.



$V_A = \delta V_T$, δ is the duty cycle $0 \le \delta \le 1$

$$\omega_m = \frac{\delta V_T}{K\phi} - \frac{R_A}{(K\phi)^2} \cdot T_{ind}$$



$1 > \delta_3 > \delta_2 > \delta_1 > 0$

$\Rightarrow \omega_{m3} > \omega_{m2} > \omega_{m1}$

Note

① $V_A = R_A I_A + E_A = R_A I_A + K\phi\omega_m$

$V_A = R_A I_A + K\phi\,\omega_m$

⊗ لا يمكن رفع ال Voltage اعلى من Rated volt، بعد ال full نقلل ال ϕ لزيادة السرعة

$\phi = \phi_r$ rated flux [when $\omega_m \leq \omega_{m,r}$ where $\omega_{m,r}$ is the rated speed
$\Rightarrow$ Armature control is used $\Rightarrow V_A$ increase with ω_m (linearly)]

when $\omega_m \geq \omega_{m,r} \Rightarrow$ Field control is used
$V_A = V_{A,r}$ = rated motor voltage

$\Rightarrow \phi \propto \frac{1}{\omega_m}$ " Field weakening "

② $T_{ind} = K\phi I_A$

$P_{conv} = T_{ind}\,\omega_m$

⊗ من طرق التحكم بالسرعة بعد Rated تقليل ال ϕ
لكن هي بتعني V_A ثابت حسب المعادلة $\phi = \frac{c}{\omega}$
لذلك $\boxed{V_A} = R_A I_A + K\frac{c}{\omega}\omega$ — constant

[when $\omega_m \leq \omega_{m,r} \Rightarrow \phi = \phi_r \Rightarrow T_{ind} = \text{constant}$
when $\omega_m \geq \omega_{m,r} \Rightarrow \phi = \phi_r \frac{\omega_{m,r}}{\omega_m} \Rightarrow T_{ind} = K\phi_r \frac{\omega_{m,r}}{\omega_m}$]

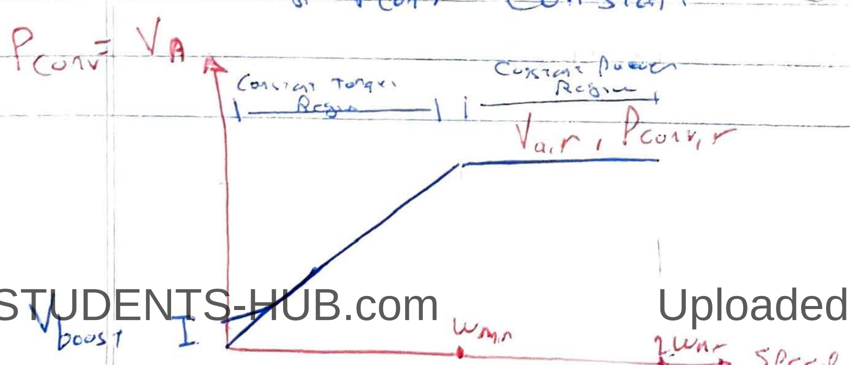
& $P_{conv} = \text{Constant}$

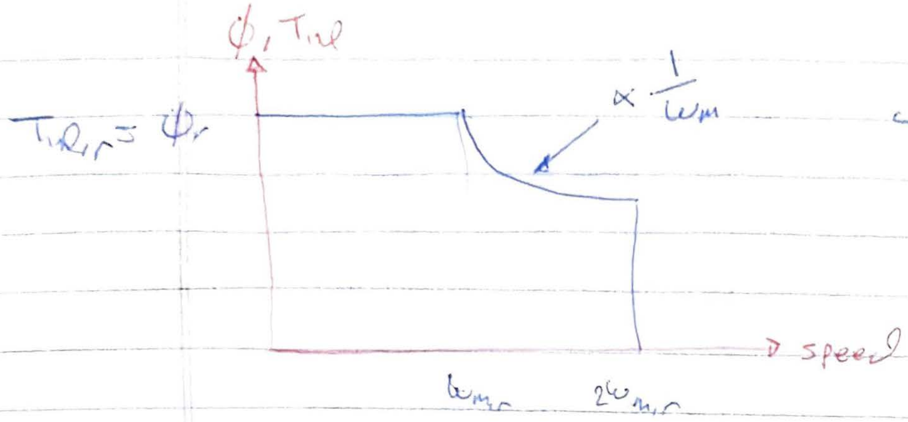
$\text{Constant} = P = K\phi_r \frac{\omega_{m,r}}{\omega_m} \cdot \omega_m$

$P = T_{ind}\,\omega_m$

$T_{ind} = K\phi\omega_m$

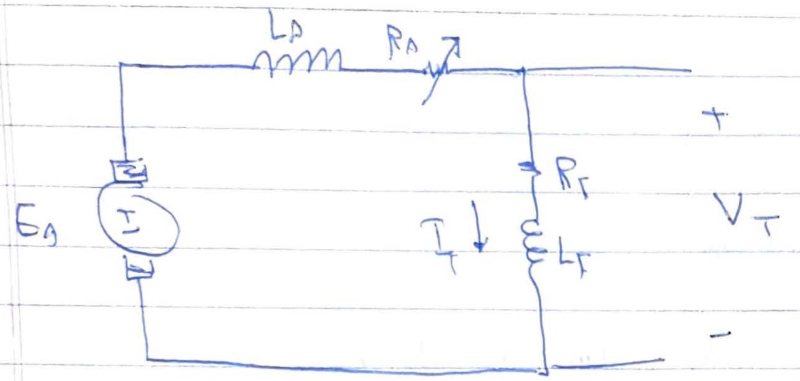
$T_{ind} = K\frac{\phi}{\omega} \cdot \omega_m \simeq \text{Const}$



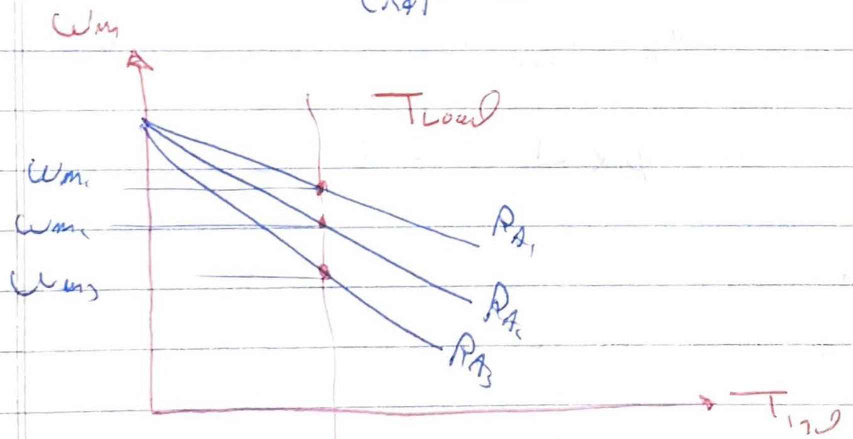


ⓧ تأتي زيادة السرعة على حساب
T_{ind}
حيث أنها تقل مع $\frac{1}{\omega_m}$

③ Inserting a resistor to the armature circuit:



$$\omega_m = \frac{V_T}{K\phi} - \frac{R_A}{(K\phi)^2} \cdot T_{ind}$$



$$R_{A_1} > R_{A_2} > R_{A_3} \Rightarrow \omega_{m_3} < \omega_{m_2} < \omega_{m_1}$$

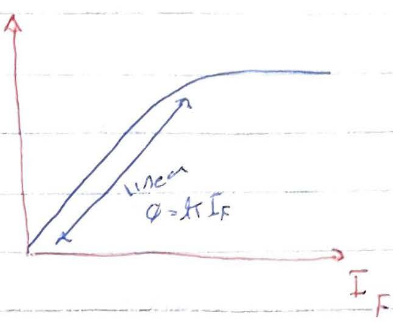
⇒ This method is inefficient because the power losses are very large ⇒ its rarely used.

Notes: The direction of shunt on separately excited Dc motor is reversed by switching the terminals of armature or field windings

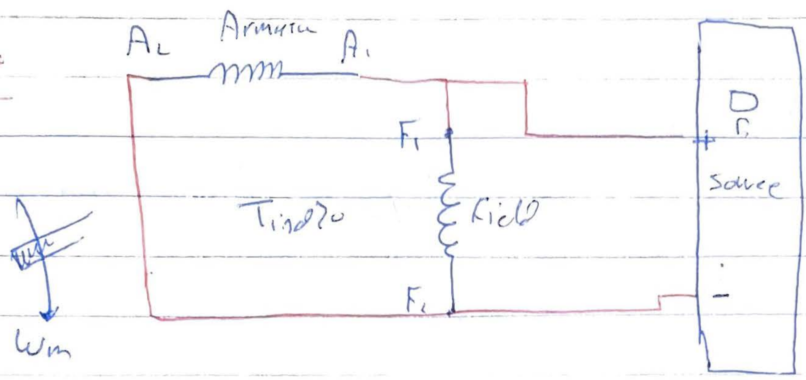
$T_{ind} = K\phi I_A$

$\phi = K I_F$ ⊕ عليك عكس احدى التيارات .

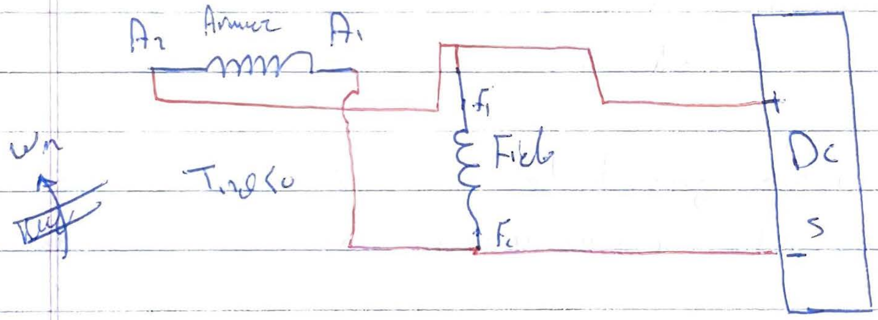
$T_{ind} = Kc I_F I_A$



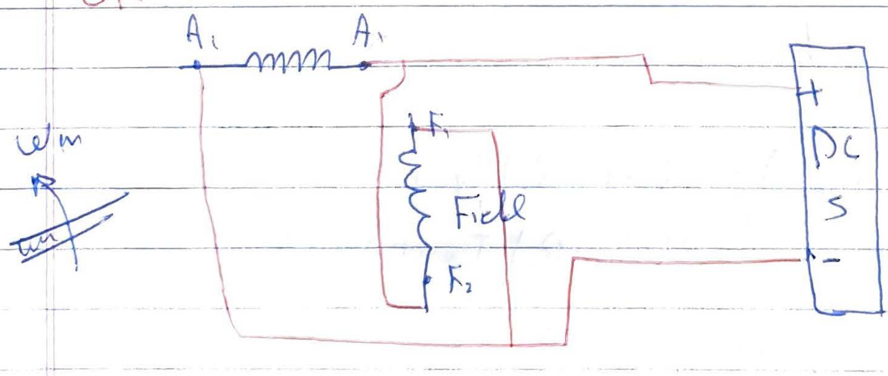
Shunt



How?



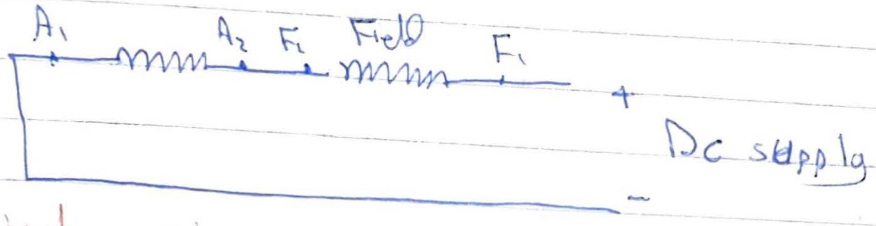
OR



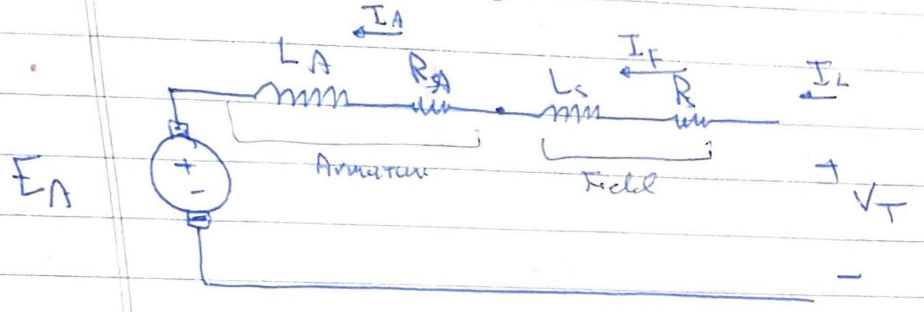
② ~~Ser.~~

③ Series Dc motor

The field winding is connected in series with the armature coil,



equivalent circuit :



Motor Current = $I_A = I_F = I_L$

Induced Torque : $T_{ind} = K\phi I_A$

$T_{ind} = K c\, I_F I_A \quad , \; I_F = I_A$

$T_{ind} = K c I_A^2 \implies T_{ind} \propto I_A^2$

The series Dc motor gives higher Torque / Ampere ratio than other Dc motors. It's usually used in applications requiring high Torques.

Torque speed characteristics of series Dc motor ?

KVL in the loop : $V_T = (R_A + R_s) I_A + E_A \;,\; E_A = K\phi\omega_m$

$V_T = (R_A + R_s) I_A + K\phi\omega_m$

$\phi = c I_F \;,\; I_F = I_A$

$V_T = (R_A + R_s) I_A + K c I_A \omega_m$ ---- ①

$T_{ind} = K c I_A^2$

$\implies I_A = \frac{\sqrt{T_{ind}}}{\sqrt{Kc}}$ ---- ②

①,② $V_T = (R_A + R_S)\dfrac{1}{\sqrt{K_C}}\sqrt{T_{ind}} + \dfrac{K_C}{\sqrt{K_C}}\sqrt{T_{ind}}\,\omega_m$

$$\frac{V_T}{\sqrt{T_{ind}}} = \frac{R_A + R_S}{\sqrt{K_C}} + \sqrt{K_C}\,\omega_m$$

$$\boxed{\omega_m = \frac{V_T}{\sqrt{K_C}} \cdot \frac{1}{\sqrt{T_{ind}}} - \frac{(R_A + R_S)}{K_C}}$$

Starting Torque:

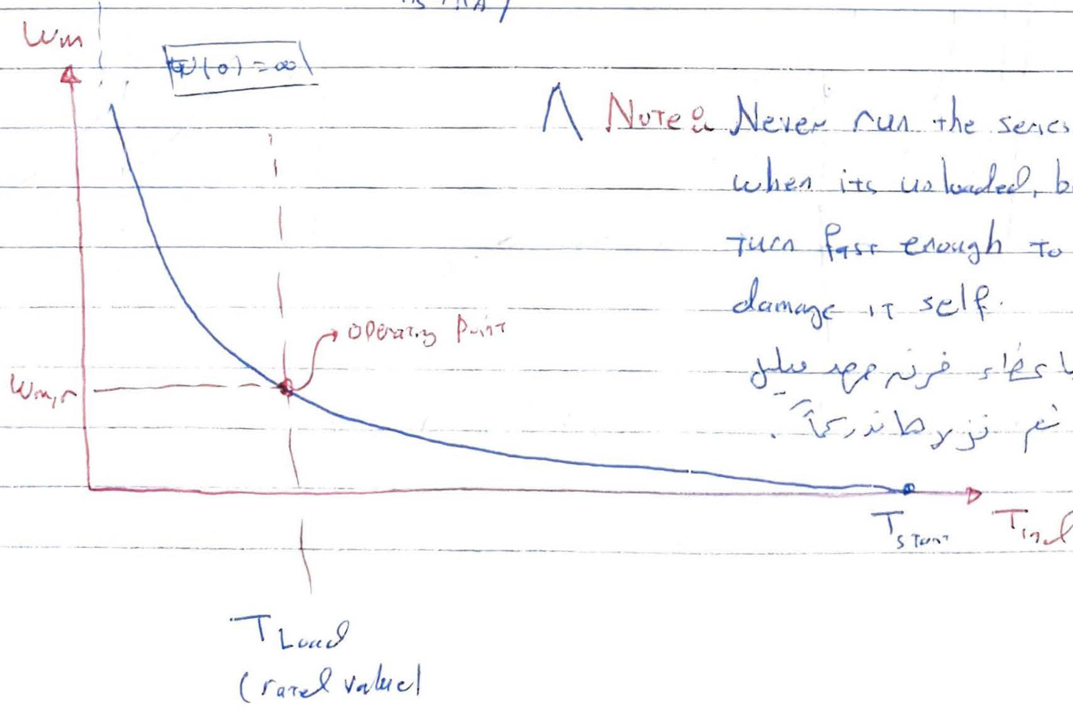
$$T_{start} = T_{ind}\Big|_{\omega = 0} \Rightarrow 0 = \frac{V_T}{\sqrt{K_C}} \cdot \frac{1}{\sqrt{T_{ind}}} - \frac{(R_A + R_S)}{K_C}$$

After solving it $\Rightarrow$ $\boxed{T_{start} = \left(\dfrac{V_T}{(R_A + R_S)}\right)^2 K_C}$

or by $E_A = K\phi\omega_m = 0$ At starting

$$T = K_C I_A^2 \quad , \quad I_A = \frac{V_T - \cancel{E_A}^{\,0}}{R_A + R_S}$$

$$\therefore \; T_{start} = K_C\left(\frac{V_T}{R_S + R_A}\right)^2$$



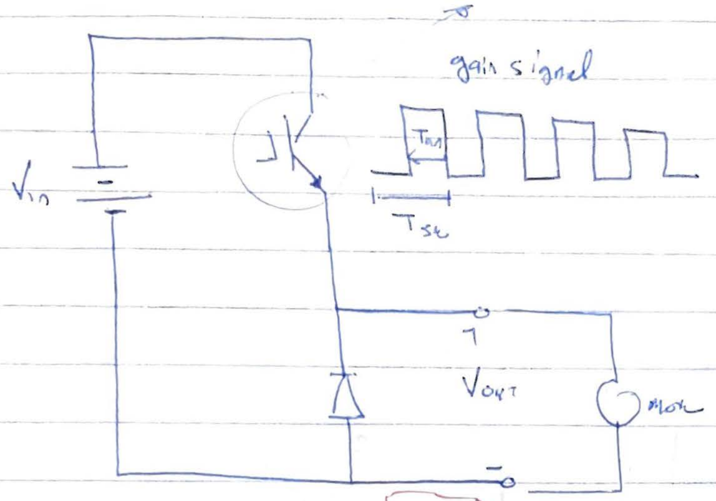
Note: Never run the series DC motor when its unloaded, because it may turn fast enough to seriously damage it self.

يمكن حلها باعطاء فرنر حمل قليل
من البداية ثم نزيدها تدريجياً.

⊛ Methods to control the speed go

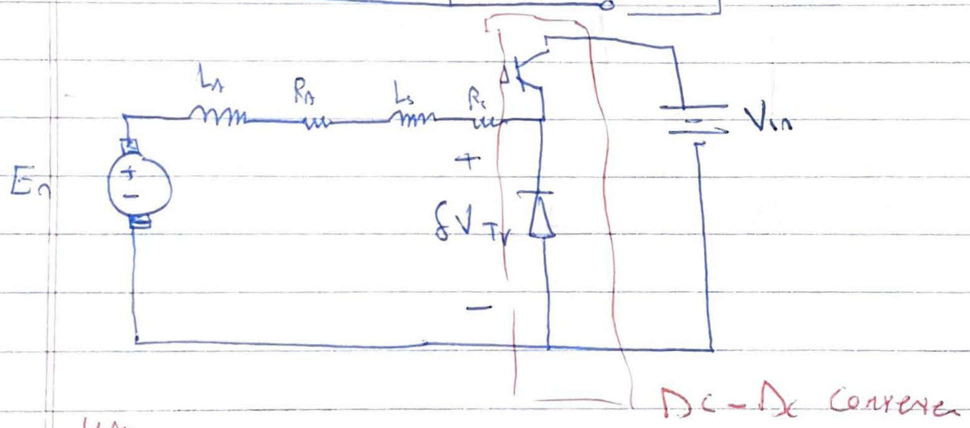
1) Adjust the motor Voltage using Dc/Dc buck converter (chopper circuit)

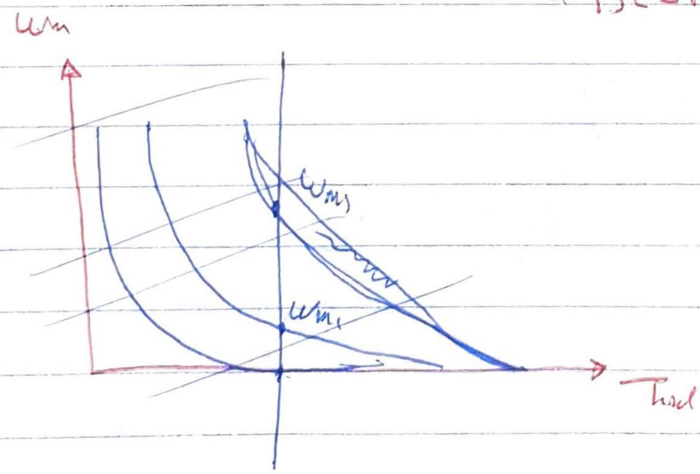
اذا أعطيته High signal بيشتغل والعكس صحيح.

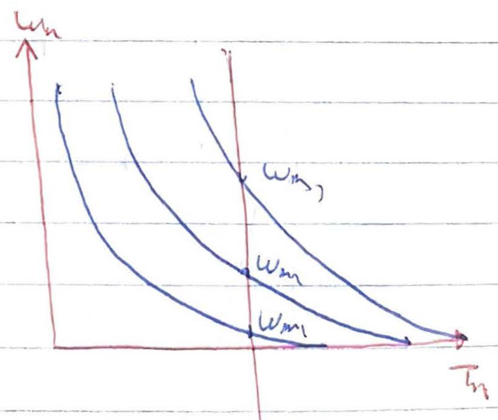


$V_{out} = \delta V_{in}$

$$\boxed{\delta = \frac{T_{on}}{T_{sw}}}$$



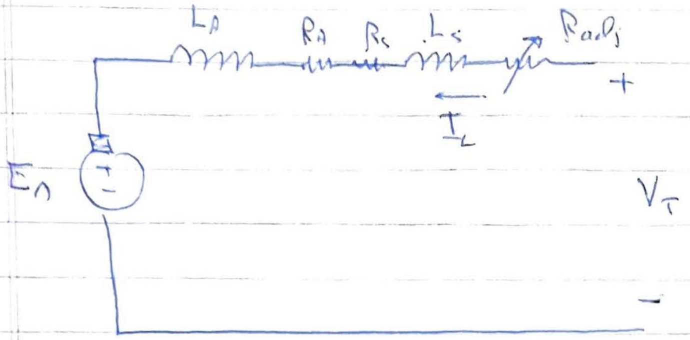




$V_1 < V_2 < V_3$, $\omega_{m_1} < \omega_{m_2} < \omega_{m_3}$

⊛ اذا بدي انزل ال Voltage بنزل ال δ والعكس صحيح.

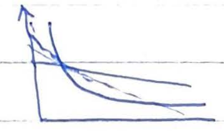
2) Adding a resistor in series with the field & armature windings.

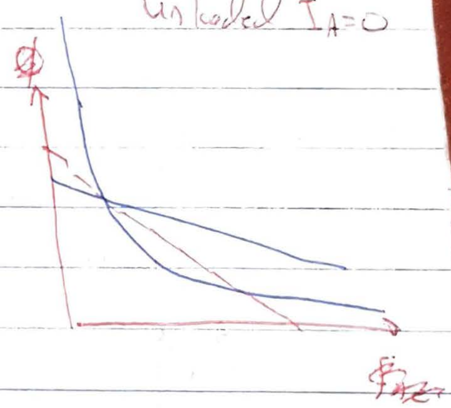


$R_{adj} \uparrow \Rightarrow \omega_m \downarrow \Rightarrow$ This method is inefficient because the power losses are very large $\longrightarrow$ its rarely used.

Note: This method is usually used for starting up the DC motor

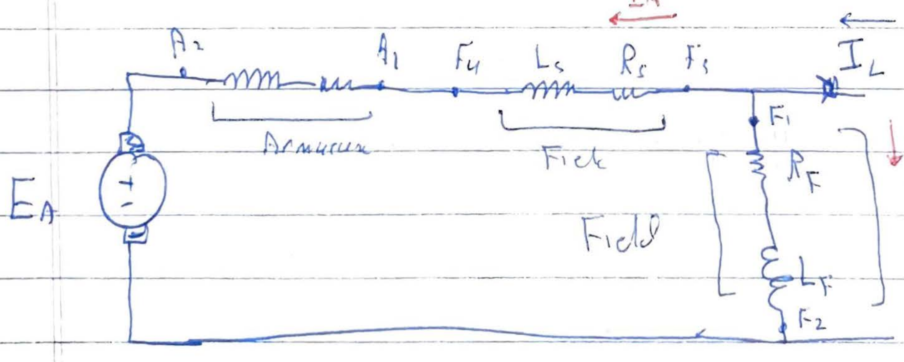
③ Compound DC Motors:





it consists of 3-windings:

1) Armature winding
2) series field windings
3) shunt field windings.



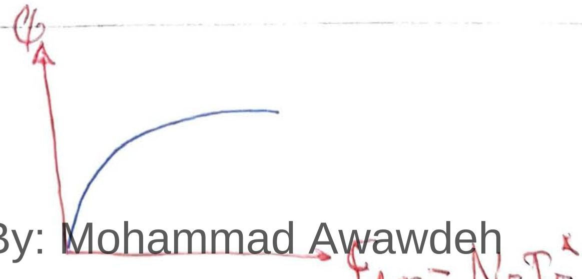
أصلاً flux يتغير
منطقي $I_A = 0$ لكن
$I_F \neq 0$
لذلك نوجد ω_s

نوع التوصيل | The net mmf is giving by , $\mathcal{F}_{net} = \mathcal{F}_F + \mathcal{F}_s$

يوجد $\mathcal{F}_{net} = N_F I_F + N_s I_A = N_F I_F^*$, I_F^* : effective field current

ثابت ϕ

$$\boxed{I_F^* = I_F + \underbrace{\frac{N_s}{N_F}}_{\text{Constant}} \cdot I_A}$$

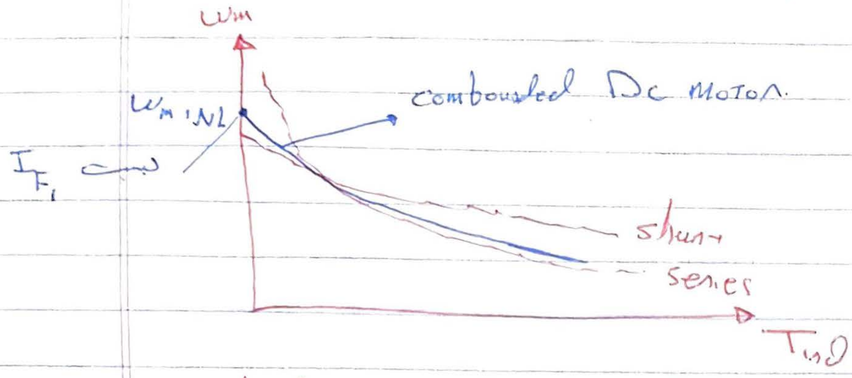


I_A No Load اذا
$I_F^* = I_F$

⊗ its combines the best features of both series and shunt DC motors

series DC motors ⟶ high Torque

shunt DC motors ⟶ it doesn't overspeed when its unloaded.

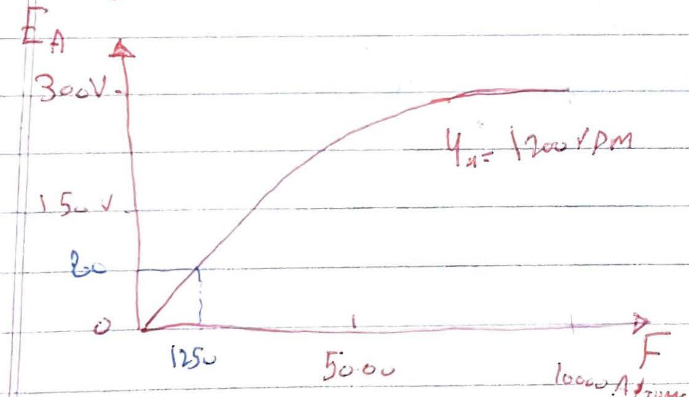


⊗ Methods, to control the speed?

1) changing the Terminal Voltage (Buck converter)
2) changing the field shunt resistor
3) changing the field series resistor } Power losses ↑

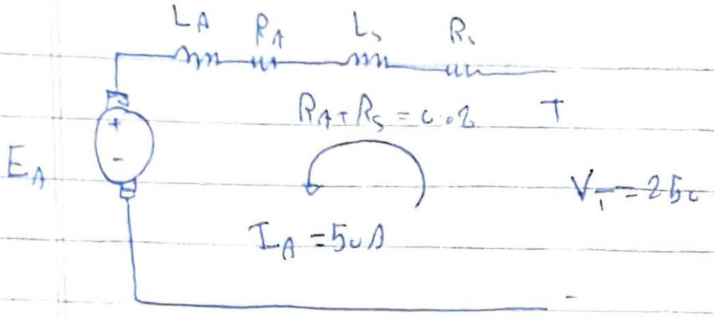
Example A 250V series DC motor has a total series resistance of 0.08Ω. The series field consists of 25 turns per-pole, with the magnetizing curve shown in Figure

$E_A = K\phi\omega$



* عند رسمة منحنى لاسه
E_A بدل ال H_T
* نرسم $K\phi$ vs
ثم نكمل للسرعة الجديدة

◇ Find the speed & Induced Torque when the motor current is 50 A?



KVL in the loop ⇒

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

$E_A = 246$ Volt

$E_A = K\phi\omega_m$

$F = N_F I_F = N_S I_A = (25)(50) = 1250$ A.turn

From magnetizing curve ⇒ $E_{A_0} = 80V = K\phi\left(1200\frac{\pi}{30}\right)$

$K\phi = \cancel{246}$, $\omega_m = 3690\frac{\pi}{30}$ rad/sec

0.6369 $\quad n_m = 3690$ rpm

$T_{ind} = K\phi I_A$

or $P_{conv} = T_{ind}\omega_m = E_A I_A$ ⇒ $\boxed{T_{ind} = 31.8 \text{ N.m}}$

Control circuit in Dc motors

⊗ Function of control circuits

1. protection against short circuit (Fuses)
2. Protection against overloading (OL heater)
3. protection against high starting current
4. speed control

Starting problems in Dc motors

The armuture current of the Dc motor is giving by (KVL) ⇒

$$I_A = \frac{V_T - E_A}{R_A} \quad \text{" seperately or shunt excited "}$$

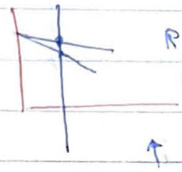
At starting $\Rightarrow \omega_m = 0 \Rightarrow E_A = K\phi\omega_m = 0 \Rightarrow I_{A,\,start} = \frac{V_T}{R_A}$

المشكلة هو عدم وجود E_A في البداية لذلك نحط اول R في البداية ثم ازالها لزيادة E_A

$R_A = (3\% - 6\%)$ (per-unit) $\Rightarrow I_{A,start} \approx (20-30)\, I_{A,rated}$

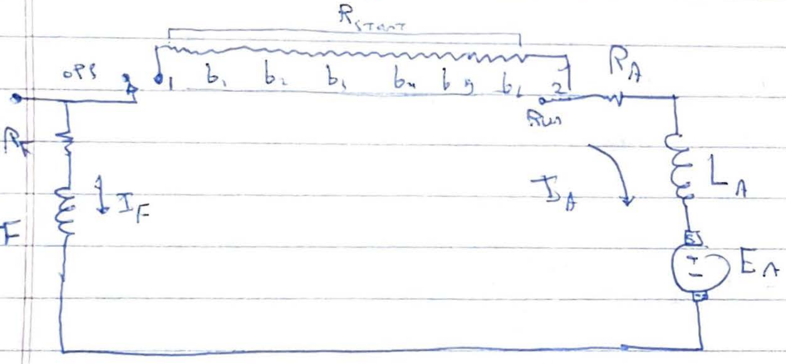
Starters of DC motors

⊗ كل الطرق عن طريق تغيير R ، بطريقة مختلفة -



⊗ بعد ازالة R بيرجع ... للدائرة ... السرعة حسب ↑

① Manual starter

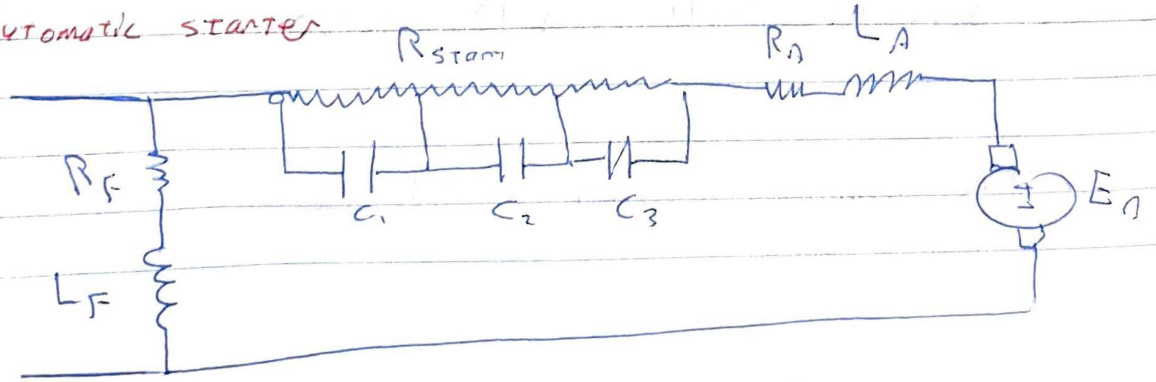


⊗ Continous starting resistor, which is gradually cut out of the circuit by a person moving his handle.

⊗ The handle shouldn't be moved slowly to prevent burning up the resistor

⊗ The handle shouldn't be moved quickely to prevent the resulting current of being large.

② Automatic starter



$$I_{start} = \frac{V_T - E_A \uparrow}{R_A + (R_{...}\ )}$$

$C_1, C_2, C_3 \longrightarrow$ contacts of relay C_1, C_2 & C_3 (Normally opened contacts)

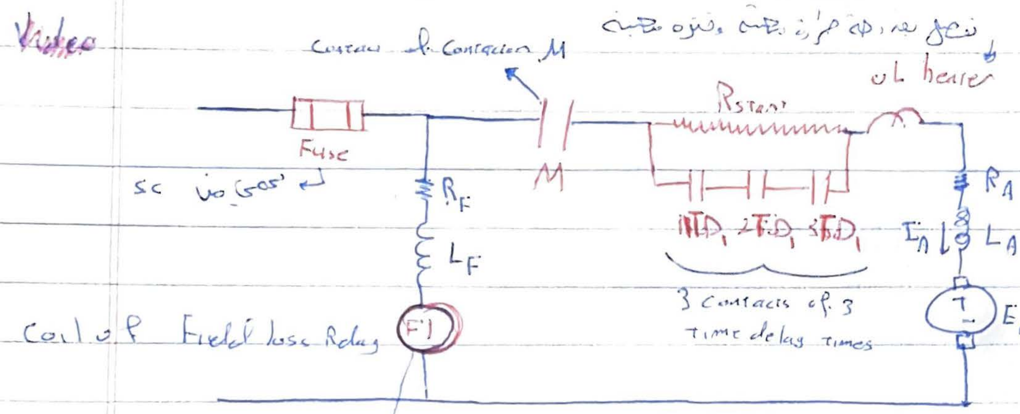
The Resistor, R_{START} is divided into 3 parts, which are Removed sequentially via the contact C_1, C_2 + C_3

① C_1, C_2 & C_3 are 3 contacts of time delay relays on

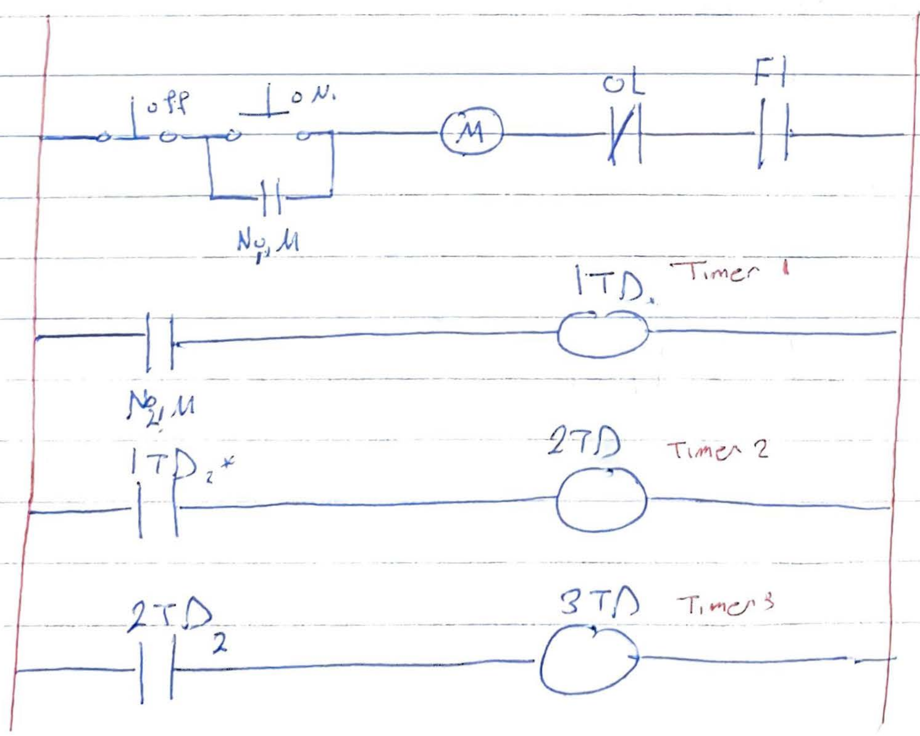
② armature voltage sensing relays.

Video

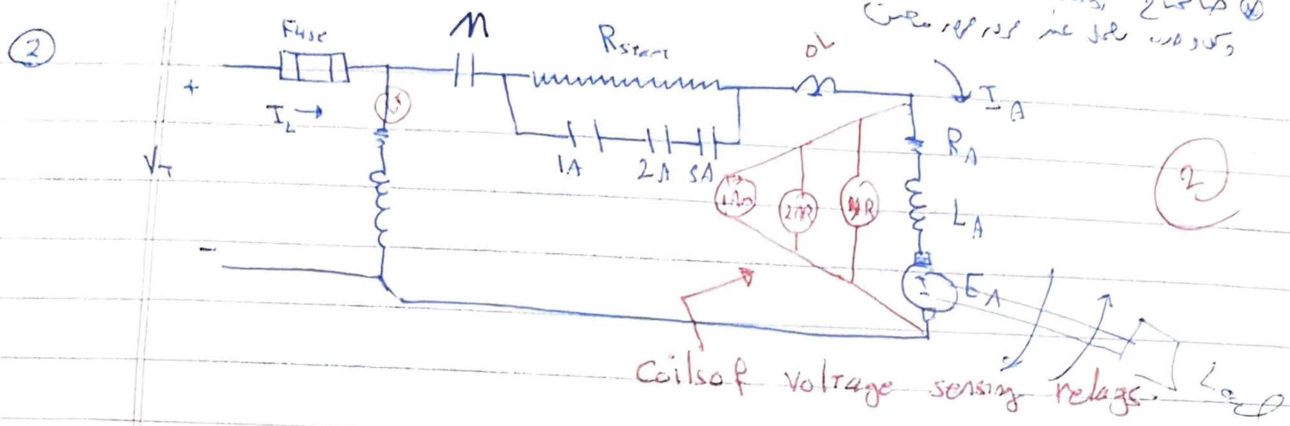
shunt



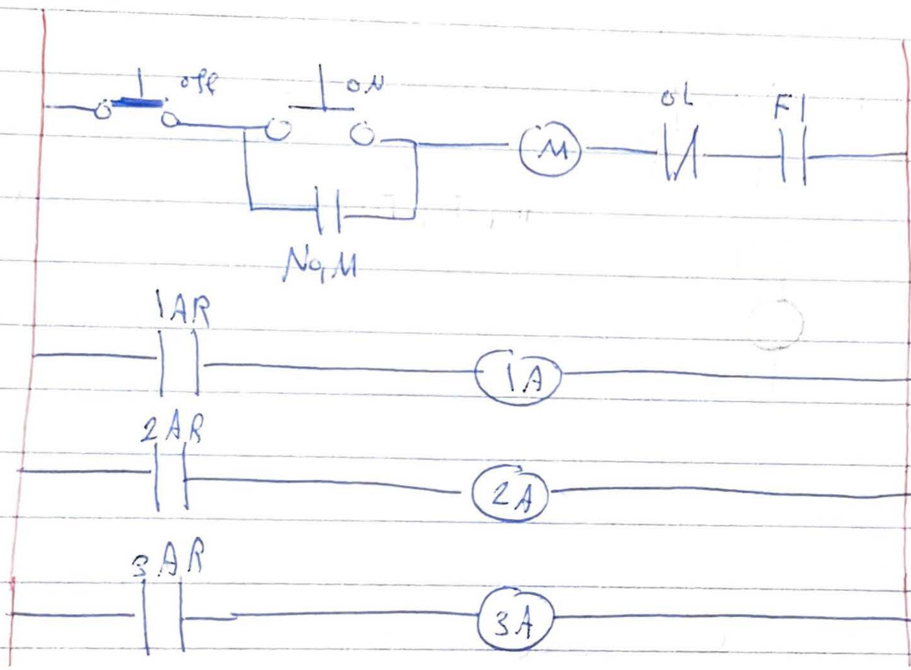
Control Circuit



محتاجين 3 relays لنراقب مقدار الجهد
ويكون عند كل قيمة جهد معين



Control circuit



Fuse: To protect the motor and the source from short circuit.

OL: Cut off the current when the Temp increased too much than Normal Temp (for long Time)