ElCoM
ELECTRICAL COMPUTER MECHATRONICS

تقدم لجنة

ملخص لمادة:

آلات كهربائية

جزيل الشكر للطالب:

حمزة اسماعيل

Electrical Machines :-

* Introduction to Electrical Machines:-

* Electromechanical energy converter

Electrical energy → $\boxed{\text{Transformer}}$ → Electrical energy

Mechanical energy → $\boxed{\text{generater}}$ → Electrical energy

Electrical energy → $\boxed{\text{Motors}}$ → Mechanical energy.

* Conversions :-

* $1\ rpm = \frac{2\pi\ (rad)}{60\ (sec)} = \frac{\pi}{30}\ [r/s]$

$\boxed{1\,[rpm] = \frac{\pi}{30}\,[r/s]}$, $\boxed{1\,[r/s] = \frac{30}{\pi}\,[rpm]}$

* $\boxed{1\ hp = 746\ Watt}$

* Electrical and Mechanical Power :-

1. Mechanical Power :-

$\boxed{\text{Power [W] = Torque [N.m] * Speed [r/s]}}$

2. Electrical Power :-

→ DC Machine :-

$\boxed{\text{Power [W] = Current [A] * Voltage [V]}}$

→ AC Machine : 1θ :-

Active Power [W] = Current * Voltage * $\underbrace{\cos\theta}_{\text{Power factor}}$

→ AC Machine - 3θ :-

Power [W] = $\sqrt{3}$ line Current [A] * line Voltage [V] * Cosθ.

Power [W] = 3 * Phase Current [A] * Phase Voltage [V] * Cos θ

$\boxed{V_L = \sqrt{3}\,V_P}$ $\boxed{I_L = \sqrt{3}\,V_P}$

* Principles how magnitic fields are used in these devices :-

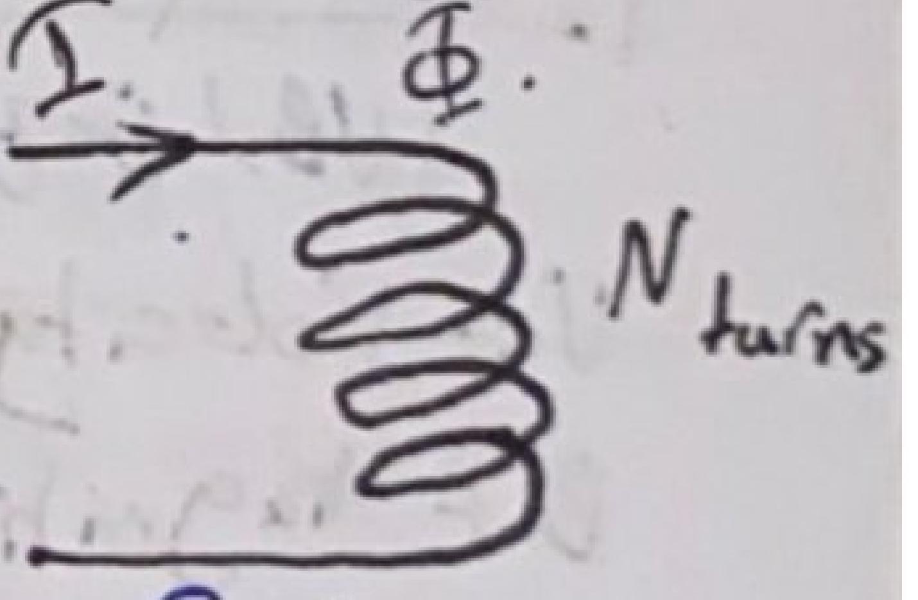
1. Current Carrying wire Produces a magnitic field in area around it.
السلك الحامل للتيار ينتج مجال مغناطيسي حوله.

2- time Changing magnitic field induced a Voltage in a coil of wire.
(basis of Transformer action)
تغير المجال المغناطيسي ينتج فرق جهد على أطراف السلك.

3- Current Carrying wire in magnitic field has a force induced on it.
(basis of motor action)
السلك الحامل للتيار داخل مجال مغناطيسي يتأثر بقوة.

4- moving wire in a magnitic field has a Voltage induced in it.
(basis of generator action).
تحريك سلك داخل مجال مغناطيسي ينتج فرق جهد.

* Magnitic Circuits :-



$$\boxed{\underbrace{\Phi}_{\text{total flux (weber)}} = \underbrace{B}_{\text{magnitic field dencity (Tesla)}} A = \mu \frac{NI}{L_c} A}$$

μ : Permeability

$$\boxed{\Phi = BA = \underbrace{\mu}_{\text{Pereamability}} \underbrace{H}_{\text{maginatic field Intensity}} A}$$

$$\boxed{\Phi = NI \left(\frac{\mu A}{L_c}\right) = \frac{\overset{\text{magnetomotive force}}{F}}{\underset{\text{Reluctance}}{R}}}$$

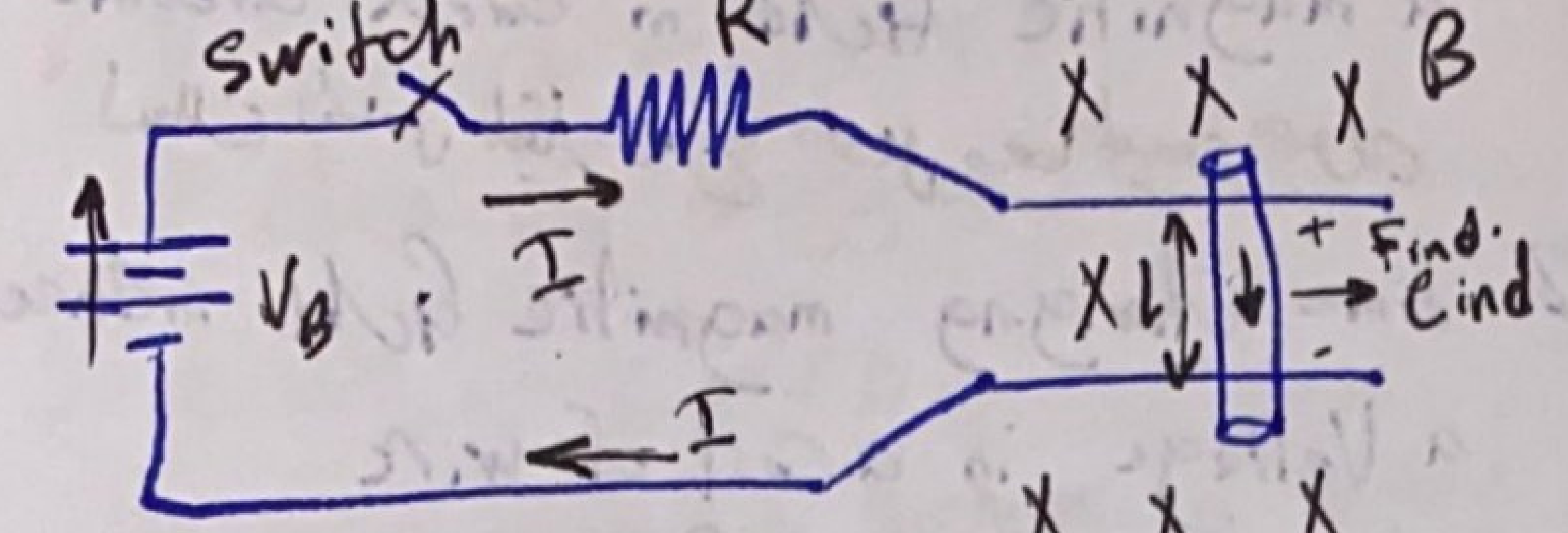
$\boxed{\Phi = \frac{F}{R}}$ → Magnitic Circuit.

$\boxed{I = \frac{V}{R}}$ → Electrical Circuit.

Electrical Machines :-

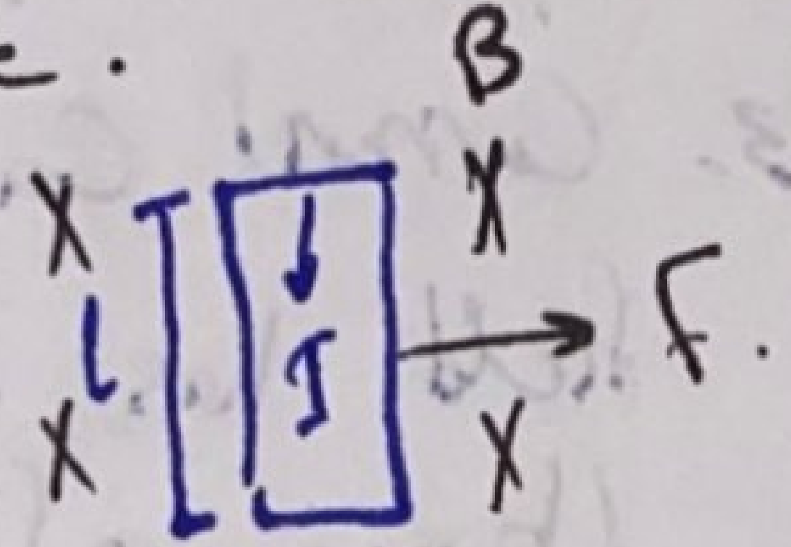
* Introduction to Electrical Machines :-

* Linear DC Machine :-



Linear DC Machine behavior :-

1- force on a wire.



$F = I(L * B)$

$\boxed{F = I L B \sin\theta}$

force on wire → F, current → I, length → L, magnitic field density → B

2- Voltage induced on a wire moving in a magnitic field.

$e_{ind} = (V * B) \cdot L$

$\boxed{e_{ind} = (VB \sin\theta_1)(L \cos\theta_2)}$

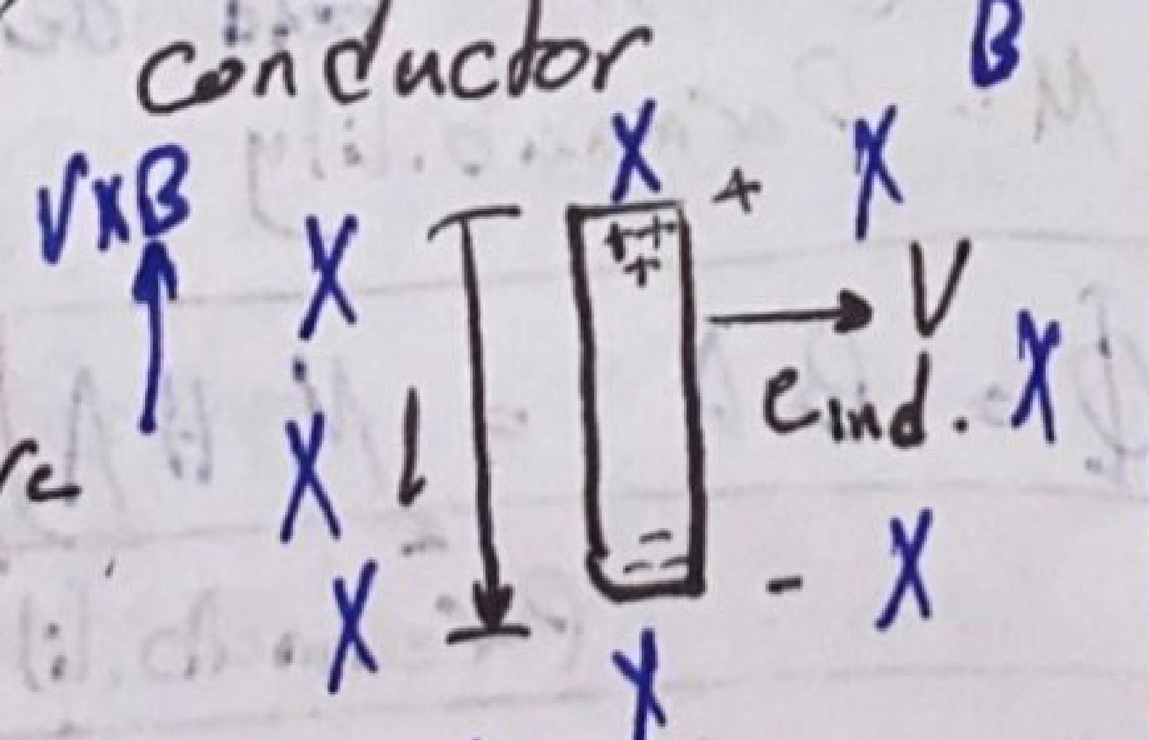
θ_2 بين (L) والمحصلة الناتجة من (VB)

V :- Velocity of the wire.

B :- Magnitic field dencity.

L :- Length of conductor

e_{ind} :- Voltage induced in wire



3- Kirchoft's Voltage law

$V_B - e_{ind} - IR = 0$

$\boxed{V_B = e_{ind} + IR}$

4- Newton's law for the bar

$\boxed{F_{net} = m\,a}$ → acceleration, m → mass

* Linear DC Machine :-

1- $\boxed{I = \frac{V_B}{R}}$: starting current
maximum current

2- Current flow produce an induced force

$\boxed{F = I L B}$: $\boxed{ق = ت ل غ}$

3- The bar accelerate due to the induced force. $\boxed{a = \frac{F_{ind}}{m} = \frac{\Delta V}{\Delta t}}$

4- bar moves, producing induced Voltage

$\boxed{e_{ind} = (V \times B) \cdot L}$ $\boxed{ق. = ع غ ل}$

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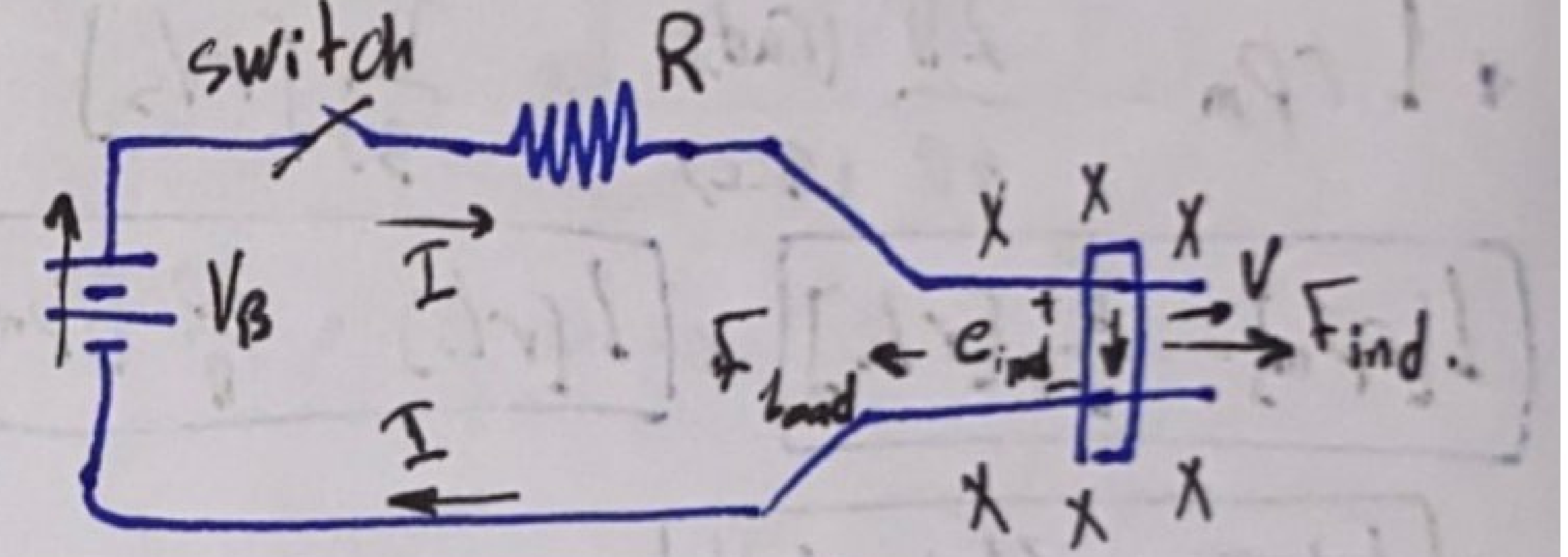
* Linear DC Machine :-



if we applied a force (F_{load}) to the bar in opposite direction of motion :-

$F_{net} = -F_{load}$. frection less

1- The bar decelerates due to the load force $\boxed{a = \frac{F_{net}}{m} = \frac{\Delta V}{\Delta t}}$

2- net force reduce induced Voltage

$\boxed{\downarrow e_{ind} = V\downarrow B L} \Rightarrow \boxed{\uparrow I = \frac{V_B - e_{ind}\downarrow}{R}}$

but increase current.

3- Induced force increased

$\uparrow F_{ind} = I\uparrow L B$

in this case

$\boxed{F_{net} = F_{ind} - F_{load}}$

4- Electrical Power = $e_{ind} * I$.

Converted to Mechanical Power $= F_{ind} * V$. $\boxed{\text{The Machine} \rightarrow \text{motor}}$

Electrical Machines :-

* DC Machines :-

* DC Machines are :-

1. generators :- convert
   Mechanical energy → Electric energy
2. motors :- convert.
   Electric energy → Mechanical energy

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* DC Machines :-

- DC Machines have AC Voltages and Currents within them.
- DC Machines have a DC output only because → a mechanism (commutator) exists that converts the internal AC Voltages to DC Voltages at terminals

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* Simple Rotating loop :-

- Simple Rotating loop ⇒ Single loop of wire rotating about a fixed axis.
- rotating Part is Called ⇒ rotor
  stationary Part is Called ⇒ stator.
- to easy Calculation we assume :-
  1. the magnetic field is Perpendicular to the rotor surface evry wher.
  2. the flux is uniformly distributed (constant) every where.
- The Voltages in any real machine depend on the :-
  1. the flux in the machine.
  2. the speed of rotation.
  3. Constant representing (K).

* Total Voltages on the loop :-

$$\boxed{e_{ind} = (V * B) \cdot I}$$

↳ The Voltages on each segment

$$\boxed{E_{ind} = 2VBL}.$$

↳ Total Voltages on the loop.

$$\boxed{E_{ind} = 2VBL = \frac{2}{\pi}\underline{\Phi} w = k\underline{\Phi} w}$$

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* Total Torque on the loop :-

$$\boxed{F_{ind} = I(L * B)} \rightarrow \text{force induced.}$$

$$\boxed{\tau_{ind} = rF_{ind} = rILB}$$

↳ The Torque on each segment.

$$\boxed{\tau_{ind} = 2rF_{ind} = 2rILB}$$

↳ Total Torque on the loop.

$$\boxed{\tau_{ind} = 2rILB = \frac{2}{\pi}\underline{\Phi}\,\underline{I} = k\underline{\Phi}\,\underline{I}}.$$

- The torque in any real machine will depend on the :-
  1. the flux in the machine.
  2. the Current in the machine.
  3. Constant representing (K)

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* Commutation Problems :-

1. Armature reaction.
   the effect of the magnetic field set up by the armature current on the distribution of the flux under main Poles.
   - Armature reaction Causes :-
     1. Neutral Plane shift.
     2. Flux weakening.
2. $L\frac{di}{dt}$ Voltages.

#Electrical Machines:-

* DC Machines :-

* Power Flow and losses :-

1- Electrical or (copper) losses :-

the losses that occure in the armature and field windings.

Armature losses $\boxed{P_A = I_A^2 R_A = I_A V_A}$

Field losses $\boxed{P_F = I_F^2 R_F = I_F V_F}$

$$P_{Elec} = P_A + P_F = I_A^2 R_A + I_F^2 + R_F.$$

2- Brush losses :-

the Power lost across the contact Potential at the brushes.

Brush drop loss $\boxed{P = V_{BD} I_A}$

V_{BD} : Brush Voltage drop.

I_A : Current armature.

3- Core losses.

4- Mechanical losses.

1- friction losses. ضياعات الاحتكاك.

2- Windage losses. ضياعات احتكاك الاجزاء المتحركة مع الهواء.

core and mechanical بنحسبهم في حالة ال no-load.

$$\boxed{P_{tot} = P_{core} + P_{mech} = VI}$$

at no load ...

5- stray losses :-

$$\boxed{P_{stray} = 0.01 * P_{input}}$$

* Efficiency (η) :-

$$\boxed{\eta = \frac{P_{out}}{P_{in}} * 100\% = \frac{P_{in} - P_{Loss}}{P_{in}} * 100\%}$$

* Types of DC Machines :-

1- Permanent Magnet :-

field circuit عبارة عن اقطاب مغناطيسية طبيعية دائماً ⇐ ما عندي ~~R_f, V_f, I_f~~.

2- separately Excited :-

field circuit عبارة عن ملف كهربائي يسري فيه تيار، ويوصل مع مصدر جهد منفصل.

3- Shunt DC Machine :-

field circuit عبارة عن ملف مربوط على التوازي مع دائرة ال Armature.

4- Series DC Machine :-

field circuit عبارة عن ملف مربوط على التوالي مع دائرة ال Armature.

* Speed Regulation (SR) :-

$$\boxed{SR = \frac{W_{nL} - W_{FL}}{W_{FL}} * 100\%.}$$

$$\boxed{SR = \frac{n_{nL} - n_{fL}}{n_{fL}} * 100\%.}$$

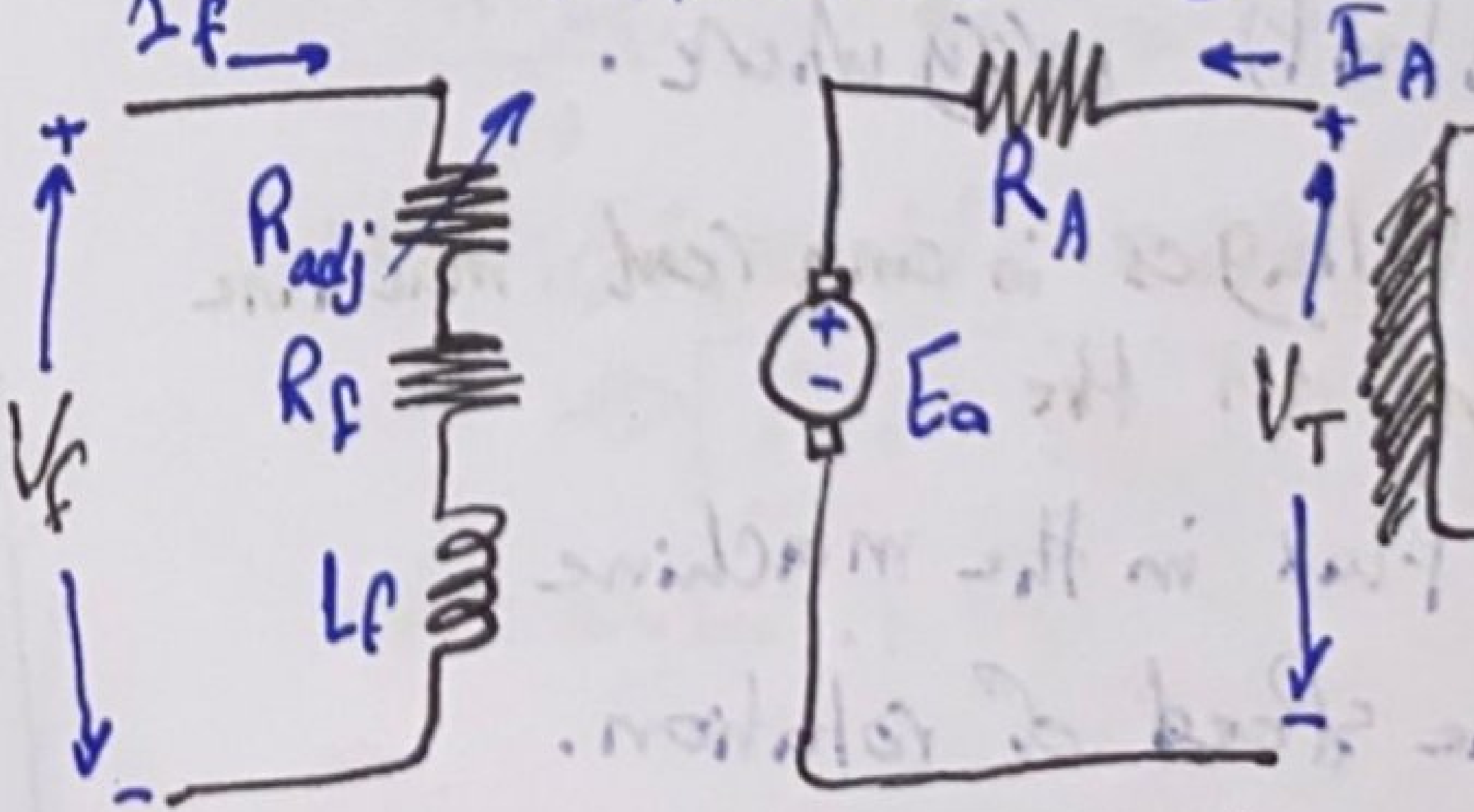
W → r/s
n → rpm
nl → no load
fL → full load.

⊕SR ⇒ Motor's speed ↓ → load ↑

⊖SR ⇒ Motor's speed ↑ → load ↑

* Separately Excited DC Motors :-

دائرة ال field عبارة عن ملف يسري فيه تيار، منفصل عن دائرة ال Armature.



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

$$\boxed{E_A = K\phi\, w}$$

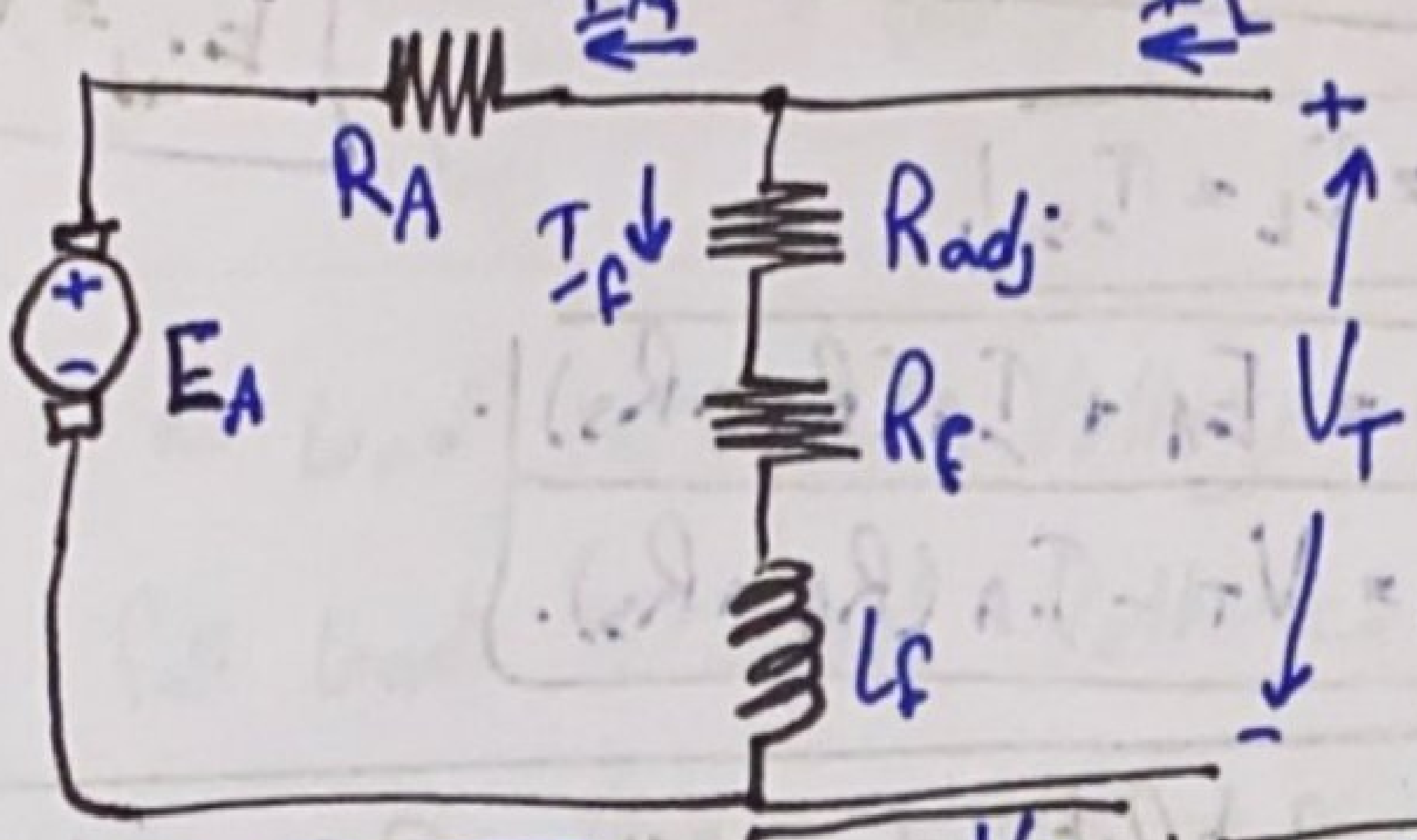
$$\boxed{I_f = \frac{V_f}{R_f}}, \quad \boxed{V_T = E_a + I_A R_A}$$

* Electrical Machines :-

* DC Machines :-

* Shunt DC Motors :-

دائرة ال field عبارة عن ملف موصول على التوازي مع دائرة ال Armature .



$\boxed{\begin{matrix} \tau_{ind} = K\Phi I_A \\ E_A = K\Phi W \end{matrix}}$ $\boxed{I_f = \frac{V_f}{R_f}}$ $\boxed{I_L = I_A + I_f}$

$\boxed{\begin{matrix} V_T = E_a + I_A R_A \\ E_a = V_T - I_A R_A \end{matrix}}$

* The Output of a separately excited and a shunt DC motors (W) :-

$V_T = E_A + I_A R_A$. $E_A = K\Phi W$.

$V_T = K\Phi W + \frac{\tau_{ind}}{K\Phi} R_A$ $I_A = \frac{\tau_{ind}}{K\Phi}$.

$$\boxed{W = \frac{V_T}{K\Phi} - \frac{R_A}{(K\Phi)^2} \tau_{ind}}$$

حفظ ... بس. برضو لا تحفظ، اشتقها

* Some of equations :-

1- $\boxed{E_A = K'\Phi n}$ where $\boxed{n \rightarrow rpm}$ $\boxed{E_A = K\Phi W}$ where $\boxed{W \rightarrow r/s}$

$\boxed{\frac{E_{A2}}{E_{A1}} = \frac{K'\Phi_2 n_2}{K'\Phi_1 n_1}}$, $\boxed{\frac{E_{A2}}{E_{A1}} = \frac{K\Phi_2 W_2}{K\Phi_1 W_1}}$

DC motor with compensating windings

$\Rightarrow$ no armature reaction $\Phi = Const$ لا تتغير مع التحميل

$\boxed{\frac{E_{A2}}{E_{A1}} = \frac{n_2}{n_1}}$ $\boxed{\frac{E_{A2}}{E_{A1}} = \frac{W_2}{W_1}}$

* Some of equations :-

2- $\boxed{I_f^* = I_f - \frac{F_{AR}}{N_F}}$

$F_{AR} \rightarrow$ magnetiomotive force

$N_F \rightarrow$ number of turns.

$I_f^* \rightarrow$ Current under effect of armature reaction (AR) .

DC motor without compensating windings.

$\Rightarrow$ have an armature reaction .

$\Phi \neq const$. تتغير مع التحميل

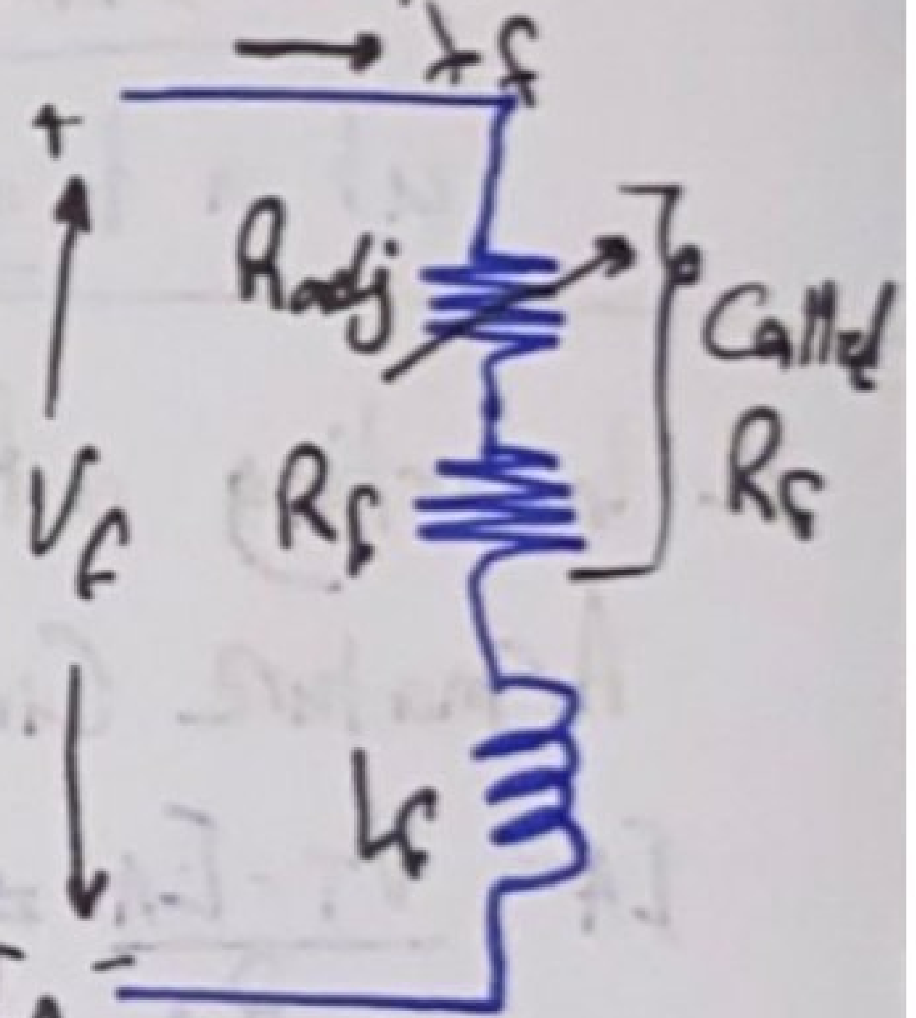
$I_f \xrightarrow{\text{متغير}} I_f^* \Rightarrow E_{A1} \xrightarrow{\text{متغير}} E_{A0}$ مو زي

3. $P_{conv} = \tau_{ind} W = E_A I_A$.

$\boxed{\tau_{ind} = \frac{E_A I_A}{W}}$ $\boxed{W = \frac{E_A I_A}{\tau_{ind}}}$.

* The Ways Which the speed of a separately excited and shunt DC motors can be controlled :-

1- Changing the field resistor Control method :-



$I_f = \frac{V_f}{R_f} \Rightarrow \uparrow R_f \rightarrow \downarrow I_f$

$\Phi_f = K I_f \Rightarrow \downarrow I_f \rightarrow \downarrow \Phi$

$E_A = K\Phi W \Rightarrow \downarrow \Phi \rightarrow \downarrow E_A$

$I_A = \frac{[V_T - E_A]}{R_A} \Rightarrow \downarrow E_A \rightarrow \uparrow I_A$

$\tau_{ind} = K\Phi I_A \Rightarrow \uparrow I_A \rightarrow \uparrow \tau_{ind}$

$\uparrow \tau_{ind} \Rightarrow \boxed{\tau_{ind} > \tau_{load}} \Rightarrow \uparrow \tau_{ind} \rightarrow \uparrow W$

$E_A = K\Phi W \Rightarrow \uparrow W \rightarrow \uparrow E_A$ again.

$I_A = \frac{(V_T - E_A)}{R_A} \Rightarrow \uparrow E_A \rightarrow \downarrow I_A$.

$\tau_{ind} = K\Phi I_A \Rightarrow \downarrow I_A \rightarrow \downarrow \tau_{ind}$

until $\Rightarrow \boxed{\tau_{ind} = \tau_{load}}$

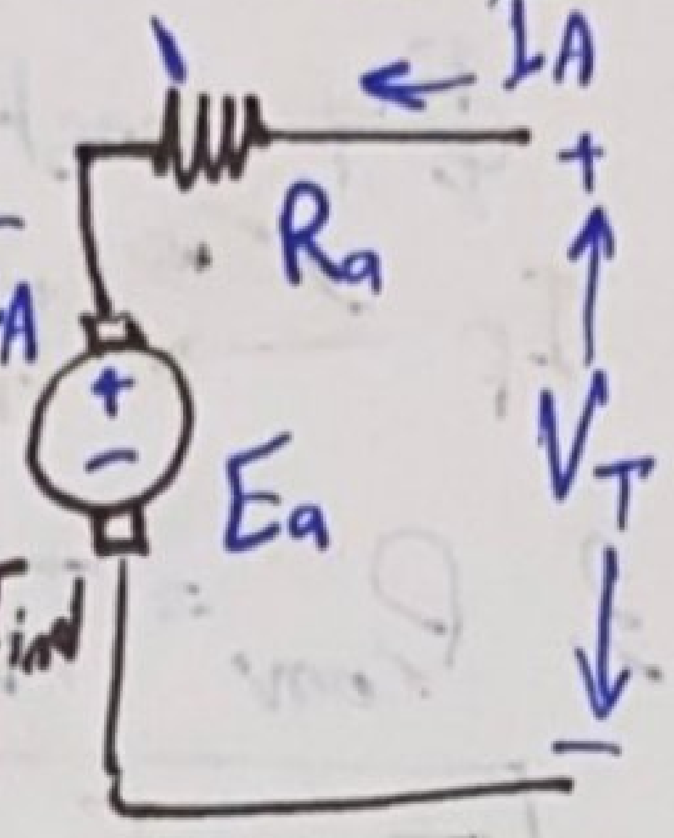
at a higher speed.

* Electrical Machines:-

* DC Machines:-

* The Ways which the speed of a separately excited and shunt DC motors can be controlled :-

2- Changing the Armature Voltage Control method.



$I_A = \frac{(V_T - E_A)}{R_A} \Rightarrow V_T\uparrow \rightarrow \uparrow I_A$

$\tau_{ind} = K\Phi I_A \Rightarrow \uparrow I_A \rightarrow \uparrow \tau_{ind}$

$\uparrow \tau_{ind} \Rightarrow \boxed{\tau_{ind} > \tau_{load}} \Rightarrow \uparrow \tau_{ind} \rightarrow \uparrow W$

$E_a = K\Phi W \Rightarrow \uparrow W \rightarrow \uparrow E_a$.

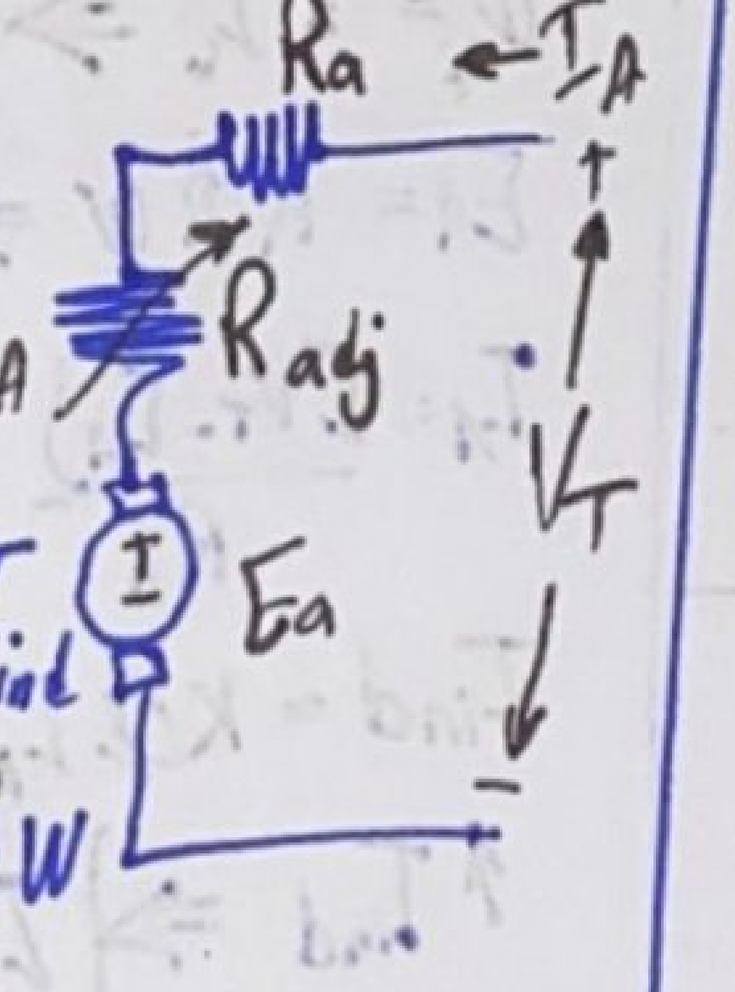
$I_A = \frac{V_T - E_a}{R_a} \Rightarrow \uparrow E_a \rightarrow \downarrow I_A$.

$\tau_{ind} = K\Phi I_A \Rightarrow \downarrow I_A \rightarrow \downarrow \tau_{ind}$

until $\boxed{\tau_{ind} = \tau_{load}}$.

at a higher speed.

3- Inserting a Resistor in Series with Armature Circuit :-



$I_A = \frac{V_T - E_A}{R_A} \Rightarrow \uparrow R_A \rightarrow \downarrow I_A$

$\tau_{ind} = K\Phi I_A \Rightarrow \downarrow I_A \rightarrow \downarrow \tau_{ind}$

$\downarrow \tau_{ind} \Rightarrow \boxed{\tau_{ind} < \tau_{load}} \rightarrow \downarrow W$

$E_a = K\Phi W \Rightarrow \downarrow W \rightarrow \downarrow E_a$.

$I_a = \frac{V_T - E_A}{R_a} \Rightarrow \downarrow E_a \rightarrow \uparrow I_a$.

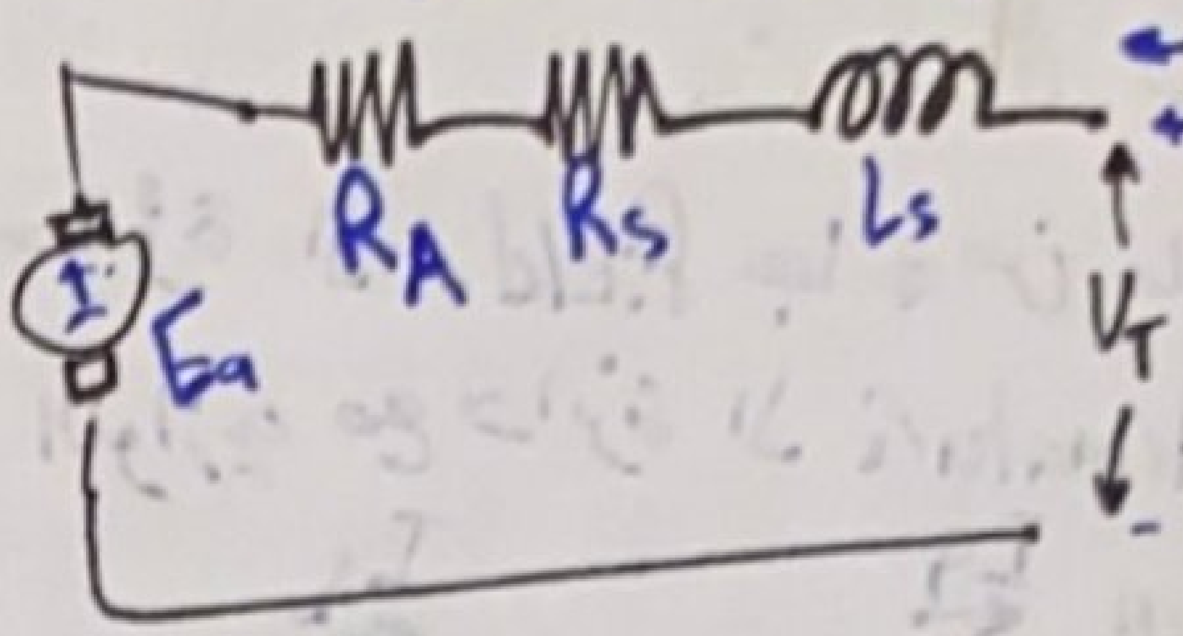
$\tau_{ind} = K\Phi I_A \Rightarrow \uparrow I_A \rightarrow \uparrow \tau_{ind}$

until $\boxed{\tau_{ind} = \tau_{load}}$

at a lower speed.

* Series DC Motors:-

دائرة الـ field عبارة عن ملف يسري فيه تيار متصل مع دائرة الـ Armature .



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

$E_{ind} = K\Phi W$

$\boxed{I_A = I_L = I_s}$.

$\boxed{V_T = E_A + I_A(R_A + R_s)}$.

$\boxed{E_a = V_T - I_A(R_A + R_s)}$.

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* The Output of series DC motors :-

$\Phi = C I_s = C I_A$. $I_s = I_A$

$\tau_{ind} = K\Phi I_A = CK I_A^2$

$\tau_{ind} \propto I_A^2 \rightarrow$ الـ series motor بيعطي عزم عالي بنفس التيار.

$\tau_{ind} = CK I_A^2 \Rightarrow I_A = \sqrt{\frac{\tau_{ind}}{CK}}$

$\Phi = C\sqrt{\frac{\tau_{ind}}{CK}} = \sqrt{\frac{C\tau_{ind}}{K}}$.

$V_T = E_a + I_A(R_A + R_s)$

$V_T = K\Phi W + I_A(R_A + R_s)$.

$V_T = K\sqrt{\frac{C\tau_{ind}}{K}}\, W + \sqrt{\frac{\tau_{ind}}{CK}}\,(R_A + R_s)$.

$$\Rightarrow \boxed{W = \frac{V_T}{\sqrt{CK\tau_{ind}}} - \frac{R_A + R_s}{CK}}.$$

*Electrical Machines :-

* DC Machines :-

* DC generators :-

* Voltage regulation (VR) :-

$$\boxed{VR = \frac{V_{nl} - V_{fL}}{V_{fL}} * 100\%}$$

V_{nl} :- no load terminal Voltage.

V_{fL} :- full load terminal Voltage.

⊕ VR → drooping , ⊖ VR → rising.

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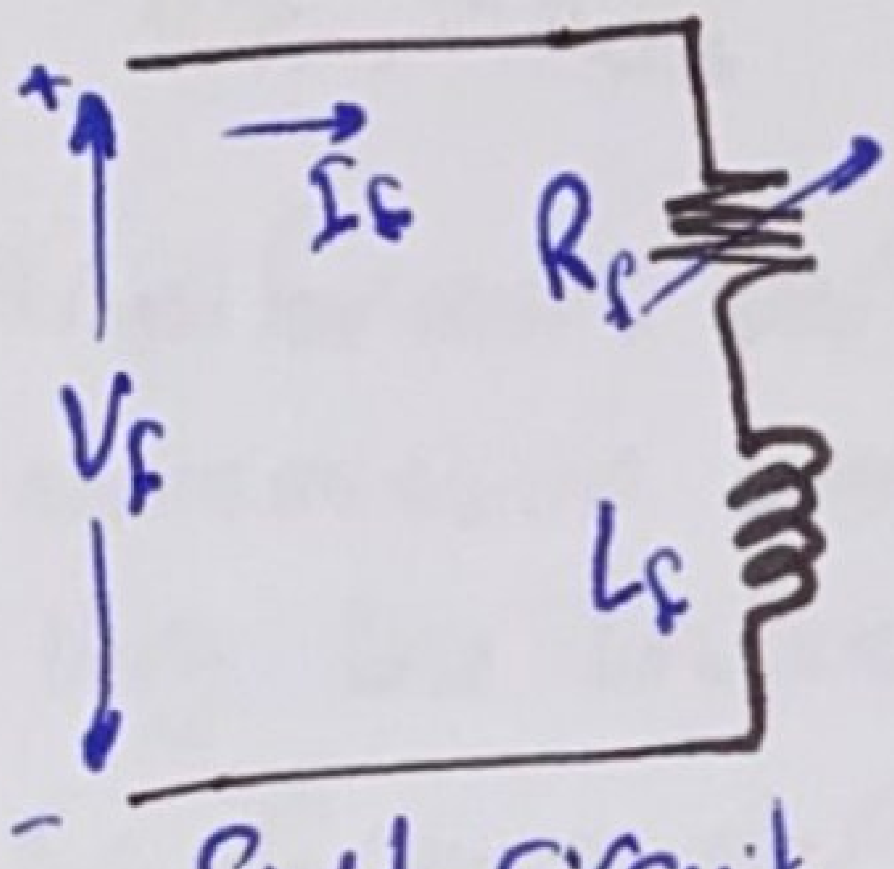
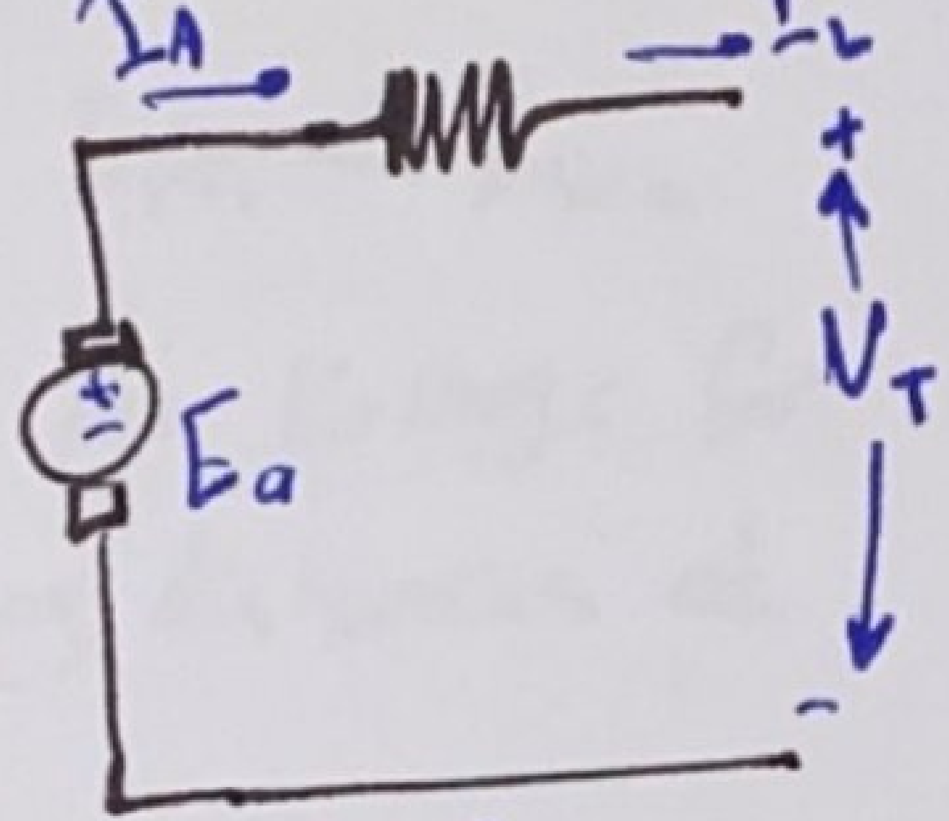
* Separately Excited DC generators :-



Field circuit



Armature circuit.

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

$I_L = I_A$.

~~$V_T =$~~ $E_a - I_A R_A$.

↳ for const speed.

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* The Ways to control the Voltage of the generators :-

1. change the speed (W) :-

$W\uparrow \rightarrow \uparrow E_A = K \Phi W\uparrow$

$\uparrow V_T = E_A\uparrow - I_A R_A$.

2. Change the field current (I_f) :-

$\uparrow I_f = \frac{V_f}{R_f\downarrow} \rightarrow \uparrow \Phi = K I_f\uparrow$

$\uparrow E_A = K \Phi\uparrow W$

$\uparrow V_T = E_A\uparrow - I_A R_A$

* Total magnetomotive force :-

$$\boxed{F_{net} = N_f I_f - F_{AR}}$$

no Armature reaction $F_{AR} = 0$.

$F_{net} = N_f I_f$.

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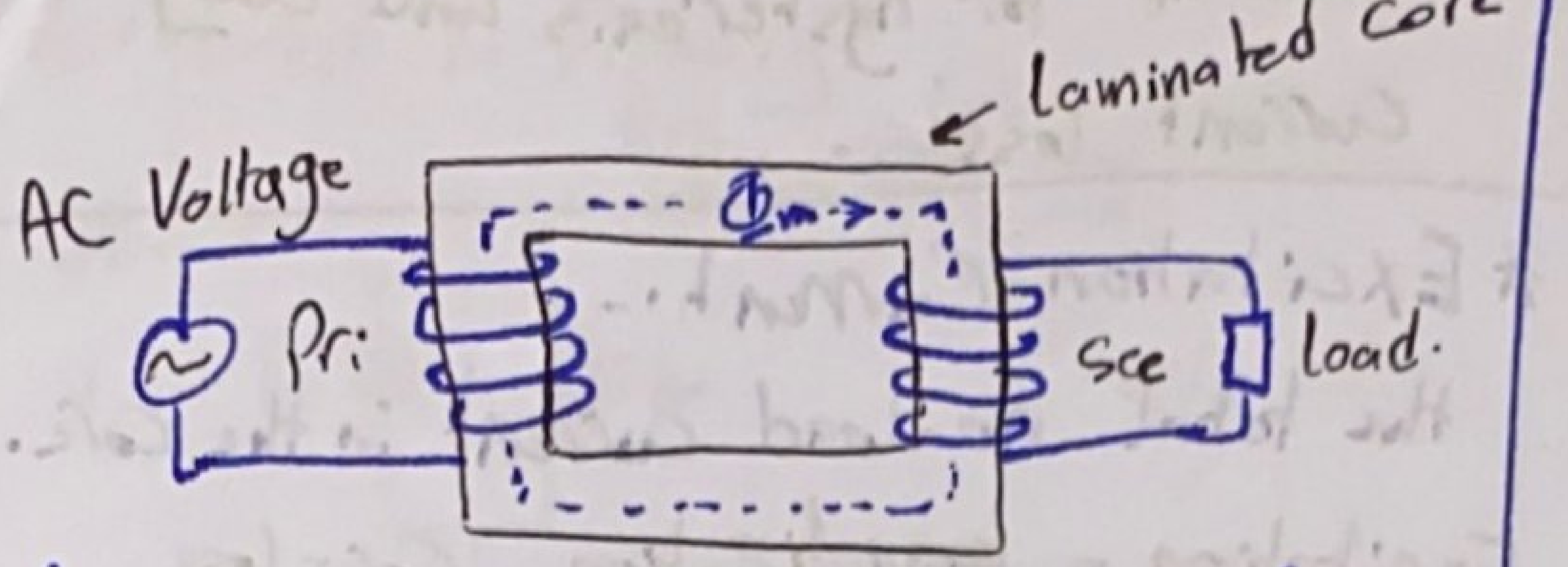
* Equivalent field ~~circuit~~ current :-

$$\boxed{I_f^* = I_f - \frac{F_{AR}}{N_f}}$$

Electrical Machines:—

* The Transformers:—



AC source ⇒ to have change in flux (Φ) in time.

* The Transformer:-

1. step up the Voltage Level of a circuit.

$V_{sec} > V_{pri.} \Rightarrow I_{sec} < I_{pri.}$

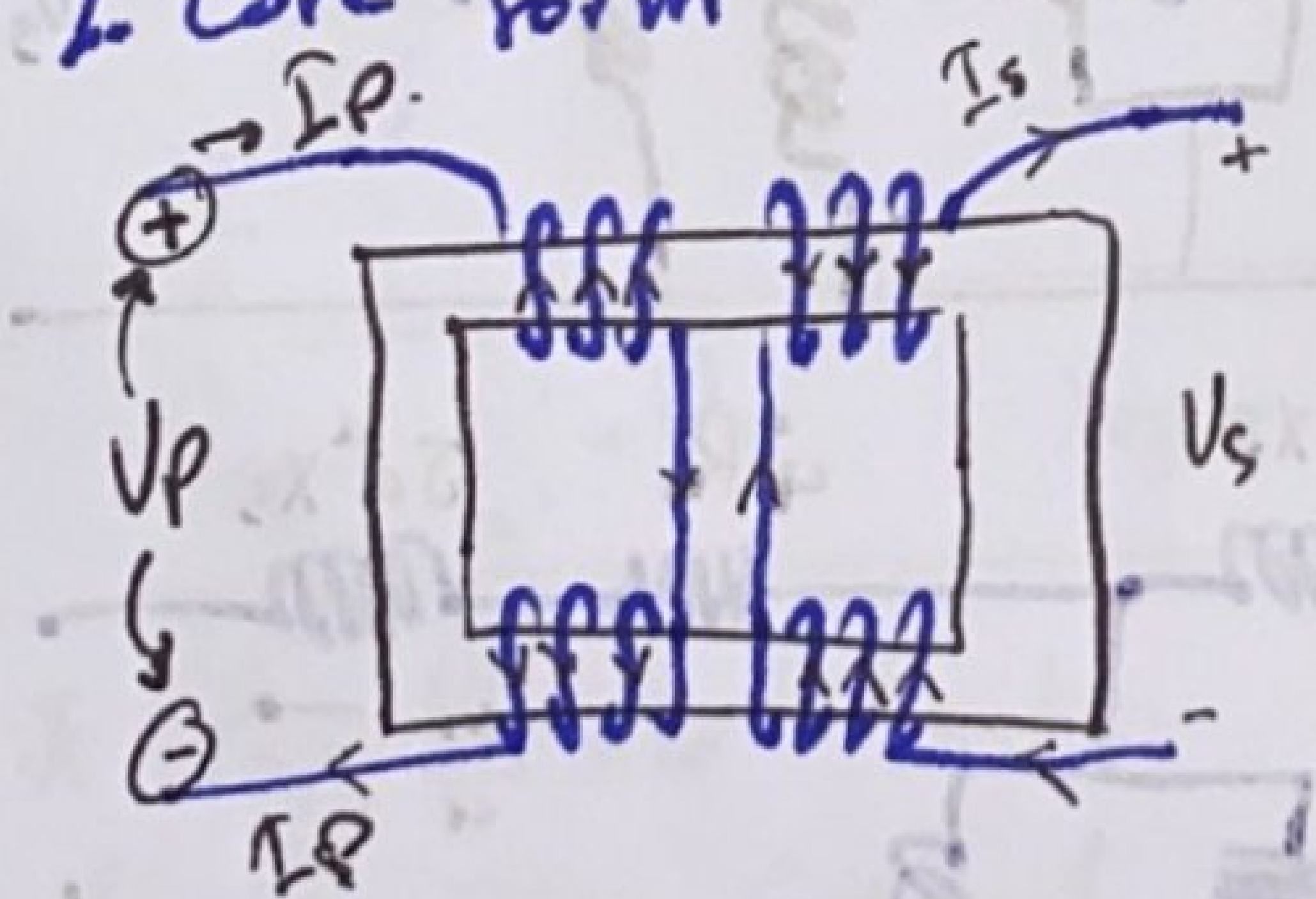
2. step down the Voltage level of a circuit.

$V_{pri} > V_{sec} \Rightarrow I_{pri} < I_{sec}$

- Transformers step up the Voltage for transmission over long distances at very low losses.
- Transformers step down the Voltage for local distribution and finally permit the power to be used safely in homes.

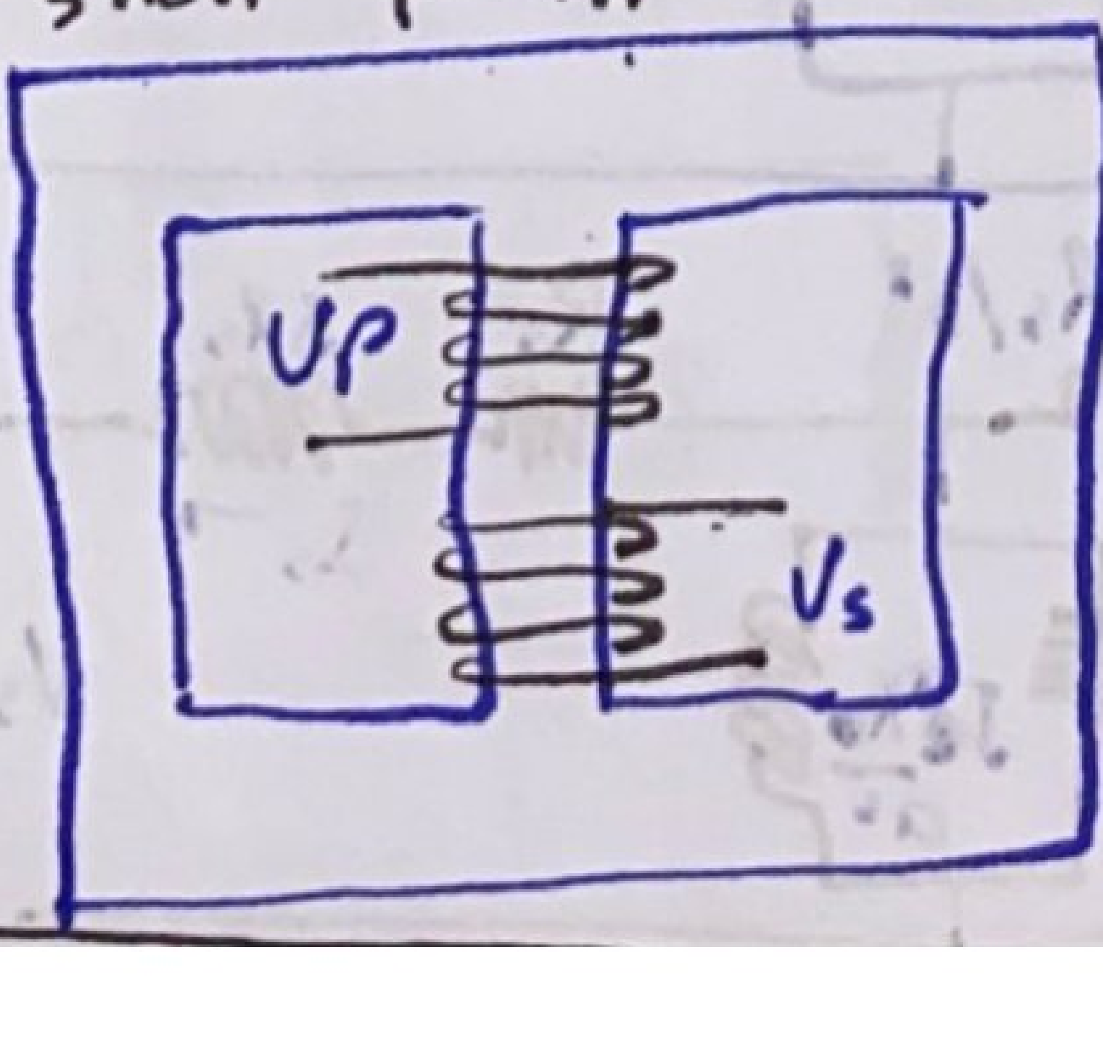
* Types of Cores:-

1. core form



rectangular laminated pice of steel.

2. shell form:-



Three legged laminated core Winding wrapped around the Center leg

* Types of Transformers:-

1. Conventional → 1- Phase
  → 3- Phase.

دائرة ال Primary منفصلة تماماً عن دائرة ال secondary ..

2. Auto transformer → 1- Phase
  → 3- Phase.

ال Primary وال secondary الهم نفس الدائرة (بيشتركو بنفس المادة) .

each type have <u>tapped type</u>. and <u>Variable type</u>.

* The Ideal Transformer:-

have no losses ⇒ $\eta = 100\%$.

$P_{in} = P_{out} \Rightarrow V_P I_P = V_s I_s$.

⇒ magnetomotive force are equal.

$F_P = F_s \Rightarrow N_P I_P = N_s I_s$.

$\Rightarrow \frac{N_P}{N_s} = \frac{V_P}{V_s} = \frac{I_s}{I_P} = a \rightarrow$ transformer turns ration

⇒ Power are equal.

$P_{in} = P_{out}$.

$V_P I_P \cos(\theta_P) = V_s I_s \cos\theta_s$

but $\theta_P = \theta_s \Rightarrow V_P I_P = V_s I_s$.

$Q_{in} = Q_{out}$.

$V_P I_P \sin(\theta_P) = V_s I_s \sin(\theta_s)$

but $(\theta_P = \theta_s) \Rightarrow V_P I_P = V_s I_s$.

$P_{in} = P_{out}$, $Q_{in} = Q_{out}$.

$\Rightarrow S_{in} = S_{out}$.

$S_{in} = V_P I_P \cos(\theta_P) + j V_P I_P \sin(\theta_P)$

$\underset{\text{Complex Power (VA)}}{S} = \underset{\text{average Power (W)}}{P_{avg}\,(W)} + j\,\underset{\text{reactive Power (VAR)}}{Q\,(VAR)}$

Electrical Machines :-

* The Transformers :-

* The Impedance (Z) :-

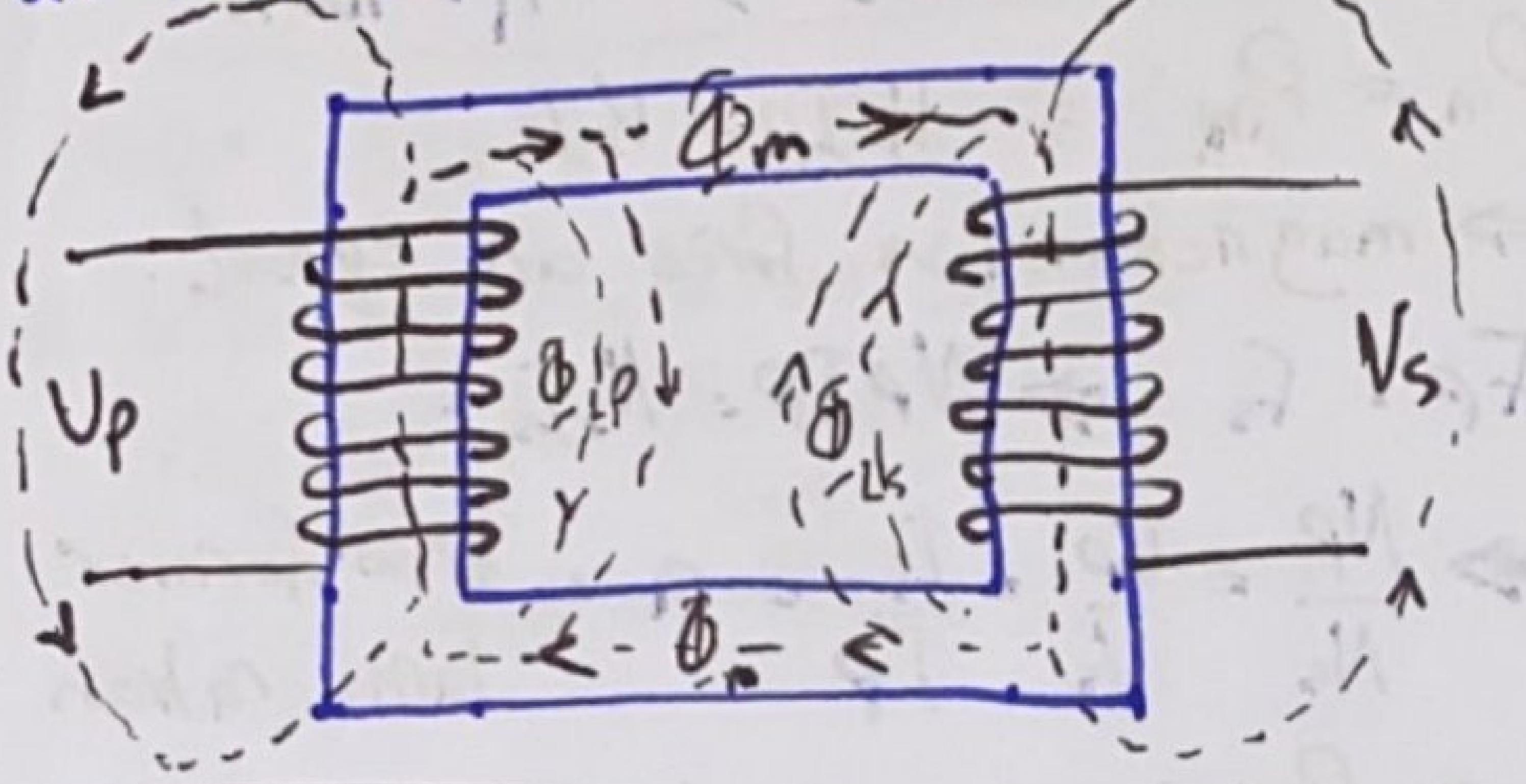
$Z_L = \frac{V_L}{I_L}$. Z_L :- load Impedance.

$Z_L' = a^2 Z_L$

---

* Operation of Real Transformers :-

Not all the flux produced in the Primary coil also. Passes through the secondary coil. some of the flux lines leaves the iron core and Pass through the air insted:



$$\boxed{\underbrace{\Phi_P}_{\text{total pri flux}} = \underbrace{\Phi_m}_{\text{mutual flux}} + \Phi_{LP}} \rightarrow \text{Leakage flux.}$$

$$\boxed{\Phi_s = \Phi_m + \Phi_{Ls}}$$

$\Phi_m >> \Phi_{LP}$. $\Phi_m >> \Phi_{Ls}$

$\Rightarrow \frac{V_P(t)}{V_S(t)} = \frac{N_P}{N_S} = a \rightarrow$ approximately

---

* The Current flows in It's Primary circ when the secondary circuit is open.

→ this current is required to produce flux in a real ferromagnetic core. and divided to two components:-

1. magnetization Current :- required to produce the flux in the transformer core.

* Component of Current :-

2. Core-loss Current :- required to make up for hysteresis and eddy current losses.

---

* Excitation Current :-

the total no-load current in the core.

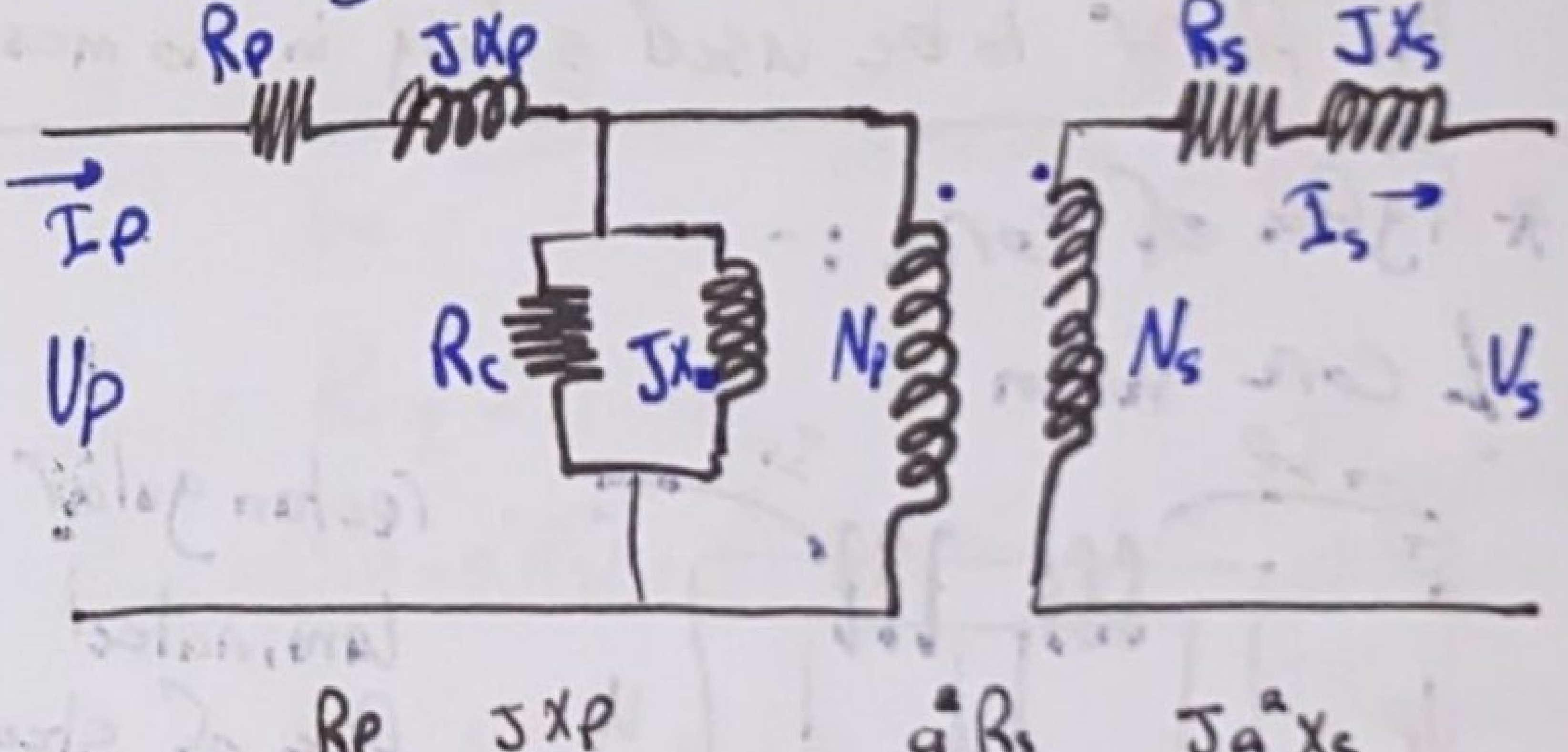
Excitation Current = magnetization Current + Core-loss Current.

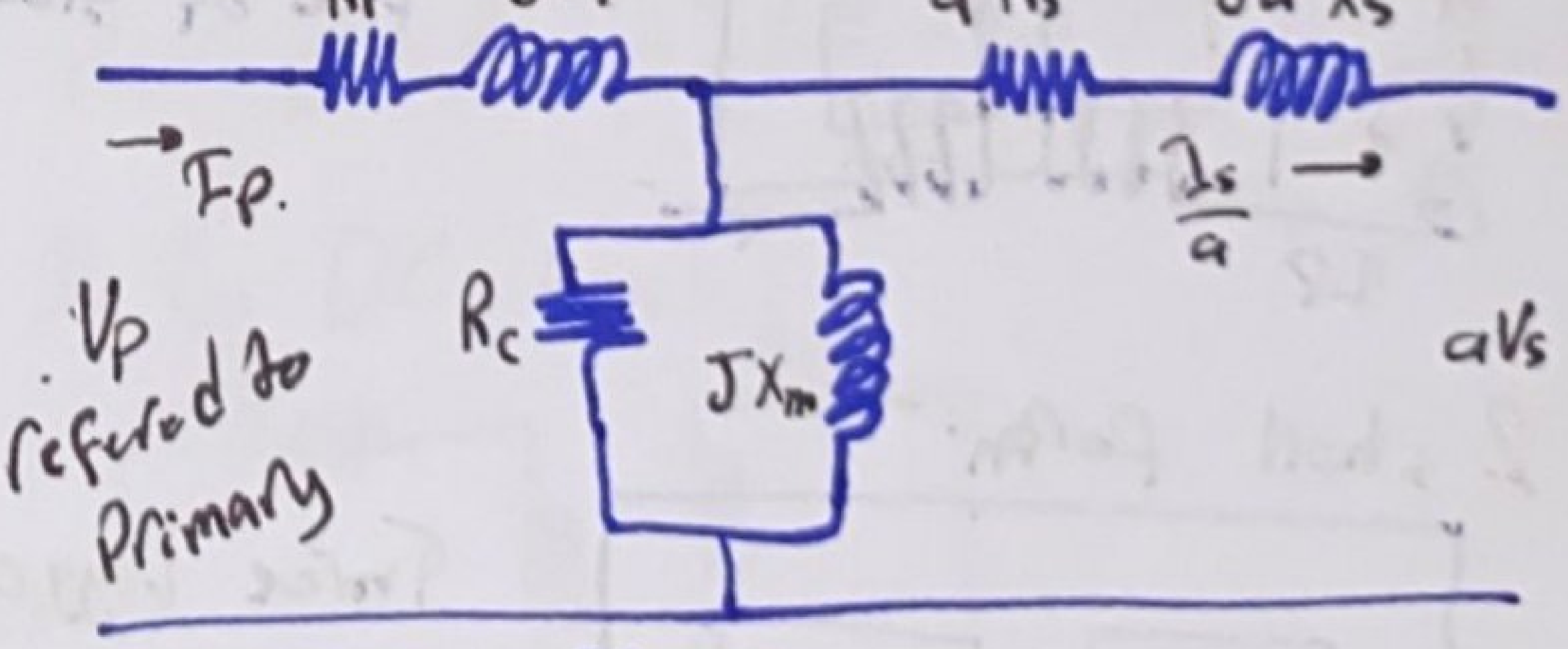
---

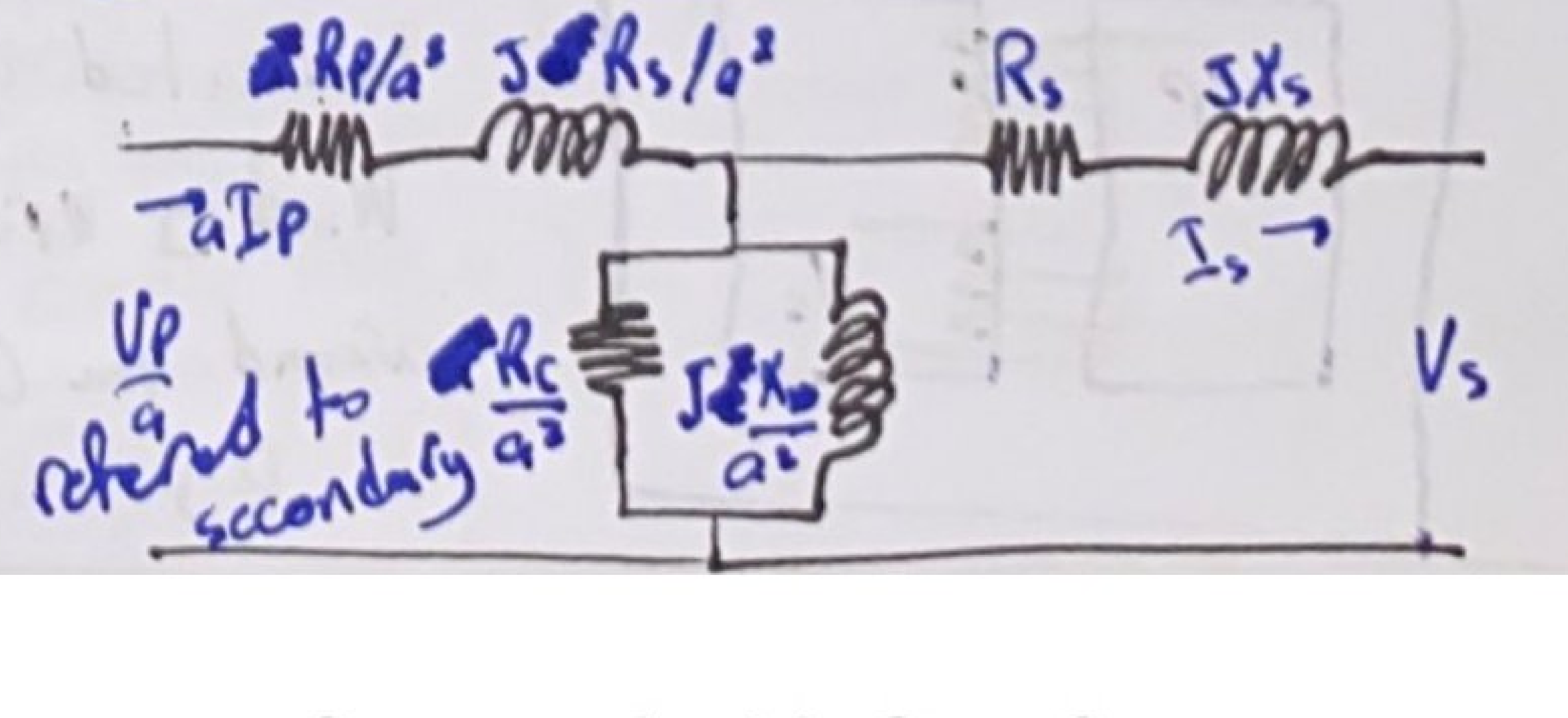
* Equivalent Circuit of a Transformer :-

* The losses :-

1. Copper losses (I^2R)
   Primary ($I_P^2 R_P$) , secondary ($I_s^2 R_s$).
   copper losses $\propto I^2_{\text{winding}}$.
2. Core losses (R_c)
   ① eddy Current losses.
   ② hysteriesis losses.
   core losses = Eddy Current losses + hysteriesis losses.
3. Leakage Flux (X_P, X_S) :-



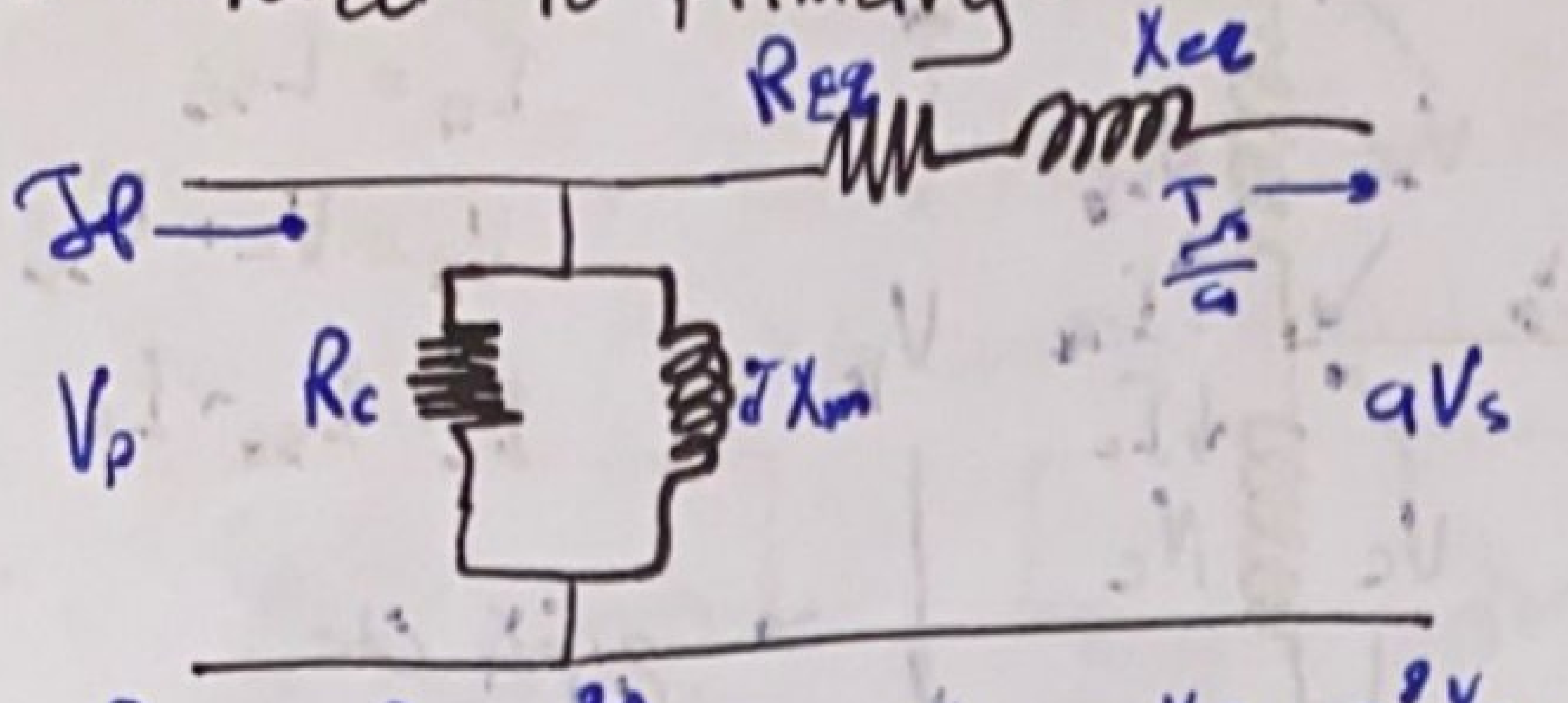




* Electrical Machines :—

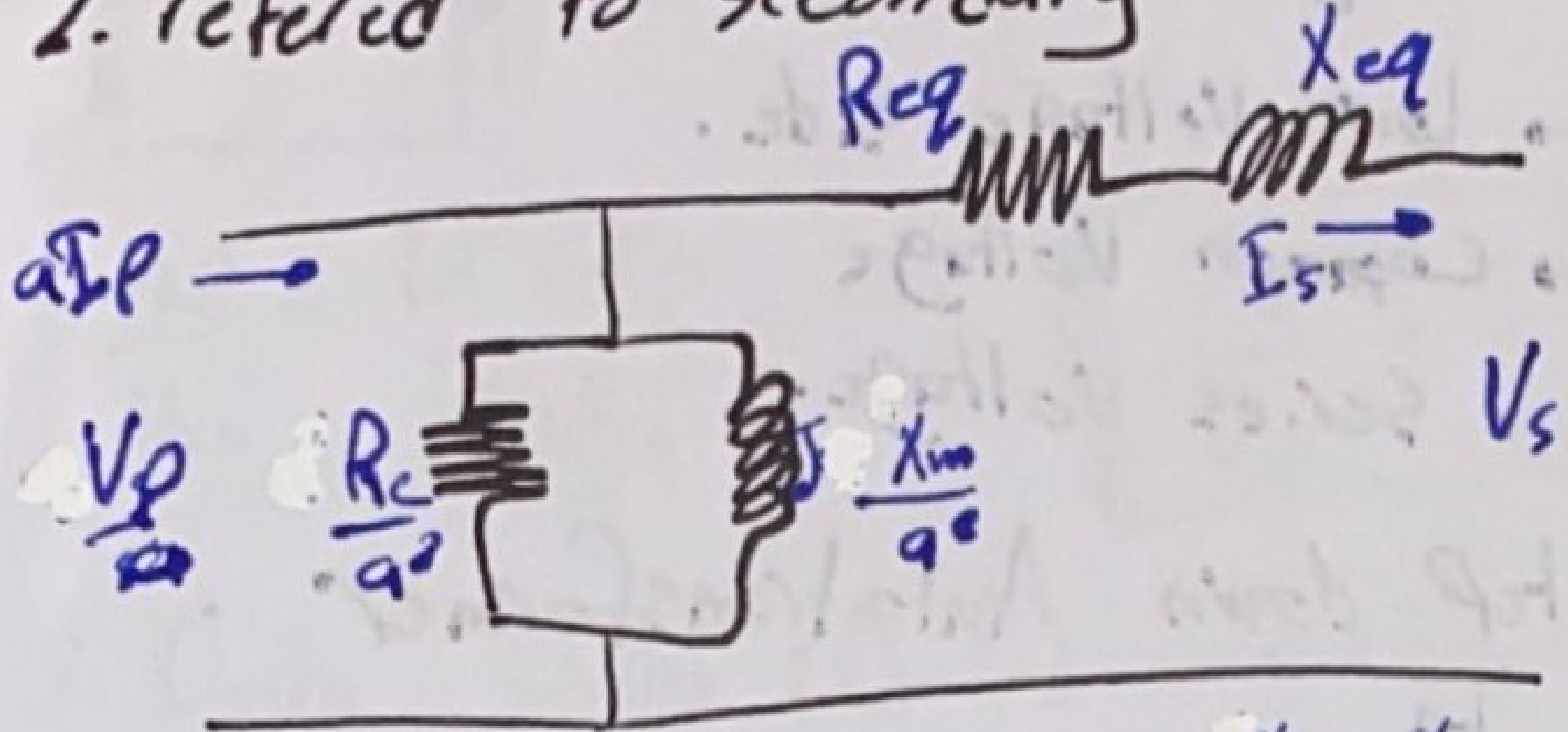
* Approximate Equivalent Circuit :-

1. refered to Primary :-



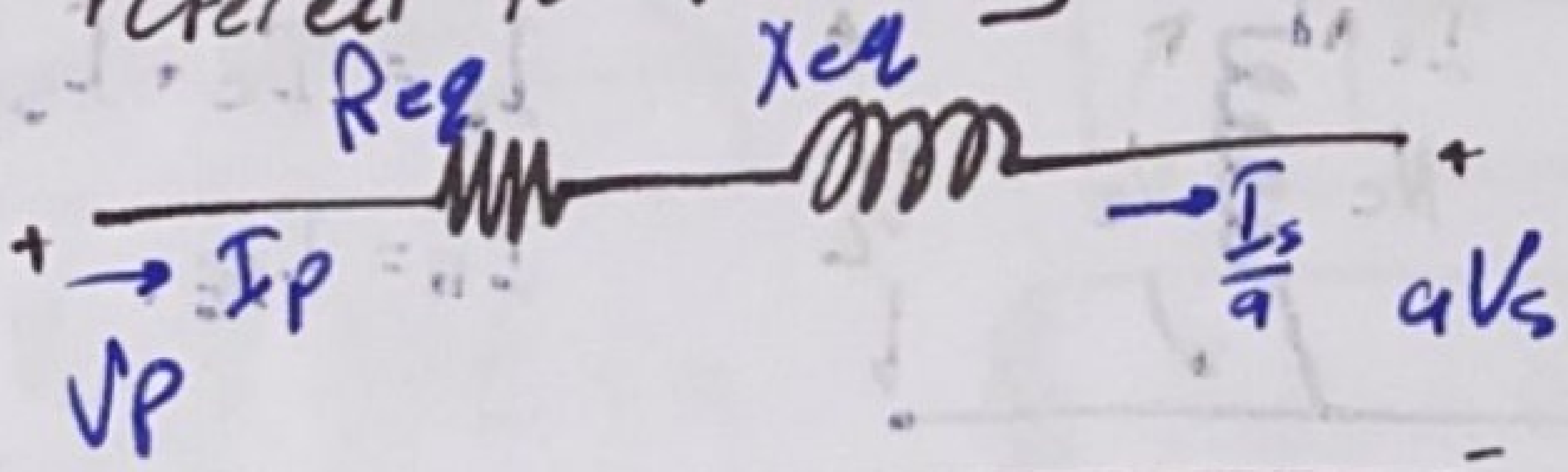
$R_{eq} = R_P + a^2 R_s \quad X_{eq} = X_P + a^2 X_s.$

2. refered to secondary :-



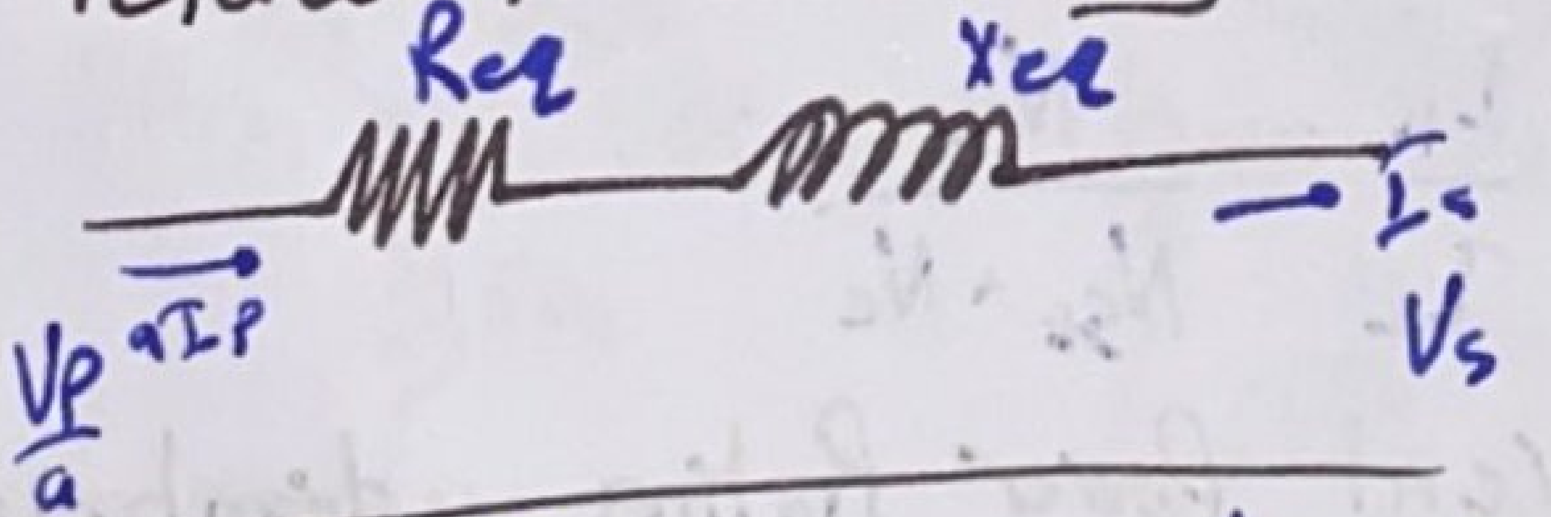
$R_{eq} = \frac{R_P}{a^2} + R_s \quad , \quad X_{eq} = \frac{X_P}{a^2} + X_s$

3- with no excitation branch refered to Primary :-



$R_{eq} = R_P + a^2 R_s \quad X_{eq} = X_P + a^2 X_s$

4- with no excitation branch refered to secondary.

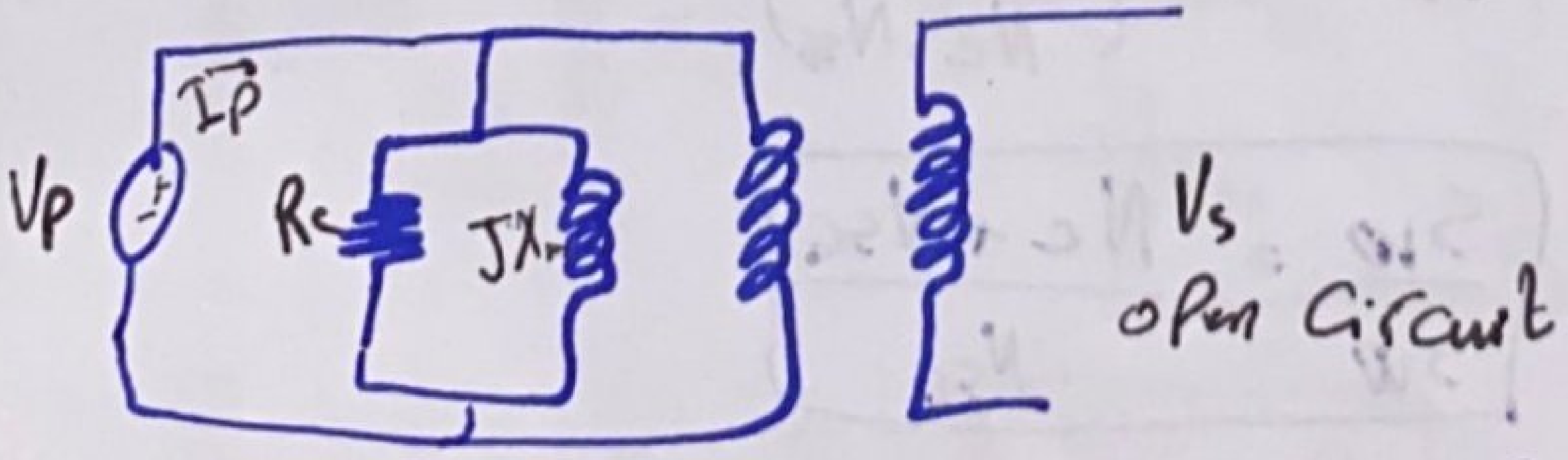


$R_{eq} = \frac{R_P}{a^2} + R_s \quad . \quad X_{eq} = \frac{X_P}{a^2} + X_s.$

* Transformer Test :-

1. The Open-Circuit test :- $\boxed{R_c \cdot X_m}$

$R_P, R_s, X_P, X_s \Rightarrow$ [illegible]



* Transformer test :-

1. Open-Circuit test :-

$G_c = \frac{1}{R_c}$. G: Conductance

$B_m = \frac{1}{X_m}$ B: susceptance

$Y_E = \frac{1}{Z}$ Y: admittance.

$$\boxed{Y_E = G_c - J B_m = \frac{1}{R_c} - J\frac{1}{X_m}}$$

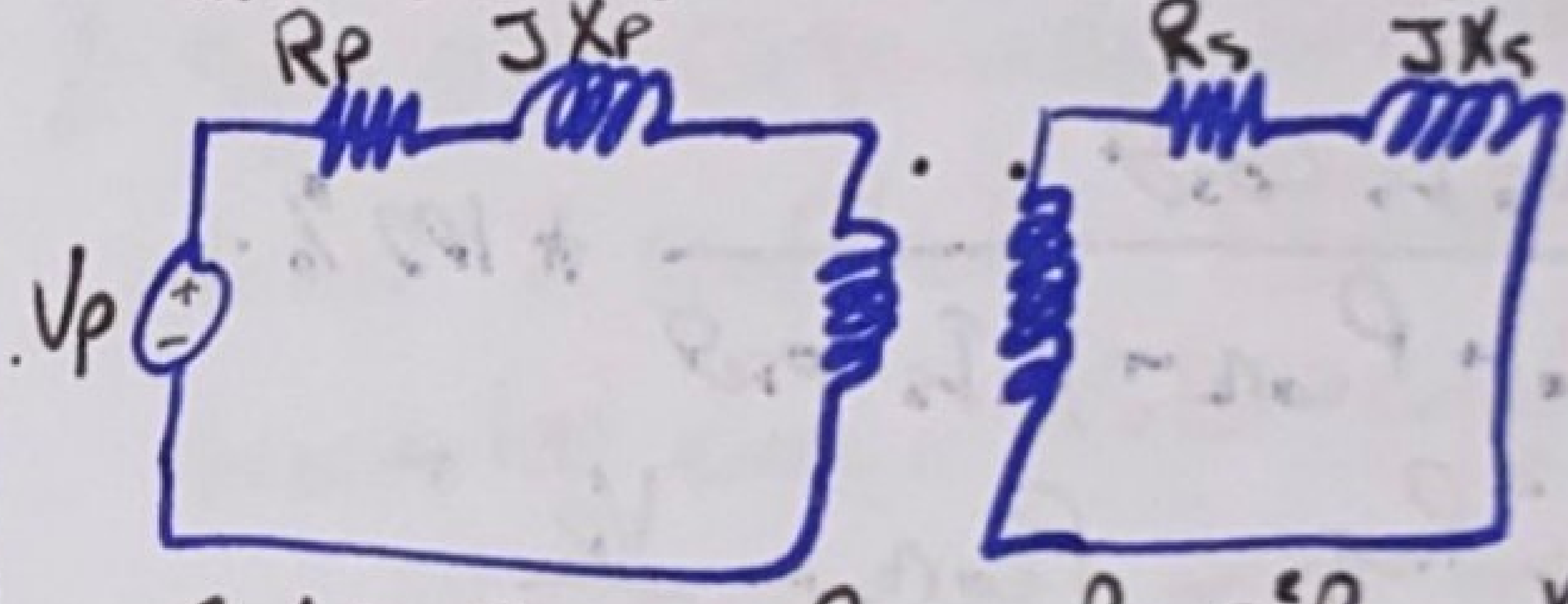
$Y_E = \frac{I_{oc}}{V_{oc}} \angle -\theta \qquad \theta = \cos^{-1}\left(\frac{P_{oc}}{V_{oc} I_{oc}}\right)$

$Y_E = |Y_E| \angle \alpha$

$G_c = |Y_E| \cos\alpha \Rightarrow \frac{1}{R_c} = \frac{1}{|Y_E| \cos\alpha}$

$B_m = |Y_E| \sin\alpha \Rightarrow \frac{1}{X_m} = \frac{1}{|Y_E| \sin\alpha}.$

2- The shourt-Circuit test :- $\boxed{R_{eq} \cdot X_{eq}}$



refered to Pri $\Rightarrow R_{eq} = R_P + a^2 R_s \ , \ X_{eq} = X_P + a^2 X_s$

refered to sec $\Rightarrow R_{eq} = \frac{R_P}{a^2} + R_s \ , \ X_{eq} = \frac{X_P}{a^2} + X_s$

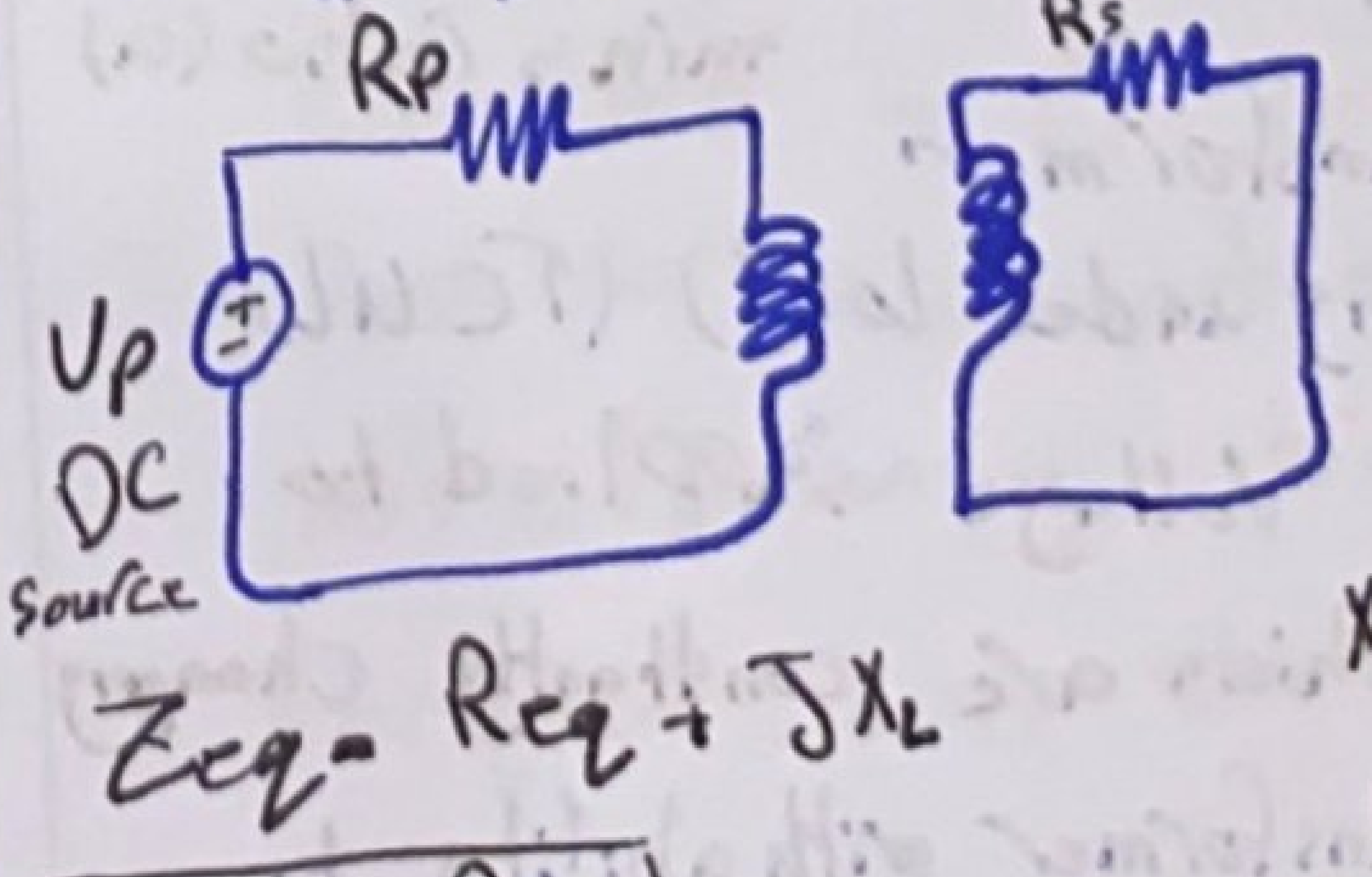
$Z_{sc} = \frac{V_{sc}}{I_{sc}} \angle \theta \qquad \theta = \cos^{-1}\left(\frac{P_{sc}}{V_{sc} I_{sc}}\right)$

$Z_{sc} = R_{eq} + J X_{eq}$

$Z_{sc} = (R_P + a^2 R_s) + J(X_P + a^2 X_s) \rightarrow$ refered to Primary

$Z_{sc} = \left(\frac{R_P}{a^2} + R_s\right) + J\left(\frac{X_P}{a^2} + X_s\right) \rightarrow$ refered to secondary

3. The DC test :-



$X_L = WL = 2\pi f L$

$Z_{eq} = R_{eq} + J X_L$

$\underline{f = zero} \Rightarrow \underline{X_L = zero}$

$$\boxed{Z_{eq} = R_{eq}}$$

*Electrical Machines :-

* Voltage regulation (VR) :-

$$VR = \frac{V_{s\,nL} - V_{s\,fL}}{V_{s\,fL}} * 100\%$$

$$a = \frac{V_P}{V_s} \Rightarrow V_s = \frac{V_P}{a}.$$

$$\boxed{VR = \frac{\frac{V_P}{a} - V_{s\,fL}}{V_{s\,fL}} * 100\%.}$$

* Efficiency :-

$$\eta = \frac{P_{out}}{P_{in}} * 100\%.$$

$$= \frac{P_{out}}{P_{out} + P_{Loss}} * 100\% = \frac{P_{in} - P_{Loss}}{P_{in}} * 100\%.$$

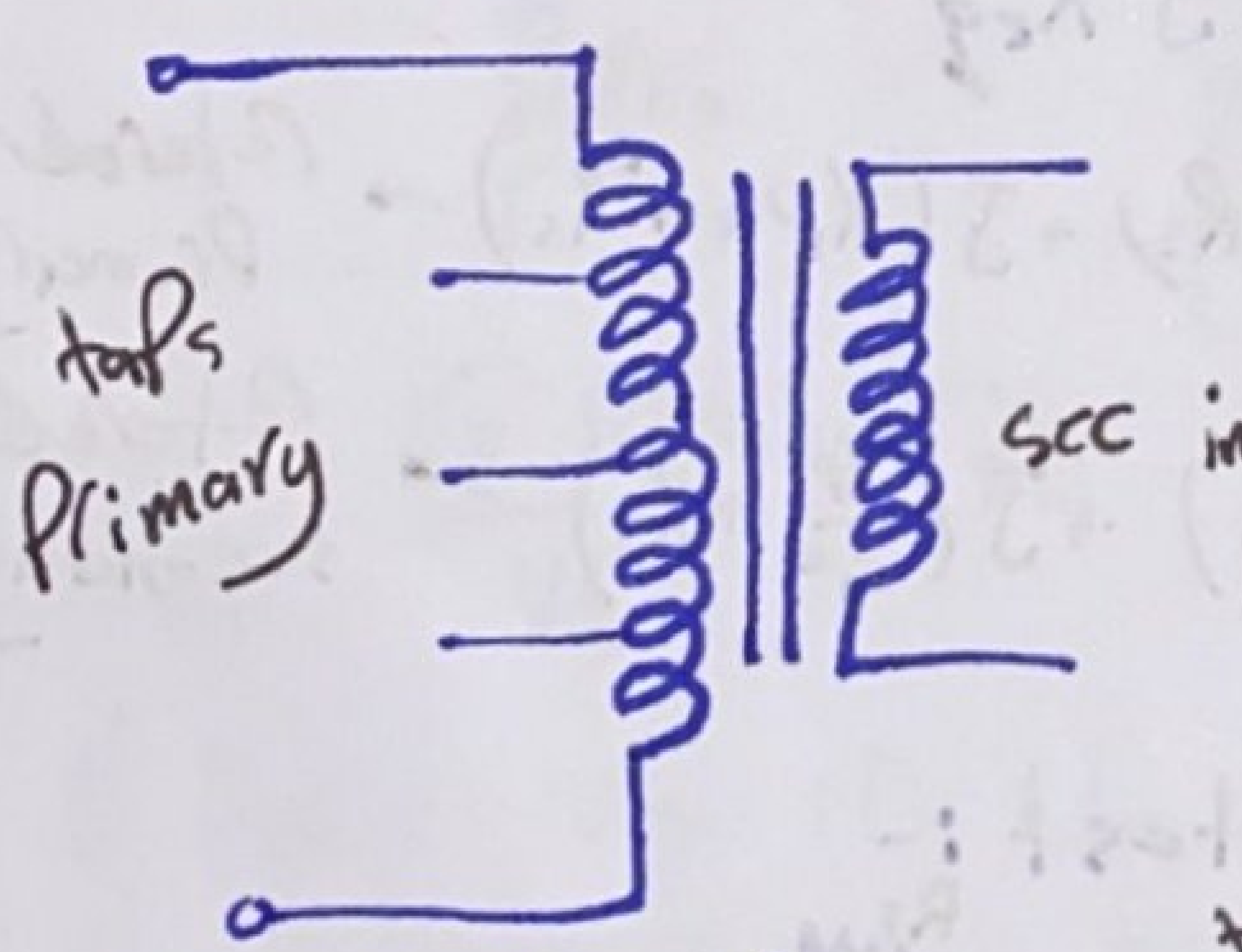
$$P_{out} = V_s I_s \cos\theta$$

$$\eta = \frac{V_s I_s \cos\theta}{P_{cu} + P_{core} + V_s I_s \cos\theta} * 100\%.$$

$$P_{cu} = I_s^2 R_{eq} \quad . \quad P_{core} = \frac{V_P^2}{a^2 R_c}.$$

* Transformer Taps :-

الهدف من ال Taps الحصول على قيمة جهد ثابتة على ال sec بتغير ال Primary.



We have a series of taps in Winding to Permit small change in the turns ratio (a)

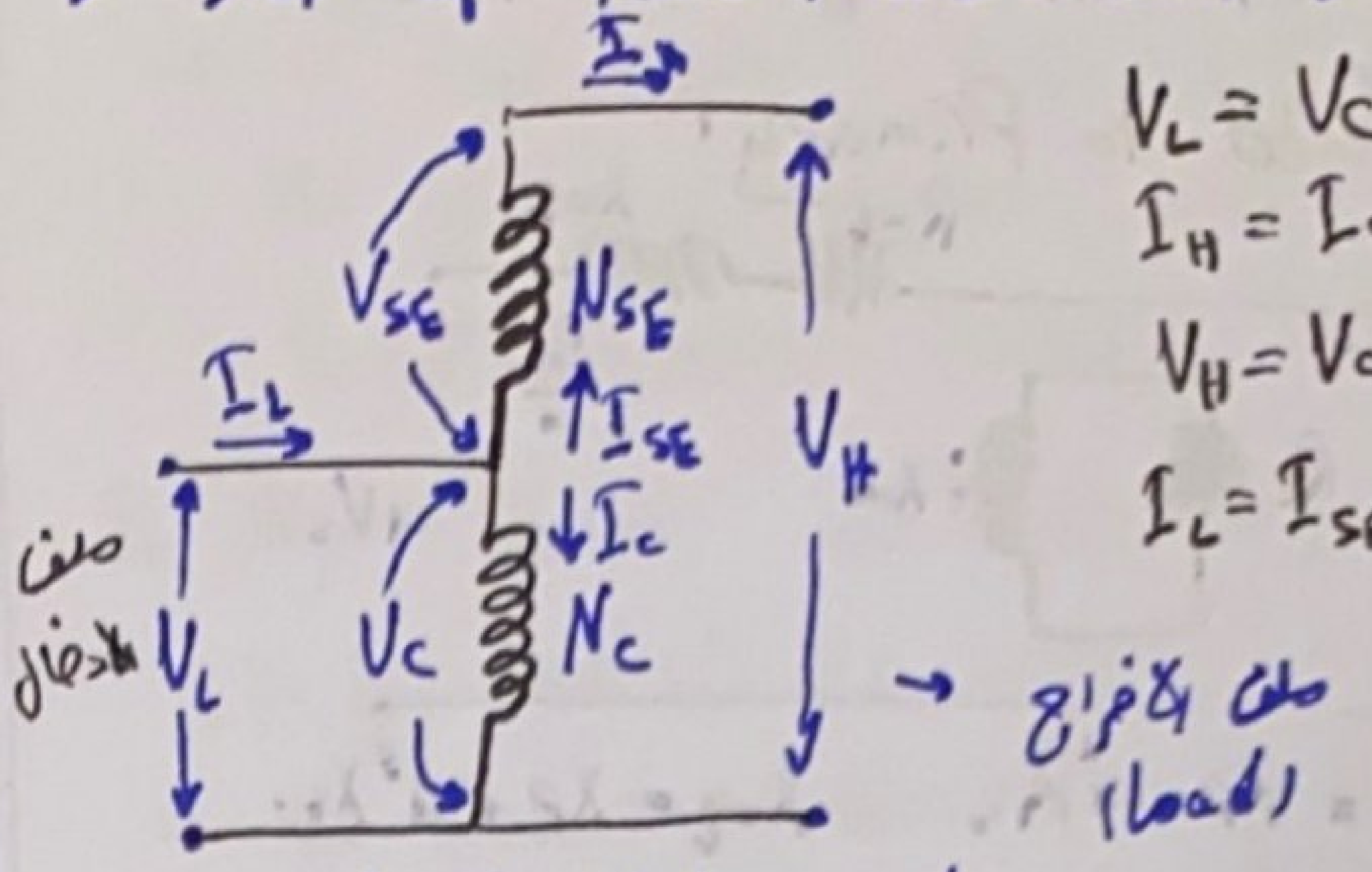
special Transformer (tap changing under load) (TCUL)

⇒ Constant Voltage supplied to loads which are constantly changing

TCUL → Transformer with ability to change taps while Power is connected

* The Autotransformer :-

1- step-up Autotransformer :-



$V_L = V_C$

$I_H = I_{SE}$

$V_H = V_C + V_{SE}$

$I_L = I_{SE} + I_c$

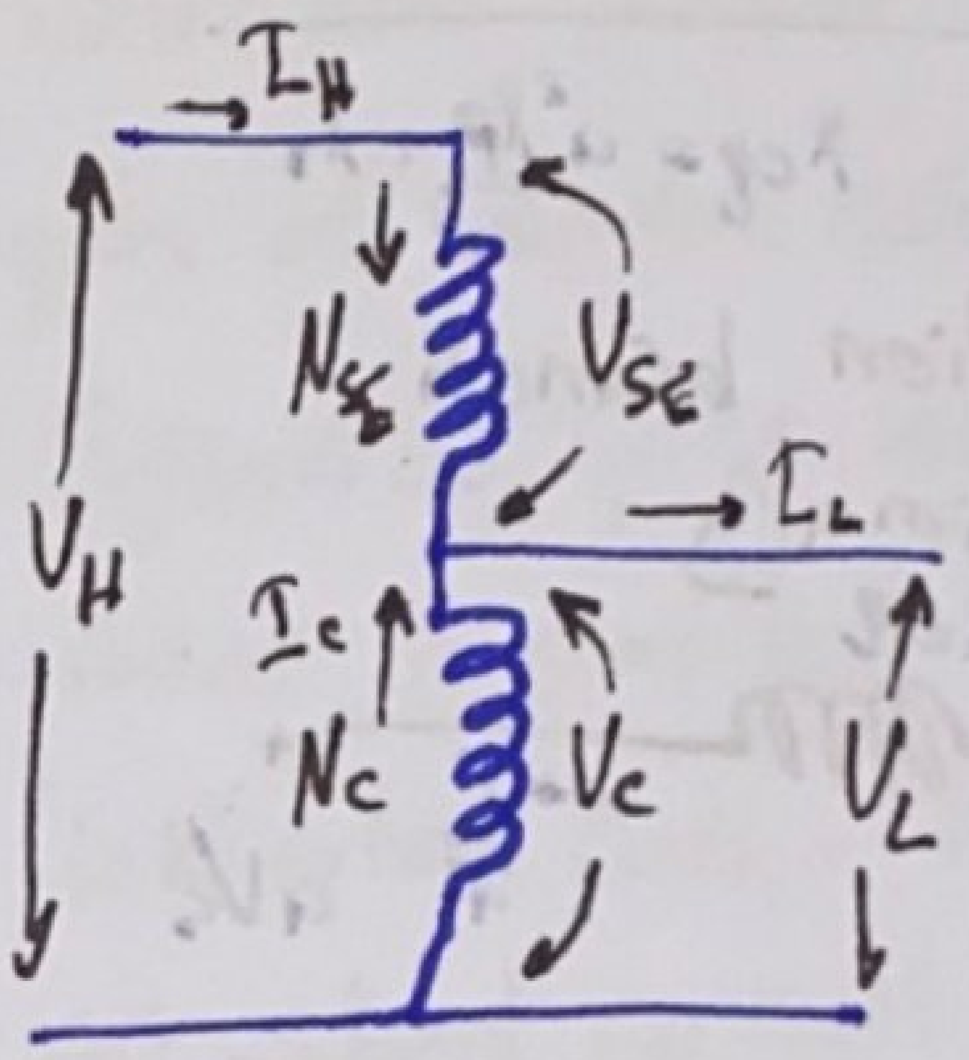
V_H → high Voltage side

V_L → low Voltage side.

V_C → Common Voltage

V_{SE} → series Voltage.

2- step-down Autotransformer :-



$V_L = V_C$

$V_H = V_C + V_{SE}$

$I_L = I_C + I_{SE}$

$I_H = I_{SE}.$

Voltage Relationship

$$\boxed{\frac{V_L}{V_H} = \frac{N_C}{N_{SE} + N_C}}$$

Current Relationship

$$\boxed{\frac{I_L}{I_H} = \frac{N_{SE} + N_C}{N_C}}$$

$$\frac{V_L}{V_H} = \frac{I_H}{I_L} = \frac{N_C}{N_{SE} + N_C}$$

* Apperent Power Rating advantage.

$S_{in} = V_L I_L \quad . \quad S_{out} = V_H I_H$

$S_{in} = S_{out} = S_{IO}$ → input output Power

$S_W = V_C I_C = V_{SE} I_{SE}$ → Winding Power.

$$S_W = S_{IO}\left(\frac{N_{SE}}{N_C + N_{SE}}\right).$$

$$\boxed{\frac{S_{IO}}{S_W} = \frac{N_C + N_{SE}}{N_{SE}}}$$

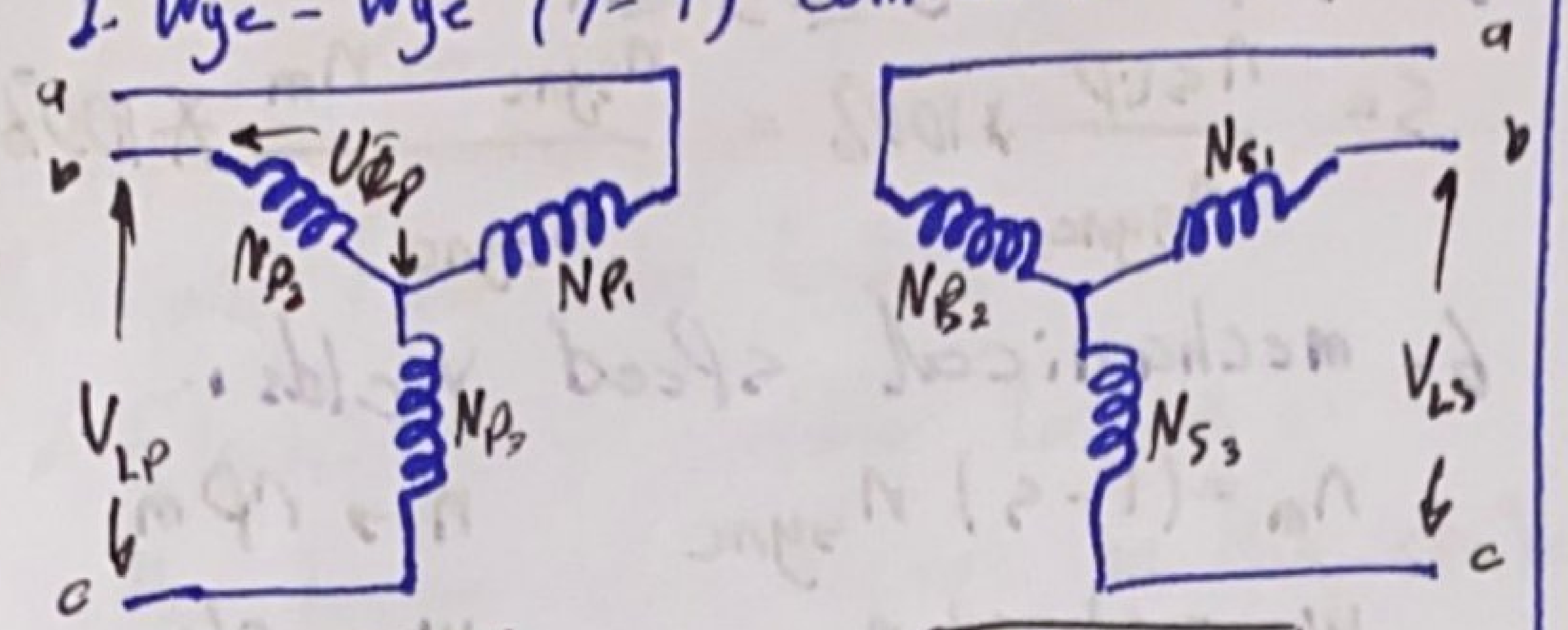
* Electrical Machines :-

* The Transformers :-

* Three-Phase Transformers

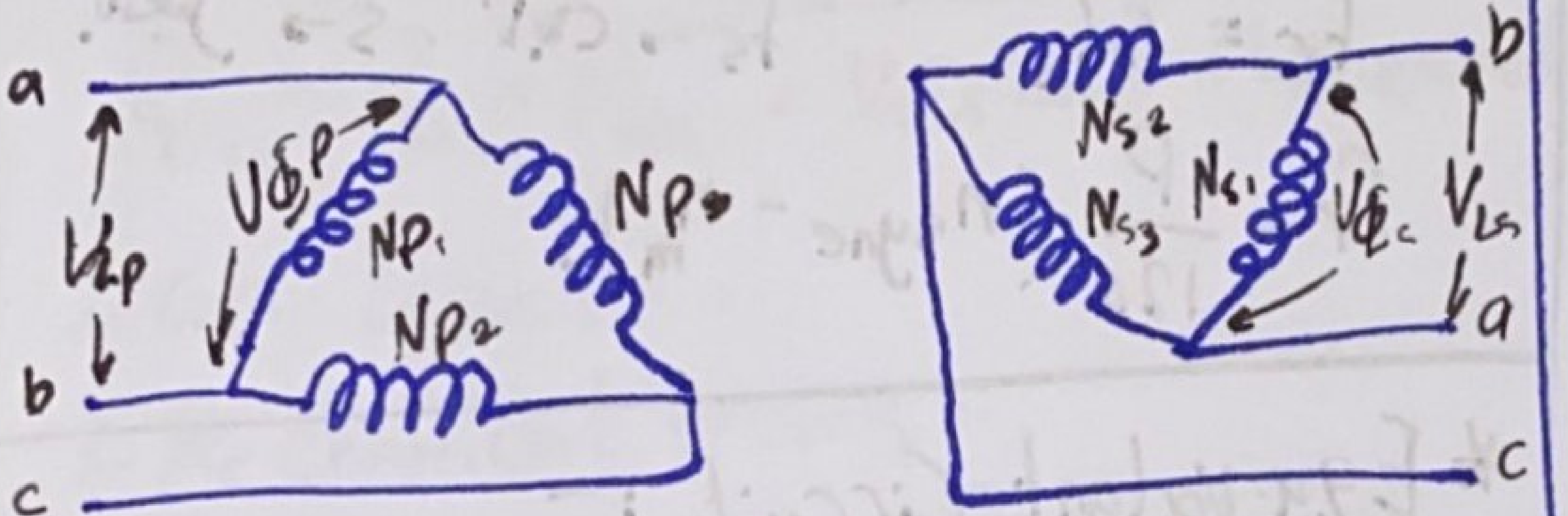
* Connection for Three Phase Transformers :-

1. Wye - Wye (Y-Y) connection :-



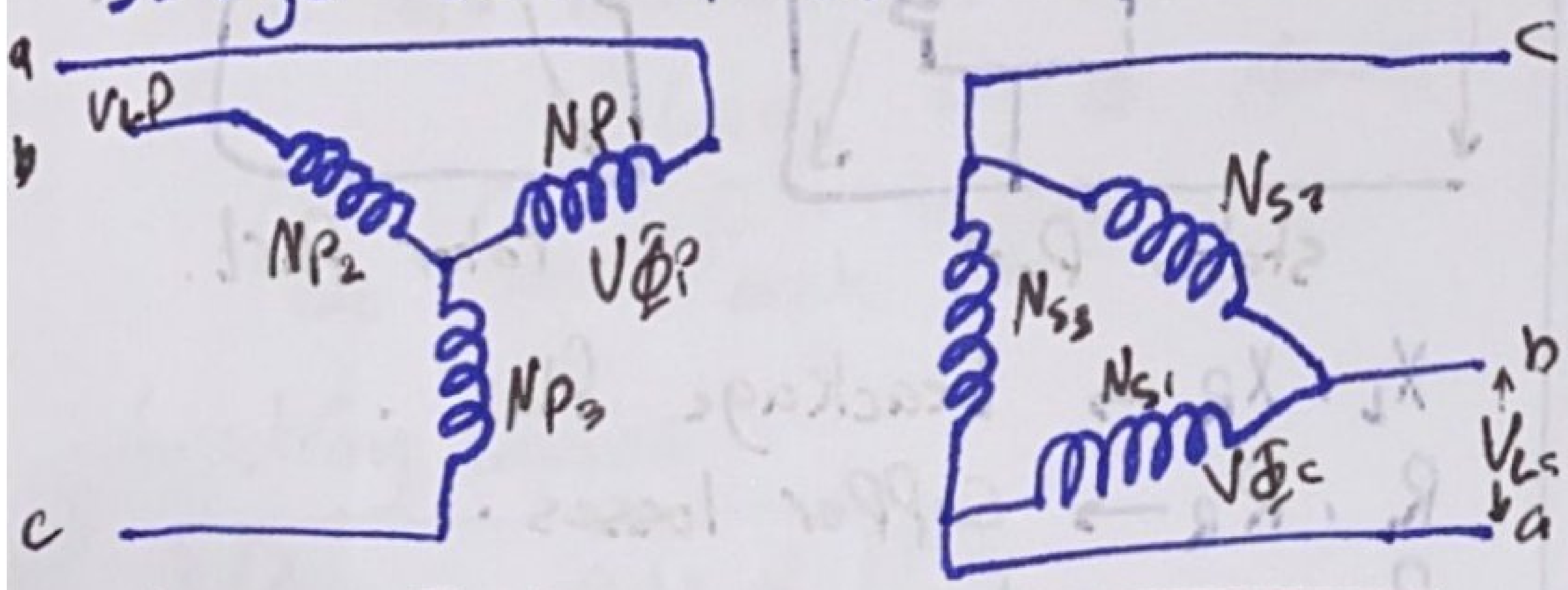
$$\frac{V_{LP}}{V_{LS}} = \frac{\sqrt{3}\, V_{\phi P}}{\sqrt{3}\, V_{\phi S}} = a \qquad \boxed{\frac{V_{LP}}{V_{LS}} = a}$$

2. Delta - Delta (Δ-Δ) connection :-



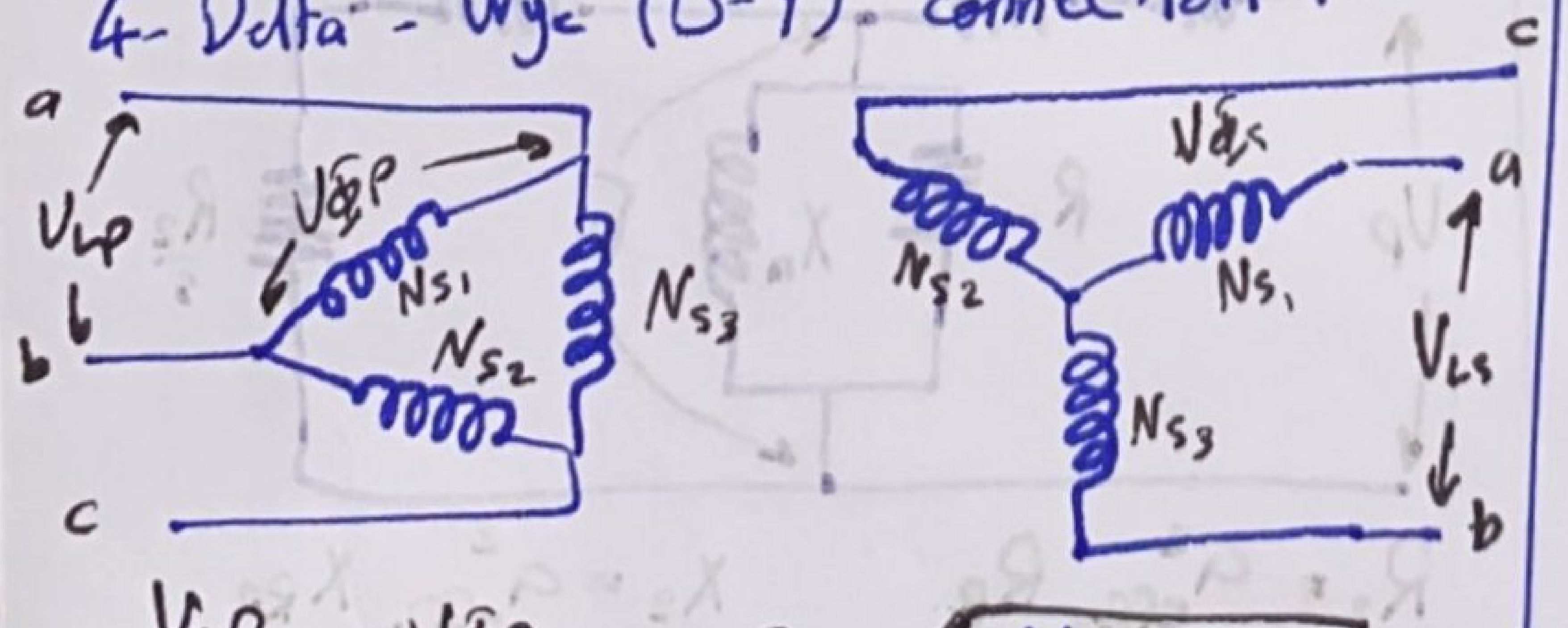
$$\frac{V_{LP}}{V_{LS}} = \frac{V_{\phi P}}{V_{\phi S}} = a \qquad \boxed{\frac{V_{LP}}{V_{LS}} = a}$$

3. Wye - Delta (Y-Δ) connection :-



$$\frac{V_{LP}}{V_{LS}} = \frac{\sqrt{3}\, V_{\phi P}}{V_{\phi S}} = \sqrt{3}\, a \qquad \boxed{\frac{V_{LP}}{V_{LS}} = \sqrt{3}\, a}$$

4. Delta - Wye (Δ-Y) connection :-



$$\frac{V_{LP}}{V_{LS}} = \frac{V_{\phi P}}{\sqrt{3}\, V_{\phi S}} = \frac{a}{\sqrt{3}} \qquad \boxed{\frac{V_{LP}}{V_{LS}} = \frac{a}{\sqrt{3}}}$$

* Problems of connections :-

1. Wye - Wye (Y-Y) connection
   - a- If loads are unbalanced, then the Voltages become unbalanced.
   - b- Third-harmonic Voltages be large.
2. Wye - Delta and Delta - Wye. (Y-Δ) and (Δ-Y) connection :-
   - a- the secondary Voltage is shifted 30° relative to the Primary Voltage
3. Delta - Delta (Δ-Δ) connection :- has no phase shift and no Problems

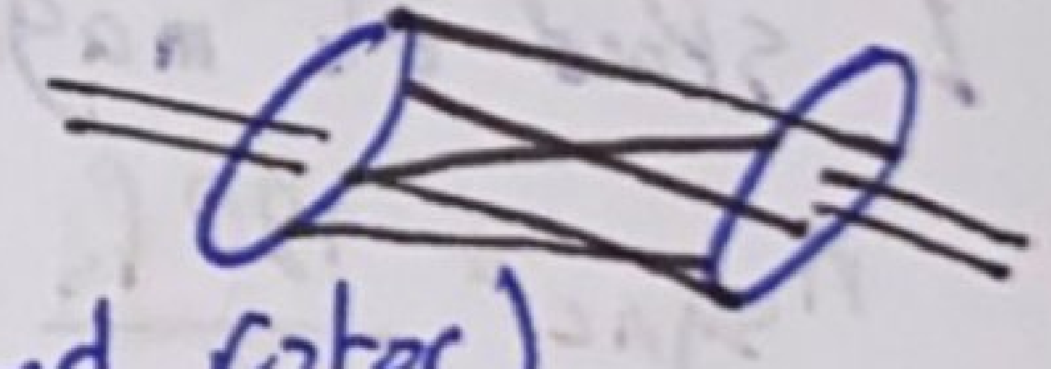
افضل توصيلة (Δ-Δ) لا فيها اي مشاكل.

---

* Induction Motors :-

* Types of Induction motors :-

1. Squirrel Cage induction motors :-
   - rotor is simplest, Cylindrical laminated core, Rotor conductors are short circuit with end rings, unpossible to conneet extra resistance Higher efficiency, low starting torque.



2. Slip ring (Wound rotor) Induction motor :-
   - rotor is wound, Carbon brushes Cylindrical laminated core starting the Windings are connected to (Y) connected rheostat Possible to conneet extra resistance less efficiency, high starting torque, Less starting current

*Electrical Machines :-

* Induction Motors :-

* Rotor Conductors are skewed because:-

1. to Prevent the cogging Phenomenon
منع ظاهرة cogging اللي بيكون فيها ال rotor
مستقيم فبيكون في فرصة كبيرة ليصير اغلاق
مغناطيسي + وبعمل قوة بين stator و rotor .

2. to avoid crawling Phenomenon.
ظاهرة ال crawling بتعمل اشارات كهربائية
ضارة بتعمل تذبذب بالعزم .

3. to increased rotor resistance
لما يكون البار مائل .بزيد طوله بالتالي بتزيد
مقاومته $R\uparrow = \frac{\rho L}{\rho}\uparrow$

4. to improve starting torque and starting Power factor

5. increasing effective magnetic coupling between stator and Rotor

---

*Basic Concepts of operation :-

1. speed of magnetic field's rotation

$n_{sync} = \frac{120 f_s}{P}$, $f_s \rightarrow$ system freq, $P \rightarrow$ # of Poles

2. Voltage induced in a rotor bar

$E_{ind} = (V \times B_s) \cdot L$

3. Induced torque in the machine

$I_s \rightarrow B_s$, $I_R \rightarrow B_R$.

$\tau_{ind} = K B_R \times B_s = K B_R B_s \sin\theta$.

$\Sigma \tau = J\alpha \Rightarrow \tau_{ind} - \tau_{load} = J\alpha$.

*Basic concepts of operation:-

4. slip speed.

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

$n_{sync} \rightarrow$ سرعة دوران المجال المغناطيسي

$n_m \rightarrow$ shaft سرعة دوران

5. slip :- $0 \le S \le 1$

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

6. mechanical speed yields:-

$n_m = (1-s)\, n_{sync}$ $n \rightarrow rpm$

$W_m = (1-s)\, n_{sync}$ $W \rightarrow r/s$

$n = \frac{\pi}{3} W$, $W = \frac{30}{\pi} n$.

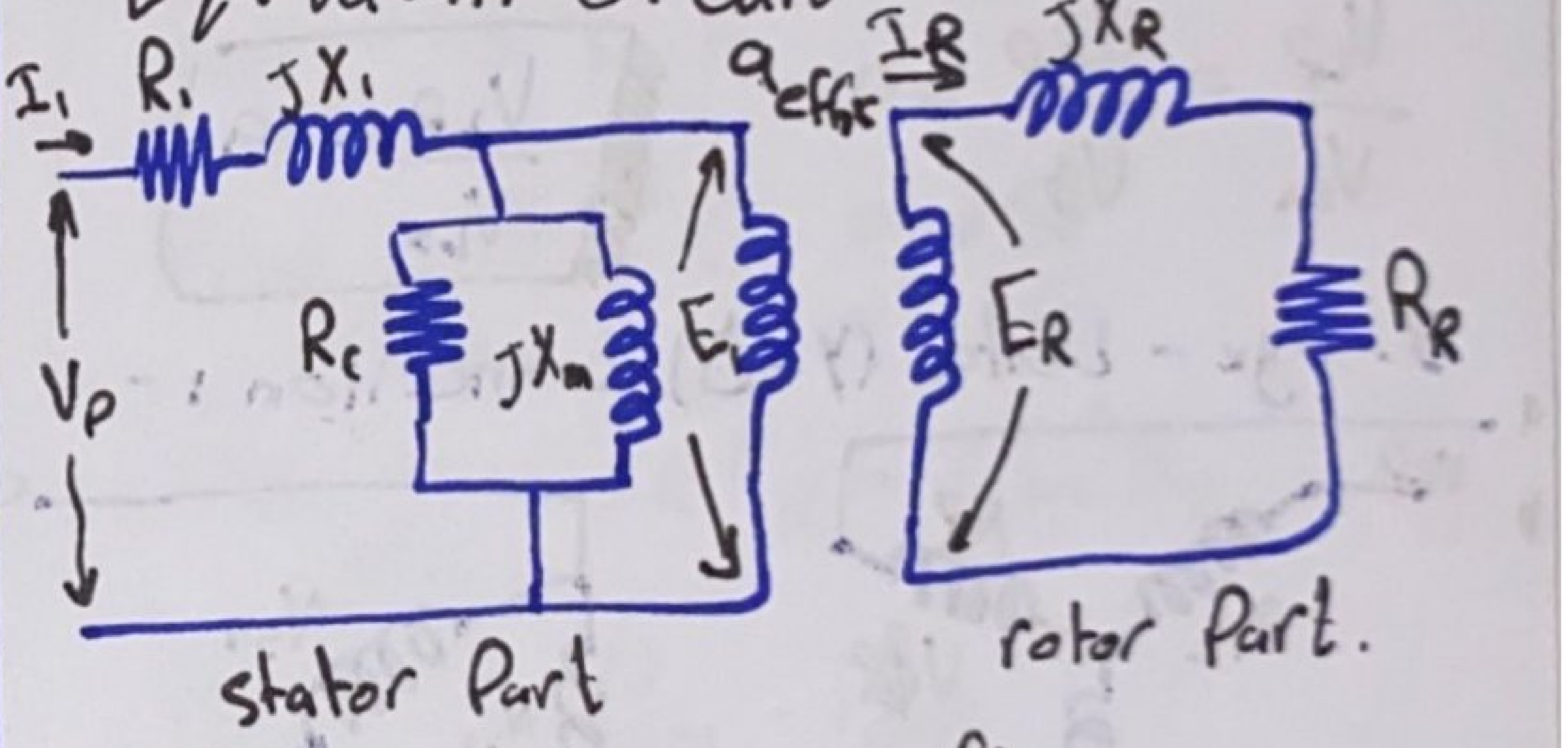
7. rotor frequency :-

$f_r = s f_s$ $f_s \rightarrow$ ثابتة ، $s \rightarrow$ بتتغير.

$f_r = \frac{P}{120}(n_{sync} - n_m)$.

---

* Equivalent Circuit :-

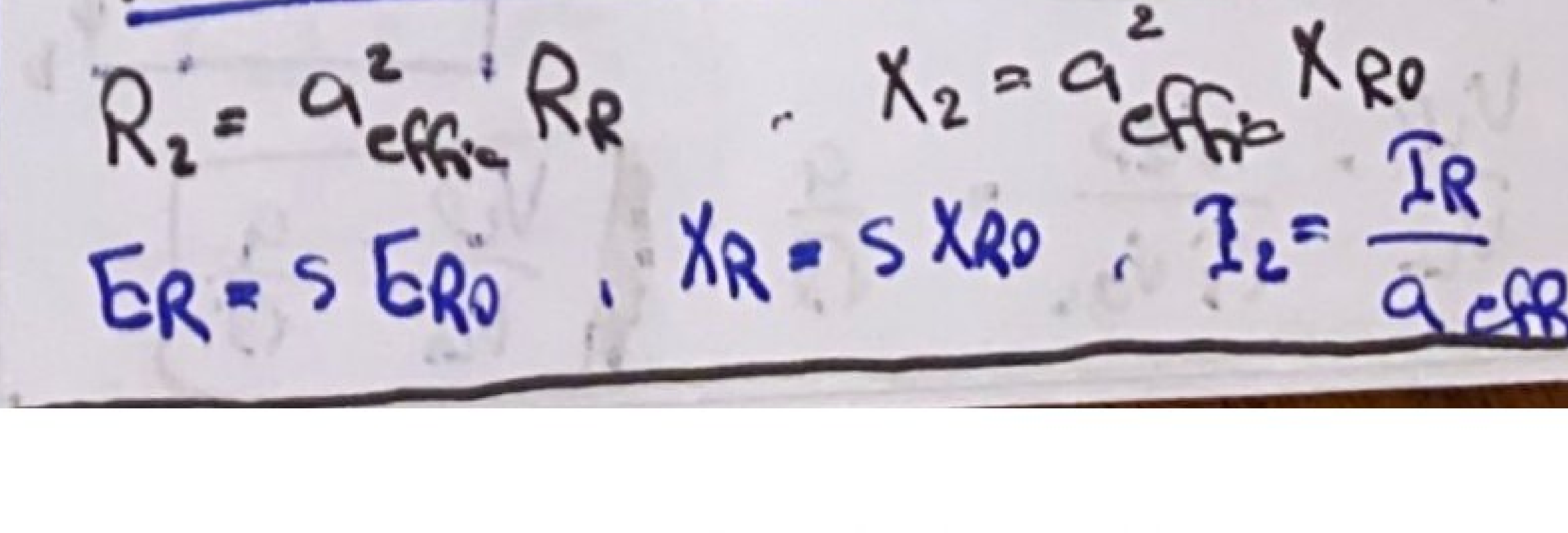


X_1 , $X_R \rightarrow$ Leackage flux.

R_1 , $R_R \rightarrow$ copper losses.

$R_c \rightarrow$ core losses.

$X_m \rightarrow$ Magnetization losses.



$R_2 = a_{eff}^2 R_R$, $X_2 = a_{eff}^2 X_{R0}$

$E_R = s E_{R0}$, $X_R = s X_{R0}$, $I_2 = \frac{I_R}{a_{eff}}$

* Electrical Machines :-

* Induction Motors :-

* The efficiency of an AC machine:-

$$\eta = \frac{P_{out}}{P_{in}} * 100\% = \frac{P_{in} - P_{loss}}{P_{in}} * 100\%$$

* Power flow and losses :-

1. Electrical or Copper losses :-

the losses that accure in the stator and rotor Winding of the machine.

stator losses $\boxed{P_{SCL} = V_s I_s \cos\theta}$.

Rotor losses $\boxed{P_{RCL} = V_R I_R \cos\theta}$.

$P_{Elec} = P_{SCL} + P_{RCL} = V_s I_s \cos\theta + V_R I_R \cos\theta$.

2. core losses.

3. Mechanical losses :-

1. friction losses. ضياعات الاحتكاك
2. Winding losses. ضياعات احتكاك الأجزاء المتحركة مع الهواء.

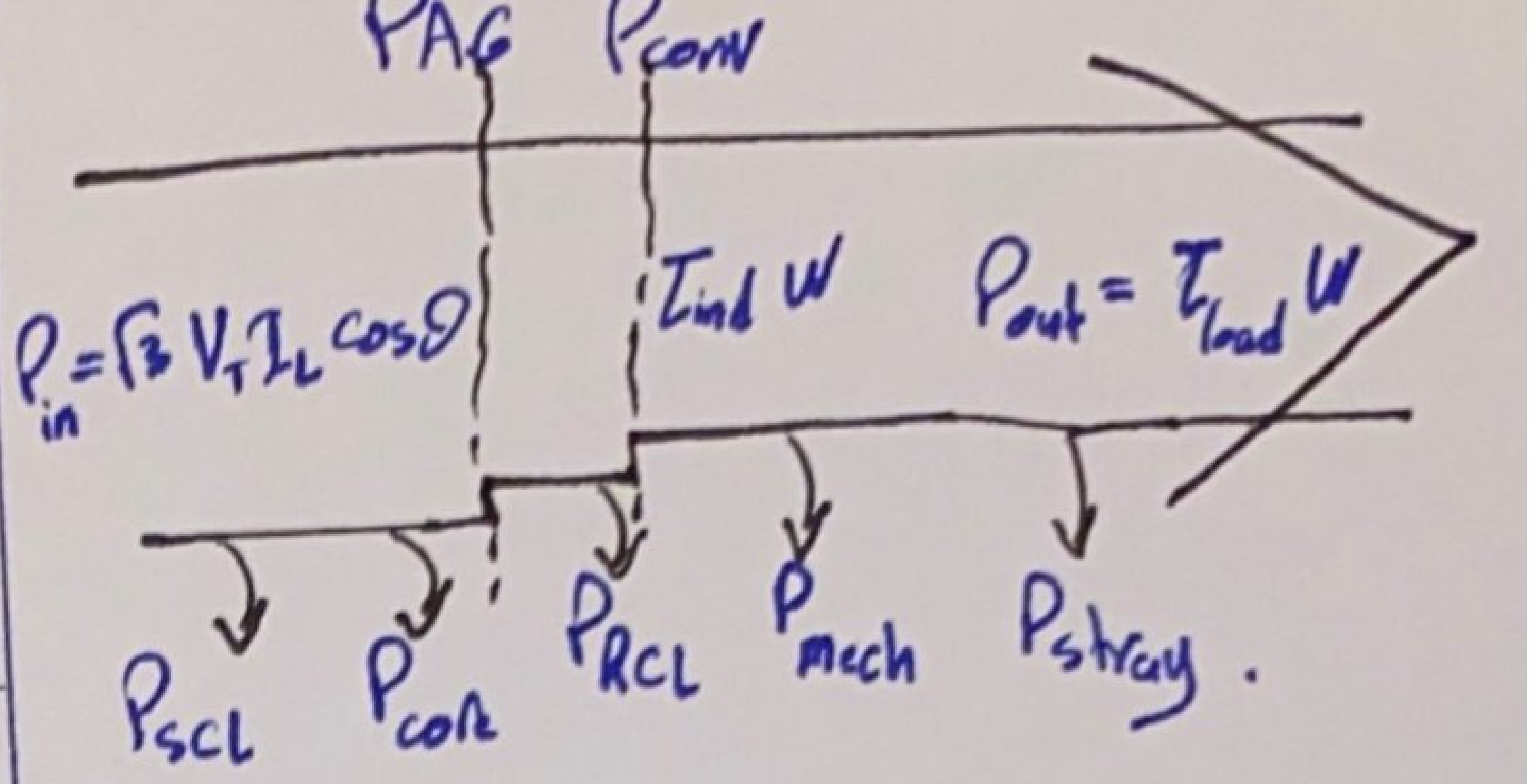
core and mechanical losses نحسبهم في حالة no load.

$P_{tot} = P_{core} + P_{mech} = VI$.

4- stray losses :-

$\boxed{P_{stray} = 0.01 * P_{in}}$.

* Power flow and losses :-



$P_{in} = \sqrt{3} V_T I_L \cos\theta$.

$P_{out} = \tau_{load} \omega_m$

$P_{SCL} = I_1^2 R_1$, $P_{RCL} = I_2^2 R_2$

$P_{AG} = P_{in} - P_{SCL} - P_{core}$.

$P_{conv} = P_{AG} - P_{RCL}$.

$P_{out} = P_{in} - P_{SCL} - P_{RCL} - P_{stray} - P_{mech} - P_{core}$

$P_{out} = P_{conv} - P_{stray} - P_{mech}$.

* Total Power on 3-Phase Winding:-

$P_{SCL_{total}} = 3 I_1^2 R_1$

$P_{core_{total}} = 3 E_1^2 G_c = 3 \frac{E_1^2}{R_c}$

$P_{RCL_{total}} = 3 I_R^2 R_R = 3 I_2^2 R_2$

$P_{AG} = P_{in} - P_{SCL} - P_{core}$

$\boxed{P_{AG} = 3 I_2^2 \frac{R_2}{s}}$.

$P_{conv} = 3 I_2^2 R_2 \left(\frac{1-s}{s}\right)$.

$\boxed{P_{conv} = (1-s) P_{AG}}$.

$P_{conv} = \tau_{ind} \omega_m$

$\tau_{ind} = \frac{(1-s) P_{AG}}{(1-s)\omega_{sync}} = \frac{P_{AG}}{\omega_{sync}}$.

$$\boxed{\tau_{ind} = \frac{P_{AG}}{\omega_{sync}}}$$