Machines1

Summer017

Dr.Mhmd Alhajj

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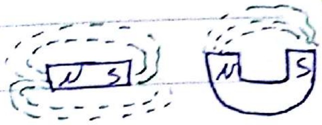
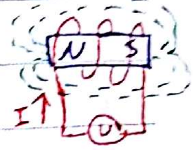
www Powerunit-ju.com

No." Machines 1 "

4/6/2017 Dr. Mohammad Al-haj Summer 2017

Magnatic field :-
"force"

→ 1) magnet 

→ 2) electro magnet 

Types of materials based on it's magnatic properties :-

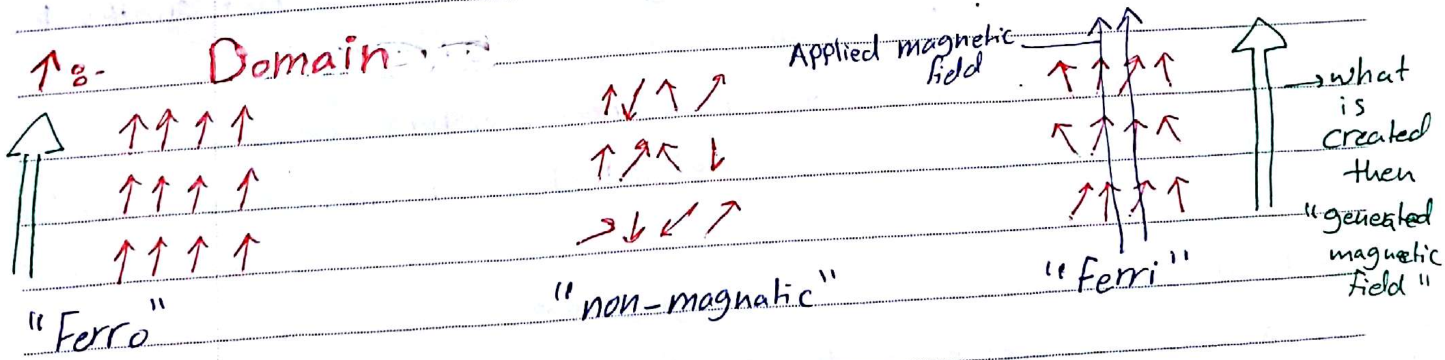
⇒ nonmagnetic material :- (No ability to "collect" magnatic field) $\mu_0 = \mu$ (permeability)
$\mu_0 \to 4\pi * 10^{-7}$

⇒ Ferri-magnetic material :- It can gain ferromagnatic material properties when we apply a magnatic field on it. "AlNiCo, SmCo"

→ we have to apply a magnatic field to have another magnatic field !!! Yes, because the magnatic field that will be generated is much stronger than the applied magnatic field.

⇒ Ferromagnetic material :- has superior capability to collect magnatic field. (Iron/steel, Ni, Co)

↑ :- Domain



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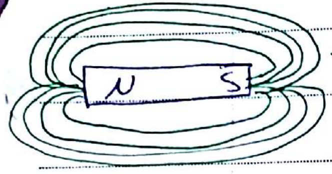
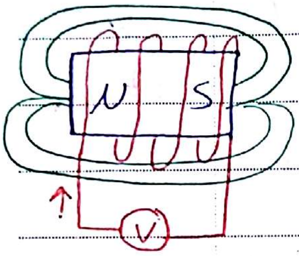


$\Phi \Rightarrow$ عدد خطوط المجال المغناطيسي

$B \Rightarrow$ عدد خطوط المجال المغناطيسي على وحدة المساحة



$H \Rightarrow$ عندما يزداد التيار تزداد "H"

linear relationship

$\oint H . dL = I_{net}$

Magnetic field is the basic force in electric machines :-

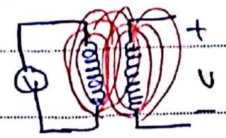
Generators :- electric machine that converts mechanical energy (in the presence of magnatic field) to electric energy

Motors :- electric machine that converts electrical energy to mechanical energy

Transformer :- converts electric Ac energy with certain V & F (frequency) to electric Ac energy with the same f but another V. "by means of magnetic field"

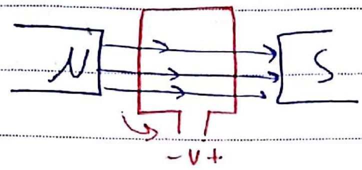
principles of magnetic field :- a current carrying conductor establishes a magnetic field around itself.

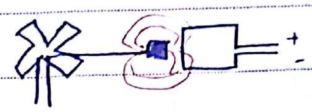
⇒ Transformer principle :- a time varying magnetic flux (Φ) induces a voltage in a conductor in the vicinity of the field



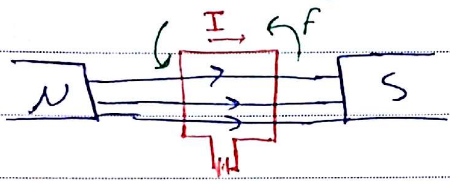
5/6/2017

⇒ generator principle :- a moving coil in the presence of a magnetic field will have voltage induced on it.

1) 

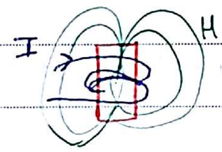
2) 

⇒ Motor principle :- a current carrying coil in the presence of a magnetic field will have force induced in it.

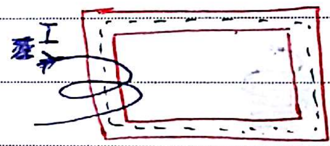


* Magnetic field :-

(H is weak)



(H is stronger)



$H.L = I_{enclosed}$

(H is much stronger)

⇒ Ampere's law

$\oint H.dl = I_{enclosed}$

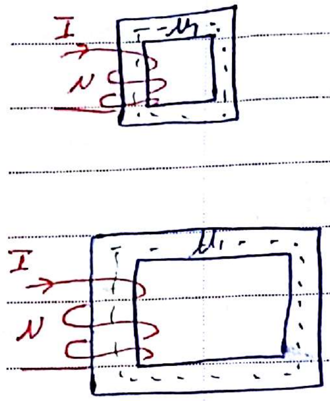
$\oint H.dl = NI = I_{net}$

$\boxed{H.L = NI}$ → unit ($\frac{A.turns}{m}$)

H ≡ magnetic field intensity

⇒ $\boxed{B = \mu H}$ → unit (Tesla)

B ≡ magnetic flux density

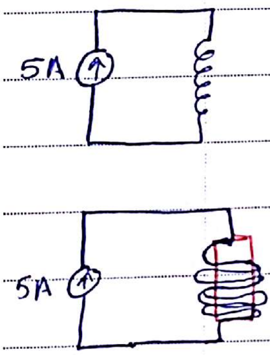


Same H
Same B → diffrent Φ ⇒ $\Phi = B \cdot A$

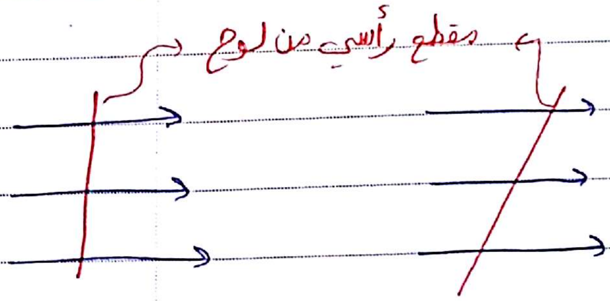
$\Phi = \oint B \cdot dA$

- Φ → flux
- B → Flux density
- A → Area
- only if B is perpendicular on A.

Φ ⇒ unit (Tesla.m^2) = wb



→ Same H
diffrent B → بسبب تغير الوسط

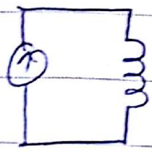


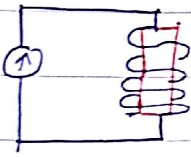
→ Same Φ
Same B

$\mu = \mu_r \mu_0$ → free space permeability

↳ relative permeability

$\mu_0 = 4\pi \times 10^{-7}$ H/m





$H = 100 \frac{A.turn}{m}$ ⇒ H is the same

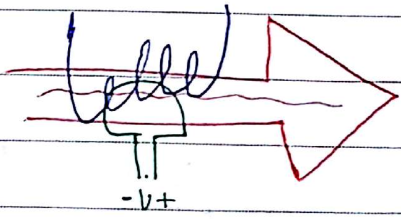
$B = \mu_0 H$ $\qquad$ $B = 2000\mu_0 H$

For Ferro $\mu_r = (2000 - 6000)$

For non-magnetic $\mu_r = 1$

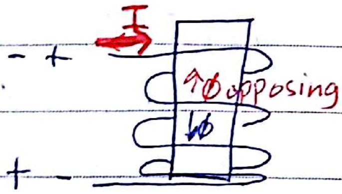
* Faradys law :-

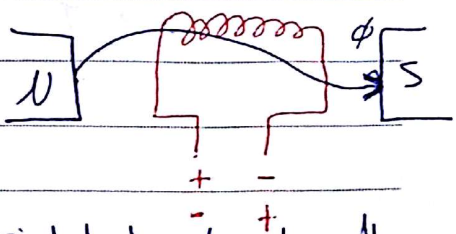
IF a flux passes through a turn of a coil of in a wire, voltage will be induced in that coil directly propotional to the rate of change of the flux.



$$e_{ind} = -\frac{d\phi}{dt}$$

$$V = -\frac{d\phi}{dt}$$





$$e_{ind} = -N\frac{d\phi}{dt}$$

— since the polarity is figured out using right hand rule, the minus sign is sometimes omitted

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6/6/2017

Faraday's law

Transformer — generator — Motor

Transformer

$V = -N\frac{d\phi}{dt}$

$\bar{\Phi} = \bar{\Phi}_s \cos\omega t$

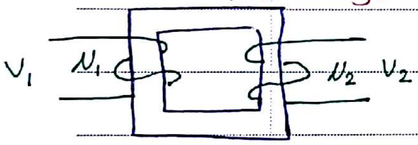
$V = +N\,\bar{\Phi}_s\,\omega \sin\omega t$, $\bar{\Phi}_s = B_p A$

$V = 2\pi N B_p A f \sin\omega t$

$V_{rms} = \frac{2}{\sqrt{2}}\pi N f A B_p$

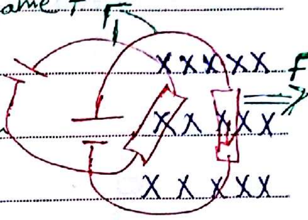
$V_{rms} = 4.44\, N f A B_p$ → peak

flux linkage equation



Motor

they both have the same F but diffrent direction



$f \propto B$

$F \propto I$

$F = (\ell \times B) I$ ~~$F = I \times B$~~

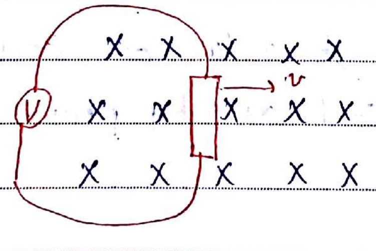
(length — ℓ, Flux density — B, current — I)

$= I B \sin\theta$ (N/m)

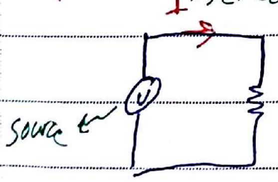
$F = I B L \sin\theta$ (N)

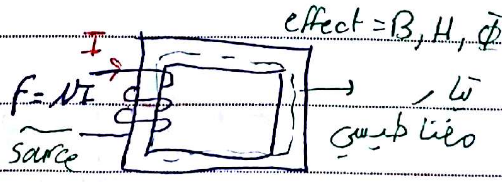
L → length of the wire

generator

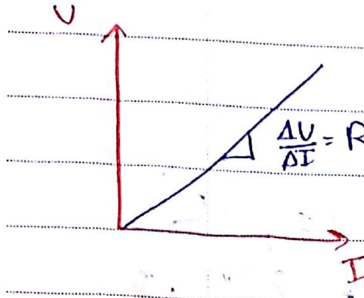


$e_{ind} = (V \times B) \cdot \ell$





mmf ≡ magneto motive force



$$\frac{\Delta F}{\Delta \phi} = \mathcal{R} \quad ; \quad \mathcal{R} \equiv \text{reluctance}$$

$F = mmf = NI$ [A.turns]

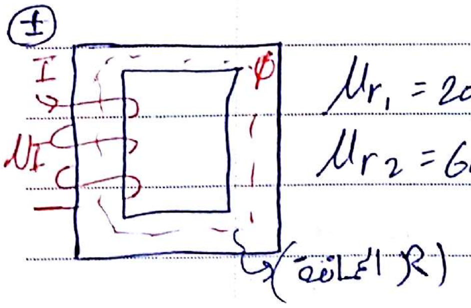
$$H = \frac{NI}{L} = \frac{F}{L}$$

$$B = \mu H = \frac{\mu F}{L}$$

$$\Phi = BA = \mu HA = \mu \frac{NI}{L} A = \mu \frac{F}{L} A = \frac{F}{(L/\mu A)} = \frac{F}{\mathcal{R}}$$

$$\mathcal{R} = \frac{l}{\mu A}$$

Reluctance ≡ measure of the opposition the magnetic circuit offer to flux



$\mu_{r_1} = 2000 \rightarrow \mathcal{R}\uparrow$ (bigger)

$\mu_{r_2} = 6000 \rightarrow \mathcal{R}\downarrow$ (smaller)

$$\downarrow \Phi = \frac{F}{\mathcal{R}\uparrow}$$

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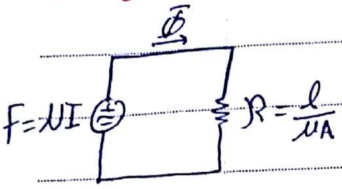
Magnetic circuit :-

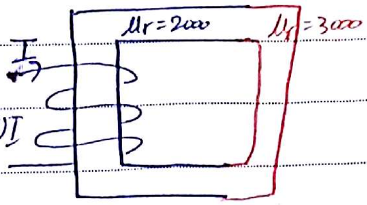


$H_1 \neq H_2$

$\Phi_1 = \Phi_2$ ⇒

$B_1 = B_2$

$A_1 = A_2$



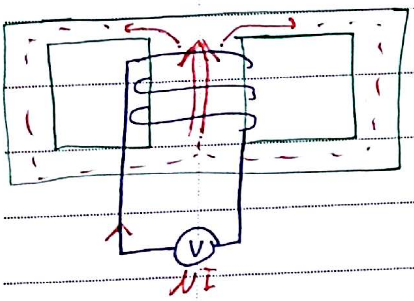
$F = \Phi [\mathcal{R}]$

$F = \Phi [\mathcal{R}_1 + \mathcal{R}_2]$

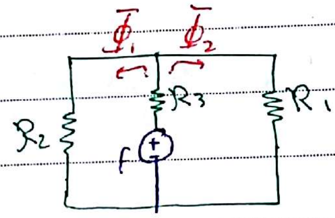
$\mathcal{R}_1 = \frac{l_1}{\mu_{r_1} \mu_0 A}$, $\mathcal{R}_2 = \frac{l_2}{\mu_{r_2} \mu_0 A}$

Reluctances in seires ⇒ $\mathcal{R}_{eq} = \mathcal{R}_1 + \mathcal{R}_2$

Reluctances in parallel ⇒ $\frac{1}{\mathcal{R}_{eq}} = \frac{1}{\mathcal{R}_1} + \frac{1}{\mathcal{R}_2}$

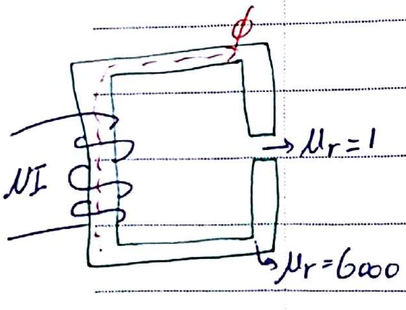


⇒

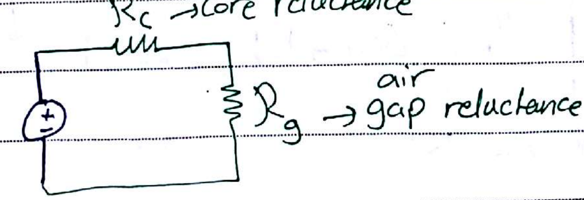


$\Phi = \Phi_1 + \Phi_2$

* Core with the Air gap



⇒



$\mathcal{R}_c = \frac{l_c}{\mu_r \mu_0 A_c}$ $\mathcal{R}_g = \frac{l_g}{\mu_0 A_g}$

$\Phi_c = \Phi_g$ $B_c = B_g$ $H_c \neq H_g$

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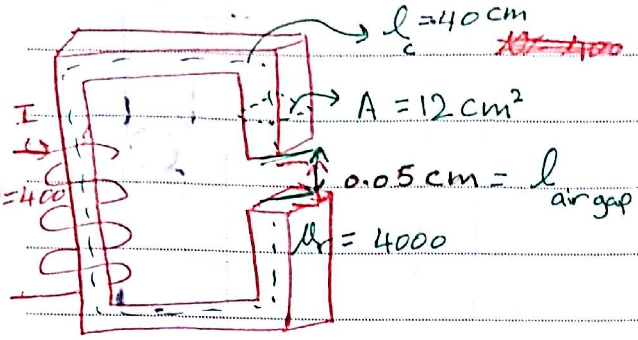
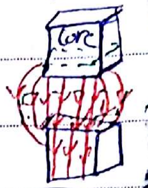
7/6/2017 ☺

Example 1.2 in the book :-



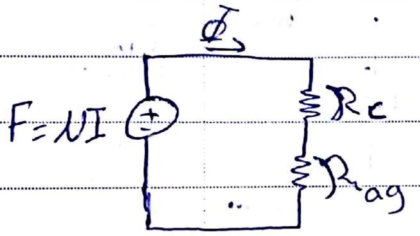
fringing : عندما يتحرك Φ في الcore وينتقل إلى airgap سيحدث انحناء في خطوط المجال عند الأطراف في محاولة للهروب فتزداد (A) في الairgap التي تمر فيها خطوط المجال



Assume fringing in air gap increases it's cross sectional area by 5%.

[1] Find the total reluctance of the system

– Convert it to it's equivalent electric circuit.



ⓐ $R_c = \dfrac{l_c}{\mu A_c} = \dfrac{40\times10^{-2}}{4000 * 4\pi\times10^{-7} * 12 * 10^{-4}}$

$R_c = 66300$ A. turns/wb → $R = \dfrac{F}{\Phi} = \dfrac{NI}{\Phi}$ $\dfrac{A.turns}{wb}$

ⓑ $R_{ag} = \dfrac{l_{ag}}{\mu_0 A_{ag}} = \dfrac{0.05\times10^{-2}}{4\pi\times10^{-7} * 12\times10^{-4} * 1.05} = 31600$ A.turns/wb

ⓒ $R_{eq} = R_c + R_{ag} = 382300$ A.turns/wb

[2] The current required to produce a flux density (B) of 0.5 Tesla in the gap.

$F = NI = \Phi R$

$I = \dfrac{\Phi R}{N} = \dfrac{BAR}{N} = \dfrac{0.5(12\times10^{-4} * 1.05) * 382300}{400} = 0.602$ A

(A → for the gap; R → equivalent)

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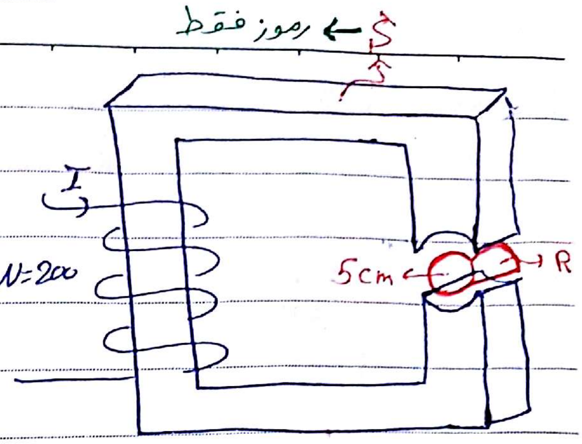


Example 1.3 :-

$l_{\xi} = 50$ cm $A_{\xi} = 12\ cm^2$ $\mu_{r\xi} = 2000$

$I = 1A$ $A_R = 12\ cm^2$ $\mu_{rR} = 2000$

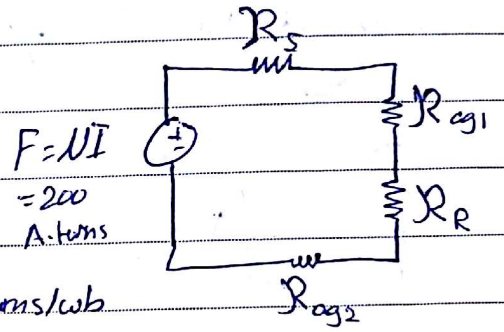
$l_{ag} = 0.05$ cm $A_{ag} = 14\ cm^2$

* note that there is two air gaps

Find flux density (B) in the air gap!

Solution :-

$F = \Phi \mathcal{R}$ → find R_{eq}



$$\mathcal{R}_\xi = \frac{l_\xi}{\mu A_\xi} = \frac{50\times10^{-2}}{2000*4\times10^{-7}*12*10^{-4}*\pi} = 166000 \text{ A.turns/wb}$$

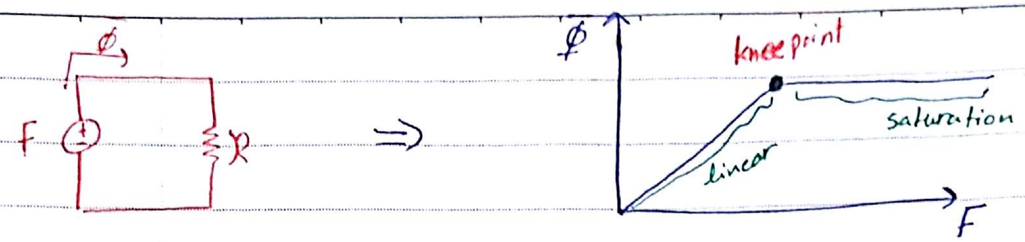
$$\mathcal{R}_R = \frac{5\times10^{-2}}{2000*4\pi\times10^{-7}*12\times10^{-4}} = 16600 \text{ A.turns/wb}$$

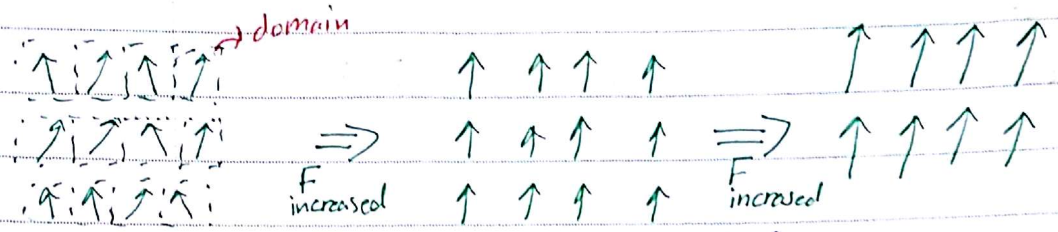
$$\mathcal{R}_{ag_1} = \frac{0.05\times10^{-2}}{4\pi*10^{-7}*14\times10^{-4}} = 284000 \text{ A.turns/wb} = \mathcal{R}_{ag_2}$$

$$R_{eq} = \mathcal{R}_\xi + \mathcal{R}_R + 2R_{ag_1} = 751000 \text{ A.turns/wb}$$

$$\Phi = \frac{F}{R_{eq}} = \frac{NI}{R_{eq}} = \frac{200*1}{751000} = 2.66*10^{-4} \text{ wb}$$

$$B_{ag} = \frac{\Phi}{A_{ag}} = \frac{2.66*10^{-4}}{14*10^{-4}} = 0.19\ T$$

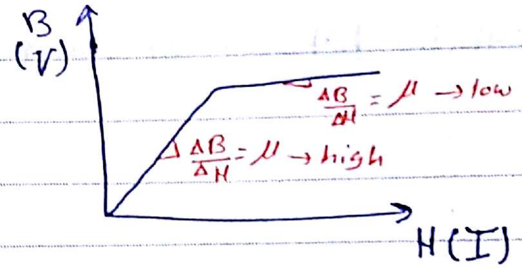




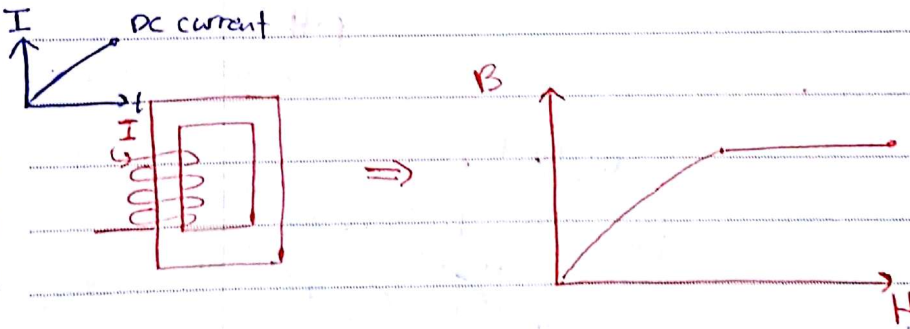
- عند كبر ما لن نؤثر زيادة F في ال domain لأننا لا نستطيع تجاوز الحدود الميكانيكية للعزل الإلكتروني

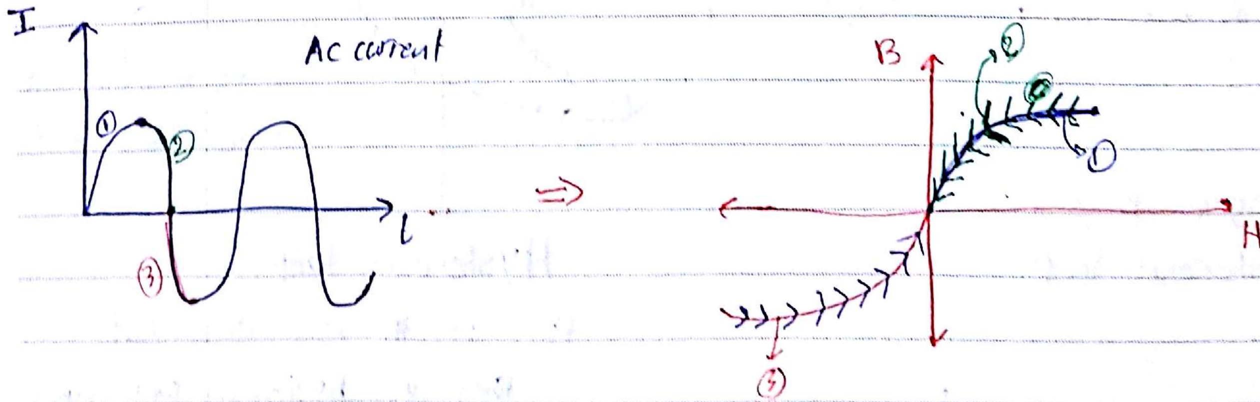
$\Phi = BA$ $\qquad \Phi \propto B$

$F = NI = Hl$ $\qquad F \propto H$ $\quad \Rightarrow$



Slope μ , μ is not constant





but actually this is not the case, the real case will be shown in next pages.

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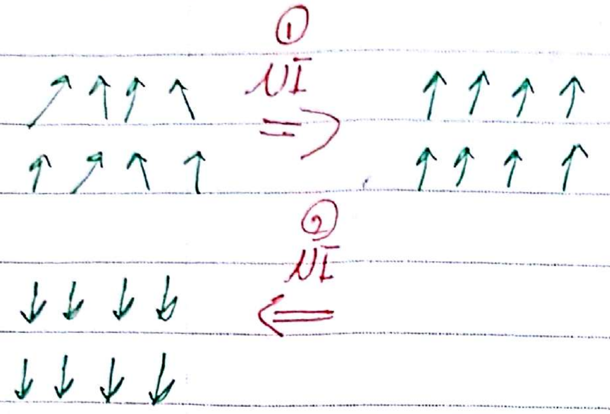
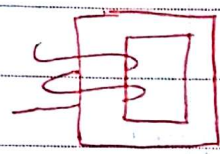
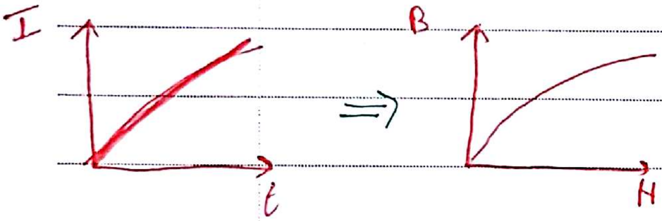
8/6/2017

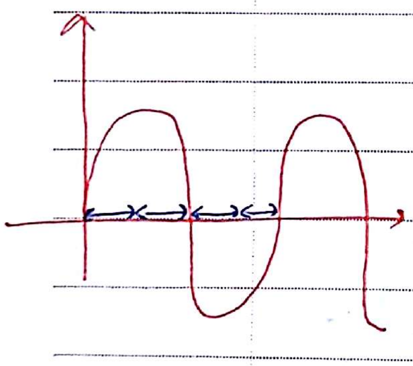


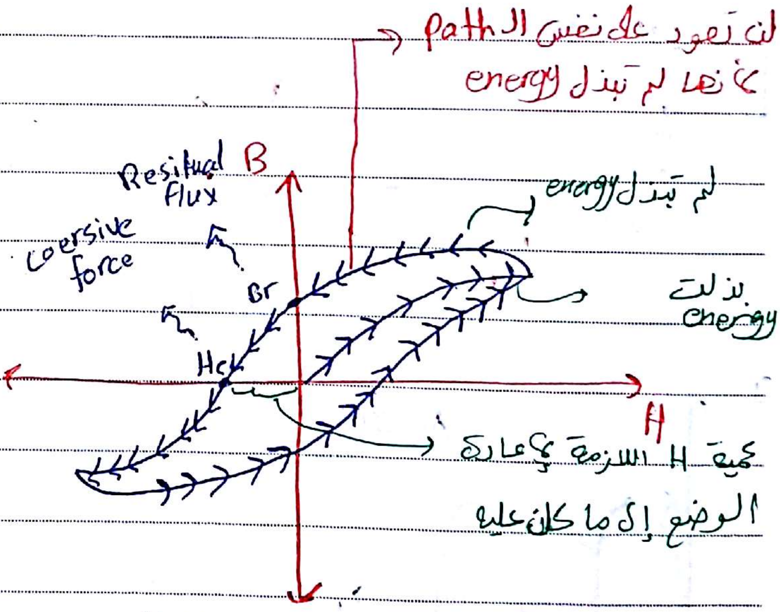
NI② > NI①

* Magnetic behavior of Ferromagnetic materials :-





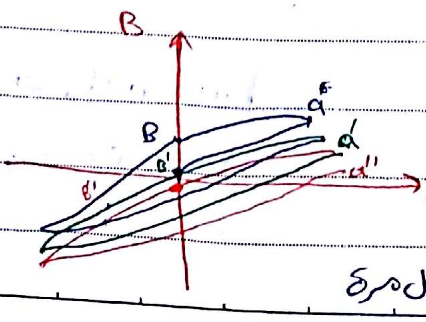




* في كل cycle سيتكون
Hysteresis loop

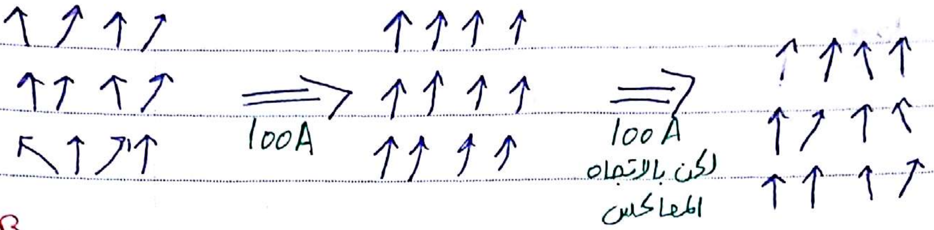
"Hysteresis loop"

this is the real case but they are hysteresis loops and we only consider one of them.

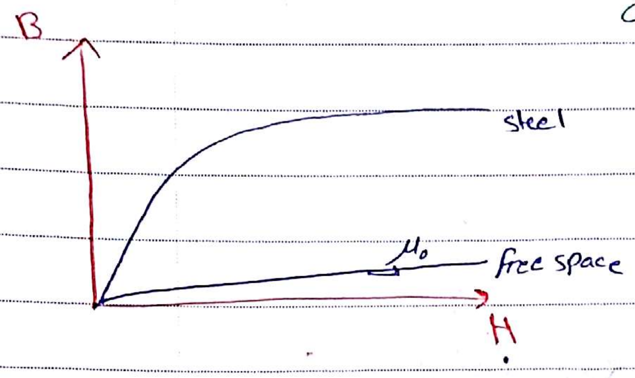


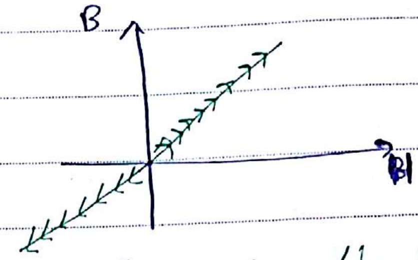
نفس مقدار التيار
لكن "B" تقل في كل مرة

No.

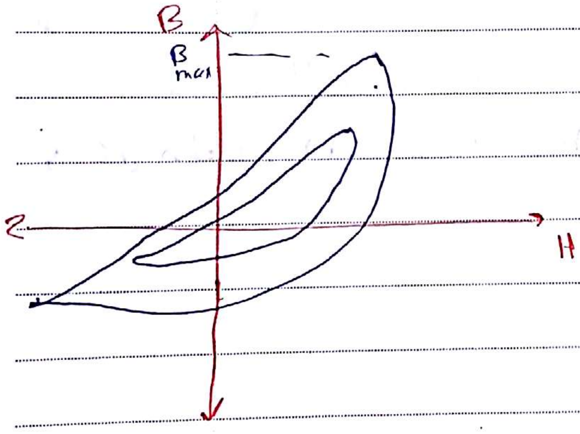


it didn't return exactly to it's original.





"there is No Hysteresis loop in free space"



تناسب طرديًا

* Area of the loop ∝ Hysteresis losses
* ↑B_{max} → ↑Area → ↑losses

* The amount of flux in any core depends on:-
1) The current applied
2) The previous history of the flux. "core قيمة ال flux الموجودة أصلاً بال"

* The dependence on the preceading Flux and failure to retrace same flux path is called (Hysteresis)

_ Hysteresis loss is the energy required to accomplish the reorientation of domains during each cycle of Ac current applied to the core.

هذه ال losses ستكون على شكل heat.

"loss ∝ Area ∝ B×H"
لا هو ضرب عادي

No.

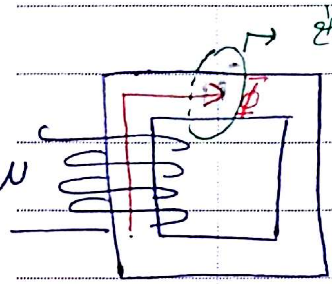
power loss in the loop

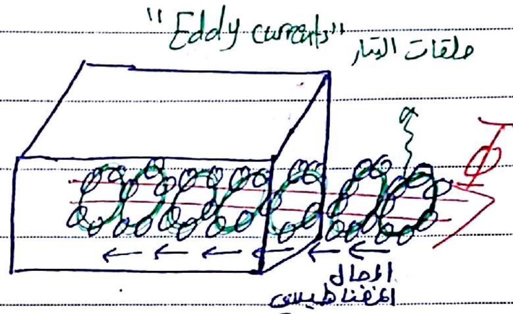
$P_n = k_n f \times B_{max}^n$ $1.5 \leq n \leq 2.5$

$n \equiv$ steinmetz exponent

k_n : depends on the material

f : frequancy





$e = -N \frac{d\phi}{dt}$

* ستكون e في ال core حسب مقاومتها الكهربائية مما يؤدي إلى ظهور تيار على شكل دوامات . "Eddy current"

* كل حلقة من التيار ستولد مجال مغناطيسي بالاتجاه المحدد في الرسمة .

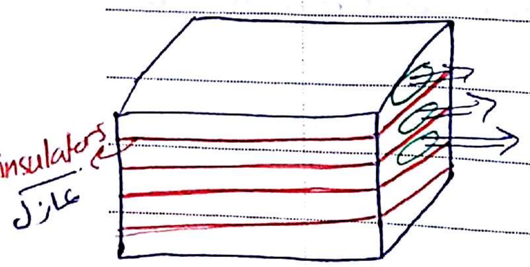
Solutions (fore Eddy currents) :-

① Reduce the core electric resistence

→ add silicon

$\downarrow R \Rightarrow \downarrow I^2 R$

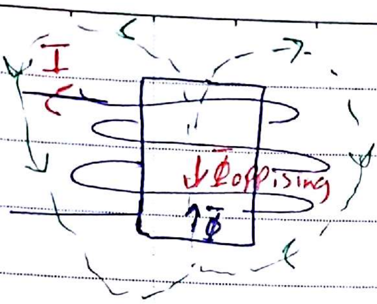
② lamination

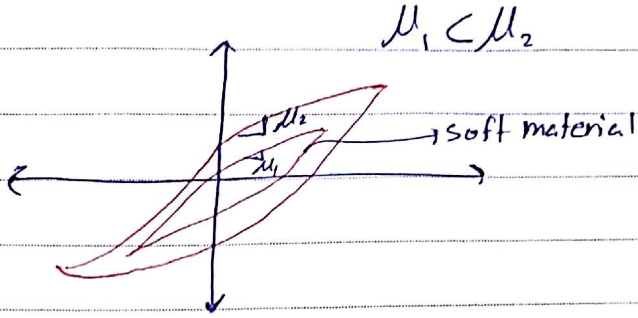


$P_e = k_e (f \, t \, B_{max})^2$

k_e → material constant; f → freq; t → thickness

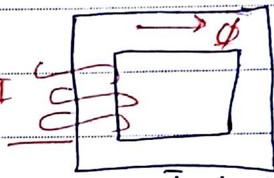
Eddy current losses is lower here.





*Self Inductance :-

$$V = e_{ind} = -N\frac{d\bar{\Phi}}{dt}$$



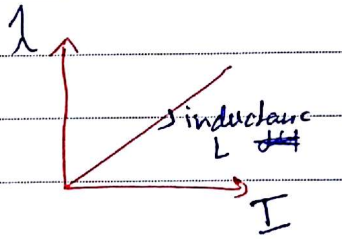
$$V = L\frac{di}{dt}$$

* كل لفة تتعرض ل $\bar{\Phi}$ ومجموعهم λ

$$\lambda = N\bar{\Phi}$$

↳ linkage flux

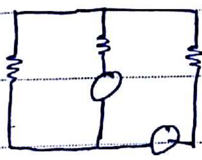
$$\lambda \propto I$$



$$\lambda = LI$$

$$L = \frac{\lambda}{I} = \frac{N\Phi}{I} = \frac{NBA}{I} = \frac{N\mu_o HA}{I} = \frac{N\mu \overset{H}{NI} A}{lI} = \frac{N^2}{l/\mu A} = \boxed{\frac{N^2}{\mathcal{R}}}$$

⟹



equ. electric circuit

Suggested problems :-

1.1, 1.5, 1.6, 1.7, 1.8, 1.9, 1.12, 1.13, 1.14, 1.15

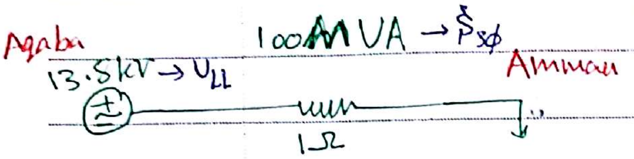
Chapman 5th edition

Chapter 2

* Transformers *

11/6/2017

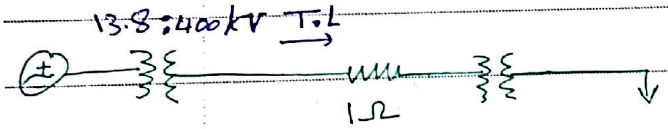
Transformer :- is a device that converts electric AC power from one voltage to another voltage at the same frequency.



$$I = \frac{100\,MVA}{\sqrt{3} * 13.8\,kV} = 4.18\,kA$$

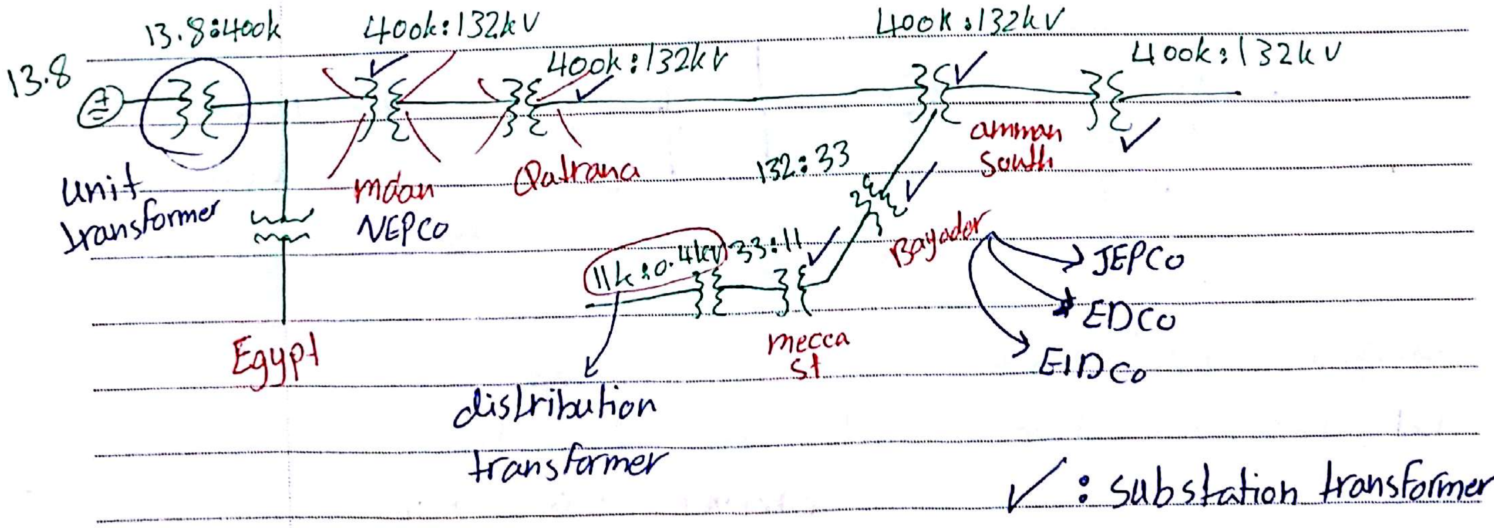
$$V_{load} = \frac{13.8}{\sqrt{3}} - 4.1(1) = 3.86\,kV$$

$$P_{losses} = (4.18)^2 * 10^6 * 1\ W$$



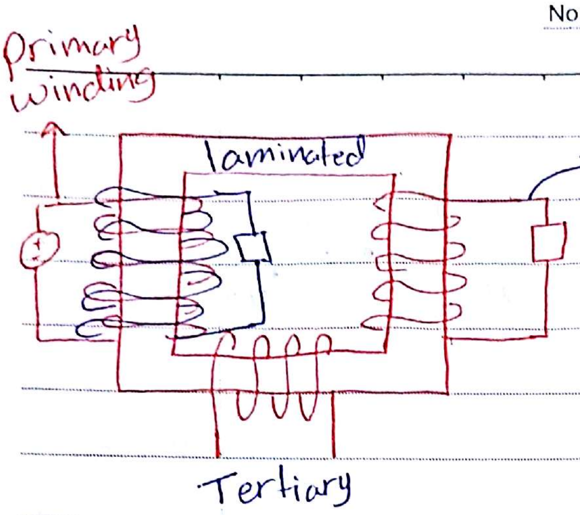
$$I = \frac{100\,MVA}{\sqrt{3} * 400000} = 144.3\ A$$

$$P_{losses} = (144.3)^2 * 1\ W \quad , \quad V_{load} = \frac{13.8}{\sqrt{3}} - 144.3$$



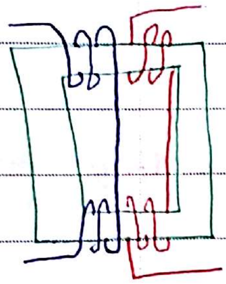
$0.4\,kV \rightarrow$ line to line voltage $= 220$ phase voltage

No.

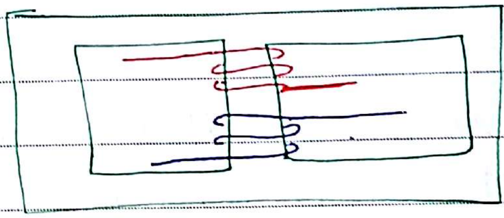


(we can put the secondary above the Primary). As long they are Isolated.

Transformer construction :-



"Core type"



"Shell type"

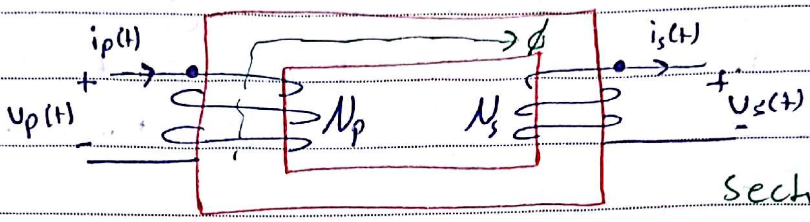
physics of the design :-

→ voltage levels
→ losses
→ material

pri & sec
→ They are wrapped on top of each other
→ low-voltage side is wrapped on the core and the high-voltage side is wrapped on top of it. why ;
[1] less leakage current.
[2] isolate the high voltage from the core (because spark can happen).

No.

– Ideal Transformer :-



larger cross sectional Area because it needs to hold large current

$$\frac{V_p(t)}{V_s(t)} = \frac{N_p}{N_s} = a$$

$$\frac{i_s(t)}{i_p(t)} = \frac{N_p}{N_s} = a$$

$$\frac{V_p}{V_s} = a \quad , \quad \frac{I_s}{I_p} = a$$

⟹ There is No phase shift between the primary voltage and Secondary voltage, same for current.

⟹ The power supplied by the primary : $P_{in} = V_p I_p \cos\theta_p$

⟹ The output power on the secondary : $P_{out} = V_s I_s \cos\theta_s$

$$\theta_p = \theta_s = \theta$$

* load determins θ, always.

No.

12/6/2017

$P_p = V_p I_p \cos\theta_p$

$P_s = V_s I_s \cos\theta_s$

$\theta_s = \theta_p = \theta$ (pf angle)

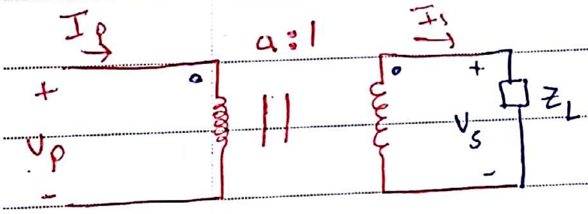
$P_s = P_p$

$Q_s = Q_p = VI \sin\theta$

$= V_s I_s \sin\theta_s$

$= V_p I_p \sin\theta_p$

$S_s = S_p = V_p I_p^* = V_s I_s^*$

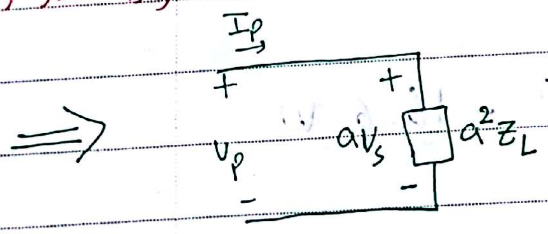


$Z_L = \frac{V_s}{I_s}$ → load

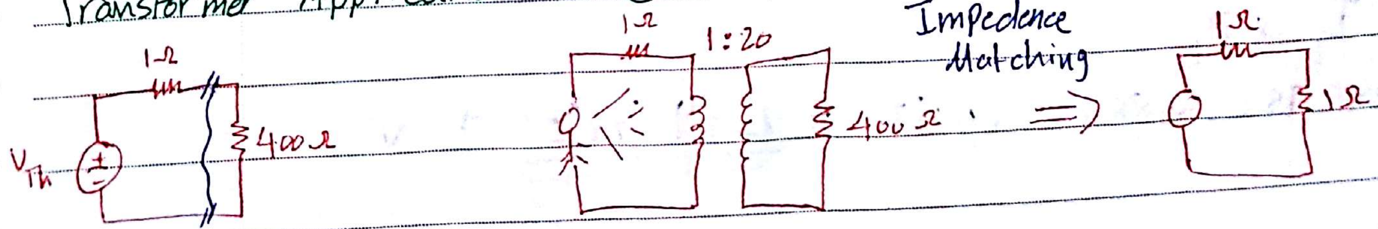
$Z_L' = \frac{V_p}{I_p} = \frac{a V_s}{I_s / a} = a^2 \frac{V_s}{I_s} = \boxed{a^2 Z_L}$

↓

as seen by the source

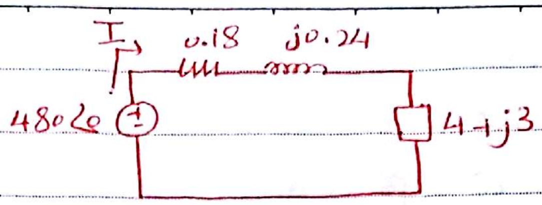


Transformer Application in ckts (2) :-



Example 2.1 :-

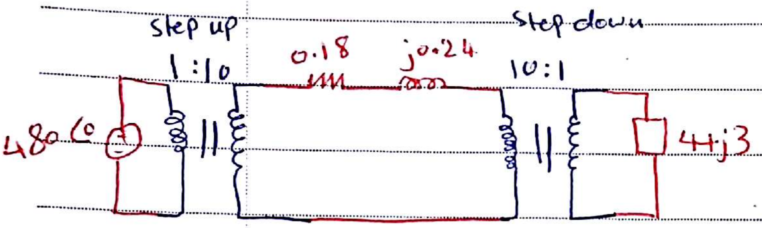
⇒ Find V_L, $P_{TL\ losses}$



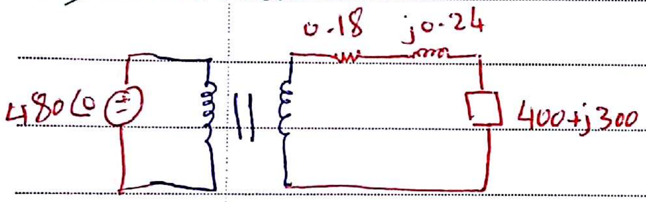
$$I = \frac{480\angle 0}{4.18 + j3.24} = 90.8\ \angle -37.8^\circ\ A$$

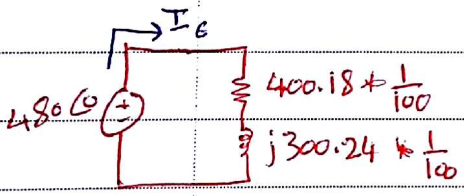
$$V_L = I(4+j3) = 454\ \angle -0.9$$

$$P_{TL\ losses} = (90.8)^2 * 0.18 = 1484\,W$$



→ Reflection





$$= 5.003\ \angle 36.88$$

$$I_G = \frac{480}{5.003\angle 36.88} = 95.95\ \angle -36.88$$

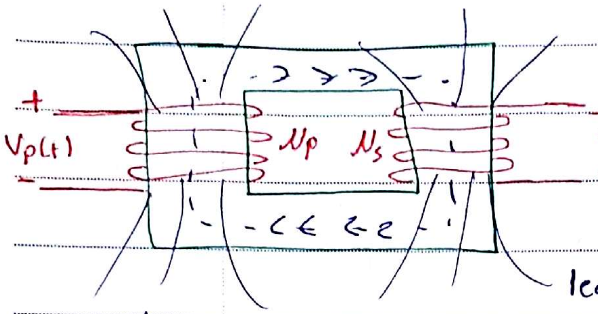
$$P_{TL\ losses} = (0.18)\left(\frac{I_G}{a}\right)^2 = 0.18(9.595)^2 = 16.6\ W$$

$$\rightarrow I_{T.L} = I_G * \frac{1}{10} = 9.595\angle -36.88 \uparrow$$

$$V_L = I_L * Z_L$$

$$= (95.95\angle -36.88) * (4+j3) = 479.7\angle -0.01\ V$$

Real Transformer :-



$$\lambda = \sum_{i=1}^{N} \bar{\Phi}_c \quad , \quad e_{ind} = \frac{d\lambda}{dt}$$

$$\bar{\Phi} = \frac{\lambda}{N} \qquad e_{ind} = N\frac{d\bar{\Phi}}{dt}$$

$$\bar{\Phi} = \frac{1}{N}\int v(t)\,dt$$

$$= \frac{1}{N_p}\int V_p(t)\,dt = \frac{1}{N_s}\int V_s(t)\,dt$$

$$\bar{\Phi}_p = \bar{\Phi}_m + \bar{\Phi}_{Lp} \quad , \quad \bar{\Phi}_s = \bar{\Phi}_m + \bar{\Phi}_{Ls}$$

$\Rightarrow$ $V_p(t) = N_p * \frac{d\bar{\Phi}_p}{dt}$

$$= N_p\left[\frac{d\bar{\Phi}_m}{dt} + \frac{d\bar{\Phi}_{Lp}}{dt}\right]$$

$$= N_p\frac{d\bar{\Phi}_m}{dt} + N_p\frac{d\bar{\Phi}_{Lp}}{dt}$$

$$= e_p(t) + e_{Lp}(t)$$

$\Rightarrow$ $V_s(t) = N_s * \frac{d\bar{\Phi}_s}{dt}$

$$= N_s\frac{d\bar{\Phi}_m}{dt} + N_s\frac{d\bar{\Phi}_{Ls}}{dt}$$

$$= e_s(t) + e_{Ls}(t)$$

$e_s(t) = N_s \frac{d\phi_m}{dt}$

$e_p(t) = N_p \frac{d\phi_m}{dt}$

$\frac{e_p(t)}{e_s(t)} = \frac{N_p}{N_s} \neq \frac{V_p}{V_s}$ (because of e_{sL} and e_{pL})

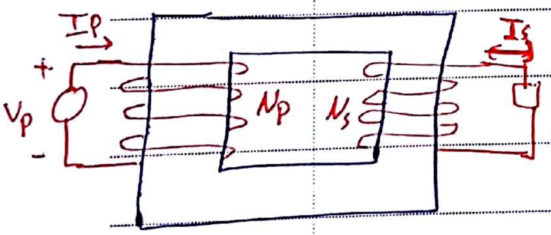
⇒ As μ ↑↑ and for well-designed transformers

$\Phi_m \ggg \Phi_{Lp}$, $\Phi_m \ggg \Phi_{Ls}$

$\frac{e_p(t)}{e_s(t)} \cong \frac{V_p(t)}{V_s(t)} \cong a$ turns ratio

* leakage secondary depend on i_s and $V_s(t)$

The excitation current in a real transformers :-



$\frac{V_p}{V_s} = a$ $\frac{I_s}{I_p} = a$

⇒ At No load , $I_p \neq 0$

مركبتين
→ magnetizing flux I_m
→ to back up Hysteresis and eddy currents

$I_p = I_s + I_{N.L}$

I_e (exitation current) $= I_m + I_{h+e}$

$I_e \longrightarrow I_m$

$I_e \longrightarrow I_{h+e}$ hysteresis and eddy current losses backup

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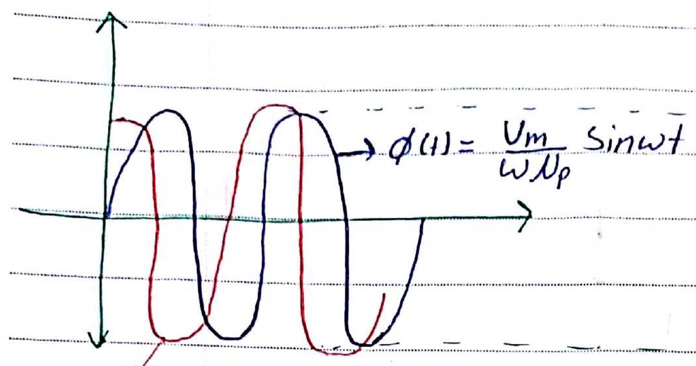
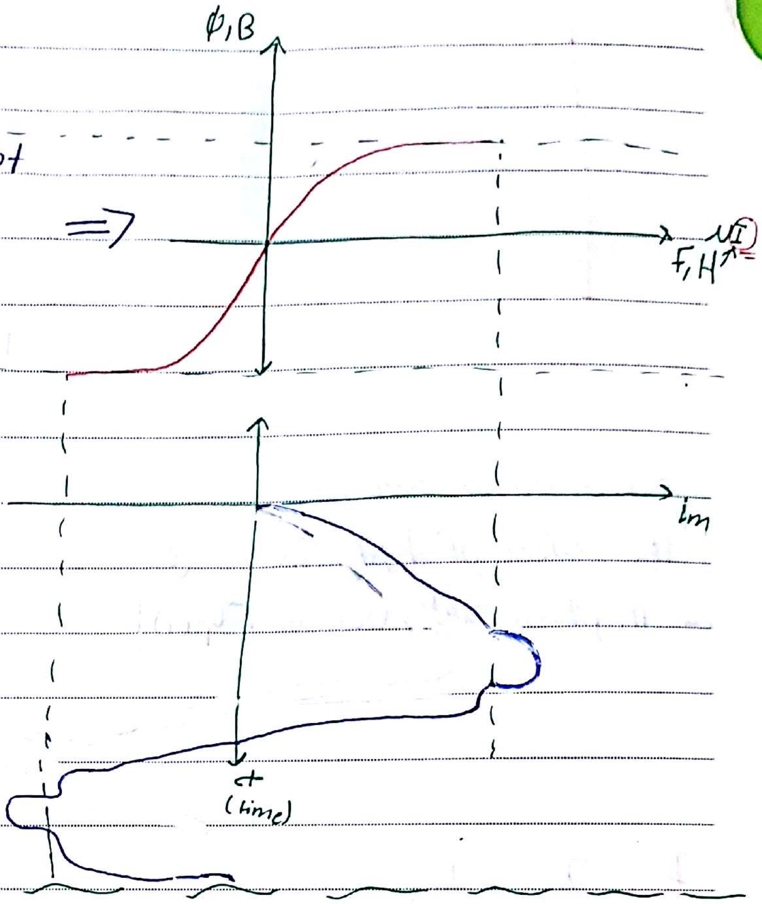
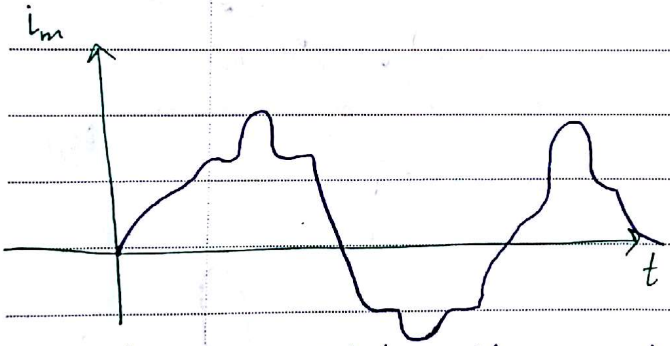


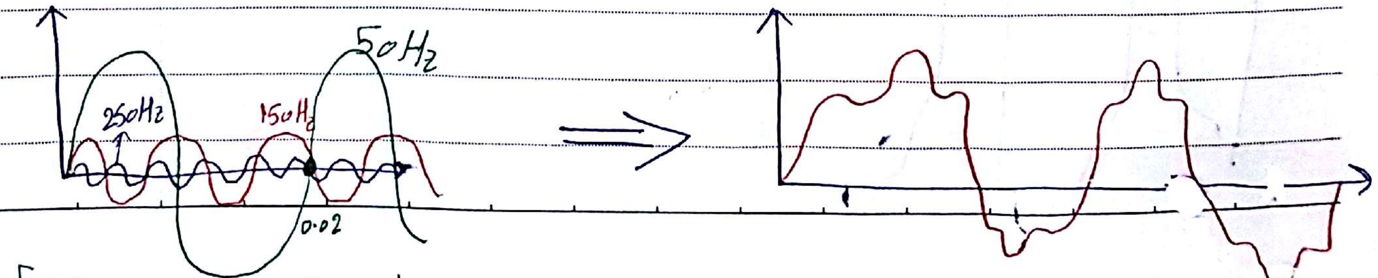
$V_p(t) = V_m \cos\omega t$

$V_m = -N \frac{d\phi}{dt}$





- not sinusoidal, there are high frequency components. because of saturation
- when saturation is reached, small increase in flux requires large increasing in current
- I_m [it's fundamental component] lags the voltage by 90°.
- high frequancy components of I_m may be large in saturation.



Frequency Components

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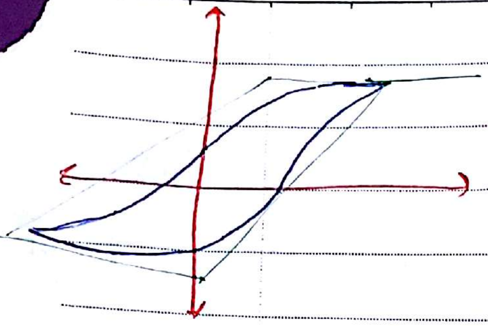
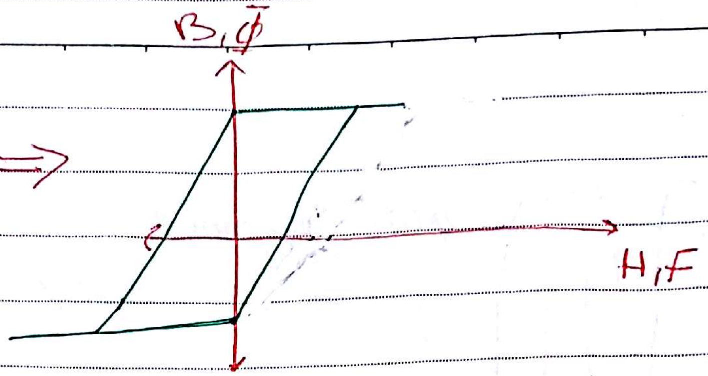
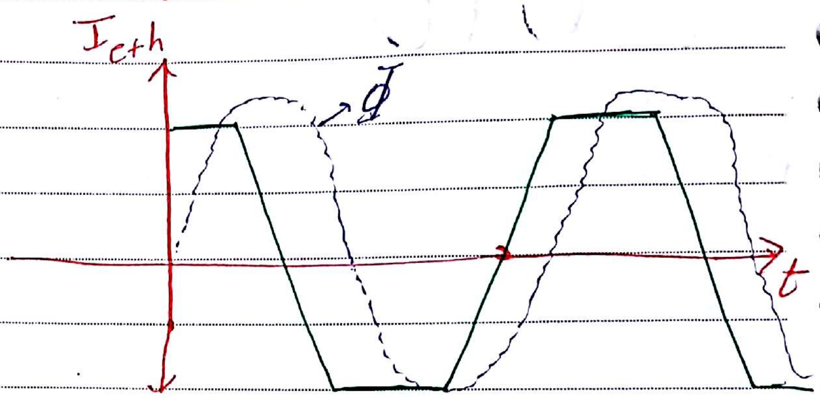


$\Rightarrow$



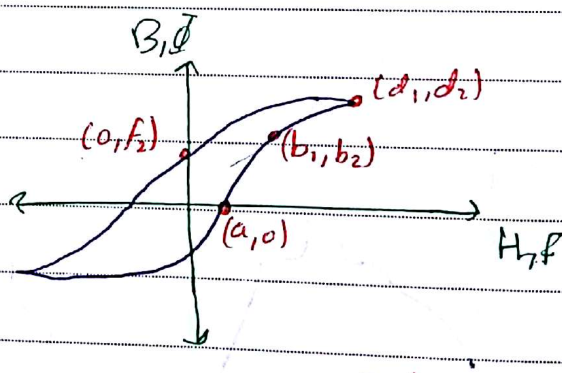


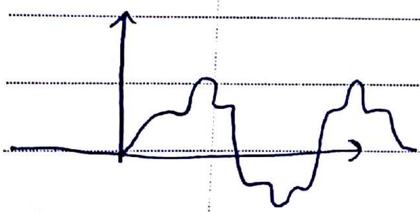
→ non-linear due to the effect of hysteresis ⇐

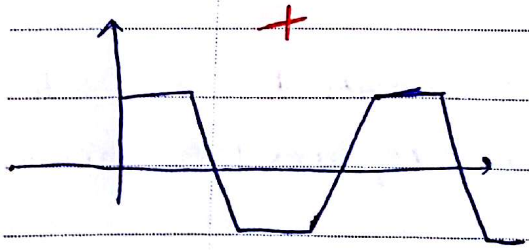
→ in phase with voltage $[v_p(t)]$

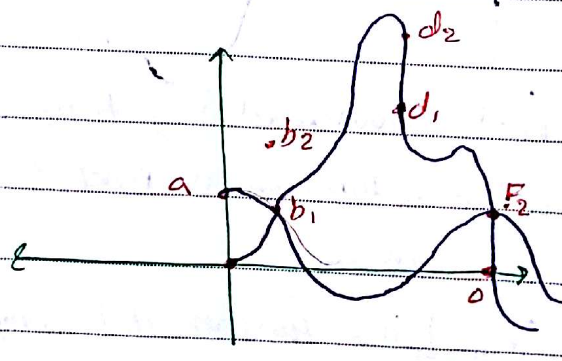
$$\nabla \times E = -\frac{\partial B}{\partial t}$$

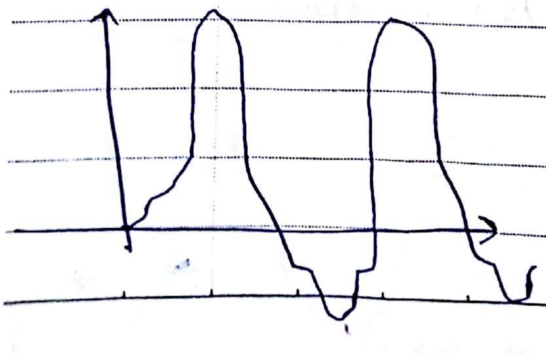
$$I_e = I_m + I_{n+h}$$





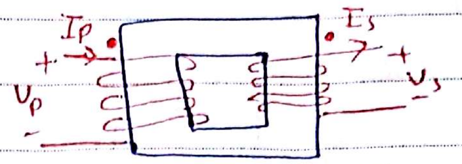






real transformer :-

$$\frac{e_p(t)}{e_s(t)} \cong \frac{V_p(t)}{V_s(t)} \cong a$$



$F_p = N_p I_p \qquad F_s = N_s I_s$

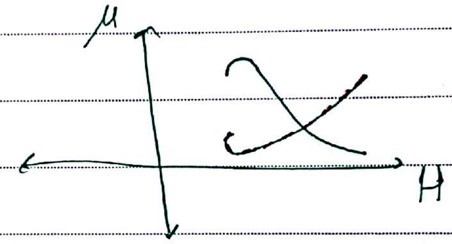
net flux in the core :-

$$F_{net} = N_p I_p - N_s I_s = R\phi$$

→ for a well-designed transformer that works in the linear region

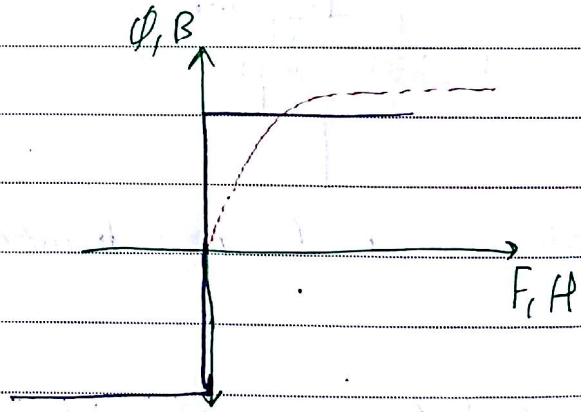
$$\Re \cong 0 \implies F_{net} = N_p I_p - N_s I_s = 0$$

$$\frac{N_p}{N_s} \cong \frac{I_s}{I_p} \cong a$$

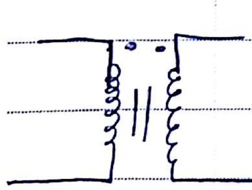


Ideal transformer :-

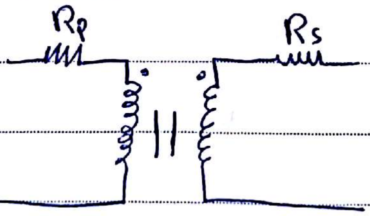
→ no core losses [no I_{h+e}].
→ leakage flux is zero.
→ the wires resistance is zero.
→ the B-H curve is ⟹



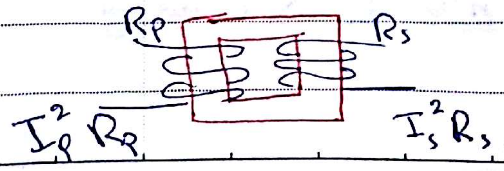
"Ideal"



"Real"



* we need a small value of (I) to get a high flux. (constant flux)



↳ full real transformer in the next page.

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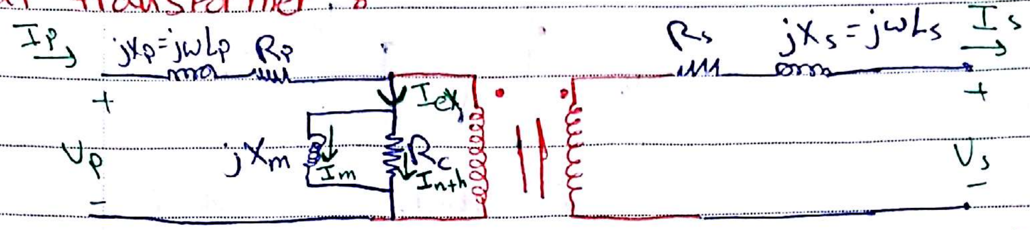
* real transformer :-



"X_p, X_s" → Flux leakage losses

"X_m, R_c" → core losses

"R_p, R_s" → copper losses

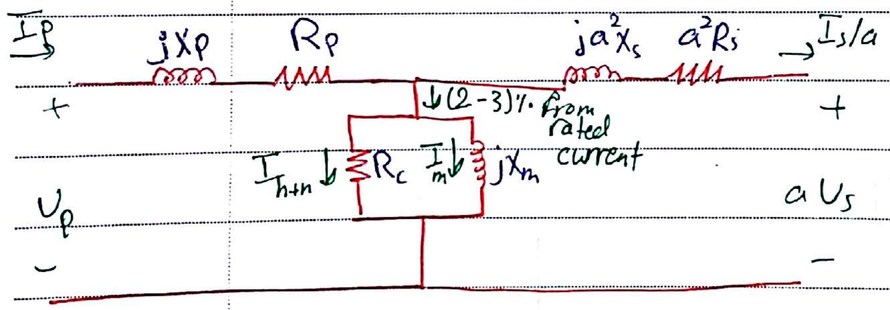
R_c $\xrightarrow{\text{تمثل}}$ eddy currents and hysteresis losses.

$$\Phi_p = \Phi_m + \Phi_{Lp}$$

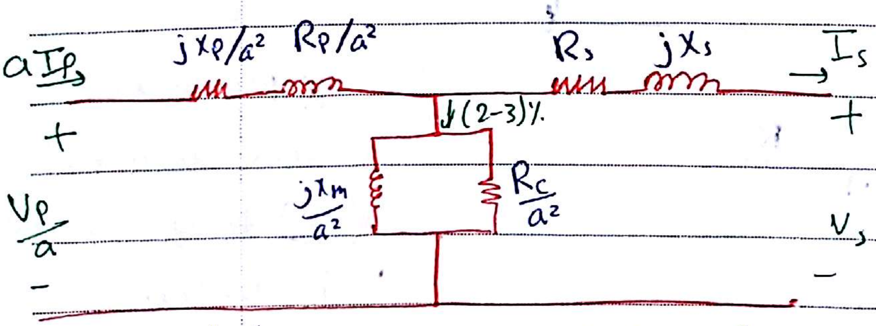
$$e_{Lp}(t) = -N_p \frac{d\Phi_{Lp}}{dt} = -N_p \frac{d}{dt}\left(\frac{N_p I_p}{\mathcal{R}}\right) = \underbrace{\frac{N_p^2}{\mathcal{R}}}_{L_p} \frac{di_p}{dt} = \boxed{L_p \frac{di_p}{dt}}$$

$$\Phi_p = \frac{N_p I_p}{\mathcal{R}_p}$$

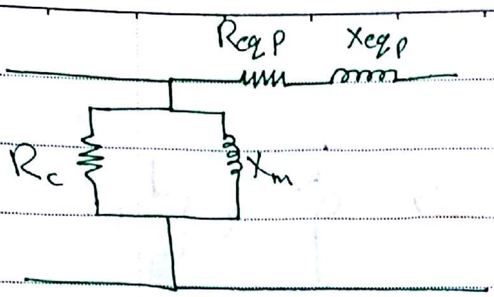
Same for Secondary



equivalent circuit of a real transformer referred to primary.



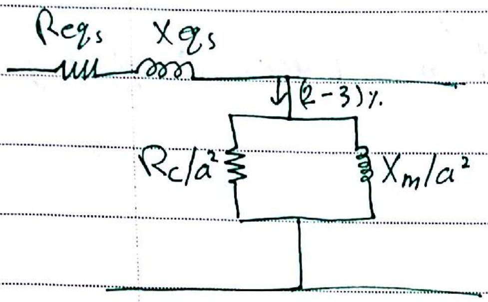
equivalent circuit of real transformer referred to secondary.



$$R_{eq_p} = R_p + a^2 R_s$$

$$X_{eq_p} = X_p + a^2 X_s$$

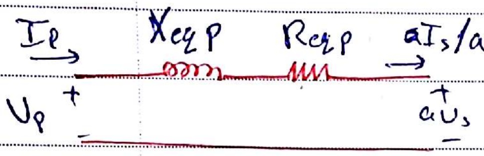
"referred to primary"

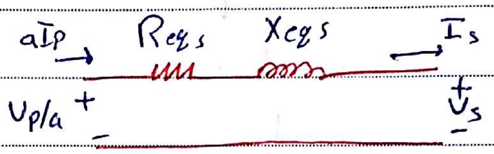


$$R_{eq_s} = R_s + R_p/a^2$$

$$X_{eq_s} = X_s + X_p/a^2$$

"referred to secondary"



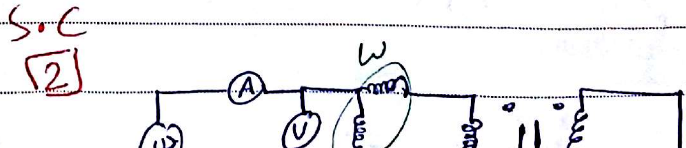


primary

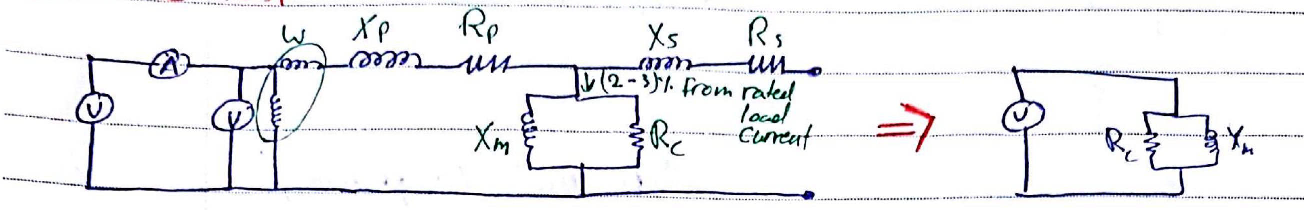
* In the lab, you have a real transformer and you're required to find it's equivalent circuit.

1. O.C test :- apply rated voltage at on side and keep the other side open.

2. Short.ck test :- apply very small amount of voltage on one side and short ckt the other side.



[1] O.C test



* Xp, Rp were neglected because they are very small values comparing with Rc, Xm

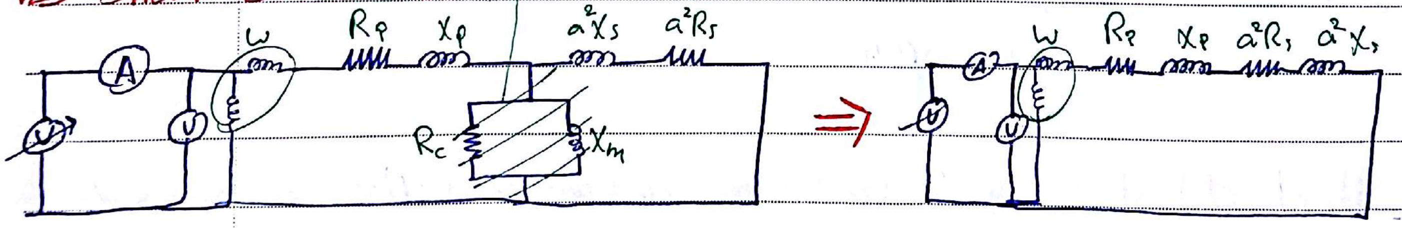
$$|Y_E| = \frac{I_{o.c}}{V_{o.c}} = |G_c - jB_m|$$

- $|Y_E|$ → excitation admittance
- G_c → Conductance $= \frac{1}{R_c}$
- B_m → susceptance $= \frac{1}{X_m}$

$$\cos\theta = p.f = \frac{P_{o.c}}{V_{o.c}\,I_{o.c}} \Longrightarrow Y_E = \frac{I_{o.c}}{V_{o.c}} \angle -\theta$$

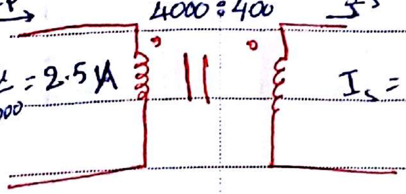
[2] Short circuit test

→ only (2-3)% from the load rated current will enter so Rc, Xm will be neglected.



$$|Z_{SE}| = \frac{V_{s.c}}{I_{s.c}}, \quad p.f = \cos\theta = \frac{P_{s.c}}{V_{s.c}\,I_{s.c}}, \quad Z_{SE} = \frac{V_{s.c}}{I_{s.c}} \angle\theta$$

Z_{SE} → series elements



$I_p = \frac{10k}{4000} = 2.5A$

$I_s = \frac{10k}{400} = 25A$

* preferred sid for the **Short ckt** test is the high voltage Side.
* preferred side for the **open** ckt test is the low voltage side.

No.

15/6/2017

ex:- determine the eq ckt impedances referred to primary of a 20 kVA 8000/240 V, 60 Hz, the o.c and s.c test results :-

O.C [Secondary]	S.C [primary]
$V_{oc} = 240$ V	$V_{sc} = 489$ V
$I_{oc} = 7.133$ A	$I_{sc} = 2.5$ A
$P_{oc} = 400$ W	$P_{sc} = 240$ W

Solution :-

1) o.c test ⇒

$$Y_E = \frac{I_{o.c}}{V_{o.c}} \angle -\cos^{-1}\left(\frac{P_{o.c}}{I_{o.c} V_{o.c}}\right)$$

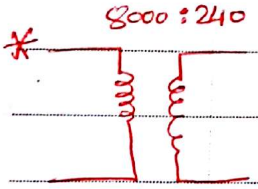
$$= \frac{7.133}{240} \angle -\cos^{-1}(0.234)$$

$$= \underbrace{0.00693}_{G_c} - j\underbrace{0.02888}_{B_m}$$

⇒ referred to secondary

$$R_c = \frac{1}{G_c} = \frac{1}{0.00693} = 144\ \Omega, \quad R_{c(pri)} = 144 * a^2 = 159\ k$$

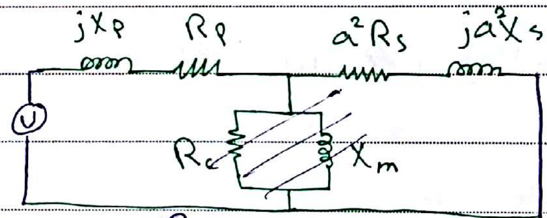
$$X_m = \frac{1}{B_m} = \frac{1}{0.02888} = 34.63\ \Omega$$



$$a = \frac{8000}{240}$$

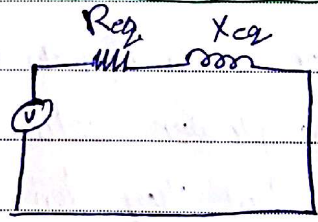
$$X_{m(pri)} = 38.3\ k\Omega$$

2) S.c test ⇒

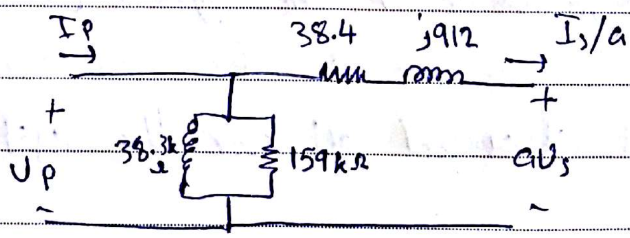


$$Z_{SE} = \frac{V_{sc}}{I_{sc}} \angle \cos^{-1}\left(\frac{P_{sc}}{V_{sc} I_{sc}}\right)$$

$$= \frac{489}{2.5} \angle \cos^{-1}\left(\frac{240}{489 * 2.5}\right)$$



$$= \underbrace{38.4}_{R_{eq}} + j\underbrace{912}_{X_{eq}}\ \Omega$$



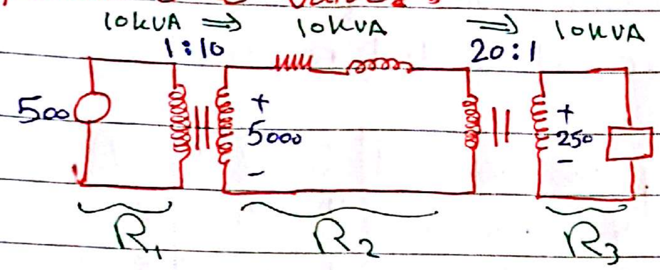
$$R_{eq} = 38.4 = R_p + a^2 R_s$$

$$X_{eq} = 192 = X_p + a^2 X_s$$

✱ End of first material ✱

No.

Power base values :-



base value ⇒	600	5000	200

→ $V_{p.u} = \frac{250}{200} = 1.25\ p.u$

$V_{p.u} = \frac{V_{real}}{V_{base}} = \frac{500}{600} = 0.83\ p.u$

↙ perunit

→ $V_{p.u} = 1\ p.u$

$$\text{Quantity in p.u} = \frac{\text{actual quantity}}{\text{base value quantity}}$$

base value power → 10 kVA

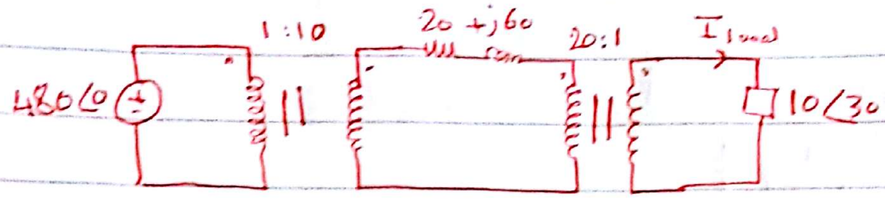
* In the perunit system the voltages, powers, currents are measured as decimal fractions of some base level instead of convention values :-

usually for each region in a system we choose a base voltage value and a base power value. Since the transformers change the voltage ~~value~~ level but they don't change the power level. The base voltage value of the system changes from region to another [based on transformer's turn ratio] but, the base power isn't changed all over the system.

No.

18/6/2017

ex 2.3 :-



choose base voltage of generator side = 480 & base power 10 KVA

R1 | R2 | R3

R1:

$V_{base} = 480\ v$

$S_{base} = 10kVA$

$I_{base} = \frac{S_{base}}{V_{base}} = 20.83A$

$Z_{base} = I_{base} V_{base} = 23.04\ \Omega$

R2:

$V_{base} = \frac{1}{a} * 480 = 4800v$

$S_{base} = 10kVA$

$I_b = 2.083A$

$Z_b = 2304\ \Omega$

R3:

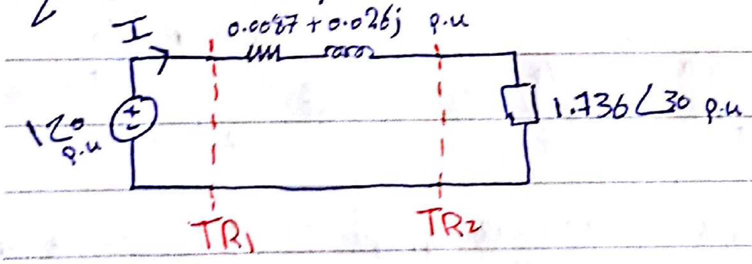
$V_{base} = 240v$

$S_{base} = 10kVA$

$I_{base} = 41.67\ A$

$Z_{base} = 5.76\ \Omega$

eq ckt :- (perunit ckt)



$I_{p.u} = \frac{1\angle 0}{(1.736\angle 30) + (0.0087 + 0.026j)} = 0.569\angle -30.6$

$P_{load}\ (p.u) = I_{pu}^2 * R_{pu} = 0.4867\ pu$

$P_{losses}\ (pu) = I_{pu}^2 * R_{T.L} = 0.00282\ pu$

$V_L(pu) = Z_{pu} * I_{pu} = 0.988\angle -0.6\ pu$

In watt :-

$P_{load} = P_{pu} * P_{base} = 4867\ kw$

$P_{loss} = 0.00282 * 10k = 28.2\ W$

$V_L = 0.988 * 240 = 237.12\angle -0.6$

No.

Voltage Regulation :-

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

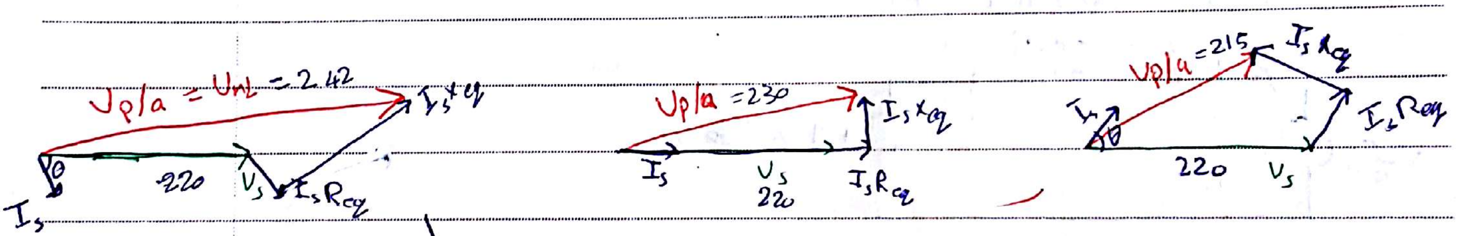
↓ measure for Voltage drop

ex :- $V_{s,nL} = 220$ $V_{s,fL} = 203$

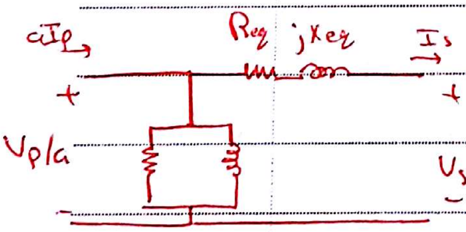
$$VR = \frac{220-203}{203} * 100\% = 8.37\%$$

* VR for diffrent p.f ⟹

lagging p.f — unity p.f — leading p.f



$\frac{242-220}{220} = 10\%$ $\frac{230-220}{220} = 4.54\%$ $\frac{215-220}{220} = -2.27\%$



$$V_p/a = V_s + R_{eq} I_s + jX_{eq} I_s$$

$$V_s = V_p/a - R_{eq} I_s - jX_{eq} I_s$$

No.

19/6/2017

efficiency :- $\eta = \frac{P_{out}}{P_{in}} \times 100\%$

$$\eta = \frac{P_{out}}{P_{out} + P_{losses}} \times 100\%$$

$$\eta = \frac{P_{out}}{P_{out} + P_{cu} + P_{core}} \times 100\%$$

$P_{cu} \rightarrow P_{s.c}$, $P_{core} \rightarrow P_{o.c}$

$$\eta = \frac{V_s I_s \cos\theta_s}{V_s I_s \cos\theta_s + P_{cu} + P_{core}} \times 100\%$$

ex :- 15kVA , 2300/230 V transformer was tested by o.c & s.c tests and the transformer data is obtained :-

o.c (high volt side)	s.c (high voltage side)
$V_{o.c} = 2300V$	$V_{sc} = 47V$
$I_{o.c} = 0.21A$	$I_{sc} = 6A$
$P_{o.c} = 50W$	$P_{sc} = 160W$

(a) Find the equivalent ckt referred to primary and to secondary.

$$Y_E = \frac{I_{o.c}}{V_{o.c}} \angle -\cos^{-1}\frac{P_{o.c}}{I_{o.c}V_{o.c}} = \frac{0.21}{2300}\angle -\cos^{-1}\left(\frac{50}{0.21 \times 2300}\right)$$

$$= 0.0000095 - j0.0000908$$

$R_c = 103k\Omega$ $X_m = 11k\Omega$

$$Z_{SE} = \frac{V_{sc}}{I_{sc}} \angle \cos^{-1}\left(\frac{P_{s.c}}{I_{s.c}V_{s.c}}\right)$$

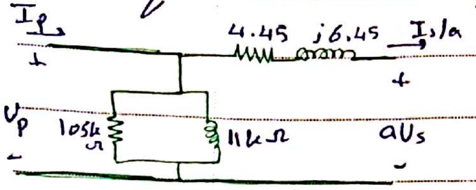
$$= \frac{47}{6} \angle \cos^{-1}\frac{60}{47 \times 6} = 4.45 + j6.45\,\Omega$$

$R_{eq} = 4.45\Omega$ $X_{eq} = j6.45\Omega$

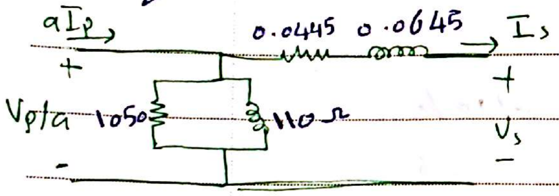
No.

the eq ckt referred to primary :-

$\frac{2300}{230} = a = 10$



the eq ckt referred to secondary :-



b find voltage regulation at rated load with pf = 0.8 lagging , pf = 1 , pf = 0.8 leading

0.8 lagging

$I_{rated} = \frac{S_{rated}}{V_s}$

$= \frac{15000}{230}$

$= 65.2\ A$

$I_s = 65.2 \angle -36.87$

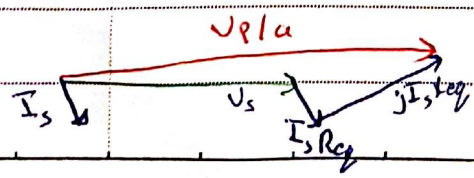
$\frac{V_p}{a} = 230 + (0.045 + j0.0645) * 65.2 \angle -36.9$

$= 234.85 \angle 0.4°$

$VR = \frac{|V_{p/a}| - |V_s|}{|V_s|} * 100\%$

$= \frac{234.85 - 230}{230} = 2.1\%$

=



pf = 1

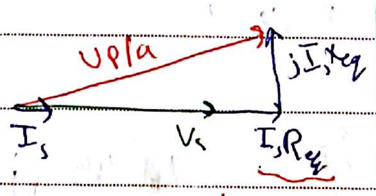
$I_{rated} = 65.2$

$I_s = 65.2 \angle 0°$

$V_p/a = 230 + 65.2 \angle 0 (0.045 + j0.0645)$

$= 232.94 \angle 1.04$

$VR = \frac{232.94 - 230}{230} = 1.28\%$



$65.2\angle 0 * 0.0445$

0.8 leading

$I_{rated} = 65.2$

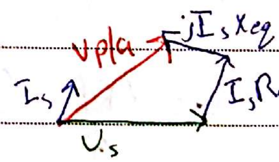
$I_s = 65.2 \angle 36.87$

$V_p/a = 230\angle 0 + 65.2 \angle 36.87 * (0.0445 + j0.0645)$

$= 229.85 \angle 1.27$

$VR = \frac{229.85 - 230}{230}$

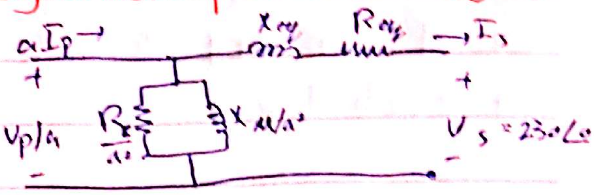
$= -0.062\%$



No.

c) Find the transformer efficiency when pf = 0.8 lagging

$$\eta = \frac{V_s I_s \cos\theta_s}{V_s I_s \cos\theta_s + P_{core} + P_{cu}}$$



$I_s = 65.2 \angle -36.87$

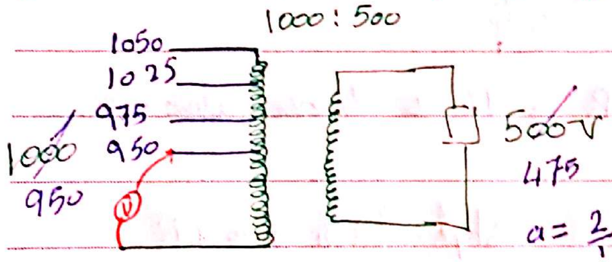
$\rightarrow P_{out} = V_s I_s \cos\theta_s = 230 * 65.2 * \cos(36.87)$
$= 12k\,W$

$\rightarrow P_{cu} = |I_s|^2 R_{eq} = (65.2)^2 * 0.0445 = 189\,W$

$\rightarrow P_{core} = \frac{(V_p/a)^2}{R_c/a^2} = \frac{(234.85)^2}{1050} = 52.5$

$$\eta = \frac{12000}{12000+189+52.5} = 98.03\%$$

1000 : 500



$a = \frac{2}{1}$

$a = 2$, $\frac{950}{2} = 457$

$a' = \frac{950}{500} = 1.9 \longrightarrow \frac{950}{1.9} = 500$

No.

20/6/2017

ex: 500 kVA, 13200/480 V transformer has four 2.5% taps on it's primary winding. what are the transformer voltage ratios at each tap:

5% tap 13860 : 480

2.5% tap 13530 : 480

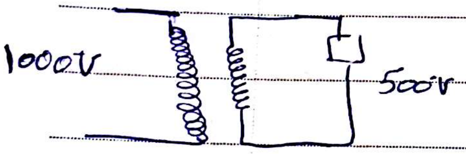
→ 13200 : 480

−2.5% tap 12870 : 480

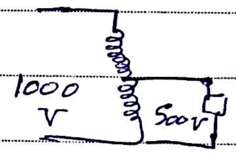
−5% tap 12540 : 480

ULTC: under load tap changer (Automatic change of tap while the transformer is in service)

The auto transformer:-

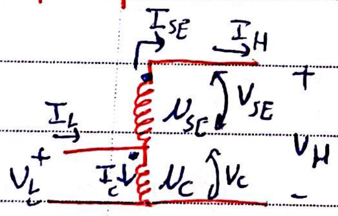


TR

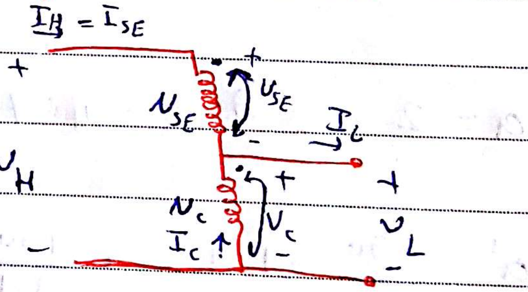


auto TR ≡ TR with one winding

step-up auto TR



step-down auto TR



N_c ≡ common winding

N_{SE} ≡ seires winding

$V_L = V_c$

$V_H = V_c + V_{SE}$

$I_L = I_{SE} + I_c$ / $I_H = I_{SE}$

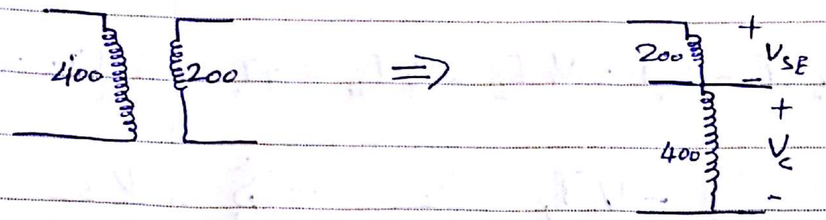
$V_H = V_c + V_{SE}$

$V_L = V_c$

$I_H = I_{SE}$

$I_L = I_{SE} + I_c$

Connect the two regular transformer winding in Seires, then you will get an auto TR



→ $\frac{V_c}{V_{SE}} = \frac{N_c}{N_{SE}}$

$N_c I_c = N_{SE} I_{SE}$

$V_H = V_c + V_{SE}$

$= V_c + V_c * \frac{N_{SE}}{N_c}$

$= V_L + V_L * \frac{N_{SE}}{N_c} = V_L \left(1 + \frac{N_{SE}}{N_c}\right) \Rightarrow \boxed{\frac{V_H}{V_L} = \frac{N_c + N_{SE}}{N_c}}$, $\boxed{\frac{V_L}{V_H} = \frac{N_c}{N_c + N_{SE}}}$

low and high voltage relationship

→ $I_L = I_c + I_{SE} = I_{SE} \frac{N_{SE}}{N_c} + I_{SE} = I_H \frac{N_{SE}}{N_c} + I_H$

$\boxed{\frac{I_L}{I_H} = \frac{N_c + N_{SE}}{N_c}}$ current relation

* Apparent input and output power (Consider Step-up TR)

$S_{in} = V_L I_L$

$S_{out} = V_H I_H = V_L * \frac{N_c + N_{SE}}{N_c} * I_L * \frac{N_c}{N_c + N_{SE}} = V_L I_L$

$S_{in} = S_{out} = S_{Io}$

* Apparent power of each winding

$$S_w = V_C I_C = V_{SE} I_{SE}$$

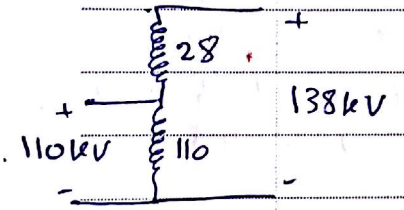
$$S_w = V_L(I_L - I_{SE}) = V_L(I_L - I_H) = V_L I_L - V_L I_H = V_L I_L - V_L \left[\frac{I_L N_c}{N_c + N_{SE}}\right]$$

$$= V_L I_L \left[1 - \frac{N_c}{N_c + N_{SE}}\right] = V_L I_L \frac{N_{SE}}{N_c + N_{SE}} = S_{I_o} \cdot \frac{N_{SE}}{N_c + N_{SE}}$$

$$\Rightarrow \boxed{S_{I_o} = S_w \frac{N_c + N_{SE}}{N_{SE}}} \Rightarrow \text{Apparent power advantage}$$

ex :- 5 MVA auto TR that connects 110 kV system to 138 kV system. turns ratio $N_c : N_{SE}$

110 : 28

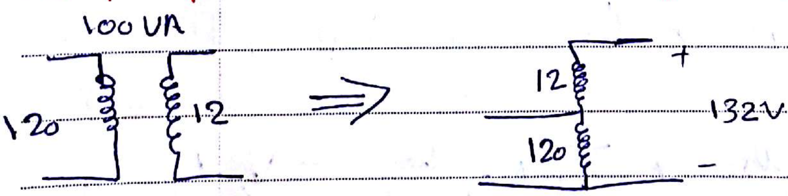


This auto TR would actually have winding ratings:

$$S_w = S_{I_o} * \frac{N_{SE}}{N_c + N_{SE}} = 5M * \left[\frac{28}{28 + 110}\right]$$

$$= 1.015 \text{ MVA}$$

ex :- A 100 VA, 120/12 V TR will be connected to form a step-up auto TR with the primary voltage of 120 V



* what will be the secondary voltage ?!

$$V_H = V_L * \frac{N_{SE} + N_c}{N_c} = 120 \left[\frac{120 + 12}{12}\right] = 132 \text{ V}$$

No.

* what will be the maxi power rating ?! ⇒ " S_{IO} "

$S_{w} = 100 \Rightarrow S_{IO} = S_{w} \frac{N_{SE}+N_{C}}{N_{SE}} = 100 * \frac{120+12}{12} = 1100\ VA$

Power advantage $= \frac{1100}{100} = 11$

* I_H ?!

$S_{out} = I_H V_H$

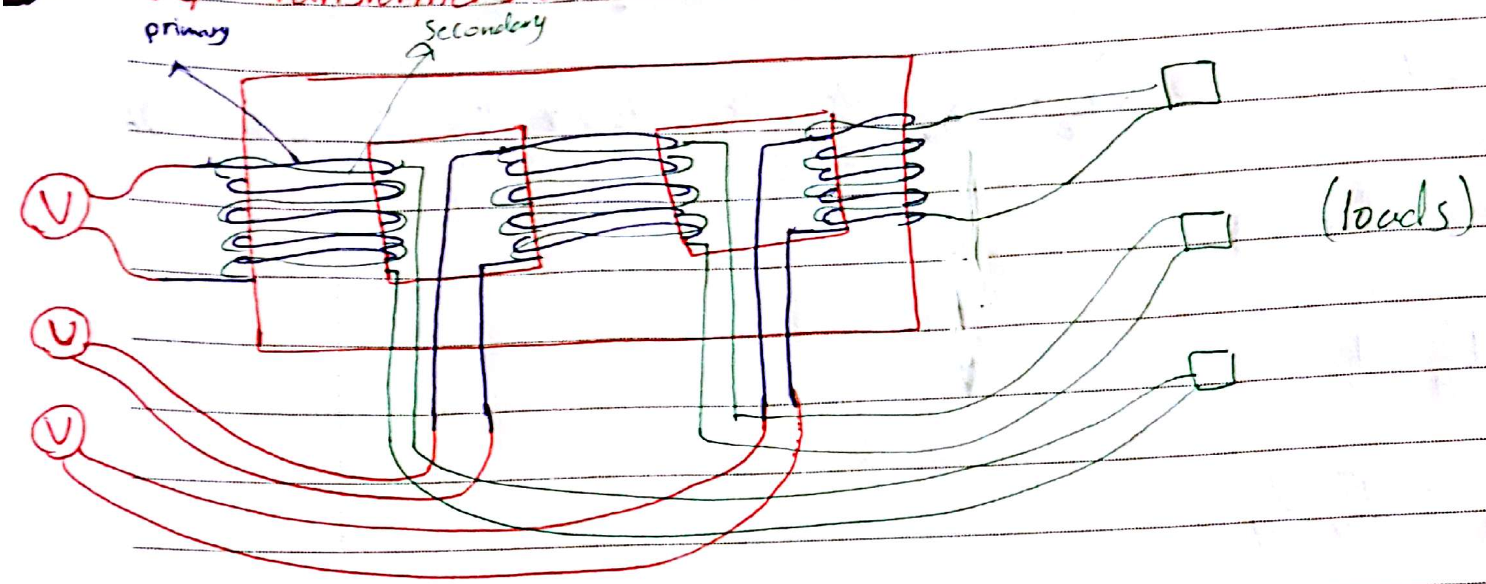
$1100 = I_H * 132$

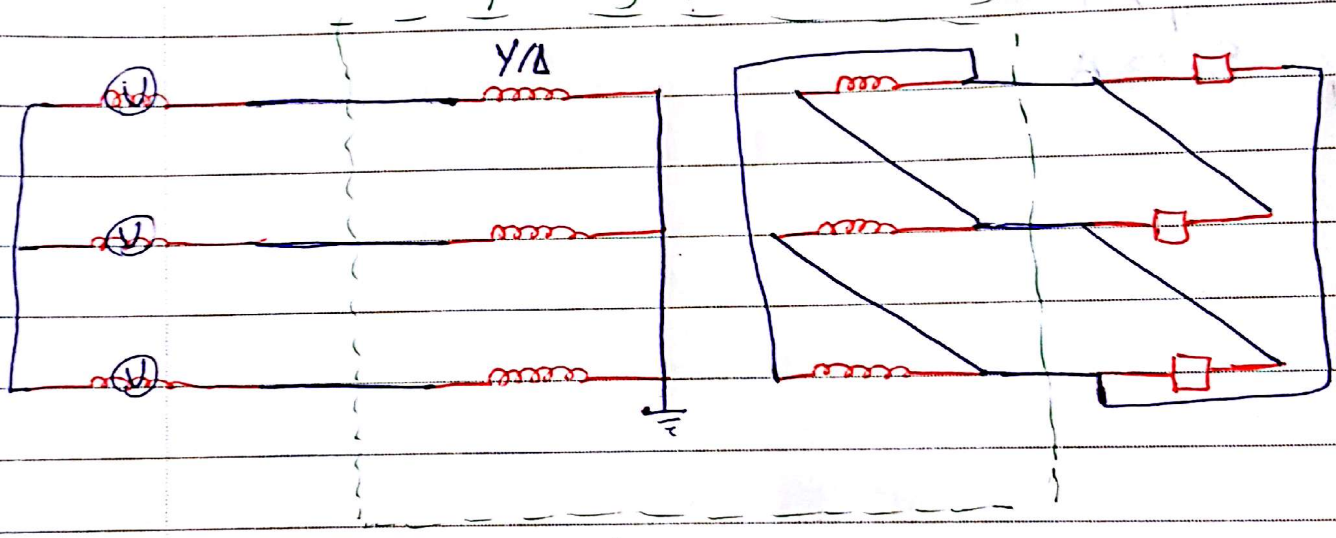
$I_H = 8.33A$

No.

21/6/2017

3ϕ Transformers :-





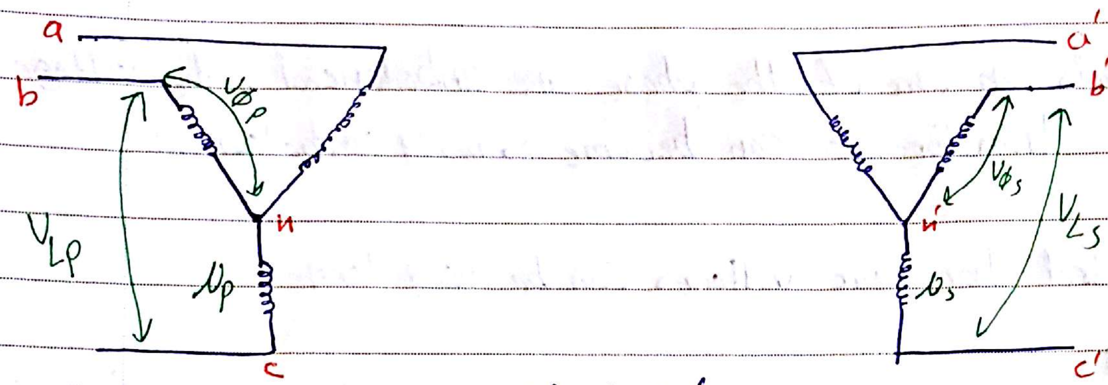
YΔ

→ 4 possible Connection for 3 phase TRS :-

1) Y - Y
2) Y - Δ
3) Δ - Y
4) Δ - Δ

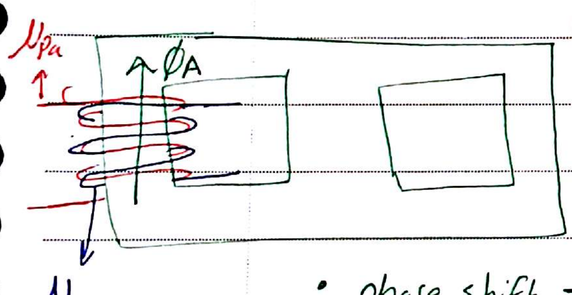
No.

① Y - Y

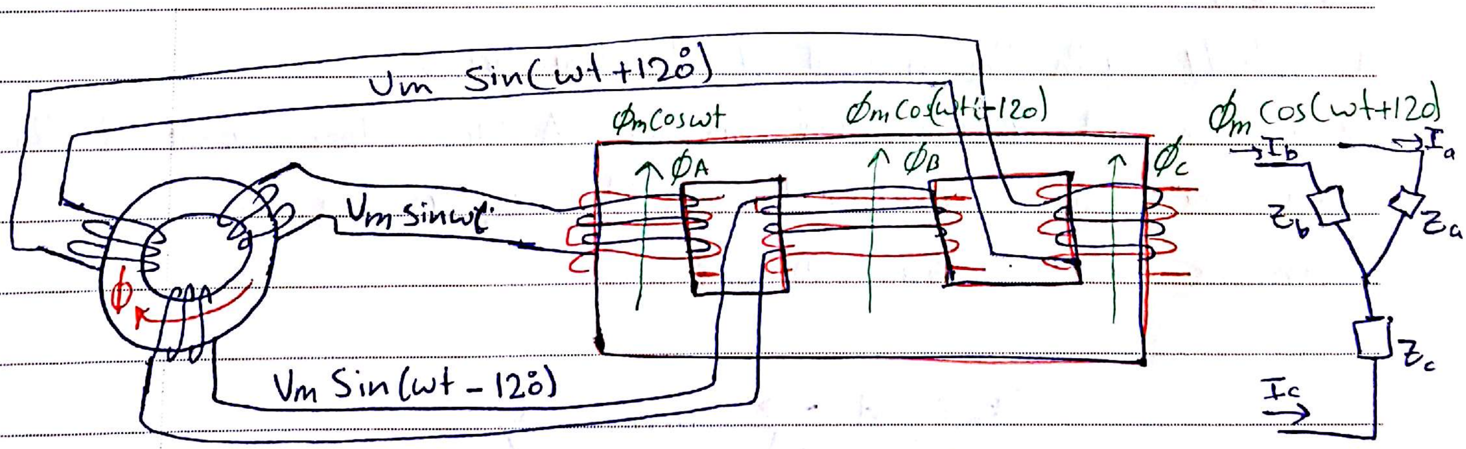


Y-Y 3ϕ

$$\rightarrow \frac{N_p}{N_s} = a = \frac{V_{\phi p}}{V_{\phi s}} = \frac{V_{Lp}/\sqrt{3}}{V_{Ls}/\sqrt{3}} = \frac{V_{Lp}}{V_{Ls}}$$



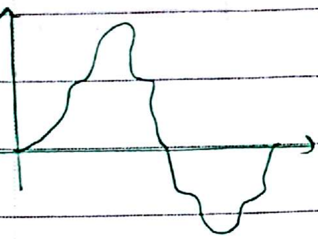
∴ phase shift = 0 (same ϕ_A on the primary and secondary)



Problems of Y-Y TR:-

① if loads on one of the phase are unbalanced, the voltages on the transformer can become severly unbalanced.

② The 3rd harmonic voltages can be very large.



$$i(t) = I_m \cos\omega t + I_m' \cos(3\omega t) + I_m'' \cos(5\omega t) + I_m''' \cos(7\omega t)$$

$$i_a = I_m \cos\omega t + I_m' \cos 3\omega t$$
$$i_b = I_m \cos(\omega t - 120^\circ) + I_m' \cos(3\omega t - 360^\circ)$$
$$i_c = I_m \cos(\omega t + 120^\circ) + I_m' \cos(3\omega t + 360^\circ)$$

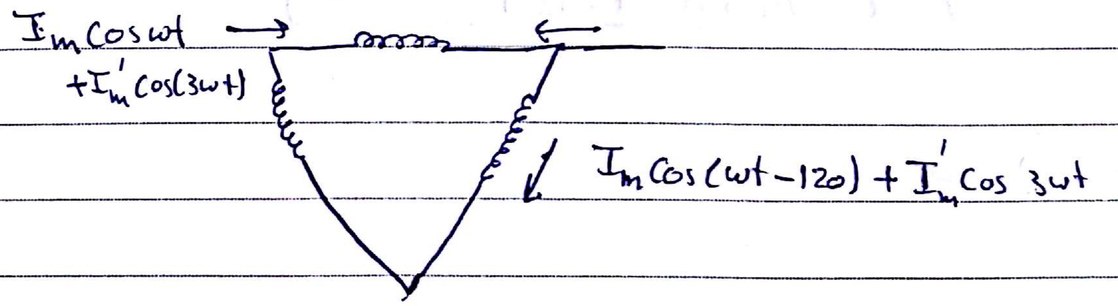
(+)

$$= 0 + 3I_m' \cos 3\omega t$$

Solution :-

① Solidly earth the neutral of the transformer

② add a 3rd Δ connected winding. A circulating current at the 3rd harmonic will flow through it suppressing the 3rd harmonic in the other winding.

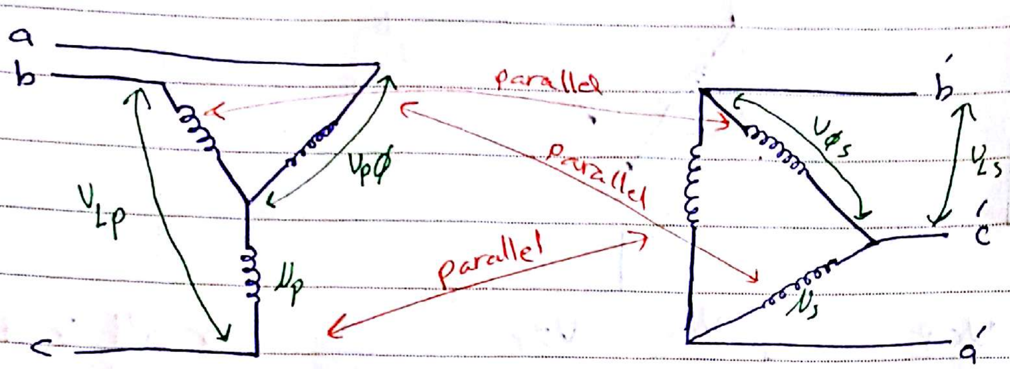


$$I_a + I_{ab} = I_{bc}$$
$$I_a = I_{bc} - I_{ab}$$
$$= \sqrt{3}\, I_m \cos(\omega t - 30^\circ)$$

22/6/2017

No.

② Y - Δ Connection :-

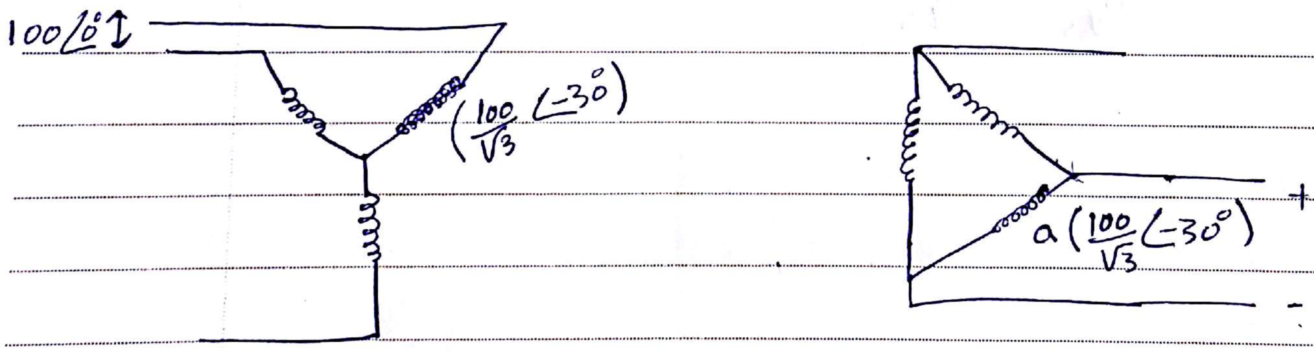


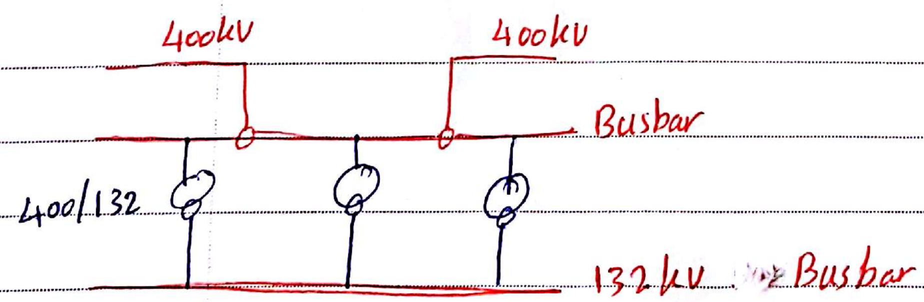
$$\frac{N_P}{N_s} = a = \frac{V_{\phi P}}{V_{\phi s}} \quad , \quad \frac{V_{LP}}{V_{Ls}} = \frac{\sqrt{3}\, V_{\phi P}}{V_{\phi s}} = \sqrt{3}\, a$$

over all voltage ratio

* No 3rd harmonic issue, because of the Δ winding.
* less unbalance when the load is unbalance, because the Δ partially redistribute any imbalance.

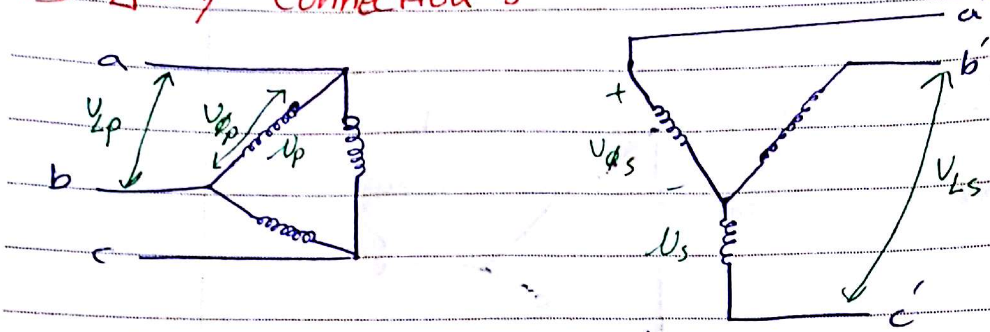
Problems :- The secondary is phase-shifted by ±30° with respect to the primary voltage.





paralling of transformers (will be discussed in vector group)

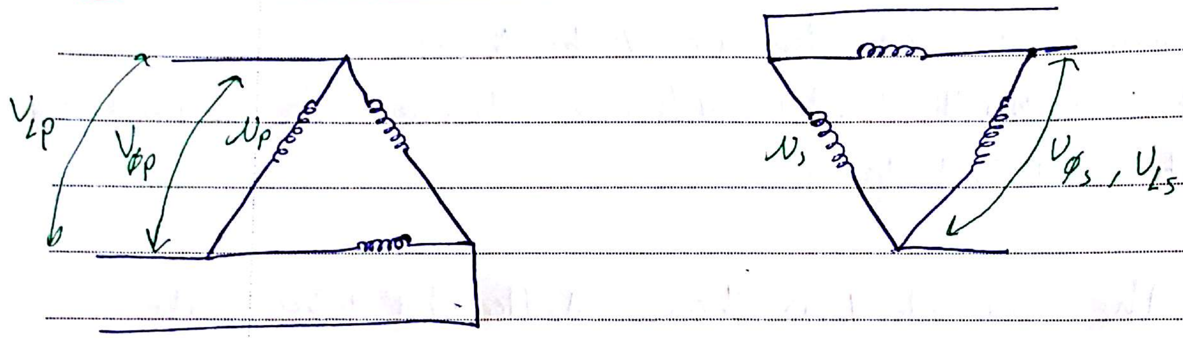
3 Δ - Y Connection :-



$$\frac{N_P}{N_S} = a = \frac{V_{\phi P}}{V_{\phi S}} \quad , \quad \frac{V_{LP}}{V_{LS}} = \frac{V_{\phi P}}{\sqrt{3}\, V_{\phi S}} = \frac{a}{\sqrt{3}}$$

overall voltage ratio

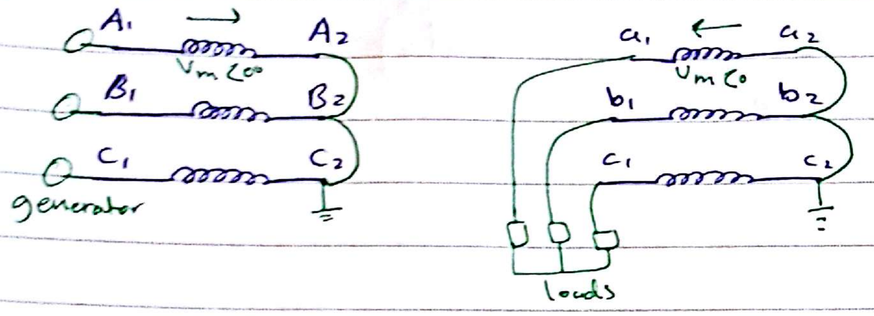
4 Δ - Δ Connection :-



$$\frac{N_P}{N_S} = a = \frac{V_{\phi P}}{V_{\phi S}} = \frac{V_{LP}}{V_{LS}}$$

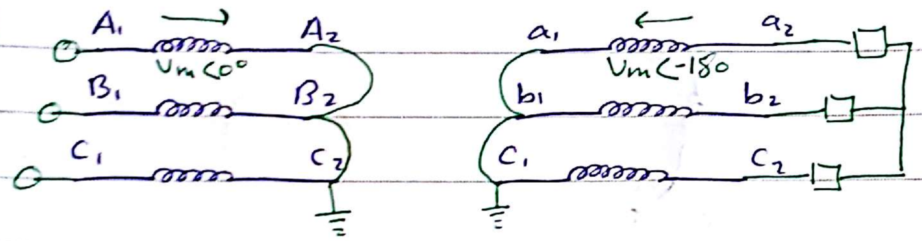
Vector groups :-

(1)



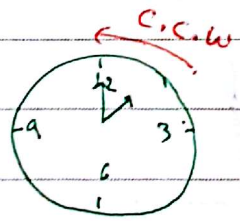
Y y 0

(2)



Y y 6

Y	y	☐
↓ primary connection "capital letter"	↓ secondary "small"	↓ phase shift



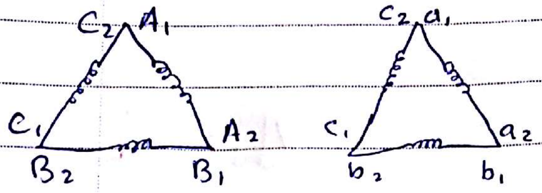
1 → 30°   6 → 180°

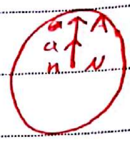
2 → 60°   11 → 330° / -30°

[1] Y d 1 (→ 30°) → L.V side lags H.V side by 30°.

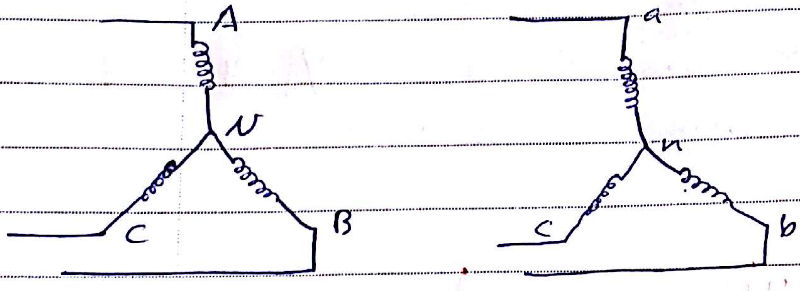
[2] Δ y 11 (→ -30° / 330°) → L.V side leads H.V side by 30°.

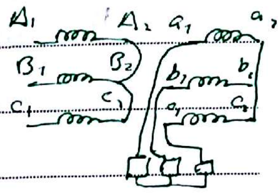
3) Δ d 0



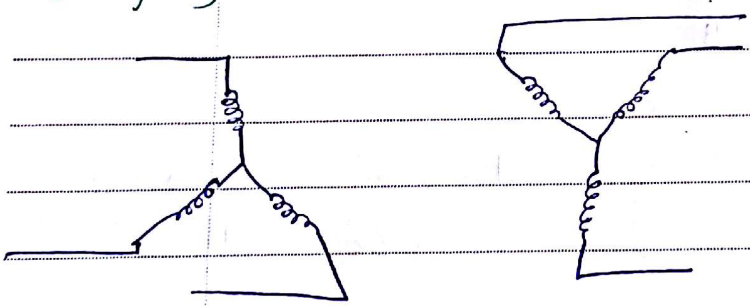


4) Y y 0



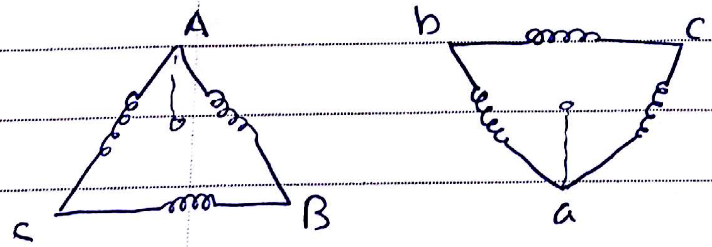


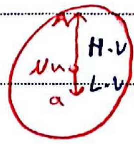
5) Y y 6

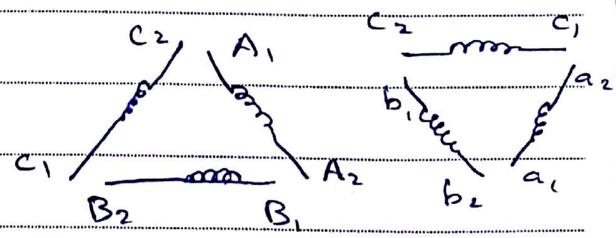


we can say
leads or lags

6) Δ d 6

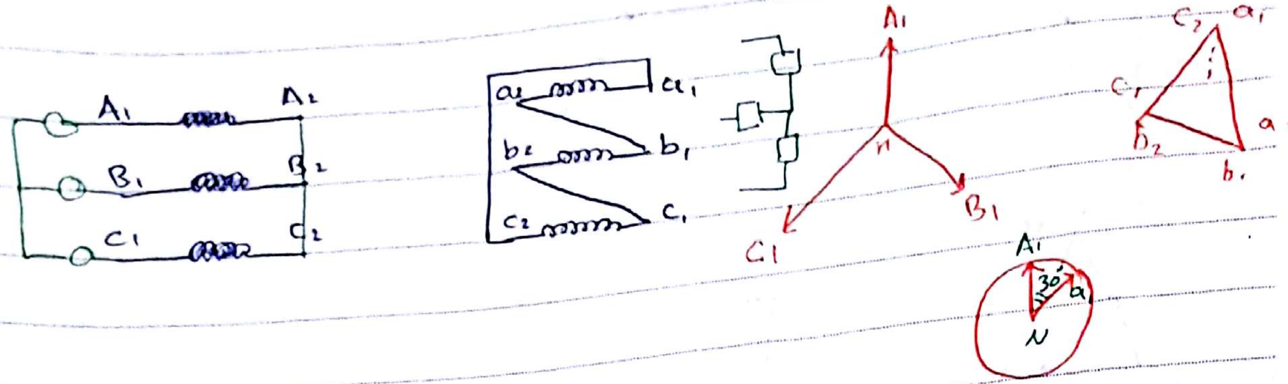






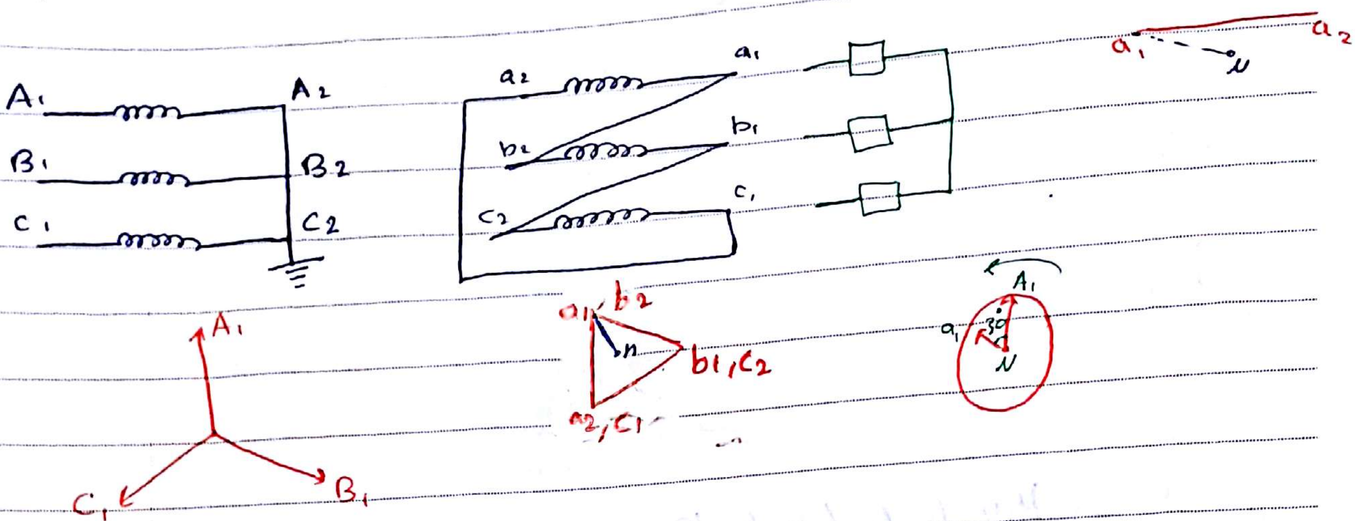
29/6/2017

Y d 1 → L.V lags H.V by 30°

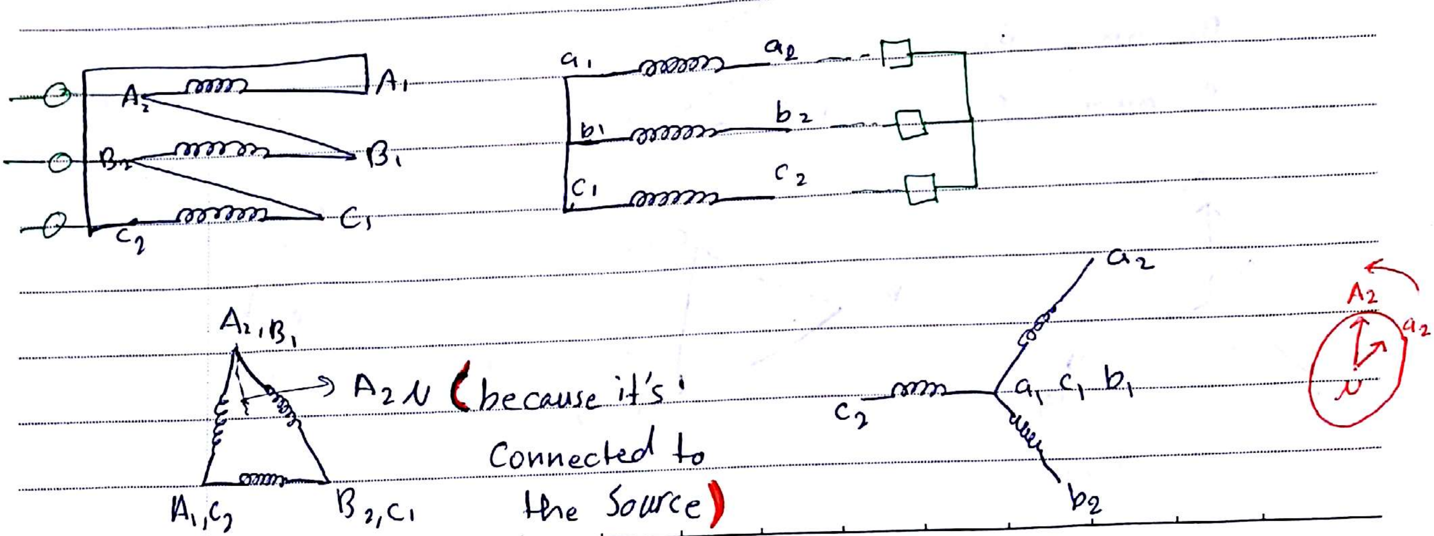


Ynd11

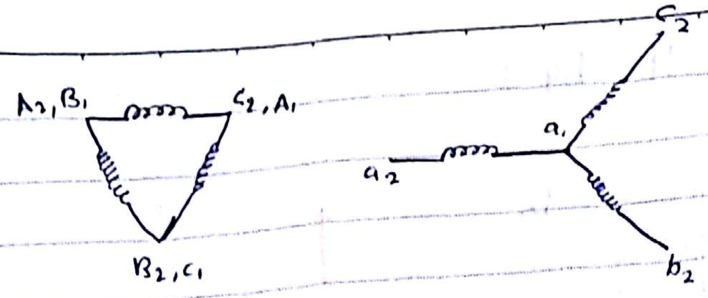
Y d 11 → L.V leads H.V by 30°

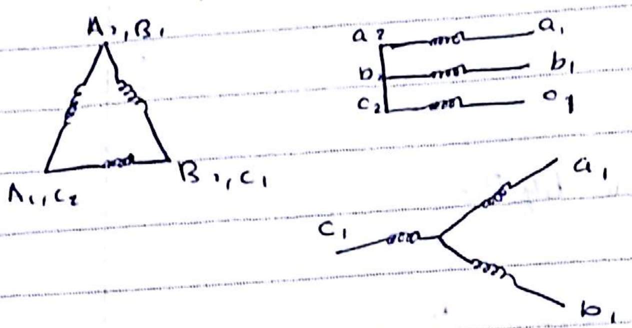


D y 1

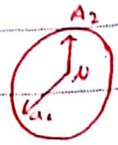


No.



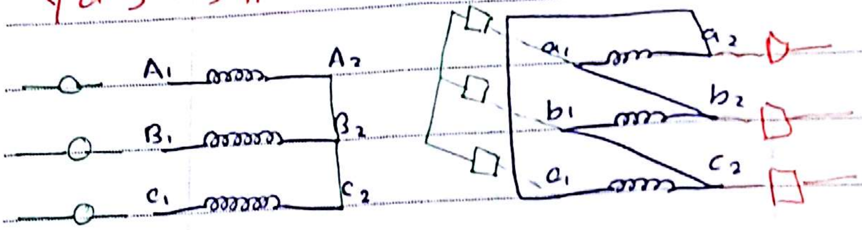


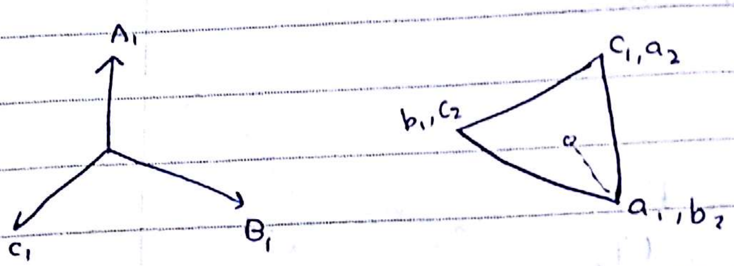
Dy 7

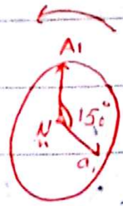


Yd 11 → L.V leads H.V by 30°

Yd 5 → H.V leads L.V by 150°







No.

Standard vector group :-

Group I (0°) 0 o'clock ΔΔ, YY

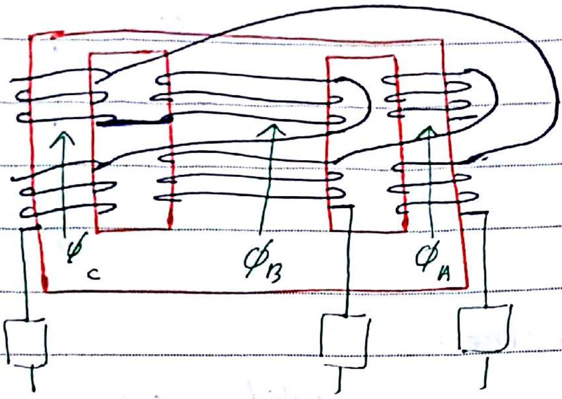
Group II (180°) 6 o'clock ΔΔ, YY

Group III (-30°) 1 o'clock YΔ or ΔY

Group IV (30°) 11 o'clock YΔ or ΔY

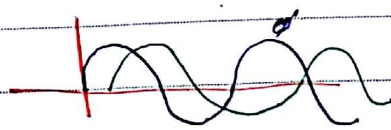
Zigzag Connection [uniformly distributes the unbalanced loads]

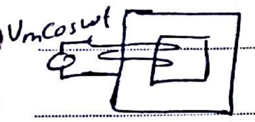
better than Δ

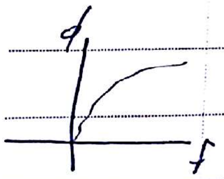


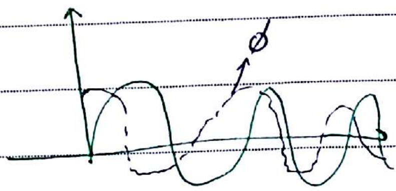
Inrush current :- [transient problem]

e_{ind} $v(t) = -N \frac{d\phi}{dt}$









TR acts as a short ckt R↓ V. low

μ↑ V. high

No.

if $v(t) = V_m \cos\omega t$

lets integrate for $\frac{1}{2}$ cycle

$$\phi = \frac{1}{N}\left[\int v(t)\,dt\right]$$

$$\phi = \frac{1}{N}\int_0^{\pi/\omega} V_m \cos\omega t\,dt$$

$$= 0$$

if $v(t) = V_m \sin\omega t$

→ lets integrate for $\frac{1}{2}$ cycle

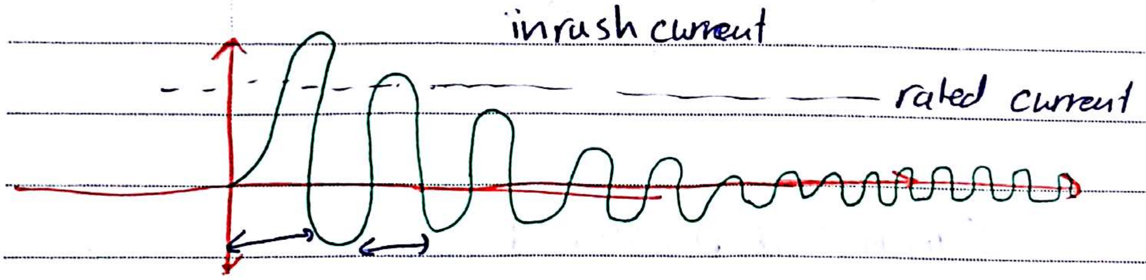
$$\phi = \frac{1}{N}\int_0^{\frac{\pi}{\omega}} V_m \sin\omega t\,dt$$

$$= \frac{2V_m}{\omega N}$$

* in general steady state

$$\phi = \frac{1}{N}\int_0^t v(t)\,dt$$

$$= \frac{V_m}{\omega N}$$



1/7/2017 No.

Per unit system in 3ϕ transformers :-

a $\frac{100\ MVA}{3\phi\ S}$ $\underline{0.480}/\underline{33}$ kV TR

$V_{LL_{pri}}$ $V_{LL_{sec}}$

$$S_{1\phi,base} = \frac{S_{3\phi,base}}{3}$$

$$I_{\phi,base} = \frac{S_{1\phi,base}}{V_{1\phi,base}} = \frac{S_{3\phi,base}}{3 * V_{1\phi,base}}$$

$$Z_{base} = \frac{(V_{\phi,base})^2}{S_{1\phi,base}} = \frac{3(V_{\phi,base})^2}{S_{3\phi,base}}$$

in Δ Connections :-

$$V_{L,base} = V_{\phi,base}$$

in Y Connections :-

$$V_{L,base} = \sqrt{3}\ V_{\phi,base}$$

The base line current :

$$I_{L,base} = \frac{S_{base}}{\sqrt{3}\ V_{L,base}}$$

No.

Example 8- (2.9)

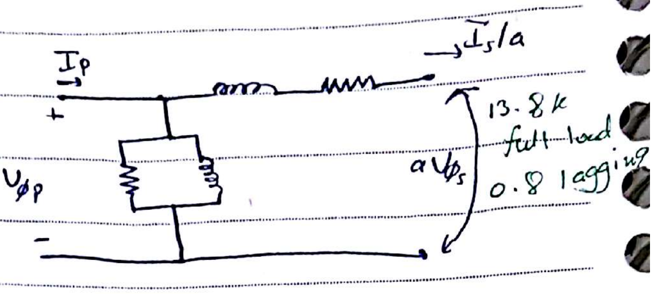
50 kVA, 13800/208 V ΔY TR has a resistance of 1 p.u and reactance 7 p.u.

1) what is the transformers phase impedence referred to H.V side?!

$Z_{eq} = Z_{base} * Z_{p.u}$

H.V ← $Z_{base} = \frac{3 * (13800)^2}{50 \times 10^3} = 11426\ \Omega$

L.V ← $Z_{base} = \frac{3 * (\frac{208}{\sqrt{3}})^2}{50 \times 10^3} = \ldots$



$Z_{\Omega} = 11426 * (0.01 + j0.07)$

$= 114 + j\,800\ \Omega$

100% of the current is passing

2) the voltage regulation at full load and 0.8 p.f lagging !

$VR = \frac{V_p/a - V_s}{V_s} * 100\%$ → L.V side

$VR = \frac{V_p - aV_s}{aV_s} * 100\%$ → H.V side

→ $aV_s = 13800 \angle 0°$

$I = ?!$, $S_{3\phi} = 3\, V_\phi\, I_\phi$

$I_\phi = \frac{S_{3\phi}}{3\, V_\phi} = \frac{50 \times 10^3}{3 * 13800} = 1.208\ A$

$V_{\phi p} = 13800 + (114 + j800) * 1.208 \angle -36.9 = 14506 \angle 2.73$

$VR = \frac{14506 - 13800}{13800} * 100\% = 5.1\%$

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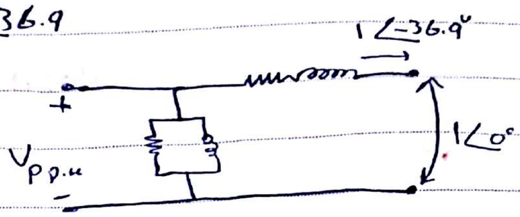
No.

$V_{P\,p.u} = 1\angle 0^\circ + (0.01 + j0.07) * 1\angle -36.9$

$= 1.051 \angle 2.73$

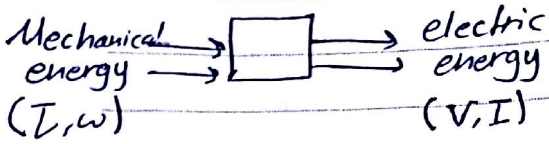


$VR = \frac{1.051 - 1}{1} = 5.1\%$

electric Machines

electric Machines → generators, Motors

generators



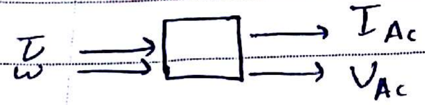
Motors

→ for Ideal machines $VI = \tau\omega$, $P = \tau\omega$

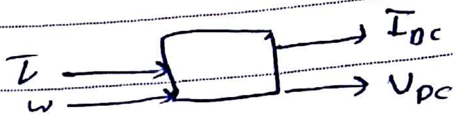
generators

generators → Ac generator, Dc generator

Ac generator



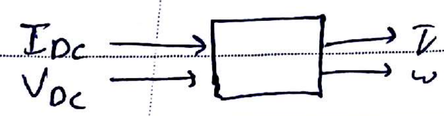
Dc generator



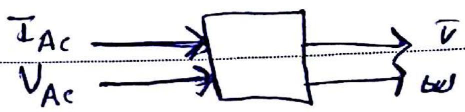
Motors

Motors → Dc motors, Ac motors

Dc motors



Ac motors



No.

* most of electric machines are **AC**
* **DC** motors are - Some times - preffered where :-
→ easier to Control
→ they develop rated torque at all speeds [from Stand still to rated speed].
→ develop torque at stand still is several times greater than an AC machine of an equal power and speed rating.

Applications of DC motors :-

→ printing presses → cranes → speed control of other larger machine
→ fans → mills → auto mobile
→ pumps → traction → air crafts
→ electronics

* DC generators are almost absolete because of the use of power electronics.

parts of DC machine

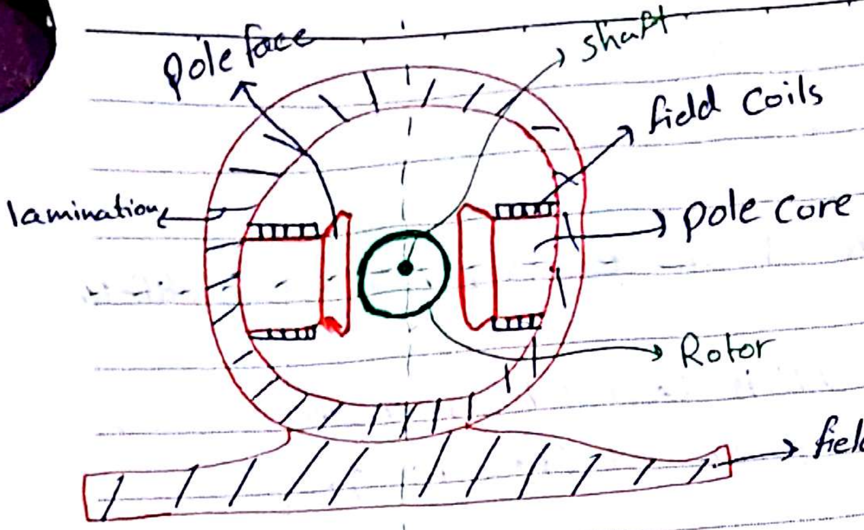
- Stator (Stationary Part)
- Rotor (Rotating part)

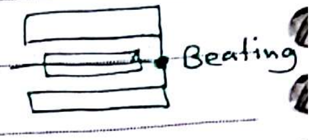
Winding

- field winding [magnetic flux]
- Armature winding [the winding where the voltage is induced]

→ In DC machines :- field winding → Stator
armature winding → Rotor

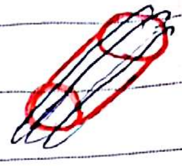
No.



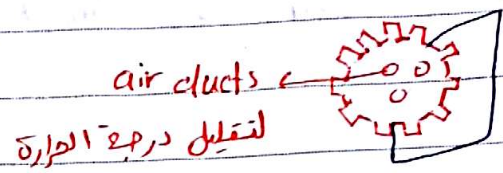


Stator

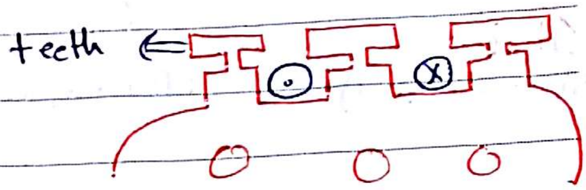
* field yoke gives physical support
* field coils gives magnetic field

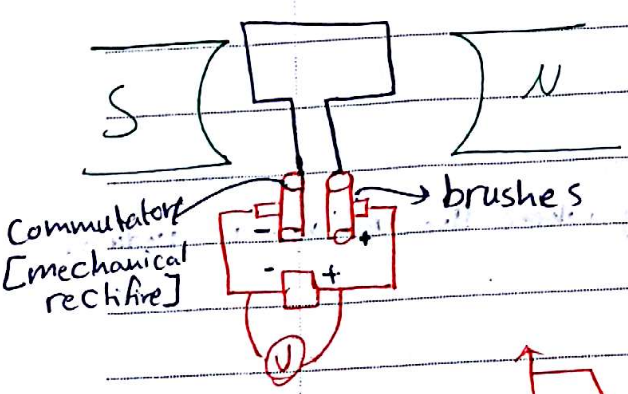


* Armature winding on the rotor



هذه هي طريقة اللف لتجنب الاحتكاك





Brushes → highly conductive
→ and friction coefficient very low

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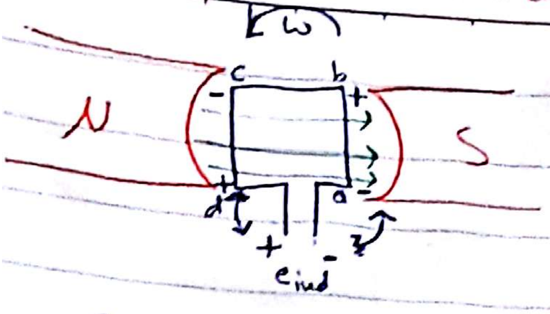
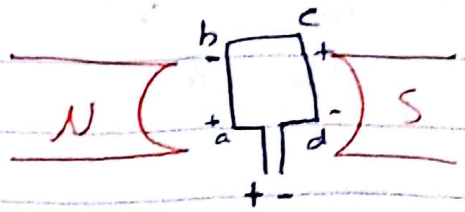
Commutating machines

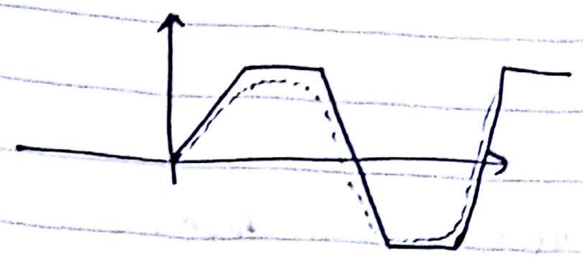
No.

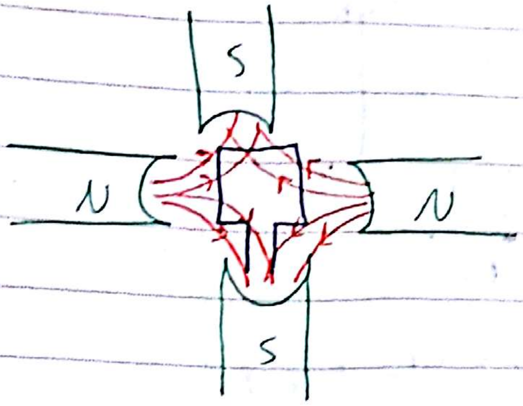


$\theta_m = \theta_e$



$e_{ind} = V_{ba} + V_{cb} + V_{dc} + V_{ad}$





$n_{mec} = \frac{60 * f}{P}$

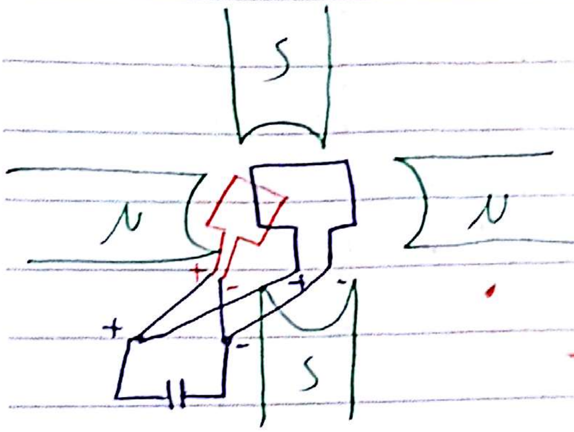
f → frequency

P → # of pole pairs

n_{mec} → mech speed

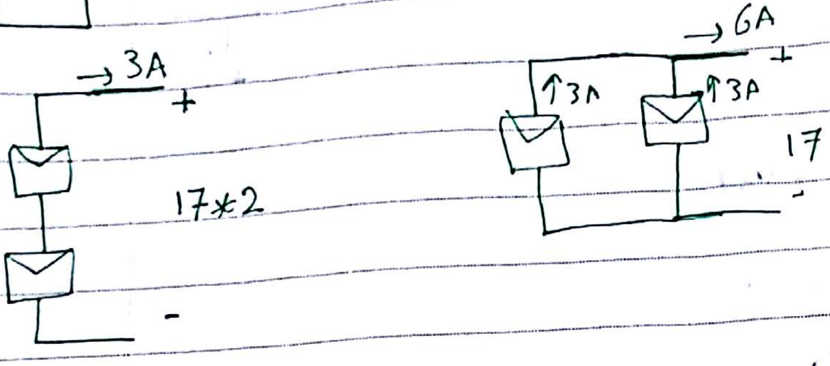
$f = \frac{n_{mec} * P}{60}$

$\theta_e = P\,\theta_m$

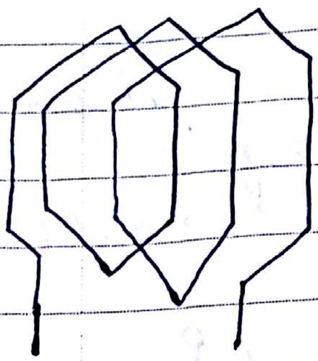


No.

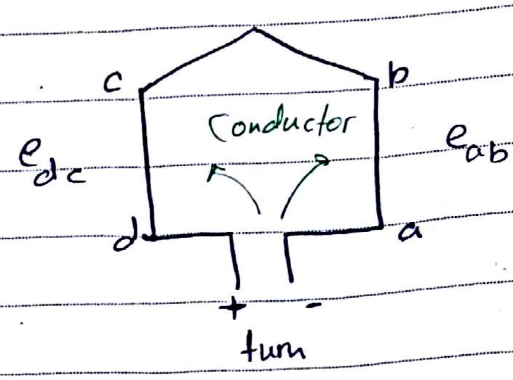
$U_{DC} = 17\text{-}20\ V$
$I_{DC} = 3\ A$



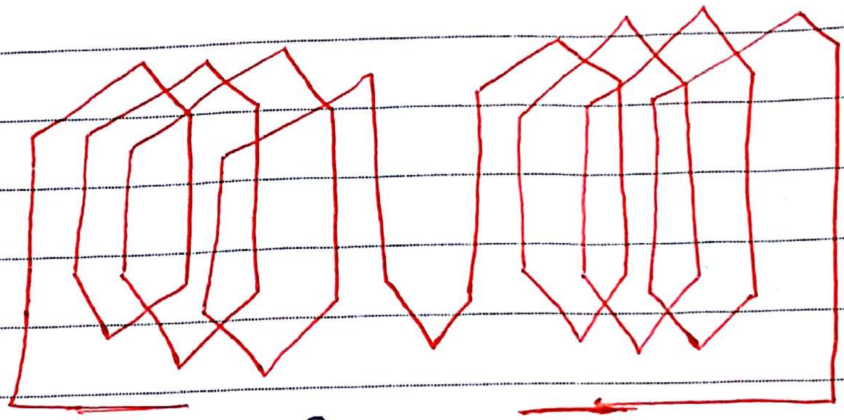
Armature winding :- (usually drawn in a diamond shape)



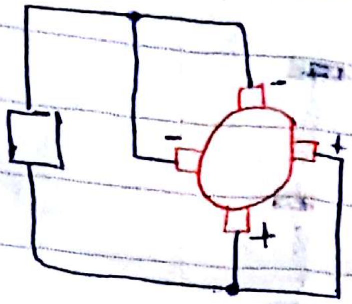
e_{ind} coil

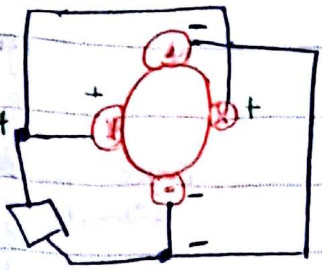


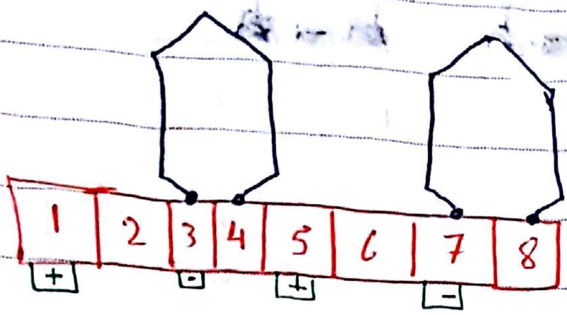
$e_{ind} = e_{ba} + e_{cd}$



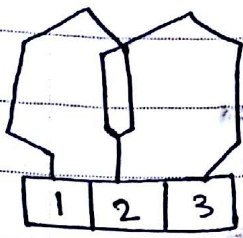
e_{ind}





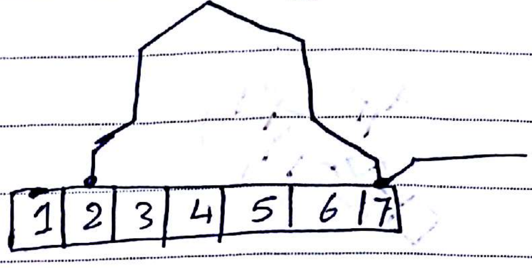


lap winding



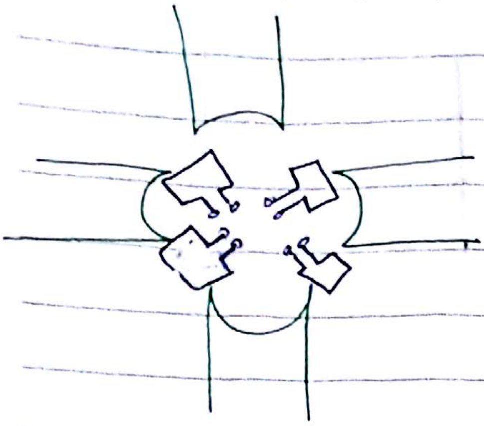
* Coil Conteining one or more turns of wire with the two ends of each coil coming out at adjacent Commutator Segment

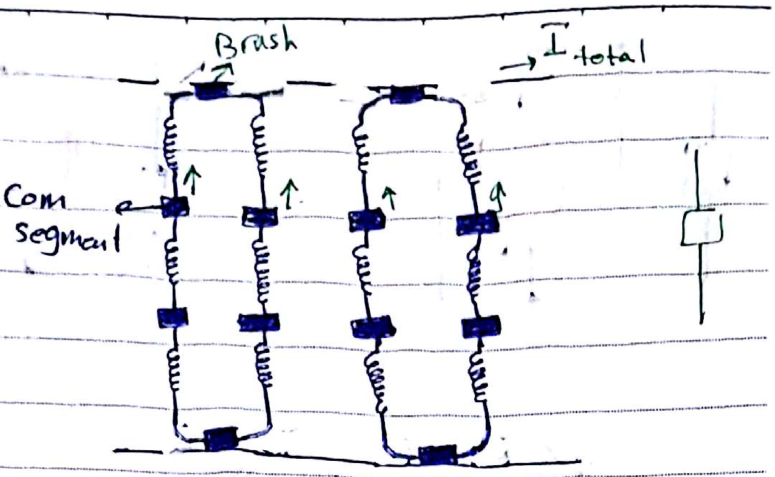
wave winding



* the end of the Coil must be Connected just before or just after the mid point of the electric circuit.

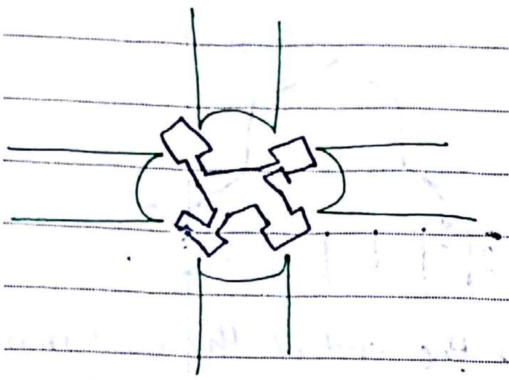
No.

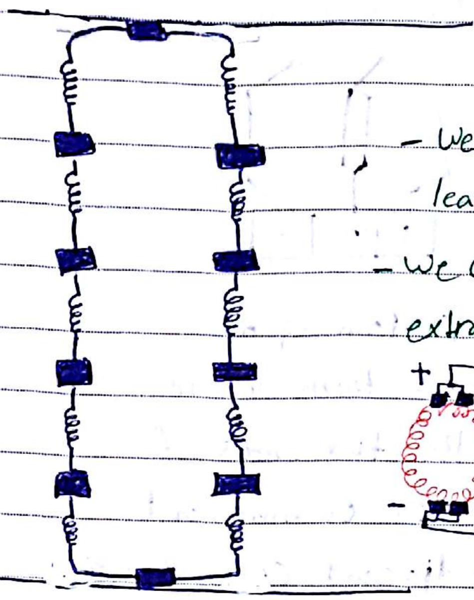




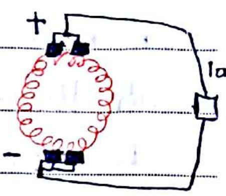
lap winding

low voltage / high current because of parallel connection





- We need at least 2 brushes
- We can add extra brushes



wave winding

high voltage / low current

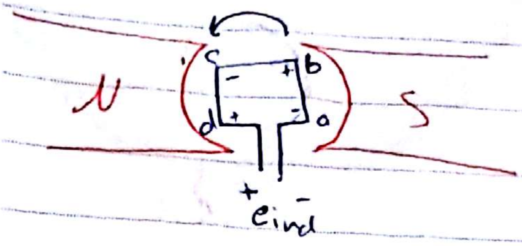
# of parallel current paths (a) = 2

# of current paths = # of poles = # of brushes

2/7/2017

No.

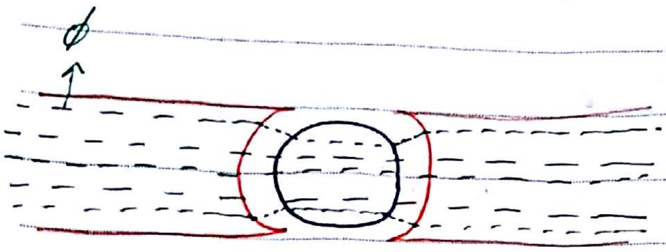
The Simplest DC machine ever



$e_{ind} = V_{ba} + V_{cb} + V_{dc} + V_{da}$

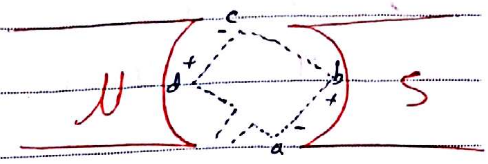
$e_{ind} = (V \times B) \cdot l$

The perp. to the hand ← l ; V → thumb ; B → fingers



* عندما يصل الـ flux إلى الـ air gap سيبحث عن أقصر طريق للوصول وحتى يتعرض لأقل مقاومة ممكنة لذلك يحدث الانحناء.

$e_{ba} = (V \times B) \cdot l = \begin{cases} VBl, & \text{into the page, under pole face} \\ 0, & \text{beyond the pole face} \end{cases}$

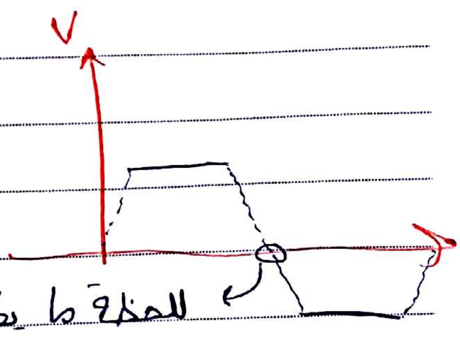


$e_{cb} = 0$

$e_{dc} = (V \times B) \cdot l = \begin{cases} VBl, & \text{out of the page, under pole face} \\ 0, & \text{beyond pole face} \end{cases}$

$e_{ad} = 0$

$e_{ind\ total} = \begin{cases} 2VBl, & \text{under pole face} \\ 0, & \text{beyond pole face} \end{cases}$



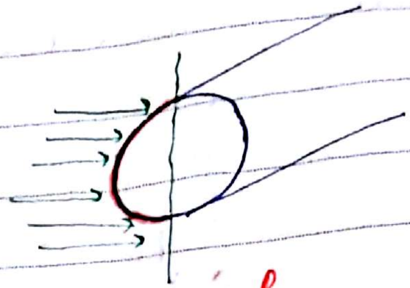
للحظة ما يكون صفر

tangential velocity

$V = r\,\omega$

r → radius

ω → angular velocity



$A = \pi r\, l$

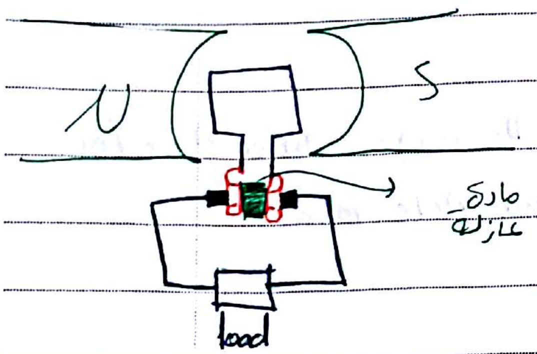
$$e_{ind} = \begin{cases} 2r\omega B l & \text{, under} \\ 0 & \text{, beyond} \end{cases}$$

$$e_{ind} = 2r\omega \frac{\phi}{A} l = \frac{2r\omega\phi l}{\pi r l} = \frac{2}{\pi}\omega\phi$$

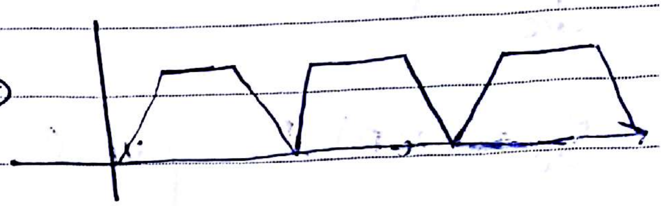
$$e_{ind} = \begin{cases} \frac{2}{\pi}\omega\phi & \text{, under} \\ 0 & \text{, beyond} \end{cases}$$

ϕ → magnetic intensity (Flux)

ω → Constant depend on the dimensions and physical structure of prime mover

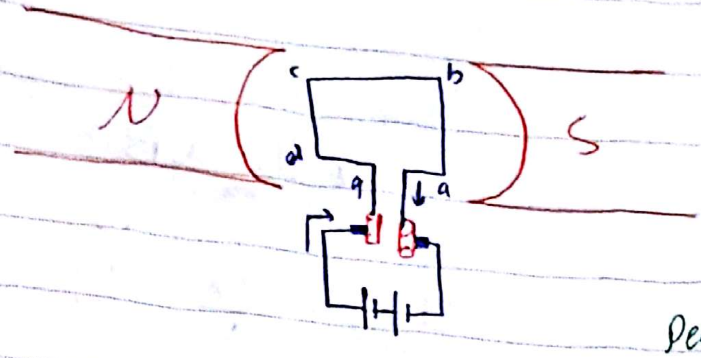


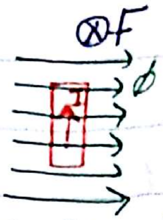
⇒



3/7/2017 No.

Motors :-



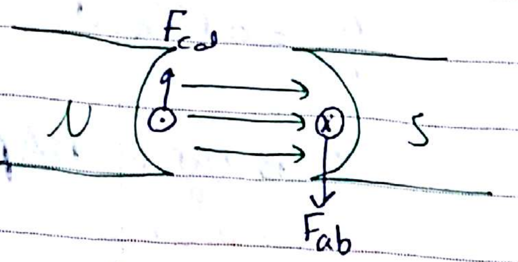


$F = (l \times B) . i$

Perp. to the hand — thumb — fingers

$\tau = r F \sin\theta$, θ = angle between r and F

$$\tau = \underbrace{\tau_{ab}}_{ilB} + \underbrace{\tau_{bc}}_{0} + \underbrace{\tau_{cd}}_{ilB} + \underbrace{\tau_{da}}_{0}$$



$$\tau_{ind} = \begin{cases} 2 i r l B & , \text{under} \\ 0 & , \text{beyond} \end{cases}$$

$$\phi = B A_p = B(\pi r l)$$

$$\tau_{ind} = \begin{cases} \frac{2}{\pi} \phi i & , \text{under} \\ 0 & , \text{beyond} \end{cases}$$

depends on :-

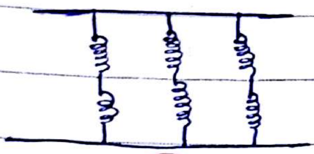
1. magnetic Flux.
2. electric Source.
3. Constant depends on the dimension and physical structure.

Generator

$E_a = k\phi\omega$

$e_{ind} = vBl$

[voltage per conductor under pole face]



$E_a = \frac{Z\, vBl}{a}$

Z → # of conductors

a → # of // current paths

$E_a = \frac{Z r \omega_m B l}{a}$

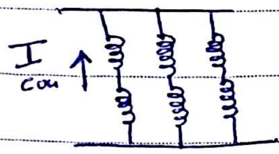
Motor

$T_a = k\phi I$

$\tau = r I_{con} l B$

$I_{cond} = \frac{I_A}{a}$

I_A → Total Armature current



$\tau_{cond} = r \frac{I_a}{a} l B$

$\tau_{ind} = \frac{Z r I_a l B}{a}$

$\phi = B \frac{2\pi r l}{p} = BA_p$

ϕ → flux per pole face

$\phi = B A_p$

$\phi = B * \frac{2\pi r l}{p}$

$E_a = \frac{Z r \omega_m B l}{a} * \frac{p}{p} * \frac{2\pi}{2\pi}$

$E_a = \left(\frac{Z p}{2\pi a}\right)\left(\frac{2\pi r l B}{p}\right)\omega_m$

$E_a = k \quad \phi \quad \omega_m \rightarrow$ rad/sec

$k = \frac{Z p}{2\pi a}$

$E_a = k' \phi \, n_m \rightarrow$ rev/min

$k' = \frac{Z p}{60 a}$

$\tau_{ind} = \left(\frac{Z p}{2\pi a}\right)\phi I_A$

$= k \phi I_A$

$k = \frac{Z p}{2\pi a}$

$k' = \frac{Z p}{60 a}$

Example 8- Determine the induced voltage in the armature of a DC machine running at 1750 rpm (ω_m) and having 4 poles (p). The flux per pole is 25 mwb (ϕ) and the armature is lap wound with 36 coils with 13 turns on each coil.

$a = p =$ brushes

$Z = 2 * 36 * 13 = 936$ Conductor

$E_a = k \phi \omega_m = \frac{p Z}{60 a} * \phi * \omega_m = \frac{936}{60} * 25\times10^{-3} * 1750 = 682.5\,V$

$P = a =$ brushes

Example 8- lap-wound armature has 567 (Z) conductors and carries an armature current (I_a) of 123.5 A. if the flux per pole (ϕ) is 20 mwb, calculate the total produced torque

$$T_a = k \phi I_a$$

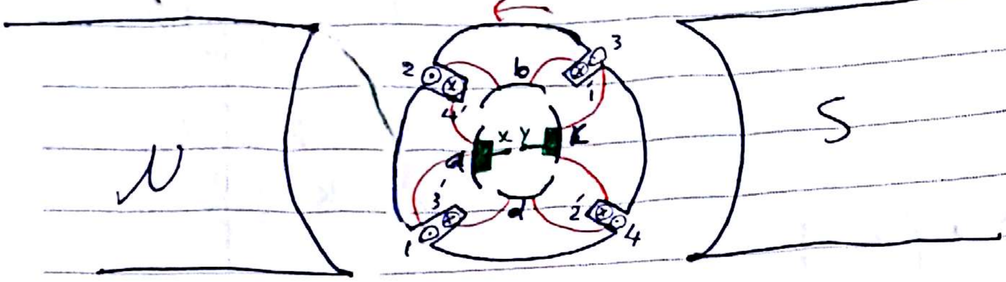
$$= \frac{PZ}{2\pi a} \phi I_a$$

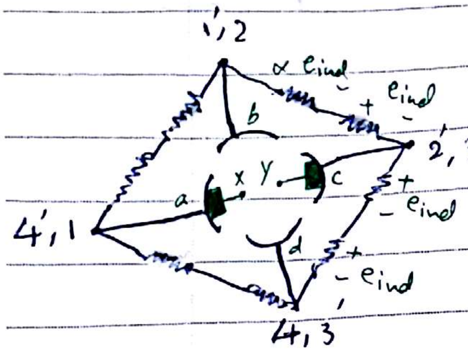
$$= \frac{567}{2\pi} * 20 \times 10^{-3} * 123.5 = 226.43 \ Nm$$

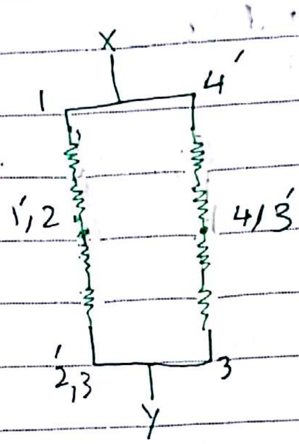
No.

* Commutation in a Simple 4 loop DC machine :

$\omega t = 0$

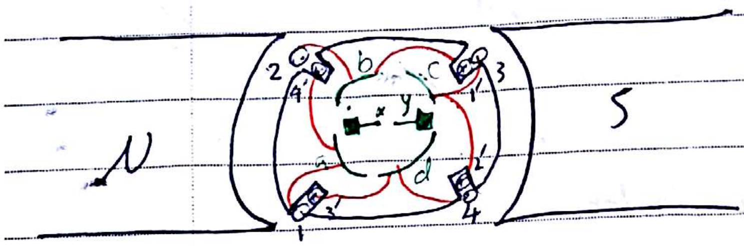


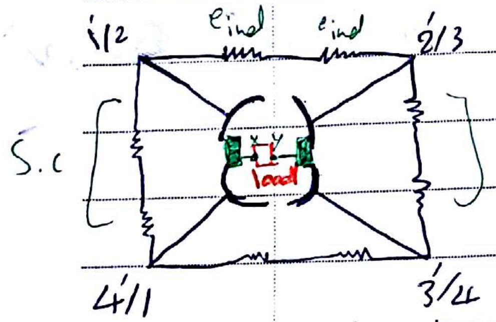




$E_a = 4vBl$ when $\omega t = 0$

$\omega t = 45^\circ$

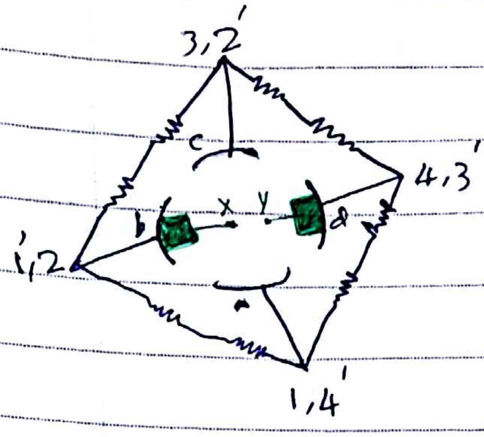




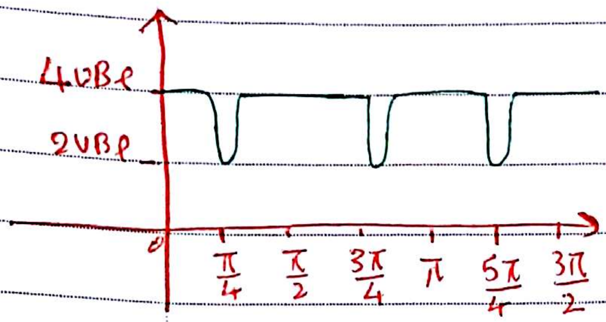
$E_a = 2vBl$
when $\omega t = 45^\circ$

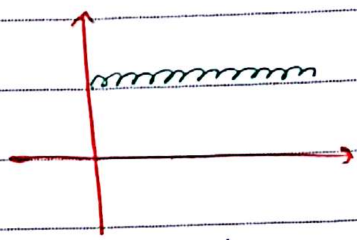
No.

* $\omega t = 90°$



$E_a = 4VBl$ when $\omega t = 90°$





* End of Second Material *

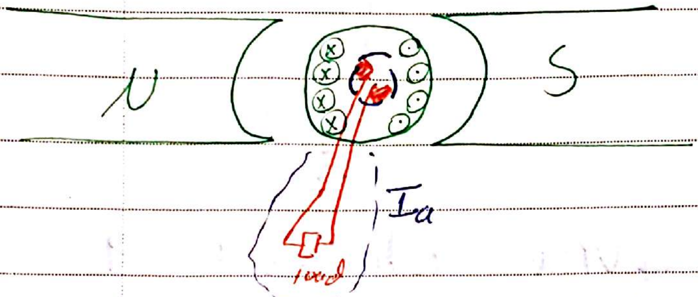
Scanned by CamScanner

No.

4/7/2017

Problems with Commutation in DC machine :-

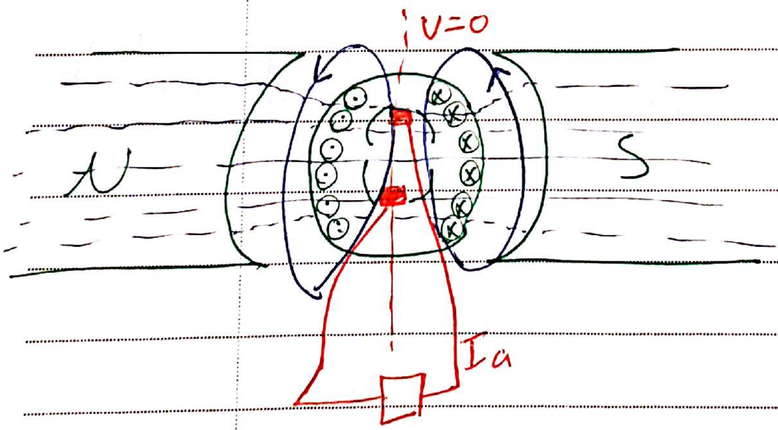
[1] Armature reaction

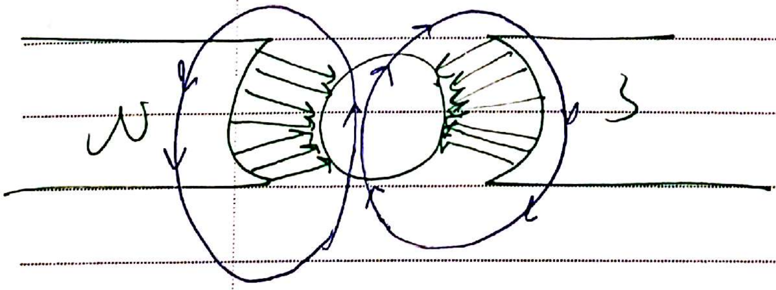


This current (I_a) produces it's own magnetic field that distorts the original magnetic field.

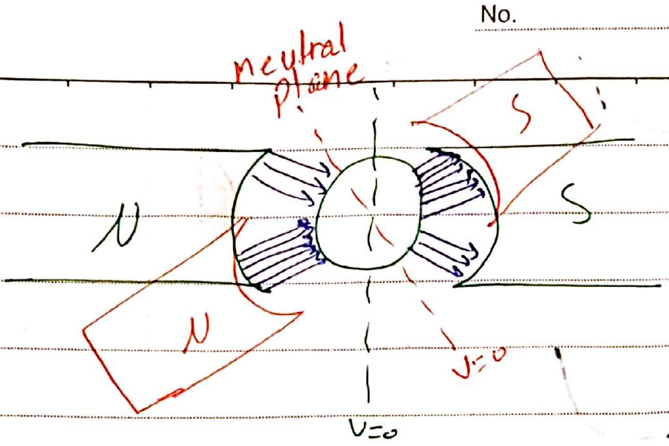
Armature reaction
- neutral-plane shift
- flux weakening

A) Neutral-plane shift



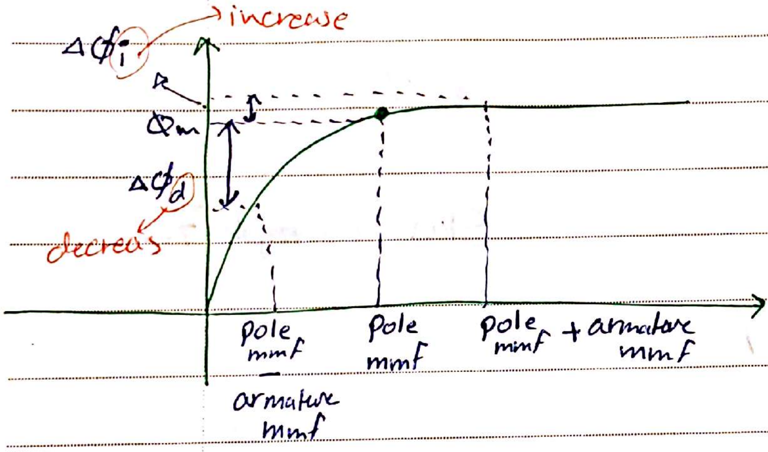


No.

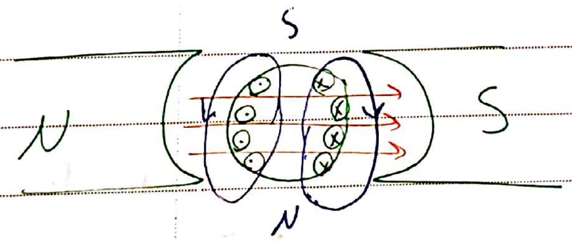


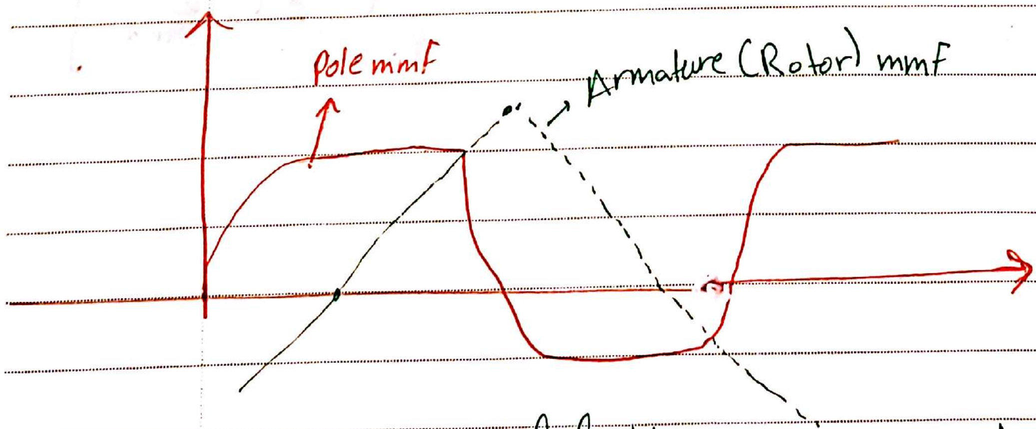
⟹ sparking & arching in the brushes

B) Flux Weakening

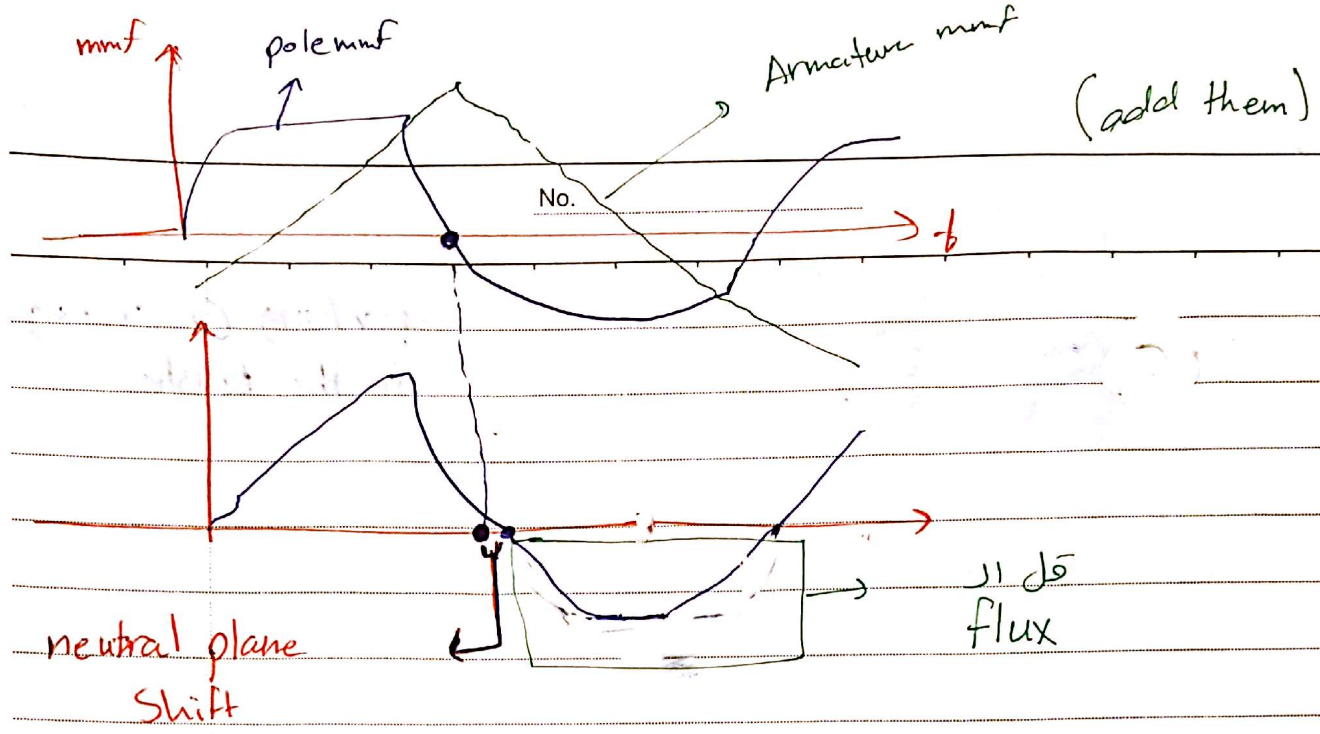


The total average flux under the pole faces decreases.





When we add them we get ⟹ in the next page



Genertor

$E_a = k \phi \omega_m$

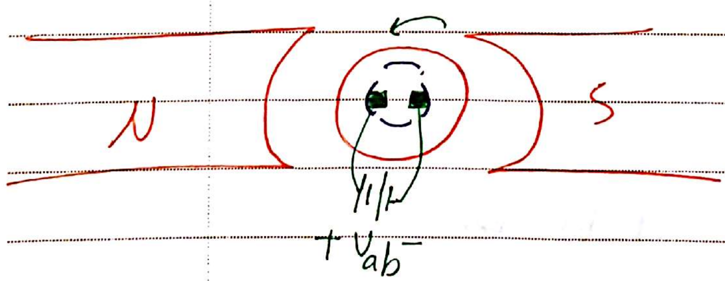
($E_a \downarrow$, $\phi \downarrow$)

[1] reduces the voltage produced by the generator

[2] leads to an increase in speed

Motor

Study example 7.1



When there is no load

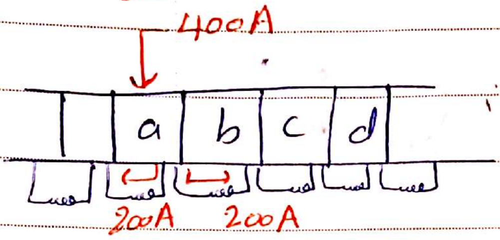
$$\begin{bmatrix} I = 0 \\ V_{ab} = e_{ind} \end{bmatrix}$$

$e_{ind} = \frac{2}{\pi} \phi \omega$

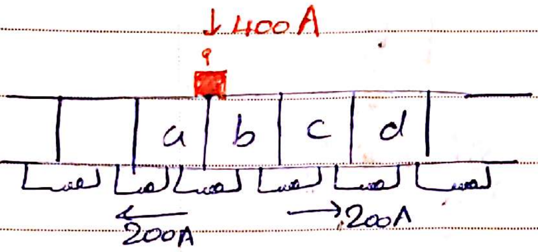
$\uparrow \omega = \frac{e_{ind}}{\frac{2}{\pi} \phi \downarrow}$

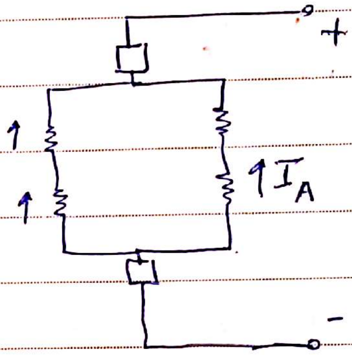
No.

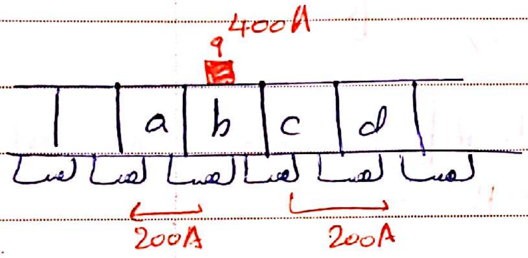
[2] $L\frac{di}{dt}$ voltages



$$\infty \leftarrow V = L\frac{\Delta I}{\Delta t} \rightarrow \text{zero}$$







DC machine running at 800 rpm and it has 50 Comm Segments

$$\frac{800}{60} = 13.3 \text{ r per sec}$$

$$t = \frac{d}{\text{speed}} = \frac{1/50}{13.3} = 0.00155$$

$$L * \frac{\Delta I}{\Delta t} = \frac{400}{0.0015} = 266667 \text{ A/s}$$

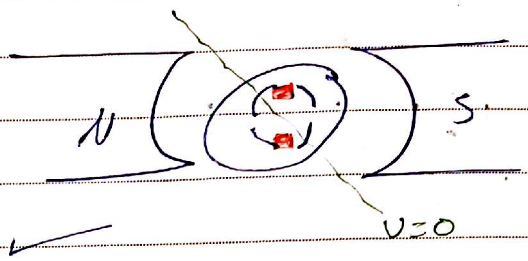
⇒ we will get a very large number

⇒ so there will be sparking and arching

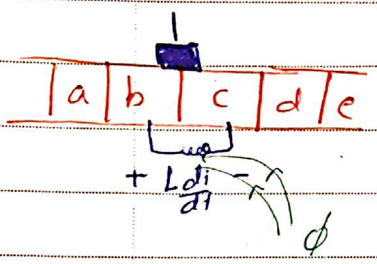
5/7/2017

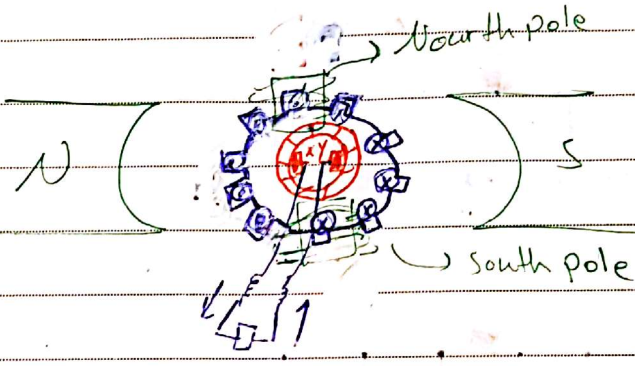
[1] Solution for neutral plane shift

→ Brush shift → X



→ Commutating poles or inter poles → ✓





* There won't be sparking on the brush if the voltage induced from the interpole equals and opposite the voltage $L\frac{di}{dt}$

* The interpoles must be connected is seires with the armature circuit.

* The interpoles produce a tiny flux that won't affect the main flux,

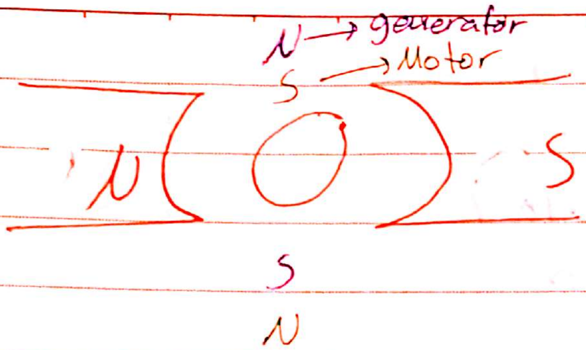
* The interpoles must be of the same polirity as the next upcoming main pole in a generator.

* Interpoles must be of the same polirity as the previous main pole in a motor.

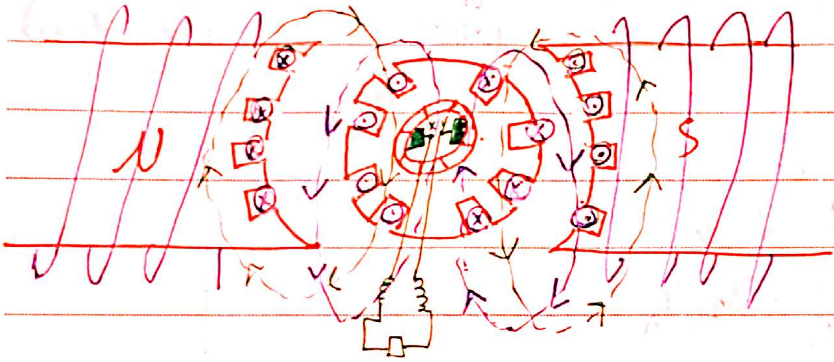
* This solution can be done at low cost

* Flux weakening problem still exist

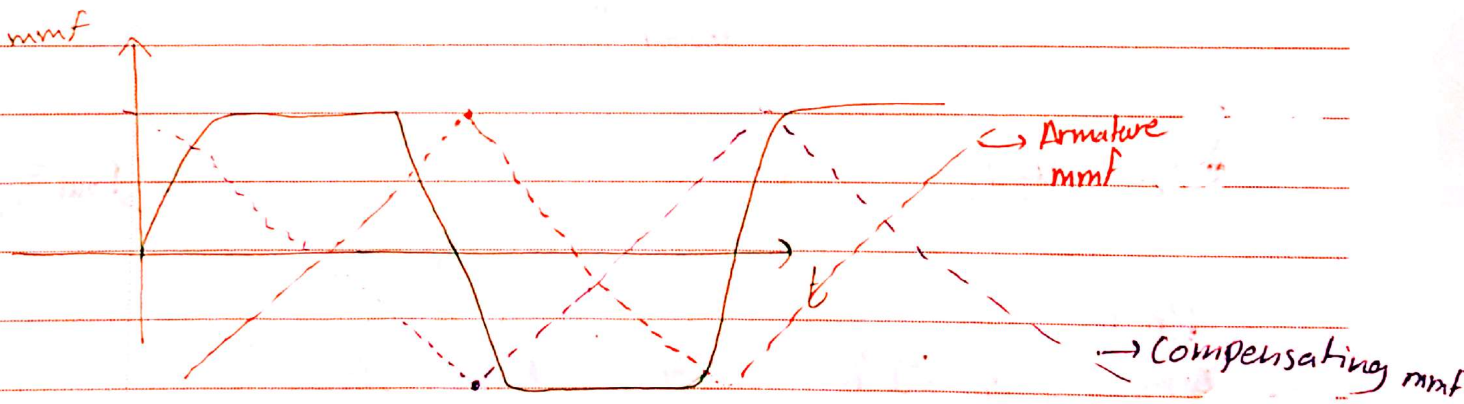
No.



[2] Compensating winding.



This solves plane phase shift and flux weakening



* The blue and the red one will cancel each other.

No.

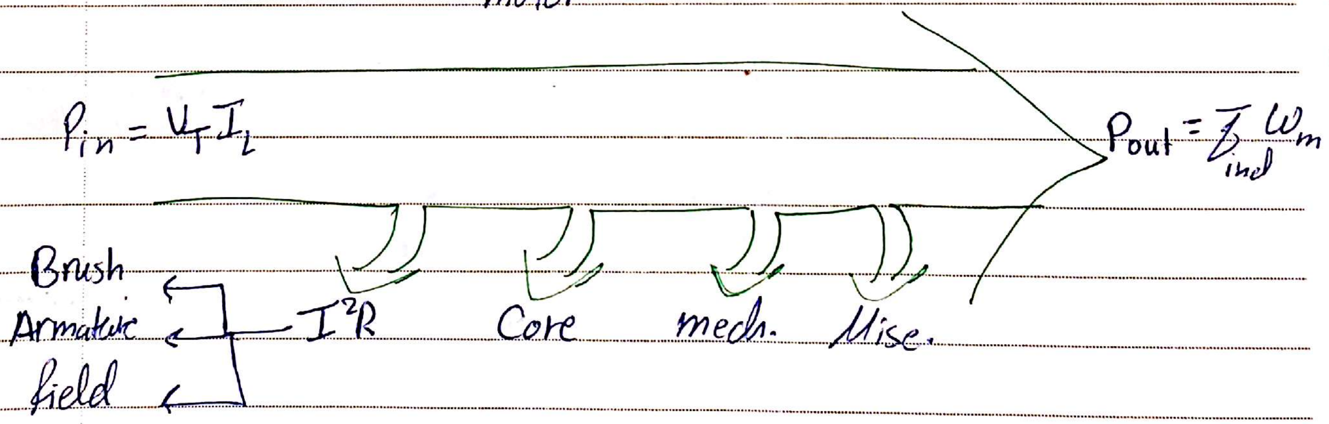
* Power flow and losses in DC machines

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

P losses

- winding losses (electrical losses)
  - $P_A = I_A^2 R_A$
  - $P_F = I_F^2 R_F$
- Miscallaneous (Design) 1%
- brush drop
  - $P_{BD} = V_{BD} I_A$
- Core losses [eddy current and hysteresis]
- mechanical (friction)

"motor"



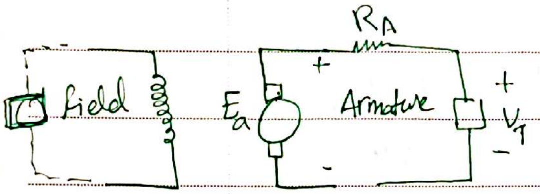
"Chapter 8"

No.

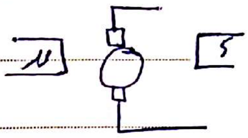
Dc machines

"Seperatly excited Dc machine"

[field winding is supplied by an external source]

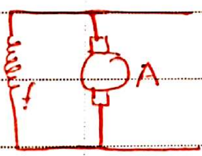


"Permanent magnet"

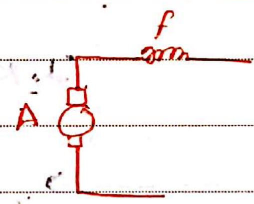


"Self excited Dc machine"

Shunt

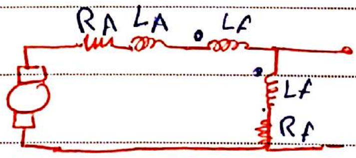


Seires

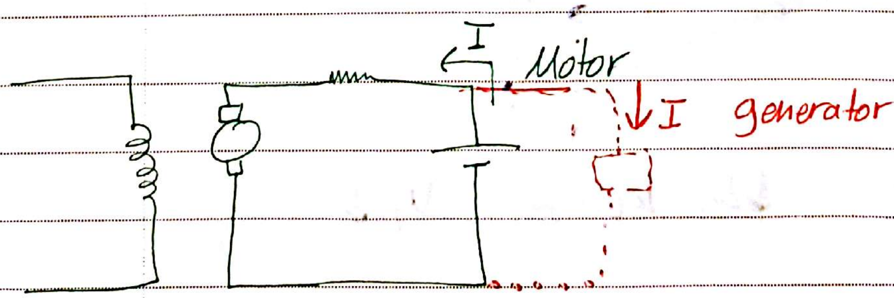


Compound

Comulative Compound



differential Compound

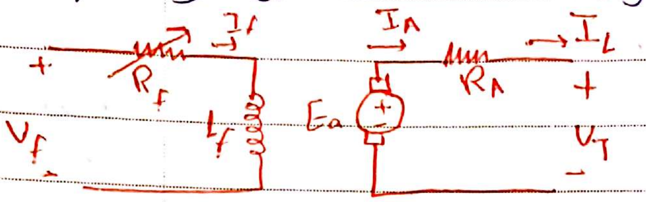


In general :-

I → generator

← I Motor

* Seperatly excited DC (generator)



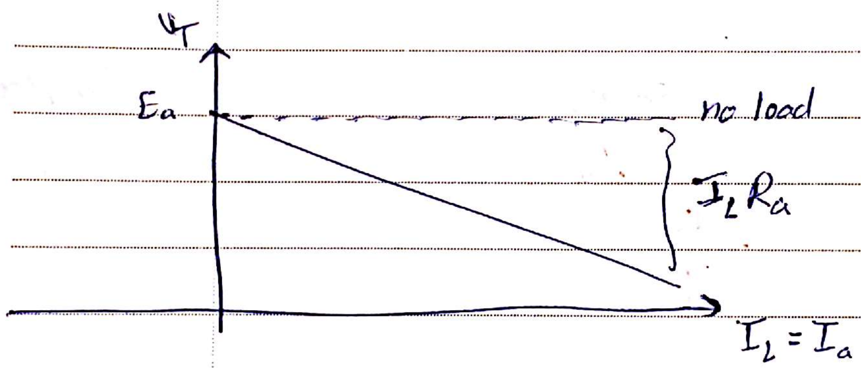
$I_A = I_L$

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

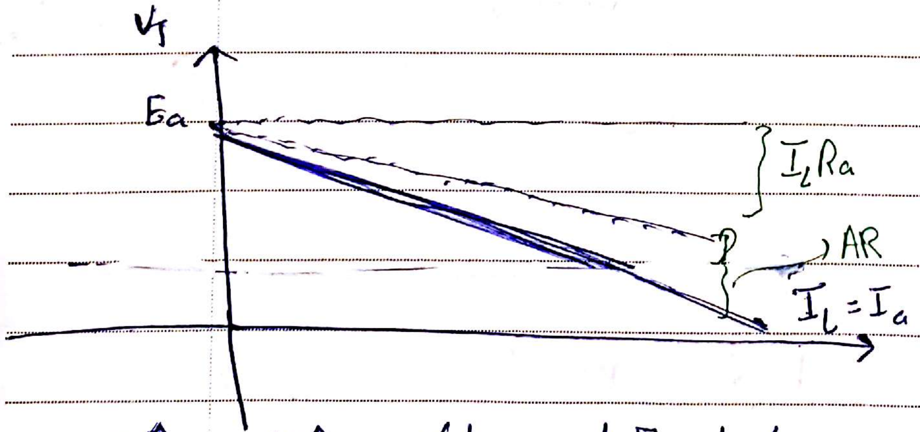
- I_f → field current
- V_f → field voltege
- R_f → field external resistance

$V_T = E_a - I_a R_A$

- V_T → terminal voltage applied to load
- E_a → internal generated voltage
- R_A → Armature



"for a Compensated DC machine [no armature reaction]"



$I_a \uparrow$ AR$\uparrow$ $\phi \downarrow$ $\downarrow E_a = k\phi\omega_m$ $V_T \downarrow$

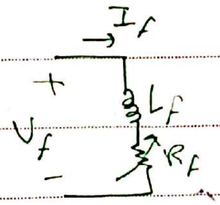
"DC Seperated excited machine with no Compensating Winding"

No.

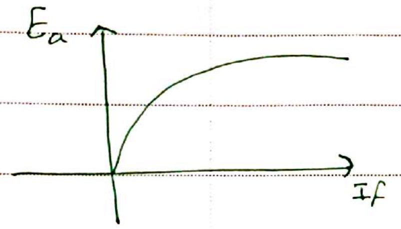
6/7/2017

* The terminal voltage of a DC sep. excited generator can be controlled by :-

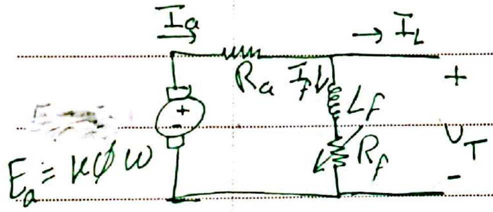
$$V_T = E_a - I_a R_a = k\phi\omega - I_a R_a$$



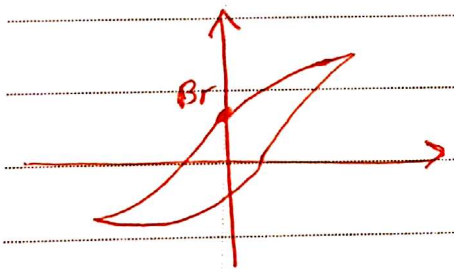
① increase the speed of rotation
② decrease the field winding resistance

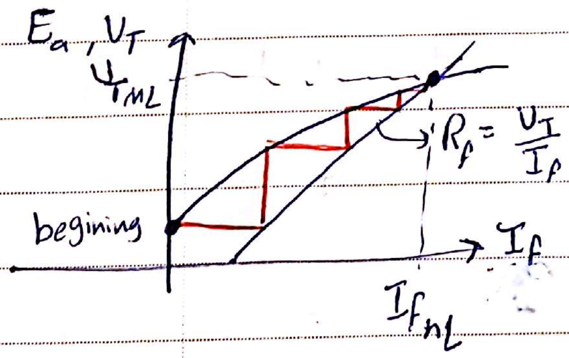


The DC shunt generator :-



$$V_T = E_a - I_a R_a$$
$$I_a = I_L + I_f$$
$$I_f = \frac{V_T}{R_f}$$





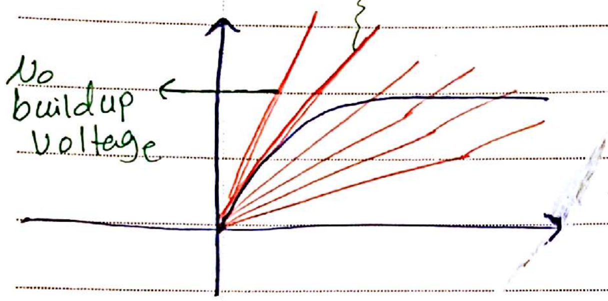
At the begining $E_a = k\phi_{res}\,\omega$

problems :-

1. if there is $B_r \rightarrow$ there is no E_a

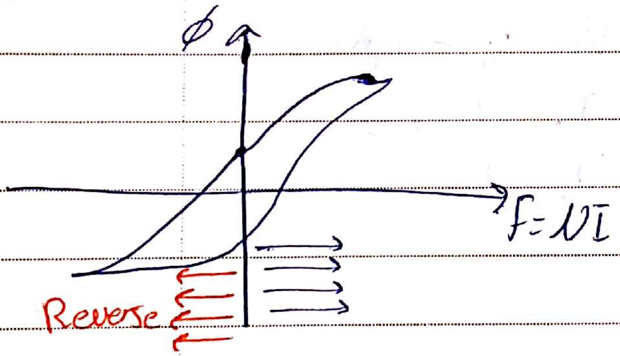
$\Rightarrow$ we need an external source. [Flashing the field].

2. critical resistance :-

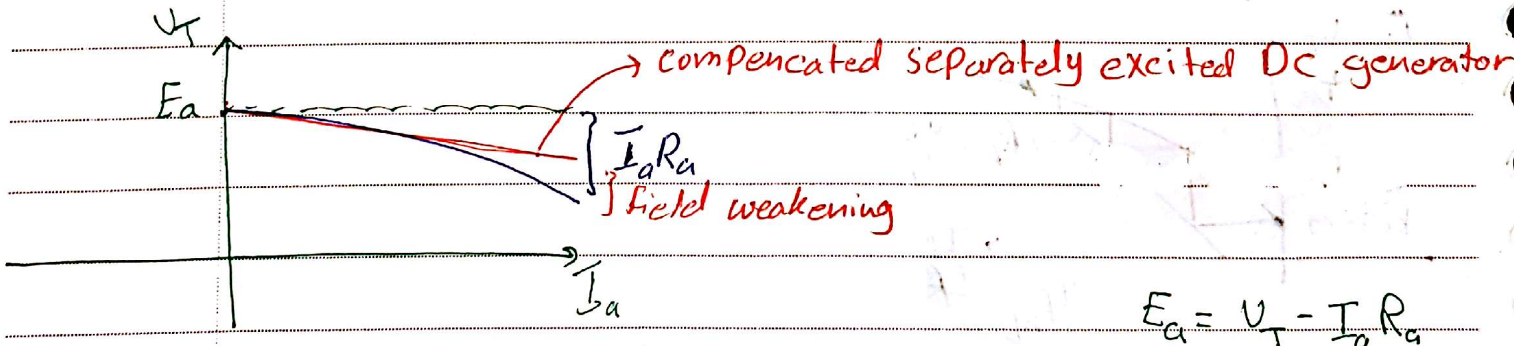


if $R_f > R_c$, there will be no buildup voltage.

3. Reverse the direction of rotation



no buildup voltage, we need external source.



$E_a = V_T - I_a R_a$

$I_a \downarrow \rightarrow V_T \downarrow \rightarrow I_f \downarrow \rightarrow \phi \downarrow \rightarrow E_a \downarrow \rightarrow V_T \downarrow$

$V_T = I_f R_f$

$VR = \frac{E_a - V_T}{V_T}$, VR in shunt is worse than "compencated separated excited DC generator"

No.

How to control V_T

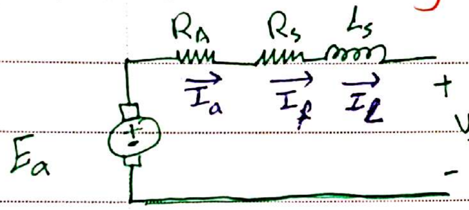
$E_a = k \phi \omega$

ϕ increase, ω increase

by changing R_f

"decrease R_f"

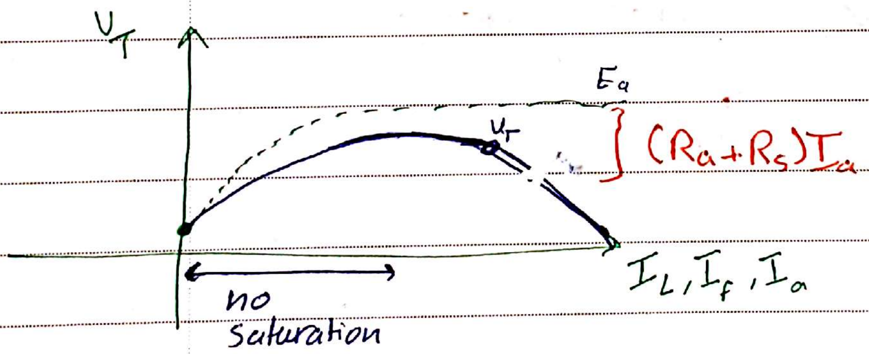
* The DC Seires generator :-



$I_a = I_f = I_L$

$V_T = E_a - I_a(R_a + R_s)$

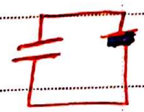
"R_s" ; Few turns with heavy wire → Should tolerate load current, don't make voltage drop.



$V_T = \uparrow E_a - \uparrow I_a (R_s + R_a)$

load → $I_a \uparrow$ → $I_f \uparrow$ → $E_a \uparrow$ this one goes first

Welding machines :-

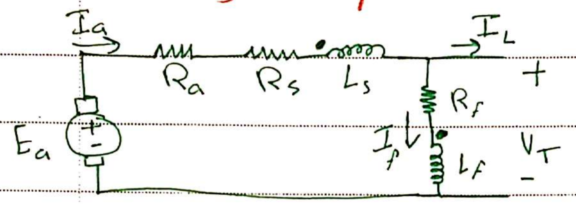


$I \uparrow$

$V = 0$

No.

* Cummubtively Compound Dc generator :-



$$I_a = I_L + I_f$$

$$V_T = E_a - I_a(R_s + R_a)$$

$$V_T = I_f R_f$$

$$f_{net} = f_{SE} + F_f - f_{AR}$$

$$\downarrow V_T = E_a - \uparrow I_a (R_a + R_s)$$

① load increase $\rightarrow I_L \uparrow \rightarrow I_a \uparrow \rightarrow V_T \downarrow$

② load increase $\rightarrow I_L \uparrow \rightarrow I_a \uparrow \rightarrow f_{SE} = I_s N_s \uparrow \rightarrow E_a \uparrow \rightarrow V_T \uparrow$

(2)

8/7/2017

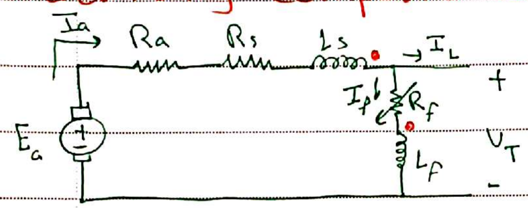
No.

How to Control DC Compound generator :-

→ $\omega\uparrow$

→ $I_a\uparrow$ by $R_f\downarrow$

* Differentially Compound DC generator.



$I_a = I_L + I_f$

$V_T = E_a - I_a(R_s + R_a)$

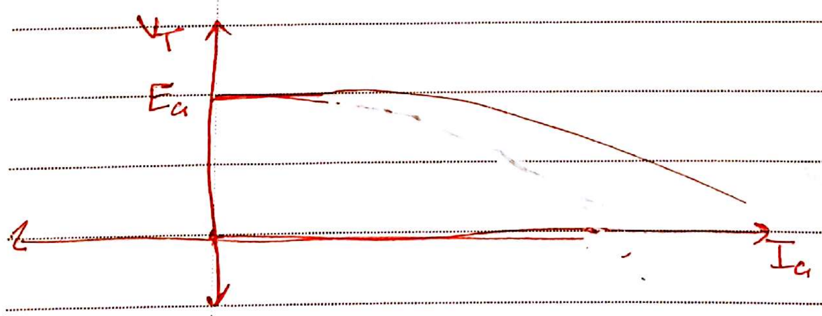
$V_T = I_f R_f$

$F_{net} = F_f - F_{SE} - F_{AR}$

$V_T = E_a - I_a(R_s + R_a)$

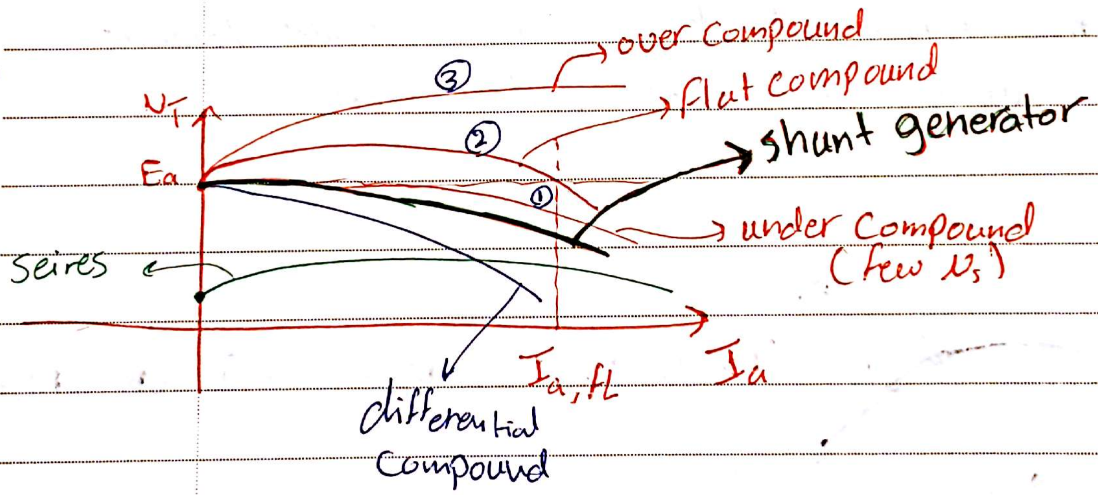
(1) $I_L\uparrow \rightarrow I_a\uparrow \rightarrow V_T\downarrow$

(2) $I_L\uparrow \rightarrow I_a\uparrow \rightarrow \uparrow F_{SE} = N_{SE} I_a \rightarrow \downarrow F_{net} \rightarrow E_a\downarrow \rightarrow \downarrow V_T$



How to Controll it ? → ω → ϕ [F_f]

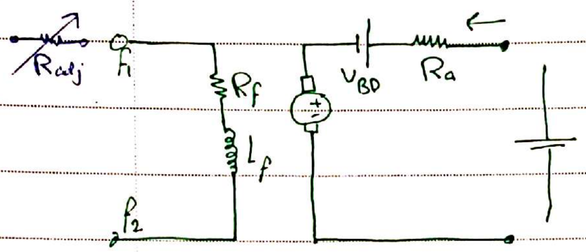
③



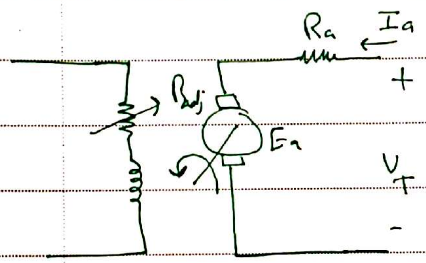
N_s Winding
① few ⇒ under Compound.
② more ⇒ flat Compound.
③ more and more ⇒ over Compound.

No.

Eq ckt for a Dc Motor :-



Simplified circuit :-



Dc motors types :-

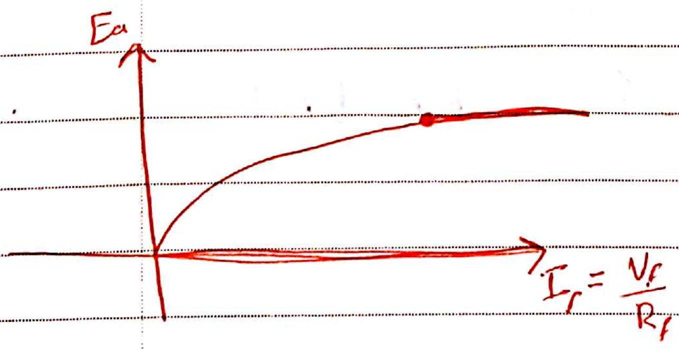
- → seperatly excited
- → shunt
- → seires
- → permanent magnet
- → compaund

(seperatly excited and shunt → the same)

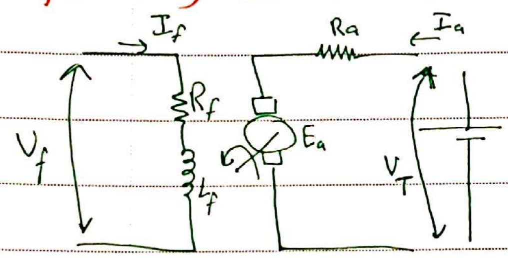
E_a → internal generated voltage

$E_a = k\phi\,\omega_m$

$\tau_{ind} = k\phi\, I_a \quad / \tau_{load}$



1 Seperately excited DC motors :-

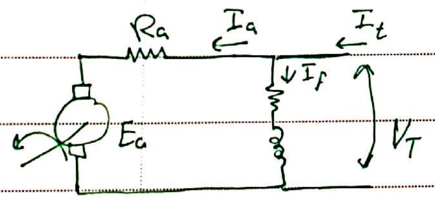


$$I_f = \frac{V_f}{R_f} \quad , \quad V_T = E_a + I_a R_a$$

$$E_a = k\phi\omega_m$$

$$\tau_{ind} = k\phi I_a$$

2 Shunt DC motor :-



$$E_a = k\phi\omega_m$$

$$\tau_{ind} = k\phi I_a$$

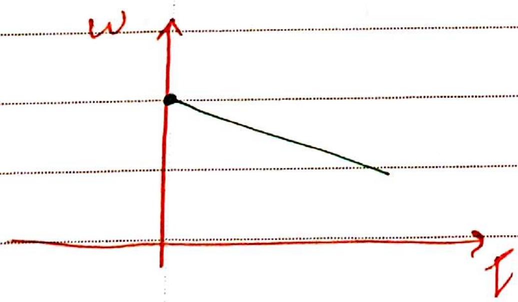
$$I_f = \frac{V_T}{R_f}$$

$$I_t = I_f + I_a$$

$$V_T = E_a + I_a R_a$$

Note :- for a generators → external characterestics are :- (V_T, I_a)

for motors → external characterestics are :- (ω, τ)



$$V_T = E_a + I_a R_a = k\phi\omega_m + \frac{\tau}{k\phi} * R_a$$

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

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No.

Before [$\tau_{load} = \tau_{ind}$]

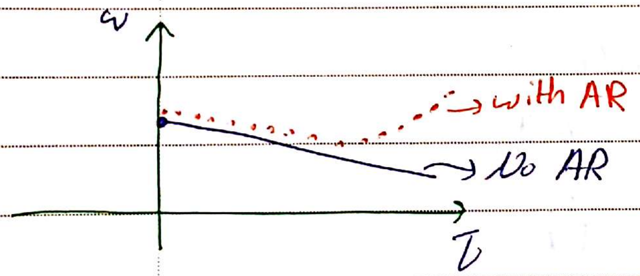
load ↑ ⟶ $\tau_{load} > \tau_{ind}$

$\omega \downarrow$ ⟶ $\downarrow E_a = k \phi \downarrow \omega_m$

$\uparrow I_a = \dfrac{V_T - \downarrow E_a}{R_a}$

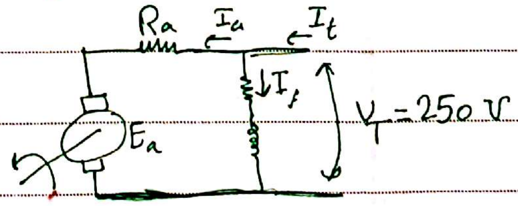
$\uparrow \tau_{ind} = k \phi \uparrow I_a$

$\boxed{\tau_{load} = \tau_{ind}}$, but at lower mechanical speed.



Example 8.1 :-

A 50 Hp (1 Hp = 746 W), 250 V, 1200 rpm DC shunt motor with compensating winding. with $R_a = 0.06\ \Omega$. it's field circuit has $R_f = 50$ which produces a no load speed of 1200 rpm. The shunt field winding has 1200 turns per pole.



Ⓐ find motor speed when input current is 100 A Ⓑ when input current = 200 A

Ⓒ $I_t = 300$ A

No.

Solution :- $E_{a_1} = k\phi\omega$

$$\frac{E_{a1}}{E_{a2}} = \frac{\omega_1}{\omega_2} = \frac{n_{m1}}{n_{m2}}$$

$$n_2 = \frac{E_{a2}}{E_{a1}} n_1$$

At no load :- $V_T = E_a = 250$

$n = 1200$ rpm

ⓐ $I_t = 100$ A

$$I_a = I_t - I_f = 100 - \frac{250}{50} = 95 A$$

$$E_a = V_T - R_a I_a = 250 - 95(0.06) = 244.3 V$$

$$n_2 = \frac{244.3}{250} \times 1200 = 1173 \text{ rpm}$$

$E_{a_1} = 250 \longrightarrow 1200$ rpm

$E_{a_2} = 244.3 \longrightarrow 1173$ rpm

ⓑ $I_t = 200$

$I_a = 195$

$E_{a_3} = 250 - 0.06(195) = 238.3$

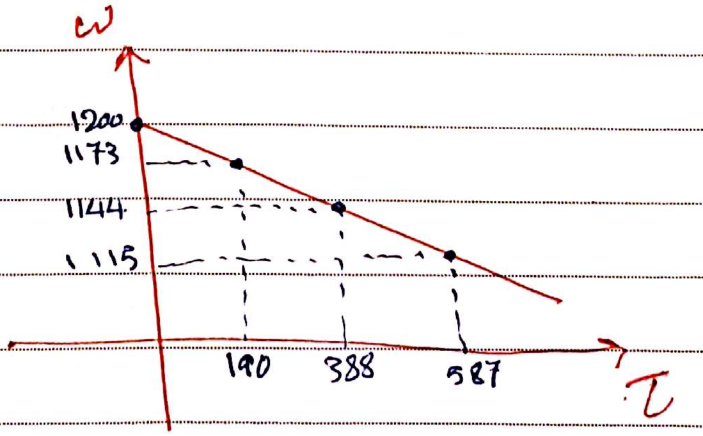
$$n_3 = \frac{238.3}{250} * 1200 = 1144 \text{ rpm}$$

ⓒ $I_t = 300$

$I_a = 295$

$E_{a_4} = 250 - 0.06 * 295$

$n_4 = 1115$ rpm



No.

$P = E_a I_a = \tau_{ind}\,\omega$

$\tau_{ind} = \frac{E_A I_a}{\omega}$

$\tau_2 = \frac{244.3 * 95}{1173 * \frac{2\pi}{60}} = 190\ N.m$

$\tau_3 = \frac{238.3 * 195}{1144 * \frac{2\pi}{60}} = 388\ N.m$

$\tau_4 = \frac{232.3 * 295}{1115 * \frac{2\pi}{60}} = 587\ N.m$

* Speed Control :-

→ Adjusting the field (R_f)

→ Adjusting the [terminal voltage].

① Adjusting the field resistence.

① $R_f \uparrow \rightarrow I_f \downarrow$

② $\phi \downarrow$

③ $E_a \downarrow = k\phi\omega$

④ $I_a \uparrow = \frac{V_T - E_a}{R_a}$

⑤ $\tau_{ind} \uparrow = k\phi I_a$

⑥ $\tau_{ind} > \tau_{load}$

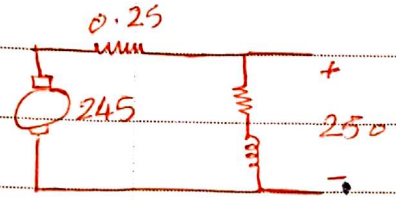
⑦ $\omega \uparrow$

⑧ $\uparrow E_a = k\phi\omega$

⑨ $I_a \downarrow$

⑩ $\tau_{ind} = \tau_{load}$ / at higher speed

Example :-



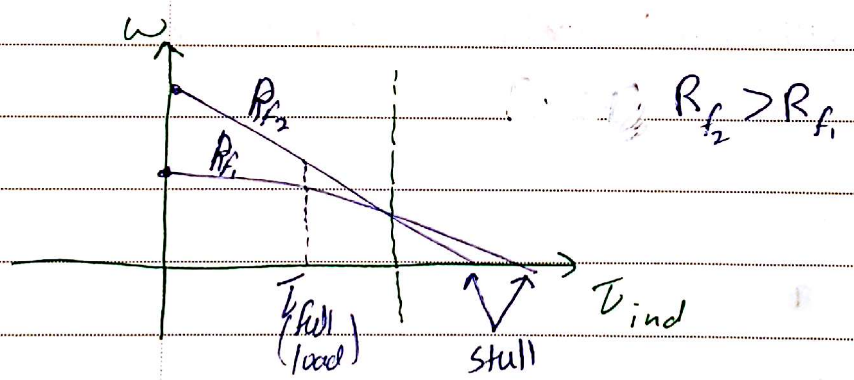
$I_a = \frac{250 - 245}{0.25} = 20\ A$

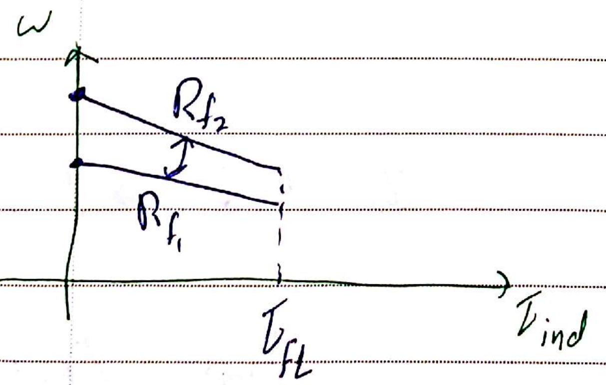
* $\phi \downarrow 1\% \rightarrow E_a = k\phi\omega \rightarrow E_a \downarrow 1\%$

$E_a' = 245 - 0.01 * 245 = 242.55$

$I_a' = \frac{250 - 242.55}{0.25} = 29.8$ (49%) $\frac{29.8 - 20}{20} = 49\%$

* $\tau_{ind} = k\,\phi\downarrow I\uparrow$; I_a increase dominate ϕ decrease.





No.

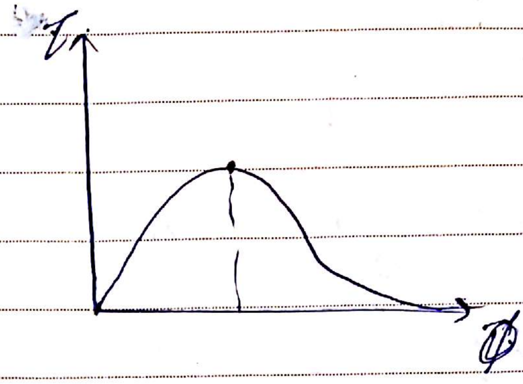
Explainations :-

(I doesn't dominate)

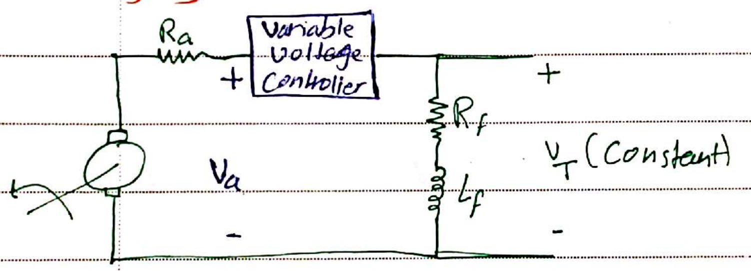
① $\tau_{ind} = k \downarrow \phi \downarrow I_a$

② $w = \frac{V_T}{k\phi} - \frac{R_a}{(k\phi)^2}\tau_{ind}$

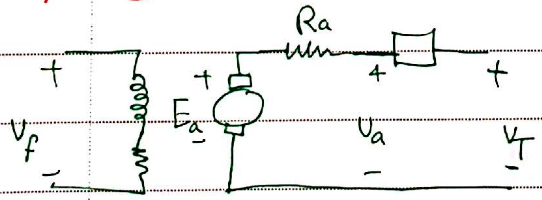
$w = \frac{\alpha}{x} - \frac{\beta}{x^2}$



II changing the armature voltage.



⇒ to maintain voltage stability, this technique is used for seperatly excited DC motors.



① $V_A \uparrow \longrightarrow I_a \uparrow = \frac{V_a - E_a}{R_a}$

② $I_a \uparrow \longrightarrow \tau_{ind} \uparrow = k\phi I_a$

③ $\tau_{ind} > \tau_{load}$

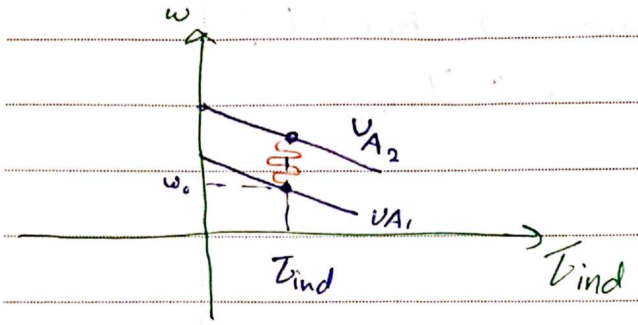
④ $\uparrow E_a = k\phi w \uparrow$

⑤ $\downarrow I_a = \frac{V_A - E_a}{R_a}$

⑥ $I_a \downarrow \rightarrow \tau_{ind} \downarrow$

$\tau_{ind} = \tau_{load}$ at higher w

No.

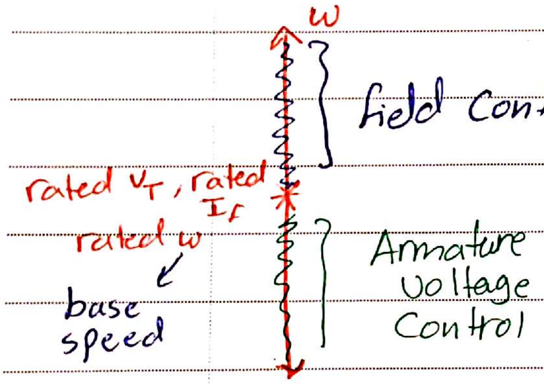


$V_{A_2} > V_{A_1}$

They are parallel, the slope doesn't change.

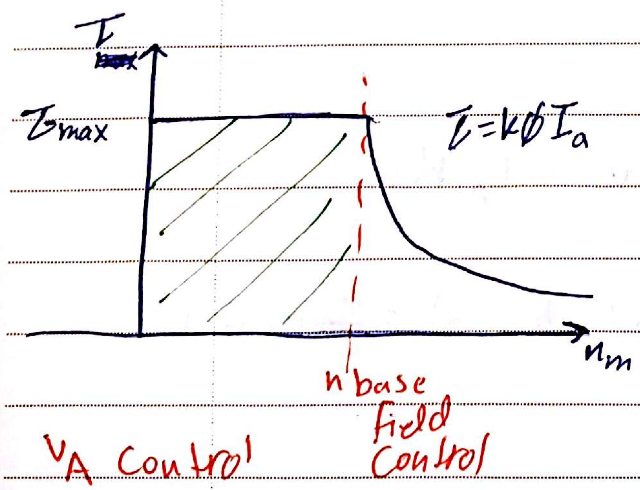
→ these two methods have different safe ranges of operations.

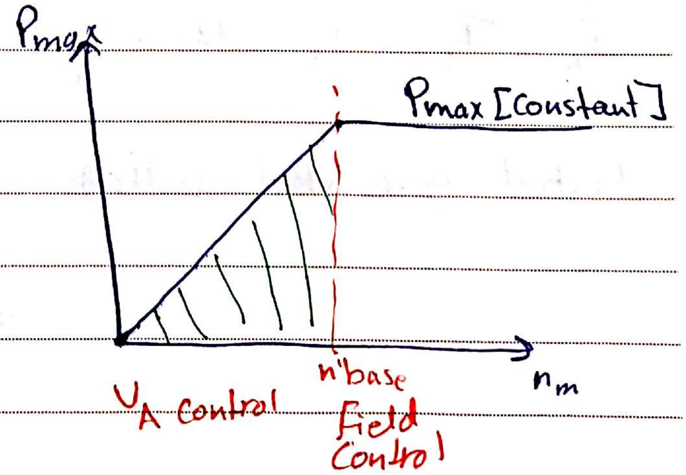
→ those methods are complementary



* if we used field control to make "ω" lower, the wire could burn because I_a increases to a very high value.

⇒ shunt motors have excellent speed control characterestics.





$$P_{max} = \tau_{max}\,\omega$$

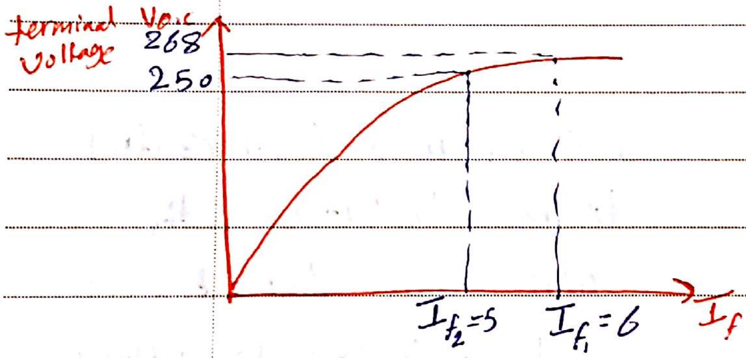
No.

The limiting factor is Armature winding heating $[I_a]$

$\tau_{ind} = k\phi I_a$ $\qquad$ $\tau_{ind\,max} = k\phi I_{a[max]}$

Example 8.3 :-

100 hp, 250 v, 1200 rpm, DC shunt motor with $R_a = 0.03\ \Omega$ and $R_f = 41.67$. No AR. The motor is driving a load with a line current 126 A $[I_L]$, and initial speed of 1103 rpm. Assume that I_a is constant and magnetization curve is as follows



① What is the motor speed if the field resistance is increased to $50\ \Omega$:-

$I_{A_1} \longrightarrow$ before increasing R_f to $50\ \Omega$

$$I_{A_1} = I_t - I_f = 126 - \frac{250}{41.67} = 120\ \Omega$$

Initial generated voltage $= E_{A_1} = V_T - I_{A_1} R_a$

$$= 250 - (120)(0.03) = 246.4\ V$$

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$I_{A_2} = I_t - I_{f_2} = 126 - \frac{250}{50} = 121\,A$

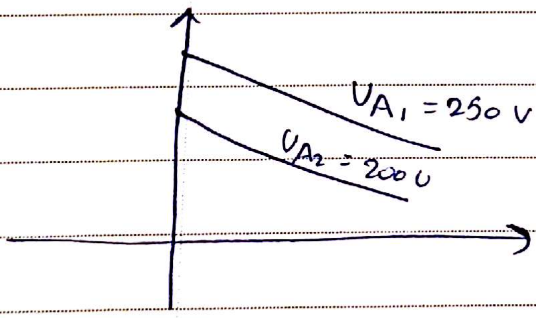
$E_{A_2} = V_T - I_{a_2} R_a = 250 - (121)(0.03) = 246.37\,V$

$\frac{E_{a_1}}{E_{a_2}} = \frac{k\phi_1 n_1}{k\phi_2 n_2}$ $\qquad E_{a_1} \approx E_{a_2}$

$n_2 = \frac{\phi_1}{\phi_2} n_1 = \frac{268}{250} * 1103 = 1187\ rpm$

$\phi(I_{f_1} = 6) = 268$
$\phi(I_{f_2} = 5) = 250$

② If the motor, then, is Connected as seperatly excited DC motor and it is initially running at $V_A = 250\,V$, $I_a = 120\,A$ $n = 1103$ rpm, while supplying a Constant torque load, find the motor speed if $V_a = 200\,V$



$\frac{E_{A2}}{E_{A1}} = \frac{k\phi_2 n_2}{k\phi_1 n_1}$

$E_{A_1} = V_A - I_a R_a$
$= 250 - (120)(0.03)$

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

$n_2 = \frac{E_{a2}}{E_{a1}} n_1 = \frac{200 - (120 * 0.03)}{250 - (120 * 0.03)} * 1103 = 879\ rpm$

→ what happens if there is an open Circuit in the field winding in a Shunt on seperately excited DC motor.

$$\uparrow \omega = \frac{V_T}{k\phi} - \frac{R_a}{(k\phi)^2} \tau_{ind}$$

runway motor
(when $\phi = 0 \rightarrow \omega = \infty$)

we need a Solution
[breaking]

→ If the motor is not Comp
AR → weakening the field
$\omega \uparrow \rightarrow$ load increase $\rightarrow I_a \uparrow \rightarrow AR \uparrow \rightarrow \omega \uparrow\uparrow\uparrow$

breaking

9/7/2017

No.

* the previous example (a better Solution)

$E_{a_2} = V_T - I_{A_2} R_a$

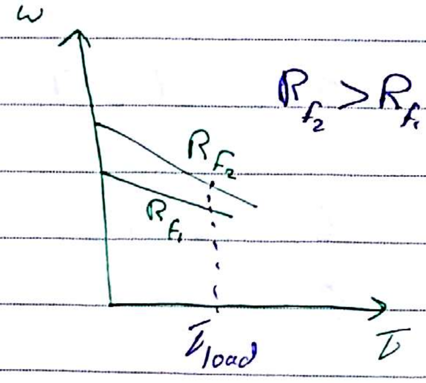
$\frac{\tau_2}{\tau_1} = \frac{k \phi_2 I_{a_2}}{k \phi_1 I_{a_1}}$

τ_{load} is Constant then $\frac{\tau_2}{\tau_1} = 1$

$\Rightarrow 1 = \frac{I_{f_2} I_{a_2}}{I_{f_1} I_{a_1}}$

$I_{a_2} = 144 A$

$E_{a_2} = 250 - (144)(0.03) = 245.7$



$\frac{245.7}{246.4} = \frac{6}{5} \frac{n_2}{1103}$

$n_2 = 1320$ rpm

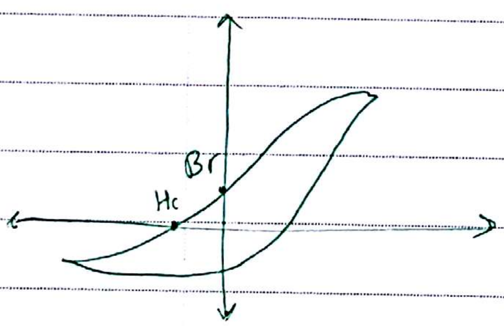
* Permenant magnet Dc motor :-

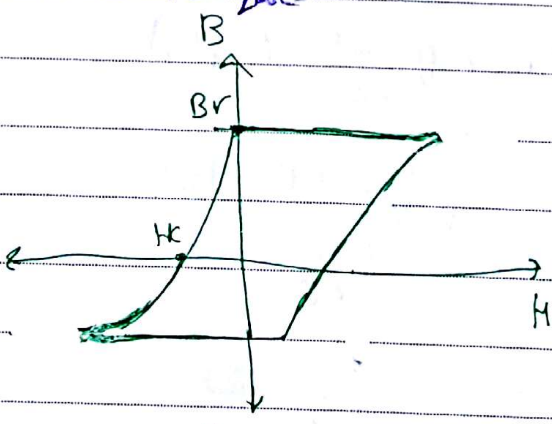
advantages :-

1. No field circuit Copper losses.
2. The structure is smaller in size.

disadvantages :-

1. There is always a risk of demagnetization due to heat AR.
2. produce weaker flux → less induced torque





"for permanant magnet"

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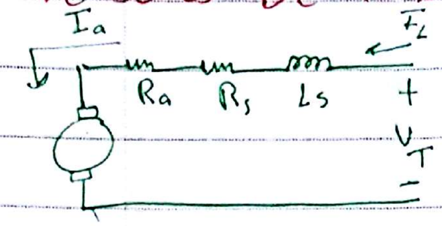
No.

* The seires Dc motor



$$I_L = I_a = I_s$$

$$V_T = E_a + I_a(R_a + R_s)$$

$$\tau_{ind} = k\phi I_a$$

$$\phi = F(I_a)$$

$$\phi = C I_a$$

C → Constant

$$\tau_{ind} = k\,C(I_a)^2$$ → as τ depends only on the square of I_a, we use this τ in elevators. Also, ω is Constant.

$$E_a = k\phi\omega$$

$$I_a = \sqrt{\frac{\tau_{in}}{kc}}$$

$$V_T = E_a + I_a(R_a + R_s)$$

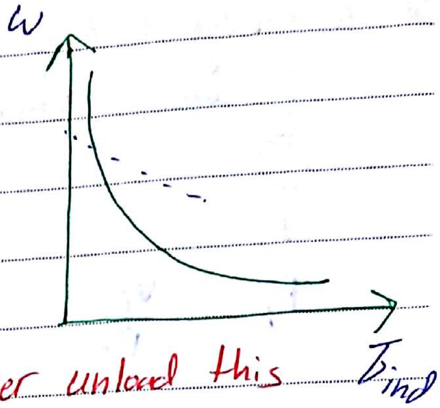
$$V_T = k\phi\omega + \sqrt{\frac{\tau_{ind}}{kc}}\,(R_a + R_s)$$

$$\omega = \frac{V_T}{k\phi} - \frac{\sqrt{\frac{\tau_{ind}}{kc}}\,(R_a + R_s)}{k\phi}$$

$$\phi = C I_a = c\sqrt{\frac{\tau_{ind}}{kc}}$$

No.

$$\omega = \frac{V_T}{kc\sqrt{\frac{\tau_{ind}}{kc}}} - \sqrt{\frac{\tau_{ind}}{kc}}\;\frac{(R_a+R_s)}{kc\sqrt{\frac{\tau_{ind}}{kc}}}$$



$$\omega = \frac{V_T}{\sqrt{kc}}\,\frac{1}{\sqrt{\tau_{ind}}} - \frac{R_a+R_s}{kc}$$

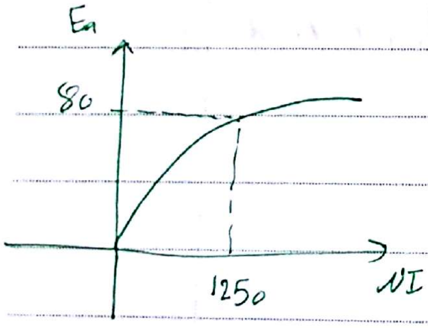
$$y = \frac{1}{\sqrt{x}}\,\alpha + \beta$$

Never unload this type of motors as τ_{ind} goes to zero, ω goes to ∞.

* to control the speed :
→ change the terminal voltage.

Example 8.5 or 8.6 :-

250 v seires DC motor with compensating winding has $R_a+R_s = 0.8\Omega$ and a seires field of 25 turns per pole. Find the speed and induced torque of this motor. when it's armature current = 50 A and has 1200 rpm.



$I_f = 50A \quad N = 25 \quad NI = 1250 = 25*50$

[No load Condition]

$\tau_{load} = 0$

→ what happens when $I_a = 50$?!

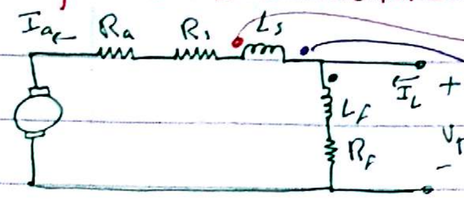
$$E_{a_2} = V_T - I_a(R_a+R_s) = 250 - 50*0.08 = 246$$

$$n_2 = \frac{E_2}{E_1} n_1 = \frac{246}{80} * 1200 = 3690 \text{ rpm}$$

$$\tau_{ind} = \frac{P_{conv}}{\omega} = \frac{VI}{\omega} = \frac{246*50}{3690*\frac{2\pi}{60}} = 31.8 \text{ N.m}$$

No.

* Compound DC motors



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

$$V_T = E_a + I_a(R_a + R_s)$$

$$I_L = I_a + I_f$$

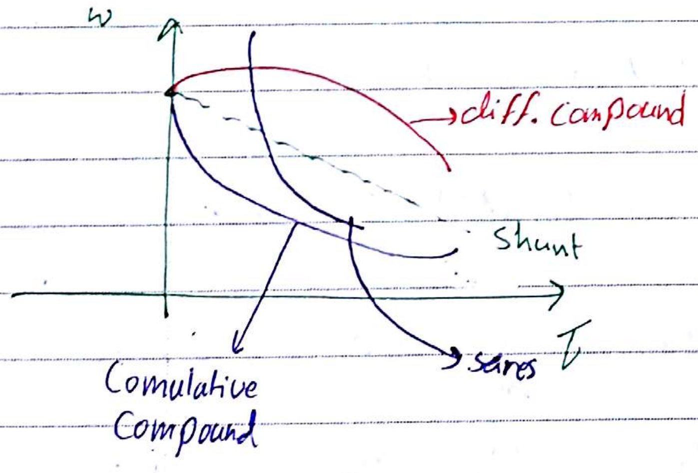
$$F_{net} = F_f \pm F_{SE} - F_{AR}$$

(+ → Comulative, − → differential)

$$V_T = k\phi\omega + \frac{\tau_{ind}}{k\phi}(R_a + R_s)$$

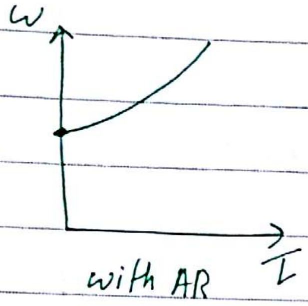
$$\omega = \frac{V_T}{k\phi} - \frac{(R_a+R_s)}{(k\phi)^2}\tau_{ind}$$

[just like Shunt motor]



No.

Dc diff Compound motors are not recognized internationally as stable motors



$I\uparrow \rightarrow I_a\uparrow \rightarrow AR\uparrow$

How to Control it ?!
① field
② terminal voltage Controller

$I_f = \frac{V_T}{R_f}$ → decrease V_T to decrease I_f
→ increase R_f to decrease I_f

* Dc motor starting
→ we need protection and control devices.
[1] protect the motor from long-term overload.
[2] protect against high starting currents.
[3] Control the speed.
[4] protect it from equipment short circuit.

At starting the motor is not running $[n_m = 0]$
→ $E_a = 0$
→ R_a is very low $I_a = \frac{V_T - E_a}{R_a} = \frac{V_T}{R_a}$

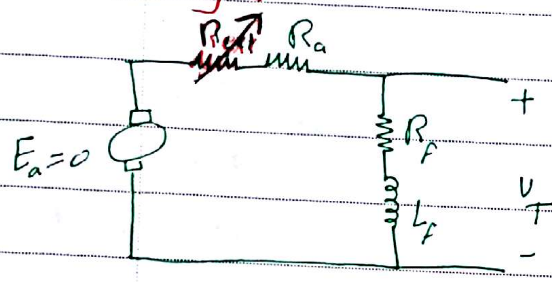
No.

(ex) 50 hp, 250 V DC motor with $R_a = 0.06$, $I_a = 200A$ is the rated armature current.

$$I_{a(start)} = \frac{250}{0.06} = 4167\ A$$

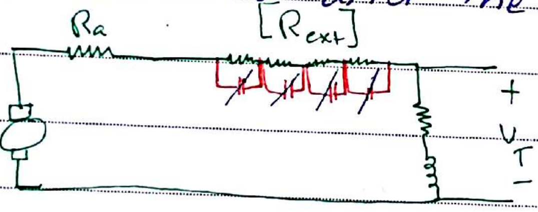
very high valle

at starting :-



Solution :- ① Rext
② V_T,

R_{ext}, must be removed after the motor runs on its rated speed.



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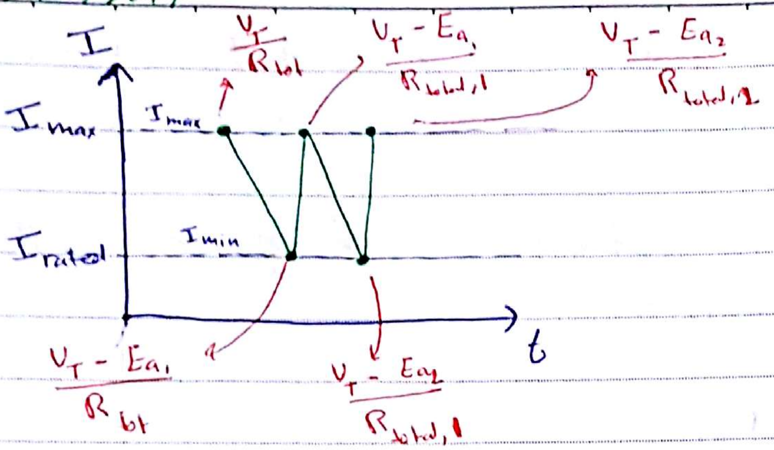


$R_{tot,1} = R_a + R_2 + R_3 + R_4 \qquad R_{tot,2} = R_a + R_3 + R_4$

$\rightarrow I_{min} R_{tot} = I_{max} R_{tot,1} = V_T - E_{a_1}$

$$R_{tot,1} = \frac{I_{min}}{I_{max}} R_{tot}$$

$\rightarrow I_{min} R_{tot,1} = V_T - E_{a_2} = I_{max} R_{tot,2}$

$$R_{tot,1} = \frac{I_{max}}{I_{min}} R_{tot,2}$$

$$\frac{I_{max}}{I_{min}} R_{tot,2} = \frac{I_{min}}{I_{max}} R_{tot}$$

$$R_{tot,2} = \left(\frac{I_{min}}{I_{max}}\right)^2 R_{tot}$$

$$\boxed{R_{tot,n} = \left(\frac{I_{min}}{I_{max}}\right)^n R_{tot}}$$

No.

(ex) 8- 100 hp, 250 V, 350 A, Shunt DC motor with $R_a = 0.05\,\Omega$, needs a starter, that will limit the max starting current $(I_r * 2) = 700$

A) How many stages (n) of starting R will be required to limit the current to the value specified.

$$R_{tot,n} = \left(\frac{I_{min}}{I_{max}}\right)^n R_{tot}$$

R_a ↙

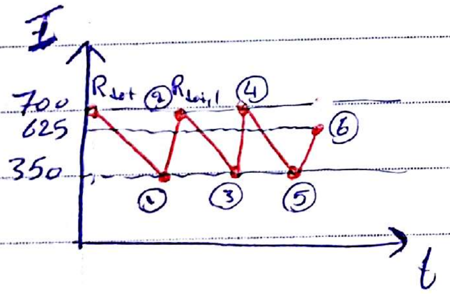
$$\frac{R_a}{R_{tot}} = \left(\frac{I_{min}}{I_{max}}\right)^n$$

$$n = \frac{\log(R_a/R_{tot})}{\log(I_{min}/I_{max})} = \frac{\log(0.05/0.357)}{\log(350/700)} = 2.85 \approx 3$$

Always round up

$$R_T = \frac{V_T}{I_{max}} = \frac{250}{700} = 0.357$$

B) what is the value of each segment and when I have to cut it out.



① $I_{min} = \frac{V_T - E_{a_1}}{R_{tot}}$

② $R_{tot,1} = \frac{250 - 125}{700} = 0.1786\,\Omega$

$E_{a_1} = V_T - I_{min}(R_{tot})$

$= 250 - (350)(0.357) = 125$ V

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No.

③ $U_T - E_{a_2} = R_{tot,1} (I_{min})$

$E_{a_2} = 187.5 \ V$

④ $R_{tot,2} = \frac{250-187.5}{700} = 0.0893 \ \Omega$

⑤ $E_{a_3} = U_T - I_{min} (R_{tot,2})$

$= 250 - (350)(0.0893)$

$= 218.75 \ \Omega$

⑥ when R_3 is disconnected, only R_a exist.

$I_a = \frac{250 - 218.75}{0.05} = 625 \ A$

$R_3 = R_{tot,2} - R_a = 0.0393$

$R_2 = R_{tot,1} - R_a - R_3 = 0.1786 - 0.05 - 0.0393 = 0.0893 \ \Omega$

$R_1 = R_{tot} - R_a - R_2 - R_3 = 0.1786 \ \Omega$

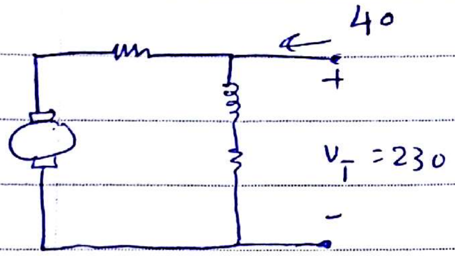
disconnect $\Rightarrow$ R_1 when $E_{a_1} = 125$

R_2 when $E_a = 187.5$

R_3 when $E_a = 218.75$

No.

ex :- A 12 hp, 230 v Shunt motor takes full load current = 40 A the armature and field windings are 0.25 and 230 Ω resp. the total brush contact drop $V_{BD} = 2$, and core and friction losses = 380 w, Calculate the efficiency of the motor.



$P_{in} = 230 * 40 = 9200 W$

$I_f = \frac{V_T}{R_f} = \frac{230}{230} = 1 A$

$I_a = 39 A$

$E_a = V_T - I_a(R_a) - V_{BD} = 230 - (39 * 0.25) - 2 = 218.25 V$

$P_{out} = E_a I_a - P_{c+f} = 218.25 * 39 - 380 = 8131.75$

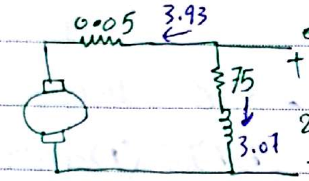
$\eta = \frac{P_{out}}{P_{in}} * 100\% = \frac{8131.75}{9200} * 100\% = 88.39\%$

No.

(EX): 230V shunt motor has $R_a = 0.05\,\Omega$, $R_f = 75\,\Omega$, the motor draws 7 A of line current while running at 1120 rpm.

A) what is the motor speed when it is loaded and $I_L = 46\,A$

$$\frac{E_{a1}}{E_{a2}} = \frac{k\phi_1 \omega_1}{k\phi_2 \omega_2} \qquad [\phi_1 = \phi_2]$$



$$I_f = \frac{230}{75} = 3.07$$

$$E_{a1} = 230 - (0.05)(3.93)$$
$$E_{a2} = 230 - (0.05)(42.93)$$

$$\frac{E_{a1}}{E_{a2}} = \frac{n_1}{n_2} = \frac{229.8}{227.85} = \frac{1120}{n_2}$$

$$n_2 = \frac{(227.85)(1120)}{229.8} = 1110.5 \text{ rpm}$$

B) At this load, if the field circuit $R = 100\,\Omega$, what is the new speed of the motor.

$$\frac{E_{a2}}{E_{a3}} = \frac{k\phi_2 \omega_2}{k\phi_3 \omega_3} = \frac{I_{f_2} n_2}{I_{f_3} n_3} \Rightarrow I_{f_3} = \frac{230}{100} = 2.3\,A$$

$$n_3 = I_{f_2} n_2 \frac{E_{a3}}{E_{a2}} = \frac{(3.07)(1110.5)(227.815)}{227.85}$$

$$E_{a_3} = 230 - I_{a_3} R_a = 230 - (46 - 2.3)(0.05) = 227.815$$

$$n_3 = 1483 \text{ rpm}$$

No." CHapter 3 "

11/7/2017

Ac machines

→ generators

P_{mech} (T, ω) → [ ] → V, I Ac(3ϕ, 1ϕ)

→ synchronous

→ motors

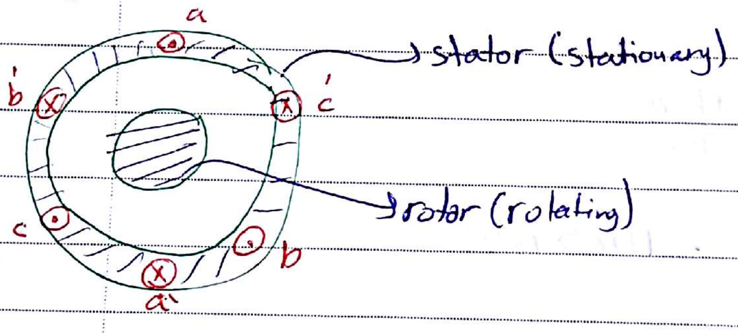
V, I 3ϕ, 1ϕ → [ ] → P_{mech} (T, ω)

→ induction (mainly as motors)

→ IG (Induction generator)

→ DFIG (Doubly fed induction generator)

* Synchronous machine structure :-

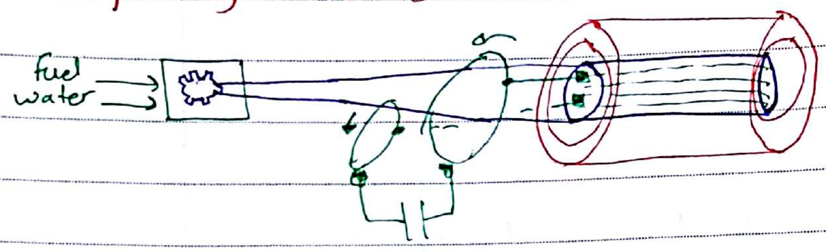


Winding

→ field [the ones that creat the magnetic field]

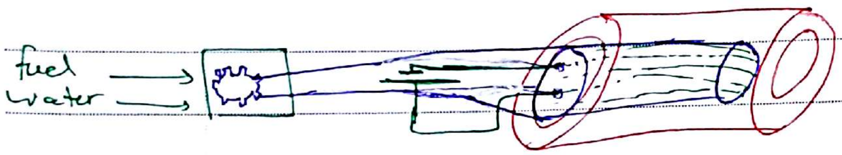
→ Armature [winding where the voltage is induced]

① slip rings and brushes

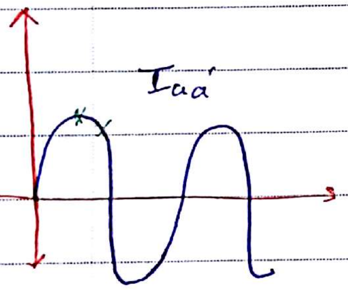


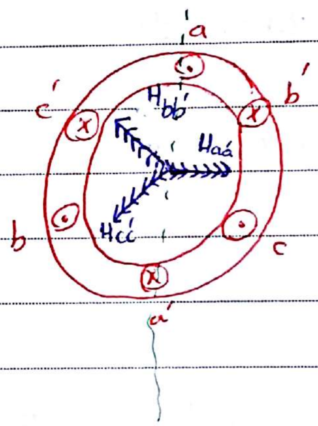
"excitation" system

② DC sourse [may be an AC scoure + rectifier] is mounted directly on the shaft



* Rotating magnetic field :-





suppose :-

$i_{aa'} = I_m \sin \omega t$

$i_{bb'} = I_m \sin(\omega t - 120)$

$i_{cc'} = I_m \sin(\omega t + 120)$

$B = \mu H$

$H_{aa'} = H_m \sin \omega t \angle 0°$

$H_{bb'} = H_m \sin(\omega t - 120) \angle 120°$

$H_{cc'} = H_m \sin(\omega t + 120) \angle -120$

$B_{aa'} = B_m \sin(\omega t) \angle 0°$

$B_{bb'} = B_m \sin(\omega t - 120) \angle 120°$

$B_{cc'} = B_m \sin(\omega t + 120) \angle -120$

120
90
210

No.

$B_{net} = B_{aa'} + B_{bb'} + B_{cc'}$

→ $\omega t = 0$

$B_{aa'} = 0$

$B_{bb'} = B_m \sin(-120) \angle 120 = -\frac{\sqrt{3}}{2} B_m [\cos 120 + j \sin 120]$

$B_{cc'} = B_m \sin(120) \angle -120 = \frac{\sqrt{3}}{2} B_m [\cos -120 + j \sin -120]$

$B_{net} = 1.5 B_m \angle -90°$

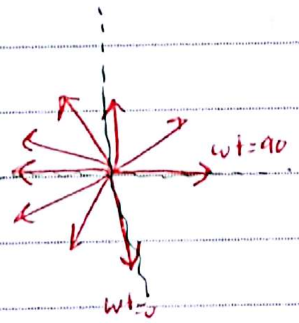
→ $\omega t = \frac{\pi}{2} = 90°$

$B_{aa'} = B_m \angle 0$

$B_{bb'} = B_m \sin(-30) \angle +120$

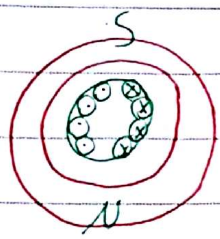
$B_{cc'} = B_m \sin(210) \angle -120$

$B_{net} = 1.5 B_m \angle 0$



⇒ This is called rotating magnetic field

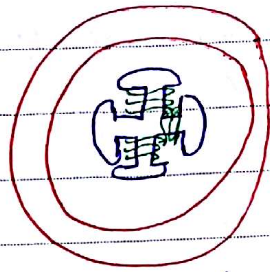
Cylindrical



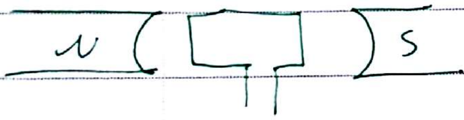
2 pole structure

*2 or 4 poles

Salient pole

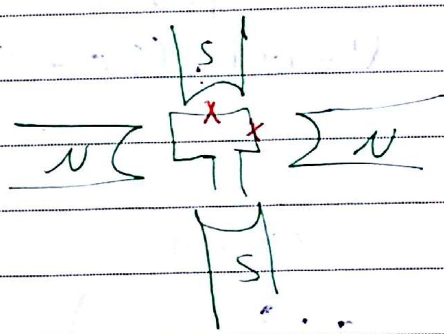


* 4 poles and up



180 electric degree

180 mech degree ;



$\theta_{mech} = 90°$

$\theta_e = 180°$

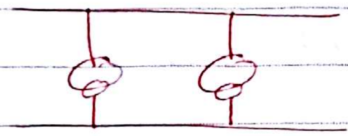
$$\theta_e = P\,\theta_m$$

pole pairs ← (P)

12/7/2017

No.

TR paralleling conditions :-

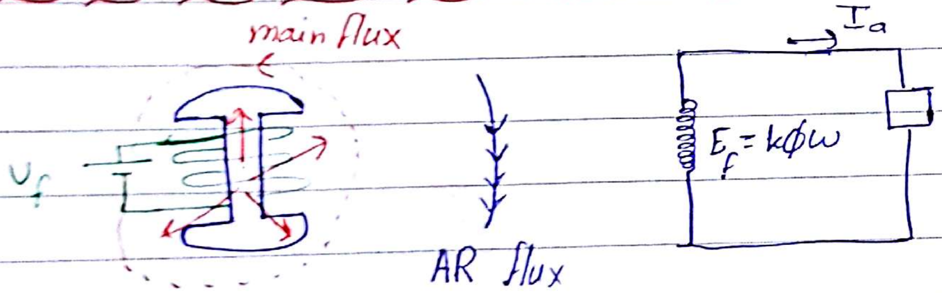


1. Same voltage level.
2. Same phase sequence.
3. Same vector group.
4. Same Z %.

In motors :-

$$SR \text{ (speed regulation)} = \frac{n_{nL} - n_{FL}}{n_{FL}} * 100\%$$

Suggested problems for CH.8 :-
(1-17), (20-23), (27)

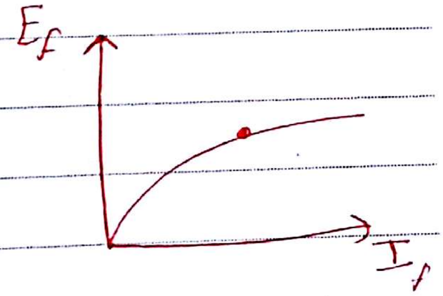


$$\phi_g = \phi_f + \phi_s$$

(ϕ_s → AR)

$$n_s = \frac{60 f}{P}$$

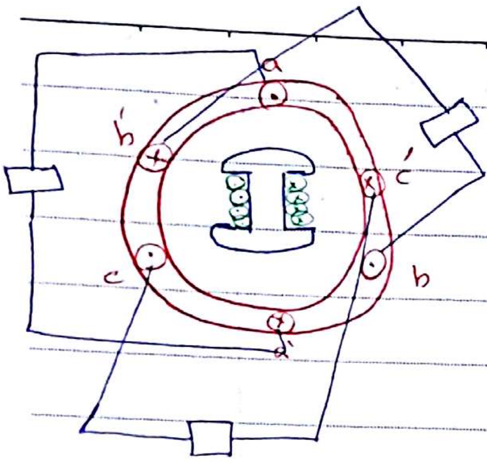
P → pole pairs

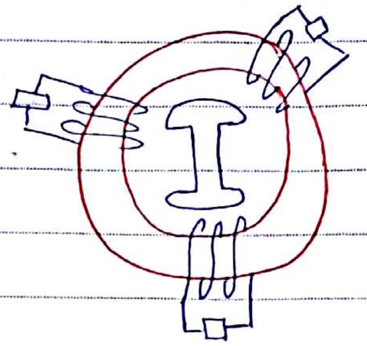


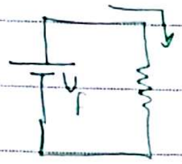
$$E_{rms} = 4.44 f N_{ph} \phi_p k_w$$

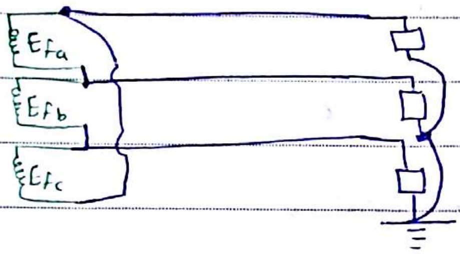
$$k_w = k_p k_d$$

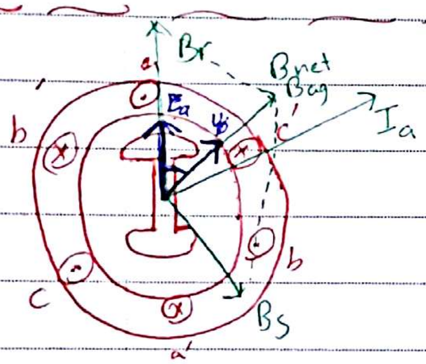
k_p → pitch factor, k_d → distribution factor

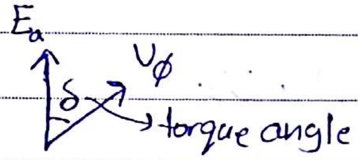

a
b'
c'
c
b
a'



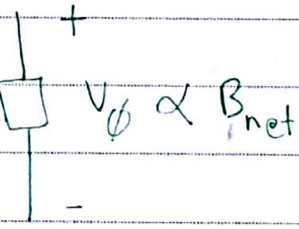

V_f


E_{fa}
E_{fb}
E_{fc}

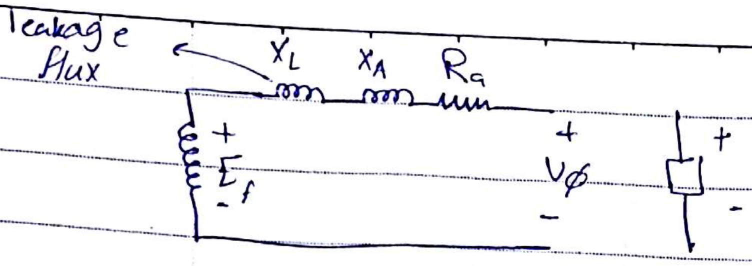

B_r
B_{net}
B_{ag}
I_a
E_a
B_s
a
b
c
c'
b
a'


E_a
V_ϕ
δ
torque angle

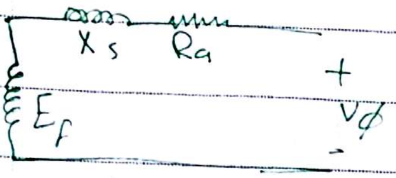

$E_f \propto B_r$


+
$V_\phi \propto B_{net}$
-

No.



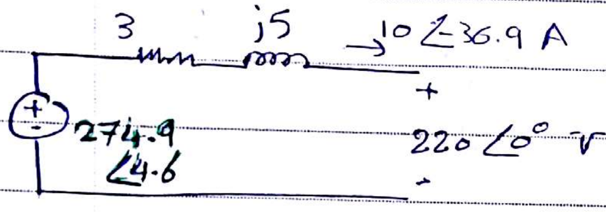
(no load → $E_f = V_\phi$)



$X_s = X_L + X_a$

X_s = synchrounous reactance

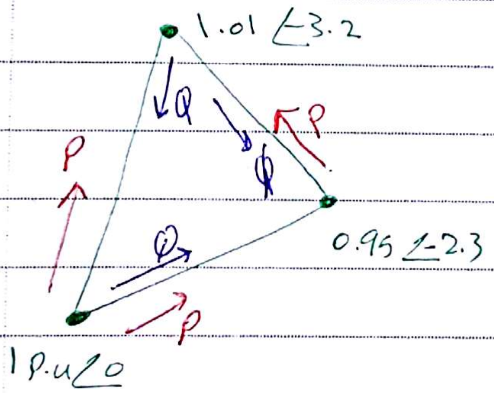
$$\vec{E}_f \angle\delta = I_a(X_s + R_a) + V_\phi \angle 0^\circ$$



$$E_f = I_a(X_s + R_a) + V_\phi$$

$$= 220 + 10\angle{-36.9}\,(3 + j5)$$

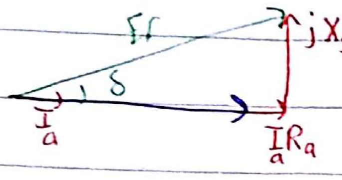
$$= 274.9\ \angle 4.6^\circ$$



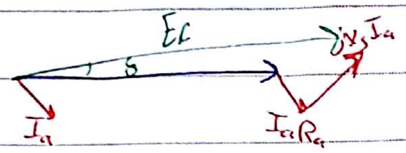
δ الأعلى هي التي تبعث الطاقة.

φ تعتمد على الفولتية الأعلى.

No.



unity p.F



lagging p.F → smallest δ

leading p.F → biggest δ

*power and torque in synchronus generator

power → prime mover

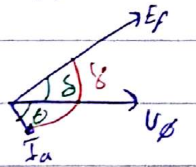
mechanical power ←

$$P_{in} = \tau_{app}\,\omega_m$$

$$P_{out} = \sqrt{3}\, V_T\, I_L \cos\theta$$

V_T: line to line voltage; I_L: line current of the stator

$$P_{in} = 3\, E_A I_A \cos\gamma$$



$\gamma = \delta + \theta$

$P_{in} = \tau\,\omega_m = 3 E_a I_a \cos\gamma \rightarrow 3 V_\phi I_\phi \cos\theta$

(stray losses, friction, core losses, I^2R copper losses)

$$Q_{out} = \sqrt{3}\, V_T I_L \sin\theta$$

13/7/2017

No.

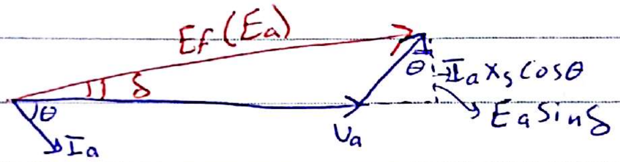
$P_{out} = \sqrt{3}\, V_T I_L \cos\theta \rightarrow$ line

$= 3\, V_p I_\phi \cos\theta \rightarrow$ phase

$Q_{out} = \sqrt{3}\, V_T I_L \sin\theta \rightarrow$ line

$= 3\, V_\phi I_\phi \sin\theta \rightarrow$ phase

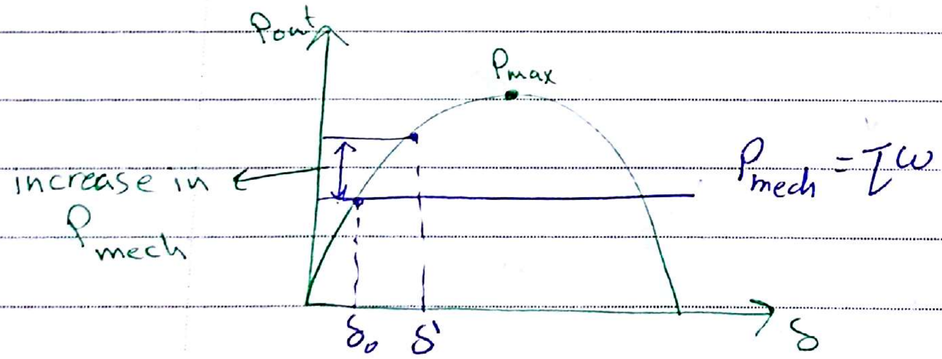
In real synch gen. $\Rightarrow R_a \lll X_s$



$\Rightarrow E_a \sin\delta = I_a X_s \cos\theta$

$P_{out} = 3\, V_T I_a \cos\theta = 3\, V_T \dfrac{E_a}{X_s} \sin\delta$

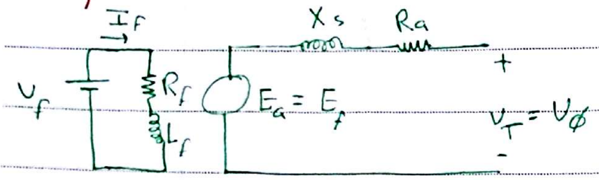
$P_{max} = \dfrac{3 V_T E_a}{X_s}$



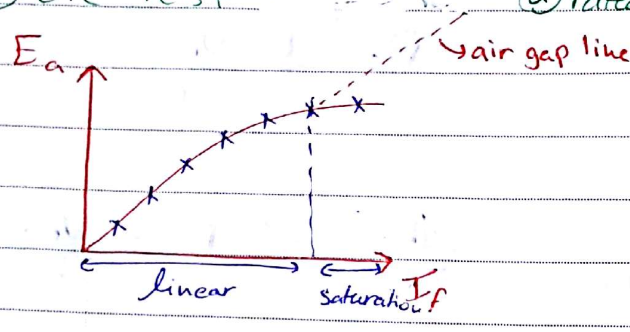
$\tau = \dfrac{3 V_T E_a \sin\delta}{X_s \omega_m}$

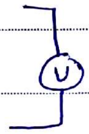
No.

* parameter determination in a synchronous gen.

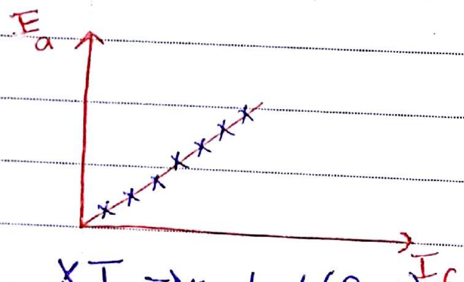


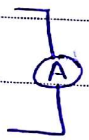
① o.c Test @ rated speed





② S.c test @ rated speed





$X_s I_a \Rightarrow$ neglect (R_a, X_l)

At any value of IR

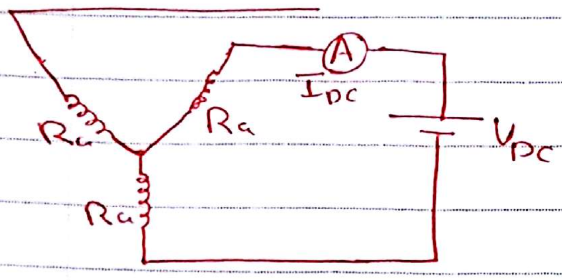
$$jX_s + R_a = Z_s = \frac{V_{o.c}}{I_{s.c}}$$

No.

عشان تقدر تحلل X_s

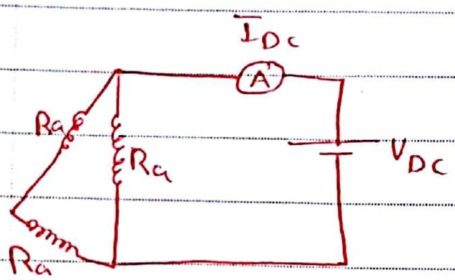
Find R_a using DC test [generator is not running]

$\omega = 0 \Rightarrow E_a = 0$



$$2R_a = \frac{V_{DC}}{I_{DC}}$$

$$R_a = \frac{1}{2}\frac{V_{DC}}{I_{DC}}$$



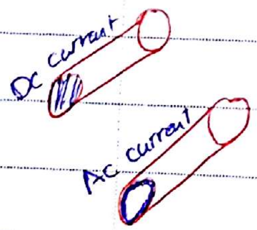
$$\frac{2(R_a)^2}{3R_a} = \frac{2}{3}R_a = \frac{V_{DC}}{I_{DC}}$$

$$R_a = \frac{3}{2}\frac{V_{DC}}{I_{DC}}$$

$$|Z_s| = \frac{V_{o.c}}{I_{s.c}}$$

$$R_a = R_{DC}$$

$$X_s = \sqrt{Z_s^2 - R_a^2}$$



$$R_{AC} > R_{DC}$$

* بقرأ V_{LL} و I_L

إذا Δ ← $\frac{I}{\sqrt{3}}$ و V

إذا Y ← I و $\frac{V}{\sqrt{3}}$

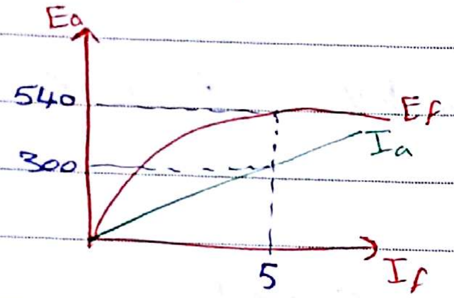
No.

Example 4.1 a- 200 kVA, 480 V, 50 Hz, Y connected synch gen. with rated field current $I_f = 5A$, was tested and following results obtained

① $V_{T,o.c} = 540\ V$ at rated I_f

② $I_{L,s.c} = 300\ A$ at rated I_f

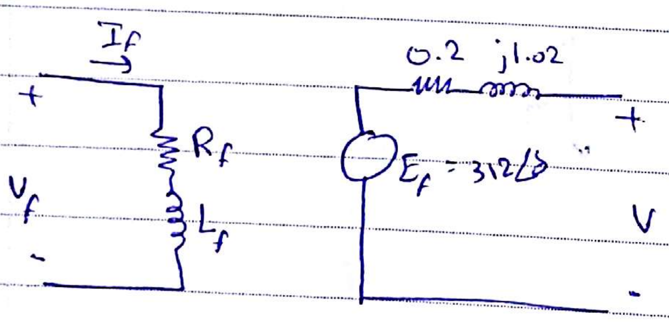
③ when a DC source of 10V was applied to two of the terminals, $I_a = 25\ A$



$$Z_s = \frac{540/\sqrt{3}}{300} = 1.039\ \Omega$$

$$2R_{DC} = \frac{V_{DC}}{I_{DC}} = \frac{10}{25} = 0.4 \Rightarrow R_a = 0.2\ \Omega$$

$$X_s = \sqrt{(1.039)^2 - (0.2)^2} = 1.02\ \Omega$$



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No.

The behaviour of a synch. generator is mainly affected by :-

① load [PF and magnitude]

② Is the generator connected to a system or not.

* synch. gen. working alone :-

⇒ speed is constant

① ⇒ if the field is not changed $E_a = k\phi\omega$, E_a is constant

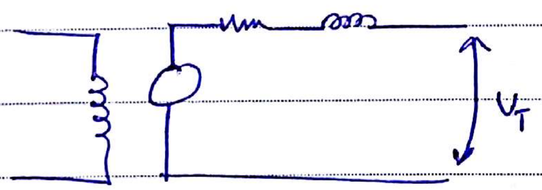
② ⇒ $E_a = V_\phi + jX_s I_a$

change of the load ⇒ E_a is constant

$$E_a = V_\phi + jX_s I_a$$

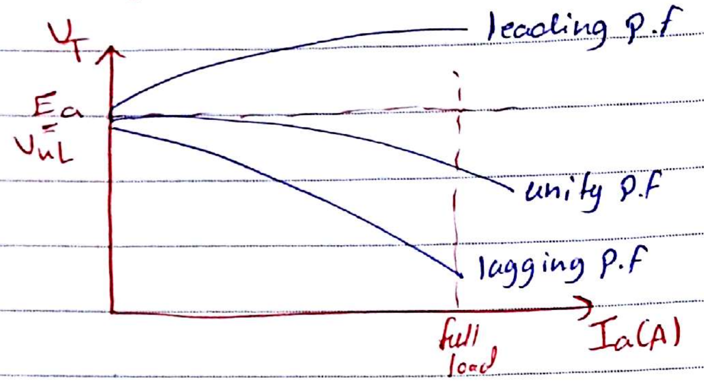
V_ϕ ↓ decrease as load increase; I_a ↑

$$V_\phi = V_T = V_{load}$$



No.

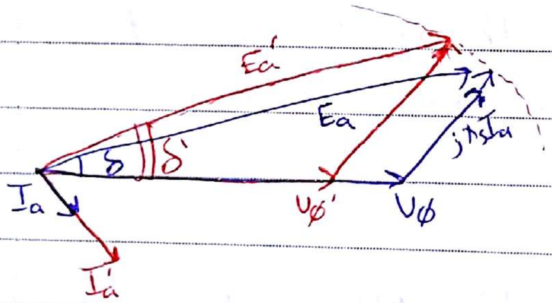
To adjust the value of V_T, increase the field.



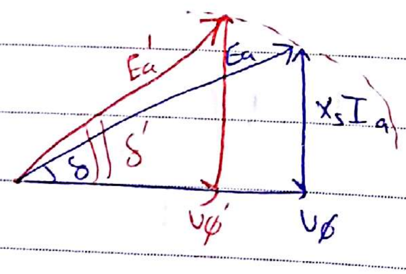
$$UR = \frac{V_{nL} - V_{FL}}{V_{FL}} * 100\%$$

$$V_{nL} = E_a$$

$$UR = \frac{E_a - V_{FL}}{V_{FL}} * 100\%$$



$$|E_a| = |E_a'|$$



No.

Stand alone :-

$$VR = \frac{E_a - V_{FL}}{V_{FL}} * 100\%$$

+ high for lagging   + low for unity   -ve for leading

$V_T \downarrow$ with $I_a \uparrow$

→ to increase V_T, $E_a \uparrow$ → by increasing ϕ → by decreasing R_f

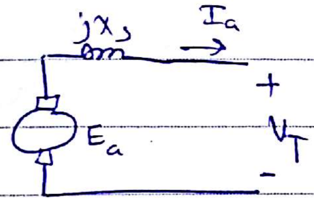
** Study example 4.2

Example :- 480 V, 60Hz, Y connected 6-pole synch. gen. per phase synch. reactance $X_s = 1\Omega$, with full load current $I_a = 60$ at 0.8 lag p.f, friction and winding losses = 1.5 kw, $P_{core} = 1$ kw at 60 Hz, $P_{copper} = 0$, The field current has been adjusted such that the no-load terminal voltage is 480.

(A) speed of rotation

$$n_m = \frac{60 * f}{P_{\text{pairs}}} = \frac{60 * 60}{3} = 1200 \text{ rpm} \Rightarrow \omega_m = 125.7$$

(B) V_T at 1) rated current 0.8 lag p.F



$$E_a \angle\delta = V_T \angle 0^\circ + jX_s I_a$$

$$\frac{480}{\sqrt{3}} \angle\delta = V_T \angle 0^\circ + j\, 60 \angle{-36.9} * 1$$

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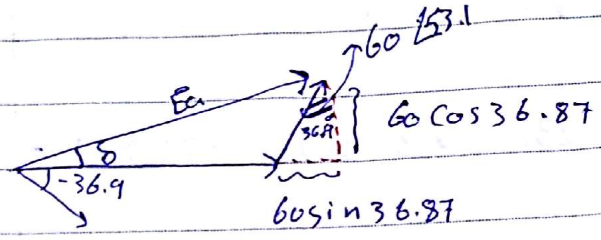
No.

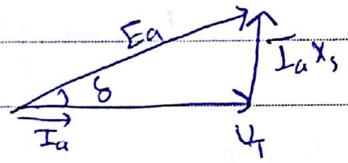


$$\left(\frac{480}{\sqrt{3}}\right)^2 = (V_T + 60\sin 36.87)^2 + (60\cos 36.87)^2$$

$V_T = 236.8\ V \rightarrow$ phase netural

$V_T = 410\ V_{LL}$

2) unity p.F



$$E_a \angle \delta = V_T \angle 0^\circ + 60 \angle 90$$

$$E_a^2 = V_T^2 + 60^2$$

$V_T = 270.4\ V$ $\quad V_T = 468.4\ V_{LL}$

3) leading 0.8 p.F

$$\left(\frac{E_a}{\sqrt{3}}\right)^2 = (V_T - \sin I_a X_s)^2 + (I_a X_s \cos\theta)^2$$

$V_T = 308.8\ V$ $\quad V_T = 535\ V_{LL}$

No.

(B) for 0.8 lagging p.f find η

$P_{out} = 3V_\phi I_\phi \cos\theta = 3 * 236.8 * 60 * \cos(36.87) = 34.1\ kw$

$P_{in} = P_{out} + P_{core} + P_{cupper} + P_{mech} = 34.1 + 0 + 1.5 = 36.6\ kw$

$\eta = \frac{P_{out}}{P_{in}} * 100\% = \frac{34.1k}{36.6k} = 93.2\%$

(C) $\tau_{ind} = \frac{P_{in}}{\omega_m} = \frac{36.6}{125.7} = 291.2\ Nm$

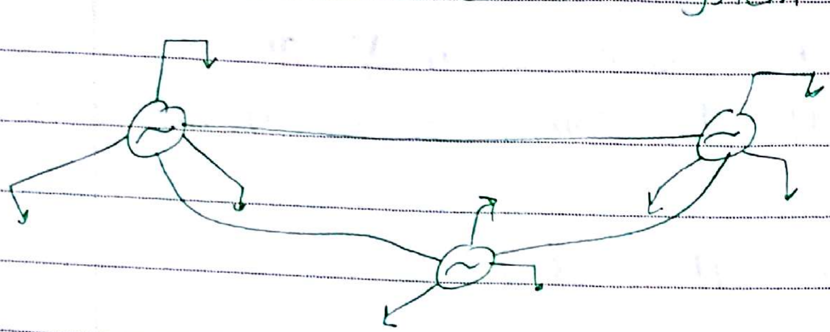
$\tau_{load} = \frac{P_{out}}{\omega_m} = \frac{34.1}{125.7} = 271.2\ Nm$

(D) $VR = \frac{480 - 410}{410} * 100\% = 17.1\%$ → (0.8 lagging p.f)

unity p.f ⇒ $VR = \frac{480 - 468}{468} * 100\% = 2.6\%$

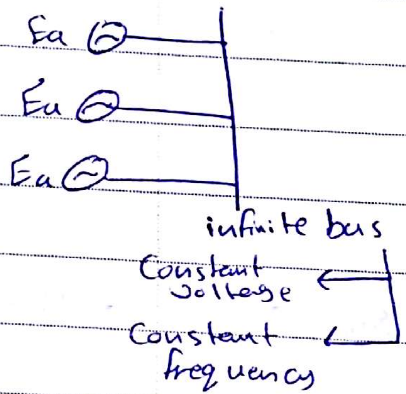
leading p.f ⇒ $VR = \frac{480 - 535}{535} * 100\% = -10.3\%$

generator is connected to a system :-



⇒ reliability, maintinance

N-1 contengency

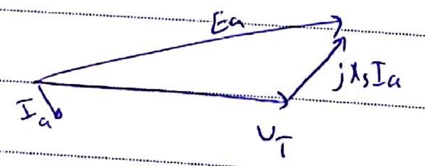


gen connected to a system V_T is Constant

E_f is a function of I_f

magnitude and phase of I_a are dependent variables :-

$E_f = V_T + jX_s I_a$



$E_a \angle \delta = V_T \angle 0° + I_a X_s \angle 90° \pm \theta$

No.

Example :- 60 Hz , 4 pole , Synch. gen has a synch reactance of 5Ω . The Stator is connected in Y and it's line - line voltage is 15kV . The line current of the generator is 1kA and 0.9 lagg p.f

ⓐ The equiv. field voltage (E_a)

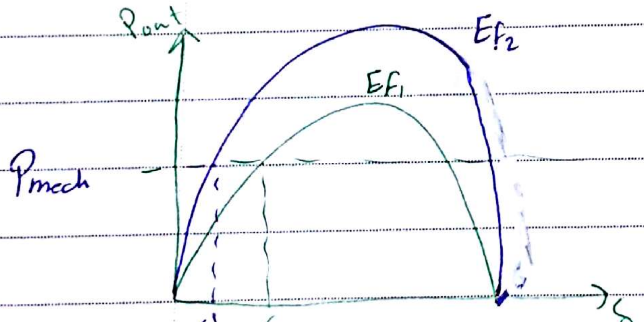
$$E_a = \frac{15}{\sqrt{3}} \angle 0^\circ + 1k \angle -\cos^{-1} 0.9 \times j3 = 11.74 \angle 22.54 \text{ kV}$$

ⓑ The power delievered to the system.

$P = \sqrt{3}\, V_{T,L.L}\, I_a \cos\theta$ ⟶ θ is the angle between V_ϕ phase and I_ϕ phase

$= \sqrt{3} \times 13 \times 10^3 \times 10^3 \times 0.9 = 23.38$ Mw

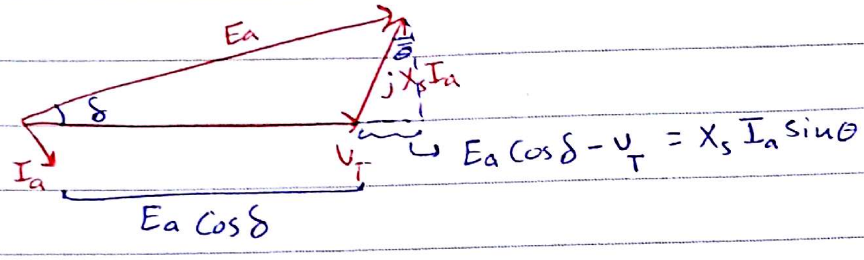
$Q = \sqrt{3}\, V_{T,L\,L}\, I_a \sin\theta = \sqrt{3} \times 15 \times 10^3 \times 10^3 \times \sin(\cos^{-1} 0.9) = 11.32$ MVAR



$$P_{out} = \frac{3 V_T E_a \sin\delta}{X_s}$$

$I_f \uparrow \rightarrow \phi \uparrow \rightarrow E \uparrow = k\phi\omega \rightarrow P_{out} \uparrow$

$E_{f_1} < E_{f_2}$



$Q_t = 3 V_T I_a \sin\theta$

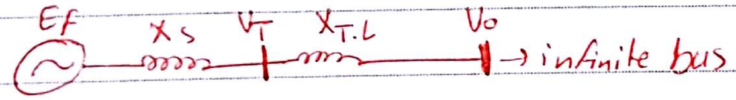
$X_s I_a \sin\theta = E_a \cos\delta - V_T$

$$Q_t = 3 V_T \frac{(E_a \cos\delta - V_T)}{X_s}$$

① $E_a \cos\delta - V_T > 0 \Rightarrow (Q + ve)$ Q is delieverd to the system

② $E_a \cos\delta - V_T = 0 \Rightarrow Q = 0$ Q is not being delievered or consumed by the system

③ $E_a \cos\delta - V_T < 0 \Rightarrow (Q - ve)$ The system deliverers Q to the generator



$$P_{out} = \frac{3 E_f V_o}{X_s + X_{T.L}} \sin\delta$$

* good luck *