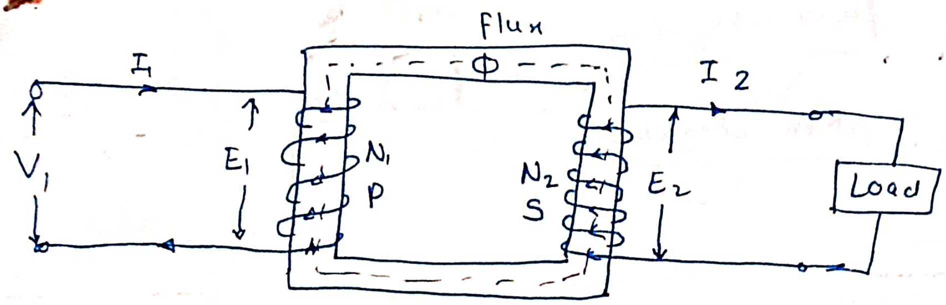
Ratios of Transformer



from emf eqn of transformer,

$E_1 = 4.44 f \phi_m N_1$

$E_2 = 4.44 f \phi_m N_2$

Taking ratio,

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = K$$

The ratio of secondary induced emf to primary induced emf is called Voltage transformation ratio denoted as K.

Thus $E_2 = K E_1$ where $K = \frac{N_2}{N_1}$

If $N_2 > N_1$ i.e. $K > 1$ we get $E_2 > E_1$ ..... Step up x'mer

If $N_2 < N_1$ i.e. $K < 1$ we get $E_2 < E_1$ -- Step down x'mer.

If $N_2 = N_1$ i.e. $K = 1$ we get $E_2 = E_1$ -- isolation x'mer or 1:1 x'mer.

Current ratio :

In ideal transformer there are no losses Hence I/P VA = O/P VA

so $V_1 I_1$ = input VA & $V_2 I_2$ = O/P VA

so $V_1 I_1 = V_2 I_2$ for ideal x'mer

$$\therefore \frac{V_2}{V_1} = \frac{I_1}{I_2} = K$$

Q. Why rating of transformer is in voltampere i-e VA or KVA or MVA and not in KW, MW ?

Full load current:

$$I_1 \text{ full load} = \frac{KVA \text{ rating} \times 1000}{V_1}$$

$$I_2 \; F.L = \frac{KVA \text{ rating} \times 1000}{V_2}$$

—x—

Ex. 1) A 10 KVA (20), 3300/240 V (3300/250 V), single phase 50Hz transformer has a core area of 300 cm² (250 cm²). The flux density is 1.3 Tesla (1.5 Tesla). Calculate
Dec-08 6 marks

1) No. of primary turns
2) No. of sec. turns
3) Primary full load current
4) Sec. full load current

⇒

10 KVA, $V_1 = 3300V$, $V_2 = 240V$, $f = 50Hz$, $B = 1.3 wb/m^2$

$a = 300 cm^2$,

$B = \phi/a$ i.e. $\phi = B \times a = 1.3 \times 300 \times 10^{-4} = 0.039 Wb$

1) $V_1 = 4.44 \phi f N_1$ i.e. $3300 = 4.44 \times 0.039 \times 50 \times N_1$

$\therefore N_1 = 381.15 \approx \underline{382}$

2) $\frac{V_1}{V_2} = \frac{N_1}{N_2}$ i.e. $\frac{3300}{240} = \frac{382}{N_2}$ $\therefore N_2 = 27.78 \cong \underline{28}$

3) $(I_1)_{F.L.} = \frac{VA}{V_1} = \frac{10 \times 10^3}{3300} = \underline{3.0303 A}$

4) $(I_2)_{F.L.} = \frac{VA}{V_2} = \frac{10 \times 10^3}{240} = \underline{41.66 A}$

—x—

Ex. 2) For a single phase x'mer having pri. & sec. turns of 440 (1000) and 880 (500) resply, determine the transformer KVA rating if half load sec. current is 7.5A (8 A) and maxm value of core flux is 2.25 mWb (2.5 mWb).

⇒

$N_1 = 440$, $N_2 = 880$ $(I_2)_{H.L.} = 7.5 \text{ Amp}$ $\phi_m = 2.25 mWb$

assume $f = 50Hz$,

$E_2 = 4.44 f \phi_m N_2 = 4.44 \times 2.25 \times 10^{-3} \times 50 \times 880 = 439.56 V$

$(I_2)_{H.L.} = \; \therefore KVA$

$(I_2)_{F.L.} = \frac{KVA\ rating}{E_2}$ and $(I_2)_{H.L.} = \frac{1}{2}(I_2)_{F.L.}$

$\therefore (I_2)_{H.L.} = \frac{1}{2}\left[\frac{KVA rating}{E_2}\right]$ i.e. $7.5 = \frac{1}{2} \times \frac{KVA rating \times 10^3}{439.56}$

$\therefore KVA\ rating \times 10^3 = I_2\ F.L. \times E_2$

$\therefore KVA\ rating = 2 \times 7.5 \times 439.56 \times 10^{-3}$

$= \underline{6.5934}$ KVA

Ex. A single phase, 50Hz, X'mer has 80 (100) turns on primary wdg, & 400 (600) turns on sec. wdg. The net cross-sectional area of the core is 200cm² (300). If the primary wdg. is connected to a 240 (250) volt 50Hz supply, determine

i) The emf induced in the sec. wdg.

ii) The maxm value of flux density in core.

[Ans. 1200V, 0.6756 Wb/m²]

$\Rightarrow$ $N_1 = 80$ turns $N_2 = 400$ turns $V_1 = 240$

$a = 200cm^2 = 200 \times 10^{-4} m^2$

$E_1 = 4.44\, f\, \phi\, N_1$ $\therefore 240 = 4.44 \times 50 \times \phi \times 80$

$E_2 = 4.44\, f\, \phi\, N_2$ $\therefore \phi = 0.01351$

$E_2 = 4.44 \times 50 \times 0.01351 \times 400 = 1199.68 \cong 1200V$

$\cancel{\frac{E_2}{E_1} = \frac{N_2}{N_1}}$ $\cancel{\therefore E_2 = E_1 \times \frac{N_2}{N_1} = 240 \times \frac{440}{80} =}$

$B = \frac{\phi}{a}$ $\therefore B = \frac{0.01351}{200 \times 10^{-4}} = \underline{\underline{0.6755\ Wb/m^2}}$

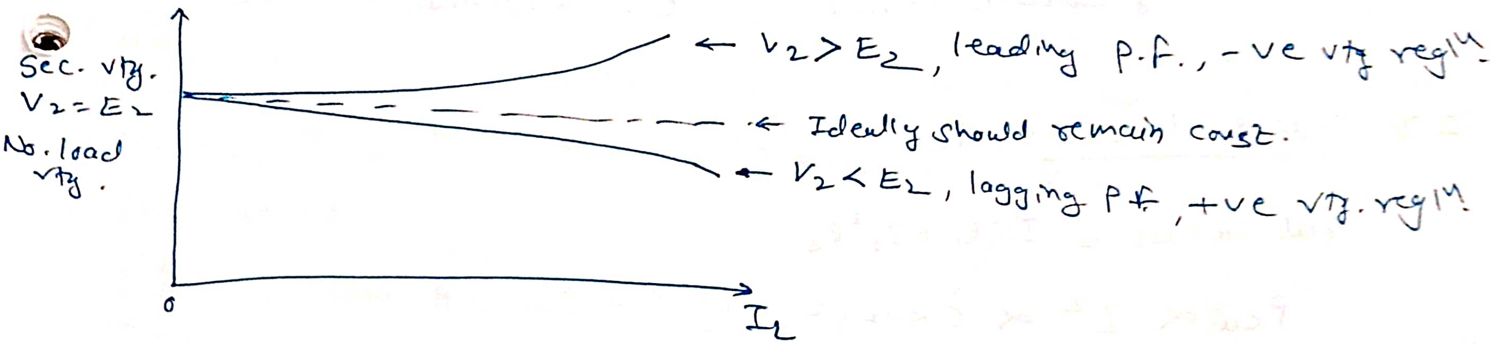
Voltage regulation of Transformer:

The vtg regulation is defined as change in magnitude of the sec. terminal voltage, when full load i.e. rated load of specified power factor supplied at rated voltage is reduced to no load, with primary voltage maintained constant expressed as the percentage of rated terminal vtg.

Let E_2 = Sec. terminal voltage on no load,
V_2 = Sec. terminal vtg on given load,

then
$$\% \text{ voltage regulation} = \frac{E_2 - V_2}{V_2} \times 100$$

The ratio of $((E_2 - V_2)/V_2)$ is called per unit regulation.



$$\% \text{ Reg}^n = \frac{E_2 - V_2}{V_2} = \frac{\text{Total voltage drop}}{V_2} \times 100$$

$R_2' = \frac{R_2}{K^2}$ & $X_2' = \frac{X_2}{K^2}$ $\qquad$ $Z_{2e} = Z_{02} = Z_2 + Z_1' = Z_2 + K^2 Z_1$

$R_1' = K^2 R_1$ & $X_1' = K^2 X_1$ $\qquad$ $Z_{1e} = Z_{01} = Z_1 + Z_2' = Z_1 + \frac{Z_2}{K^2}$

$$\% \text{ Reg}^n = \frac{I_2 R_{02} \cos\phi \pm I_2 X_{02} \sin\phi}{V_2} \times 100$$

or
$$\% \text{ Reg}^n = \frac{I_1 R_{01} \cos\phi \pm I_1 X_{01} \sin\phi}{V_1} \times 100$$

+ve for lagging p.f.
-ve for leading p.f.

* Losses in a Transformer:

In a transformer there exists two type of losses,

1) Core losses
2) Copper losses

1) Core losses: Denoted by $\underline{\underline{P_i}}$

1) Hysteresis loss $= K_h B_m^{1.67} f V$ watt

$K_h =$ Hysteresis constant , $B_m =$ Max^m flux density

$f =$ frequency , $V =$ volume of the core

2) Eddy current loss $= K_e B_m^2 f^2 t^2$ watts/unit volume

$K_e =$ Eddy current constant , $t =$ thickness of core

2) Copper losses: P_{cu}

Total Cu loss $= I_1^2 R_1 + I_2^2 R_2$

$$P_{cu} \propto I^2 \propto (KVA)^2$$

$\therefore$ $\boxed{\begin{aligned}\text{Total losses in transformer} &= \text{Iron losses} + \text{Copper losses} \\ &= P_i + P_{cu}\end{aligned}}$

Efficiency of a Transformer:

It is ratio of power output to power input

$$\eta = \frac{\text{Power output}}{\text{Power input}} = \frac{\text{Power output}}{\text{Power output} + \text{losses}} = \frac{\text{Power Output}}{\text{Power output} + P_i + P_{cu}}$$

$$\eta = \frac{V_2 I_2 \cos \phi_2}{V_2 I_2 \cos \phi_2 + P_i + P_{cu}} = \frac{(\text{VA rating}) \times \cos \phi}{(\text{VA rating}) \times \cos \phi + P_i + P_{cu}}$$

Let $n =$ Fraction by which load is different than full load $= \dfrac{\text{Actual load}}{\text{Full load}}$

For half load $n = \dfrac{\text{half load}}{\text{full load}} = \dfrac{1/2}{1} = 0.5$

When load changes, the load current change by same proportion.

$\therefore$ New $I_2 = n (I_2)_{F.L.}$

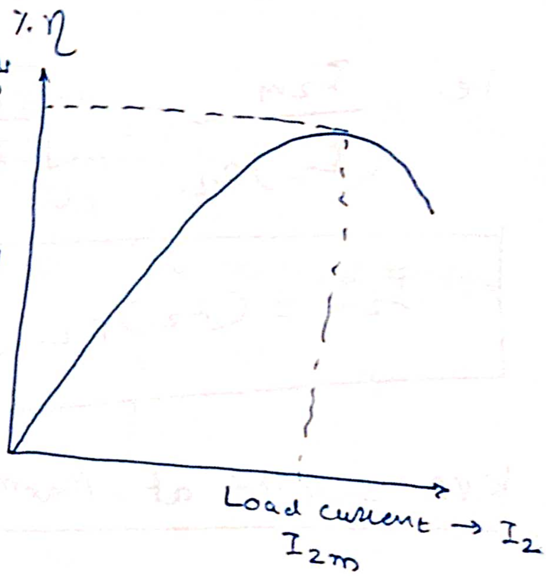
& New $P_{cu} = n^2 (P_{cu})_{F.L.}$

$$\therefore \%\eta = \frac{n(\text{VA rating}) \times \cos\phi}{n(\text{VA rating}) \times \cos\phi + P_i + n^2 (P_{cu})_{F.L.}} \times 100$$

— x —

* Condition for maximum efficiency:

- The load current at which the η attains max^m value is denoted as I_{2m} & eff^n as η_{max}
- The eff^n is function of Load i.e. load current I_2 assuming $\cos\phi_2$ const.
- The secondary terminal voltage V_2 is also assumed constant.



$\therefore$ for max^m eff^n

$$\frac{d\eta}{dI_2} = 0 \quad \text{while} \quad \eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{o2}}$$

$$\therefore \frac{d\eta}{dI_2} = \frac{d}{dI_2}\left\{\frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{o2}}\right\}$$

$R_{o2} = R_{2e}$

$$\frac{d}{dx}\left(\frac{u}{v}\right) = \frac{v\frac{du}{dx} - u\frac{dv}{dx}}{v^2}$$

$$\therefore \underbrace{(V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{o2})}_{v} \frac{d}{dI_2} \underbrace{(V_2 I_2 \cos\phi_2)}_{u} - \underbrace{(V_2 I_2 \cos\phi_2)}_{u} \frac{d}{dI_2} \underbrace{(V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{o2})}_{v} = 0$$

$$\therefore (V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{o2})(V_2 \cos\phi_2) - (V_2 I_2 \cos\phi_2)(V_2 \cos\phi_2 + 2 I_2 R_{o2}) = 0$$

Cancelling $(V_2 \cos\phi_2)$ from both terms, we get

$$\therefore (V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{o2}) - (V_2 I_2 \cos\phi_2 + 2 I_2^2 R_{o2}) = 0$$

$$\therefore P_i - I_2^2 R_{o2} = 0$$

$$\therefore \boxed{P_i = I_2^2 R_{o2} = P_{cu}}$$

So cond^n to achieve max^m eff^n is that,

Copper losses = Iron loss i.e. $\boxed{P_i = P_{cu}}$

* ## Load current I_{2m} at max^m eff^n

for η_{max} $I_2^2 R_{02} = P_i$ but $I_2 = I_{2m}$ i.e. $I_{2m}^2 R_{02} = P_i$

$$\therefore \boxed{I_{2m} = \sqrt{\frac{P_i}{R_{02}}}} \quad \text{--- (1)}$$

This is load current at max^m eff^n

Let $(I_2)_{F.L.}$ = Full load Current

Divide eq^n (1) by $(I_2)_{F.L.}$ on both side

$$\therefore \frac{I_{2m}}{(I_2)_{F.L.}} = \frac{1}{(I_2)_{F.L.}} \sqrt{\frac{P_i}{R_{02}}}$$

i.e. $$\frac{I_{2m}}{(I_2)_{F.L.}} = \sqrt{\frac{P_i}{(I_2)_{F.L.}^2 R_{02}}} = \sqrt{\frac{P_i}{(P_{cu})_{F.L.}}}$$

$$\therefore \boxed{I_{2m} = (I_2)_{F.L.} \sqrt{\frac{P_i}{(P_{cu})_{F.L.}}}}$$

* ## KVA supplied at Max^m eff^n

for constant V_2 the KVA supplied is function of load current.

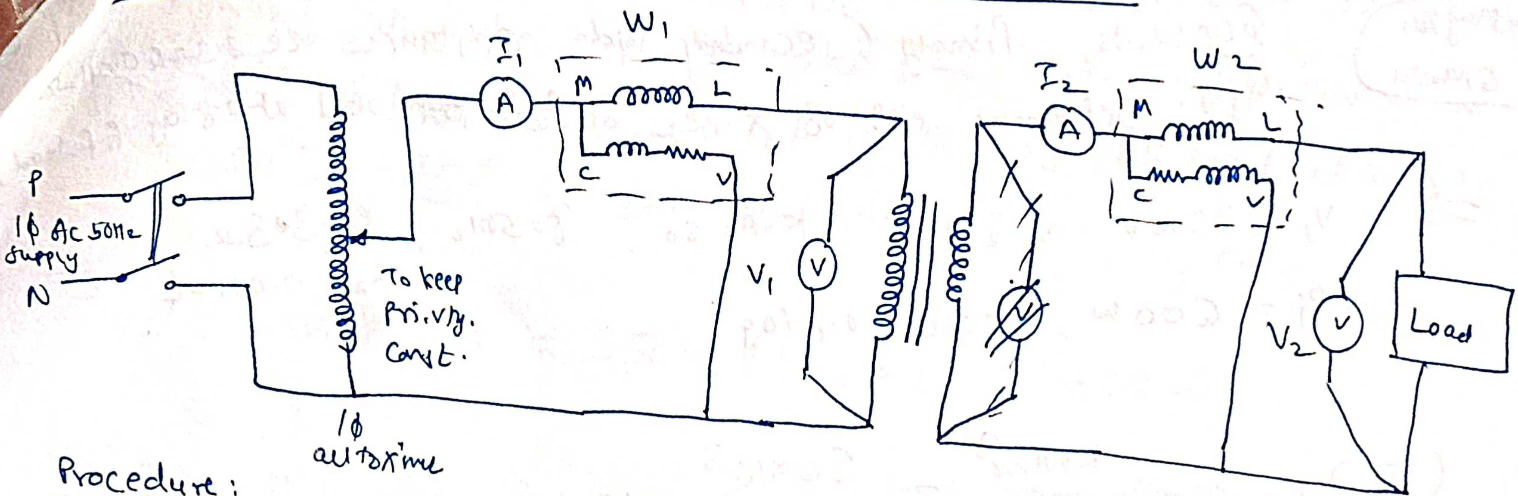
$\therefore$ KVA at $\eta_{max} = I_{2m} V_2 = V_2 I_{2\,F.L.} \times \sqrt{\frac{P_i}{(P_{cu})_{F.L.}}} = (\text{KVA rating}) \times \sqrt{\frac{P_i}{(P_{cu})_{F.L.}}}$

$$\boxed{\therefore \text{KVA at } \eta_{max} = (\text{KVA rating}) \times \sqrt{\frac{P_i}{(P_{cu})_{F.L.}}}}$$

- Substituting cond^n for max^m eff^n in expression of eff^n we can write expression for η_{max} as,

$$\boxed{\% \eta_{max} = \frac{V_2 I_{2m} \cos\phi}{V_2 I_{2m} \cos\phi + 2P_i} \times 100} \quad \text{as } P_{cu} = P_i$$

rect Loading Method of Finding Effy & Regln



Procedure:

Observation Table:

Sr. No.	Primary side			Secondary side		
	V_1	I_1	W_1	V_2	I_2	W_2
1	Rated					
2	vtg. -11-			E_2 V	0	0
3	-11-					
4	-11-					
5	-11-					

← No load reading

Calculations:

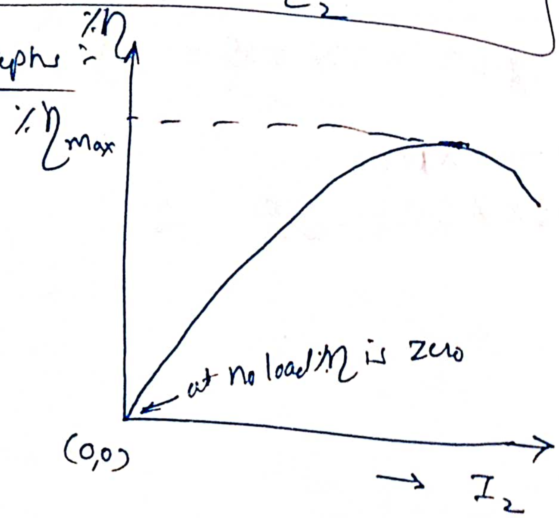
W_1 = I/p power to primary
W_2 = O/p power to load

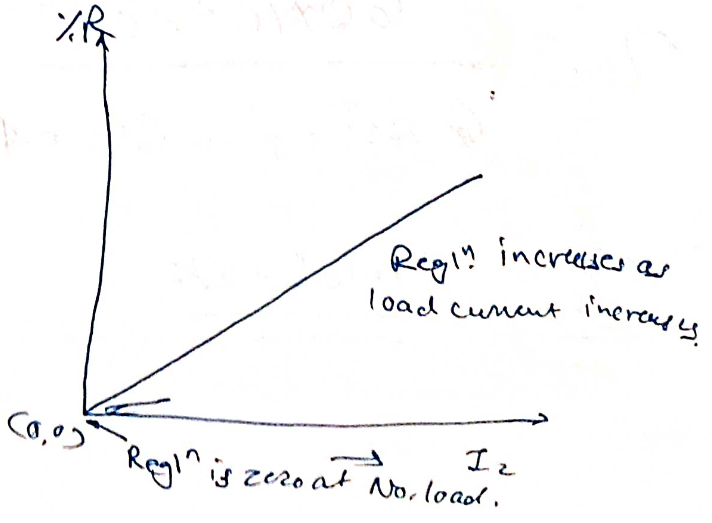
$$\boxed{\% \eta = \frac{W_2}{W_1} \times 100}$$

$$\boxed{\% \text{ Regl}^n = \frac{E_2 - V_2}{E_2} \times 100}$$

where E_2 is const

Graphs:





Ex.

May 2011
6 Marks

3300/110V, 50Hz, 60 KVA, 1Φ x'mer has iron losses of 600 Watts. Primary & secondary wdg. resistances are 3.3Ω & 0.011Ω resp'ly. Determine eff'n of x'mer on full load at 0.8 lag p.f.

3300/220, 80 KVA, 700

$\Rightarrow$ $V_1 = 3300\,V$, $V_2 = 110\,V$, $KVA = 60$, $f = 50\,Hz$, $R_1 = 3.3\,\Omega$

$P_i = 600\,W$, $\cos\phi = 0.8$ lag, $R_2 = 0.011\,\Omega$

$$(I_1)_{F.L.} = \frac{KVA \times 10^3}{V_1} = \frac{60 \times 10^3}{3300} = \underline{18.1818\,A}$$

$$\text{Primary Cu loss} = I_1^2 R_1 = (18.1818)^2 \times 3.3 = \underline{1090.9\ \text{Watt}}$$

$$(I_2)_{F.L.} = \frac{KVA \times 10^3}{V_2} = \frac{60 \times 10^3}{110} = \underline{545.4545\,A}$$

$$\text{Sec. Cu loss} = I_2^2 R_2 = (545.45)^2 \times 0.011 = 3272.7272\,W$$

$$\therefore \text{Total Cu loss} = 1090.90 + 3272.72 = \underline{4363.6272\ \text{Watts}} = \underline{(P_{cu})_{F.L.}}$$

$$\%\eta_{F.L.} = \frac{KVA \times 10^3 \times \cos\phi}{KVA \times 10^3 \cos\phi + P_i + (P_{cu})_{F.L.}} \times 100$$

$$\%\eta_{F.L.} = \frac{60 \times 10^3 \times 0.8}{60 \times 10^3 \times 0.8 + 600 + 4363.627} \times 100$$

$$\%\eta_{F.L.} = \underline{90.6282\%}$$

Q.N. May 2010 8M

A. 25 KVA, 50 Hz single phase x'mer has the iron loss and full load Cu loss of 350 & 400 watts resply. Find the effn of the transformer at i) 50% of full load at unity P.F. & ii) 75% of full load at 0.8 lagging P.F.

→

25 KVA, $P_i = 350\,W$, $(P_{cu})_{F.L.} = 400\,W$

If n is the fraction of full load, the effn is,

$$\%\eta = \frac{n\,VA\cos\phi}{n\,VA\cos\phi + P_i + n^2 P_{cu}} \times 100$$

i) 50% of full load i.e. $n = 0.5$, $\cos\phi = 1$

$$\therefore \%\eta = \frac{0.5 \times 25\times10^3 \times 1}{0.5\times 25\times10^3 \times 1 + 350 + (0.5)^2 \times 400} \times 100$$

$= 96.525\%$

ii) 75% of full load i.e. $n = 0.75$, $\cos\phi = 0.8$ lag.

$$\therefore \%\eta = \frac{0.75 \times 25\times10^3 \times 0.8}{0.75\times 25\times10^3 \times 0.8 + 350 + (0.75)^2 \times 400} \times 100$$

$= 96.308\%$

Ex. (Dec09 Marks 8) A single phase 90 kVA 3.2kV/220V, 50Hz x'mer has 89% effn at unity p.f. both at full load & half load. Determine the effn at 70% of F.L. & 0.8 p.f. leading. (May 12 Marks 6)

⇒ kVA = 90 kVA, $\eta_{HF} = \eta_{FL} = 89\%$ at unity p.f.

$$\%\eta_{F.L.} = \frac{VA\cos\phi}{VA\cos\phi + P_i + (P_{cu})_{F.L.}} \times 100$$

$$\&\ \%\eta_{H.L.} = \frac{0.5\,VA\cos\phi}{0.5\,VA\cos\phi + P_i + (0.5)^2 (P_{cu})_{F.L.}} \times 100 \qquad n = 0.5 \text{ for H.L.}$$

$$\therefore 0.89 = \frac{90\times10^3 \times 1}{90\times10^3 \times 1 + P_i + (P_{cu})_{FL}} \quad \& \quad 0.89 = \frac{0.5\times 90\times10^3 \times 1}{0.5\times90\times10^3\times1 + P_i + 0.25(P_{cu})_{FL}} \times 100$$

$\therefore P_i + (P_{cu})_{FL} = 11123.5957$ — ① & $P_i + 0.25(P_{cu})_{FL} = 5561.7977$ — ②

Solving ① & ② $(P_{cu})_{FL} = 7415.7303\ W$, $P_i = 3707.8657$

To find effn at 70% on full load i.e. $n = 0.7$ & $\cos\phi = 0.8$

$$\therefore \%\eta = \frac{n\,VA\cos\phi}{n\,VA\cos\phi + P_i + n^2 (P_{cu})_{F.L}} \times 100$$

$$= \frac{0.7 \times 90\times10^3 \times 0.8}{0.7\times90\times10^3\times0.8 + 3707.857 + (0.7)^2 \times 7415.7303} \times 100$$

$$= 87.28\%$$

ec 07
May 12
Mark 6

A 500 KVA x'mer has iron losses of 2 KW, & full load copper losses of 5 KW, Calculate the eff^n at i) 75% of full load and unity P.F. ii) F.L. at 0.8 P.F. lag.

ans i) 98.7329 %.
ii) 98.28 %

Ex. A transformer is rated at 100 KVA at full load, its copper loss is 1200W and its iron loss is 960 W, Calculate

i) The efficiency at full load, unity power factor,
ii) The efficiency at half load, 0.8 power factor
iii) The efficiency at 75% full load, 0.7 power factor
iv) The load KVA at which maxm efficiency will occur
v) The maximum efficiency at 0.85 power factor.

$\Rightarrow$ $P_i = 960$ watt, $(P_{cu})_{F.L} = 1200$ watt, 100 KVA,

i) $$\%\eta_{F.L.} = \frac{VA\text{-rating}\cos\phi}{VA\cos\phi + P_i + (P_{cu})_{F.L.}} \times 100 = \frac{100\times10^3\times1}{100\times10^3\times1+960+1200}\times100 = 97.88\%$$

ii) η at half load 0.8 P.F. $\therefore n = 0.5$

$$\therefore \%\eta_{H.L.} = \frac{0.5\times100\times10^3\times0.8}{0.5\times100\times10^3\times0.8 + 960 + (0.5)^2\times1200}\times100 = \underline{96.946\%}$$

iii) η at 75% of full load, $\cos\phi = 0.7$

$$\therefore \eta_{0.75} = \frac{0.75\times100\times10^3\times0.7}{0.75\times100\times10^3\times0.7 + 960 + (0.75)^2\times1200}\times100 = \underline{96.98\%}$$

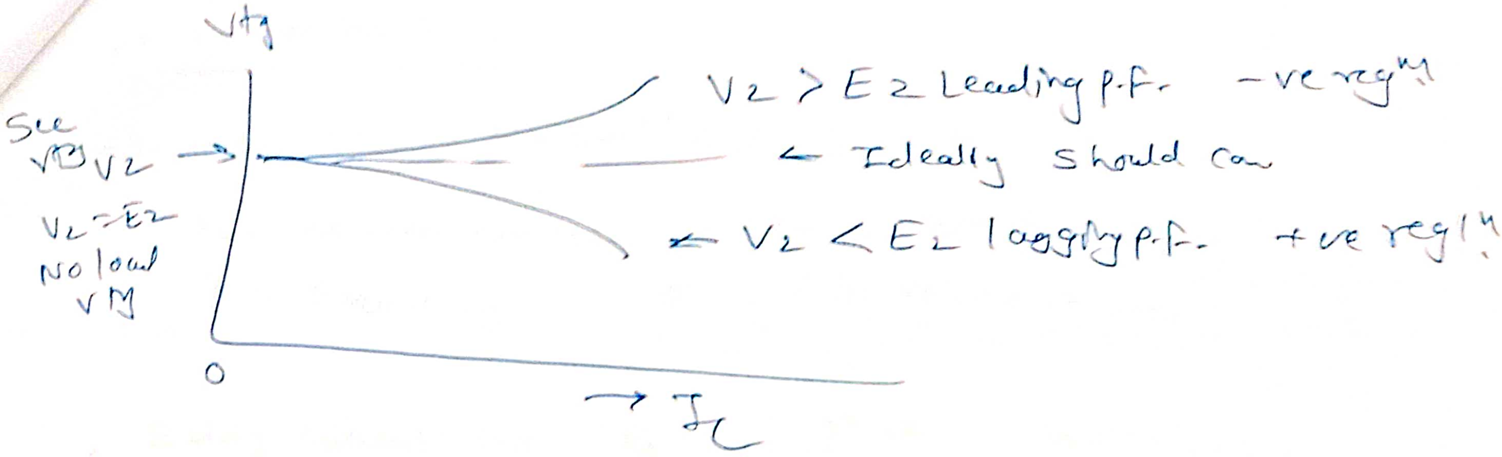
iv) $$\text{KVA at } \eta_{max} = \text{KVA}\times\sqrt{\frac{P_i}{(P_{cu})_{F.L.}}} = 100\times\sqrt{\frac{960}{1200}} = \underline{89.4427 \text{ KVA}}$$

v) η_{max} at $\cos\phi = 0.85$, $P_i = P_{cu} = 960$

$$\therefore \eta_{max} = \frac{\text{KVA at } \eta_{max}\times\cos\phi}{\text{KVA at } \eta_{max}\times\cos\phi + 2P_i}\times100 = \frac{89.4427\times0.85}{89.4427\times0.85 + 2\times960}$$

$$\Rightarrow \eta_{max} = \underline{97.536\%}$$

Voltage Regulation $= \dfrac{E_2 - V_2}{V_2} \times 100$



- Approximate voltage drop $= E_2 - V_2 = I_2 R_{2e} \cos\phi_2 - I_2 X_{2e} \sin\phi_2$

$$\% R = \frac{E_2 - V_2}{V_2} \times 100 = \frac{I_2 \{R_{2e} \cos\phi_2 - X_{2e} \sin\phi_2\}}{V_2} \times 100$$

$$\% R = \frac{I_1 \{R_{1e} \cos\phi_2 - X_{1e} \sin\phi_2\}}{V_1} \times 100$$ ref. to primary

- Generalised expr. regn is,

$$\% R = \frac{I_2 \{R_{2e} \cos\phi \pm X_{2e} \sin\phi\}}{V_2} \times 100$$

$$\% R = \frac{I_1 \{R_{1e} \cos\phi \pm X_{1e} \sin\phi\}}{V_1} \times 100$$

+ve sign for lagging p.f.

-ve sign for leading p.f.

Losses in a Transformer:

Core Loss or iron Losses

* Hysteresis Loss $= K_h B_m^{1.67} f V$ ... watts

K_h = Hysteresis Constant & B_m = Max^m flux density
f = frequency & V = Volume of core

* Eddy current loss $= K_e B_m^2 f^2 t^2$ watts/unit volume

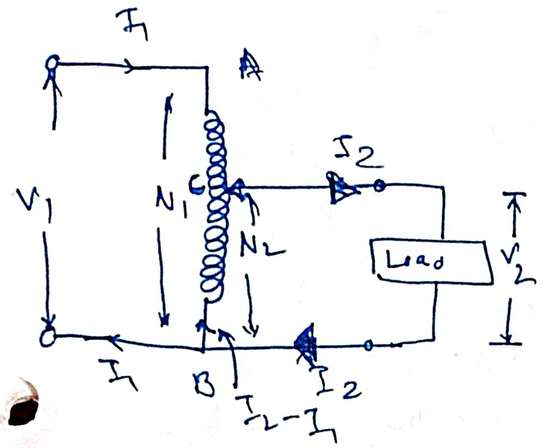
K_e = Eddy current const. & t = thickness of the core

* Copper losses $= P_{Cu} \propto I^2 \propto (KVA)^2$

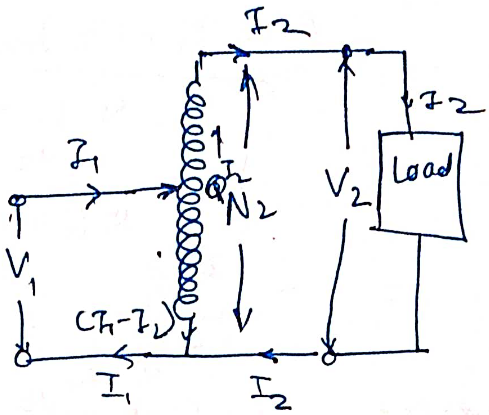
Total losses = Iron losses + Copper losses

Autox'mer:

Defn: Auto x'mer is a special type of transformer such that a part of the wdg. is common to both primary & second.
It has only one winding wound on a laminated magnetic core



step down autox'mer



stepup autox'mer

As compared to an ordinary 2-winding transformer of same output, an auto-x'mer has higher efficiency but smaller size, Its voltage regulation is also superior.

* Saving of Cu:

Volume and hence weight of Cu, is proportional to the length and area of cross-section of conductors.

Now length of conductor is proportional to the number of turns and c/s depends on current.

Hence, weight is proportional to the product of the current and No. of turns.

From fig. wt. of Cu in section AC is $\propto (N_1 - N_2) I_1$;

wt. of Cu in section BC is $\propto N_2 (I_2 - I_1)$

$\therefore$ Total weight of copper in auto-x'mer $\propto (N_1 - N_2) I_1 + N_2 (I_2 - I_1)$

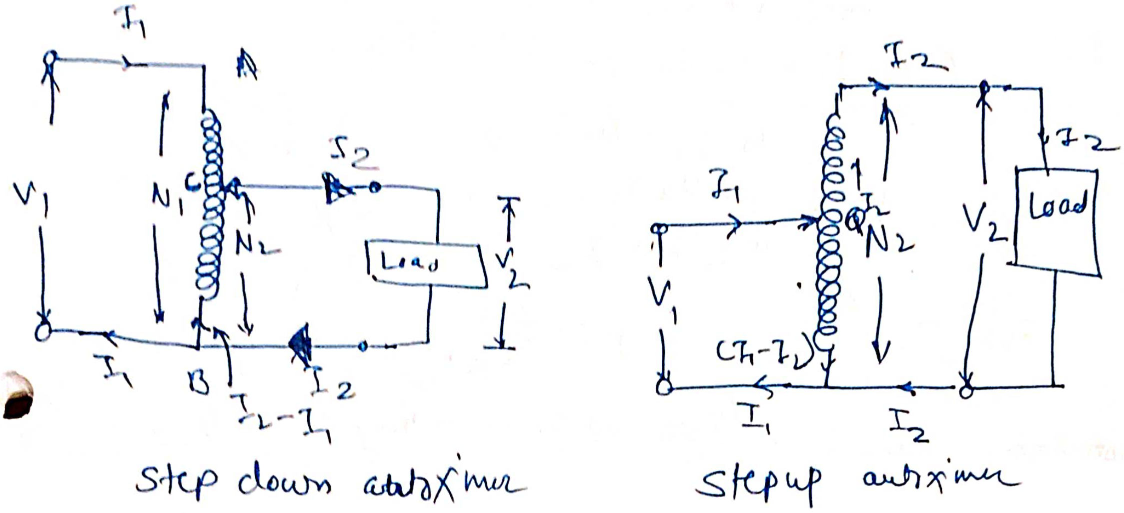
If a two winding x'mer were perform the same duty, then

wt. of Cu on its primary $\propto N_1 I_1$; wt. of Cu on secondary $\propto N_2 I_2$

Total wt. of Cu $\propto N_1 I_1 + N_2 I_2$

Autox'mer:

Defn: Auto x'mer is a special type of transformer such that a part of the wdg. is common to both primary & second. It has only one winding wound on a laminated magnetic core.



As compared to an ordinary 2-winding transformer of same output, an auto-x'mer has higher efficiency but smaller size, Its voltage regulation is also superior.

* Saving of Cu:

Volume and hence weight of Cu, is proportional to the length and area of cross-section of conductors.

Now length of conductor is proportional to the number of turns and C/s depends on current.

Hence, weight is proportional to the product of the current and No. of turns.

From fig. wt. of Cu in section AC is $\propto (N_1 - N_2) I_1$;

wt. of Cu in section BC is $\propto N_2 (I_2 - I_1)$

$\therefore$ Total weight of copper in auto-x'mer $\propto (N_1 - N_2) I_1 + N_2 (I_2 - I_1)$

If a two winding x'mer were perform the same duty, then

wt. of Cu on its primary $\propto N_1 I_1$; wt. of Cu on secondary $\propto N_2 I_2$

Total wt. of Cu $\propto N_1 I_1 + N_2 I_2$