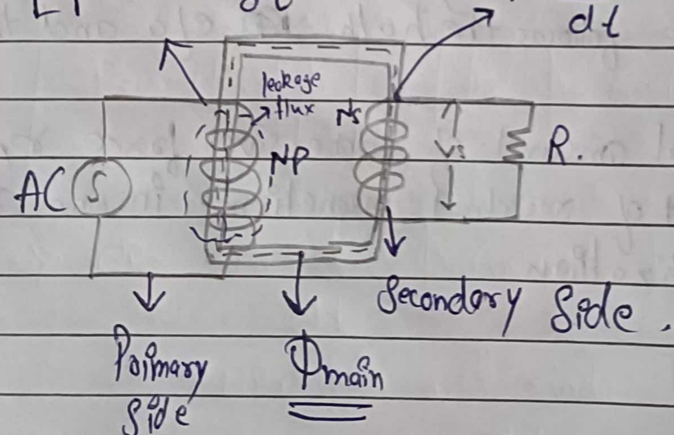
losses in magnetic circuits

- Hysteresis
- Eddy Current

Transformer.

It is a static device which transfers ac electrical power from one circuit to another without change in frequancy but voltage level may change.

$EP = -NP \cdot \frac{d\phi}{dt}$ $\qquad$ $Ns \cdot \frac{d\Phi}{dt} = Es$



ϕ_T = leakage flux + main flux.

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Construction of transformer.

(i) Magnetic Circuit (Core) → material with low permeability as well as low reluctivity.
C RGO (Cold Rolled Grain oriented) } special type of man-made
HR GO (Hot Rolled " ") } material.

(ii) Electric Circuit (winding) → We generally use Cu, but due to unavailability & Expensive we use Aluminium now.

(iii) Dielectric Circuit → for insulation purposes

(iv) Tank & Accessories. → (i) As we Add oil in the transfor for high efficiency and observtion of Heat. But due to change in temp the volume of the liquid will change so we always create a setup for this kind of problem.

(ii) Breather (silica gel) → Cooling medium ($CaCl_2$)

(ii) Bushings → To insulate the direct Connection through transformer.

* Classification.

① On the basis of Service.
(a) distribution → 24 hours. We use them.
(b) Power → we use it at a peak time.

② On the basis of Voltage level
(a) Stepup (b) Stepdown.
$V_s > V_P$ $V_P > V_s$.

(3) on the basis of Core

(a) Shell → winding is surrounding the Core.

(b) Core → Core is surrounding the winding.

Use and throw type. ~~Current distribution and power transformer.~~

Emf equation of transformer.

when an alternating Voltage is applied across the primary of transformer, it takes magnetising current and flux (ϕ) is set up in the Core. The flux ϕ is uniformly distributed over the Core and linked with both the windings. The main flux ϕ is of alternating nature and hence emf is induced in the primary winding which is given by faraday's law.

$$\boxed{e_P = -N_P \cdot \frac{d\phi}{dt}} \qquad \boxed{\phi = \phi_m \cos(\omega t)}$$

$$\Rightarrow e_P = -N_P \frac{d}{dt}(\phi_m \cos\omega t)$$

$\phi_m \rightarrow$ Constant

$$= -N_P \cdot \phi_m \cdot \frac{d\cos\omega t}{dt}$$

$$\frac{d\cos\theta}{dt} = \sin\theta$$

$$= +N_P \cdot \omega \cdot \phi_m \sin\omega t$$

for max Emf $\sin\omega t = 1$, $\omega t = 90^\circ$

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$E_{P\,max} = N_P \phi_m \omega$, $E_{P(rms)} = \frac{N_P \phi \omega}{\sqrt{2}}$ $\because \omega = 2\pi f$

$E_{P\,rms} = \sqrt{2} \cdot \pi \cdot N_P \phi f = \boxed{4.44\, N_P \phi f}$

Also $\boxed{E_{P\,rms} = 4.44\, N_P\, B_m \cdot A_i \times f}$

$E_{secondary\,(Rms)} = 4.44\, N_s\, \phi_m f$
$= 4.44\, N_s\, B_m\, A_i \cdot f$

* transformation ratio. $\Rightarrow$ $\boxed{\frac{N_P}{N_s} = \frac{V_P}{V_s} = \frac{E_P}{E_s} = \frac{I_s}{I_P} = a}$

Q A Single phase transformer have 350 primary & 1050 secondary turns. The net Cross sectional area of the core is 55 cm². if the primary winding is Connected to 400V 50 Hz single face supply. Calculate (i) Max value of ϕ density in Core (ii) voltage induced in Secondary Coil.

$\Rightarrow$

$400 = 4.44 \cdot 350 \cdot B_m \cdot 55 \times 10^{-4} \times 50$.

$B_m = 0.93\,T$

(ii) $\frac{E_P}{E_s} = \frac{N_P}{N_s}$ $\rightarrow$ 1200V why KVA is used → As seen Cu loss of a transformer depends on current and iron losses on voltage. Hence loss depends on VA ie Voltage Ampere and not on phase angle b/w Voltage and Current. And it is independent of load power factor.

Q A 25KVA transformer has 500 turns on primary and 40 turns of secondary. The primary is connected to 3000 V 50 Hz. Calculate (i) Primary and Secondary current at full load. (ii) Secondary Emf (iii) Max ϕ is the core.

⇒ Primary current at full load.

$$I_P = \frac{25KVA}{E_P} = \frac{25\times 1000 \; VA}{3000 \; V} = 8.33A$$

$$\frac{8.33}{x} = \frac{40}{500} = \frac{2}{25} \Rightarrow 104.125A$$

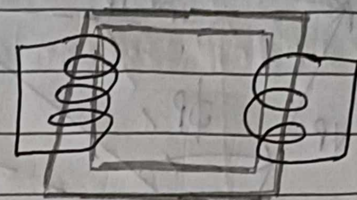
(ii) Secondary Emf

$$\frac{25\cancel{500}}{2\cancel{40}} = \frac{3000}{x} \quad X = 240V$$

(iii) $E_P = 4.4 \, N_P \phi f$

$$\phi = \frac{E_P}{4.4\times N_P\times f} = \frac{3000}{4.4\times 500\times 50} = 0.0272 \, Wb$$

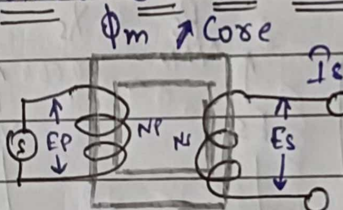
Transformer on DC



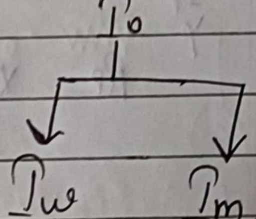
A transformer Can not work on dc supply. if a Rated DC Voltage is applied across the primary, a flux of Constant magnitude will be set up in the Core. Hence their will not be any self induced emf in the primary winding to oppose the applied voltage. The resistance of the primary winding is very low and the primary Current will be quiet high, this Current is much more than the rated full load Current. Thus it will produce lot of heat (i^2R loss) and burns the insulation of primary Coil and the transformer will be damaged that is why DC Can not be applied on a transformer.

* Transformer on different types of load.

① transformer on no-load.



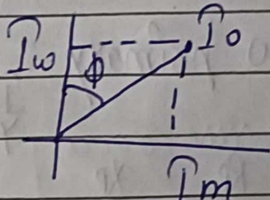
$V_s = 0$



$I_w = I_o \cos\phi_o$.

$I_m = I_o \sin\phi_o$.

$I_o = \sqrt{I_w^2 + I_m^2}$.

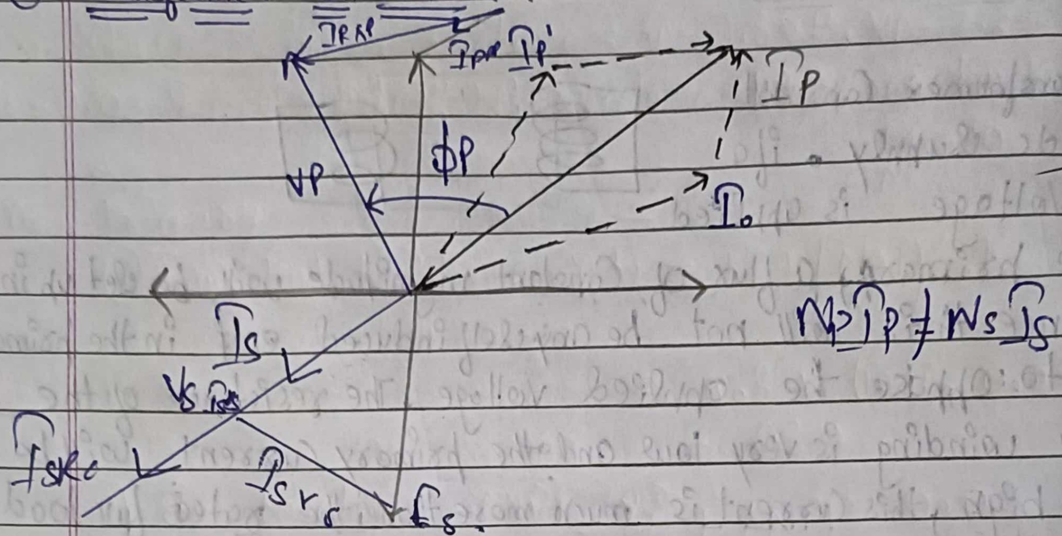


At Secondary side no Current is drawn. So

$I^2R = 0$, $I_P = I_o$.

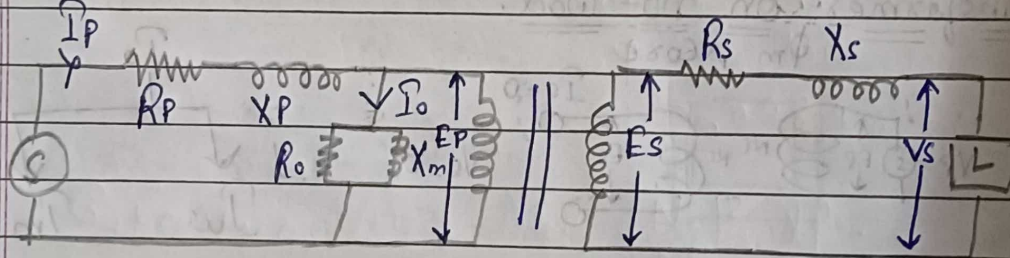
But flux is set up so Emf will be their.

② transformer on R-load

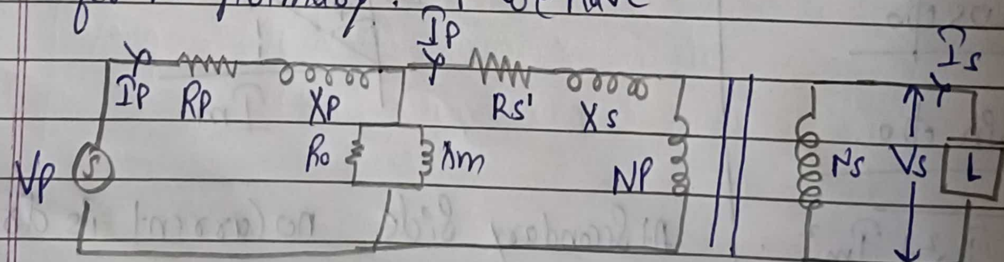


Equivalent Circuits of a transformer

The Equivalent Circuit of a transformer is quite helpful in pre determin the behaviour of the transformer under various Conditions of operations. from the Equilalent Circuit parameters.



* Refer to primary. we have.

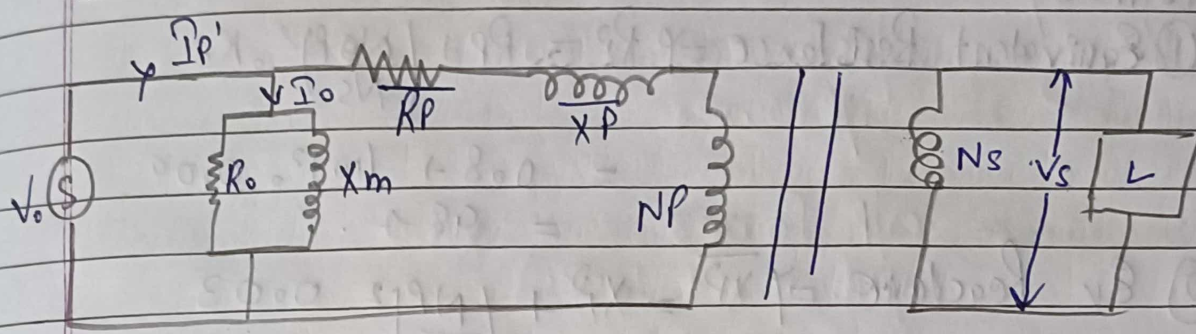


$$(I_S)^2 R_S = (I_P')^2 \cdot R_S'$$

$$\left(\frac{I_S}{I_P'}\right)^2 \cdot R_S = R_S'$$

$$\boxed{R_s' = R_s\left(\frac{N_P}{N_S}\right)^2 = a^2 R_s}$$

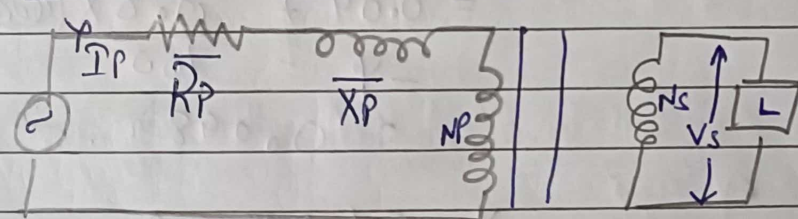
ie $$\boxed{X_s' = X_s \cdot \left(\frac{N_P}{N_S}\right)^2 = a^2 X_s}$$



$$\overline{R_P} = R_P + R_s' = R_P + a^2 R_s$$

$$\overline{X_P} = X_P + X_s' = X_P + a^2 X_s$$

final simplified Equation Circuit refer to primary.



① Equivalent Resistance ⇒ $\overline{R_P} = R_P + a^2 R_s = R_P + \left(\frac{N_P}{N_S}\right)^2 R_s$.

② Equivalent Reactance ⇒ $\overline{X_P} = X_P + a^2 X_s = X_P + \left(\frac{N_P}{N_S}\right)^2 X_s$.

③ Equivalent Impedence ⇒ $\overline{Z_P} = \sqrt{\overline{R_P}^2 + \overline{X_P}^2}$

Eqn Circuit refer to Secondary.

① Eq Resistance ⇒ $\overline{R_s} = R_s + a^2 R_P = R_s + \left(\frac{N_s}{N_P}\right)^2 \cdot R_P$.

② Eq Reactance ⇒ $\overline{X_s} = X_s + a^2 X_P = X_s + \left(\frac{N_s}{N_P}\right)^2 \cdot X_P$.

③ Eq Impedence ⇒ $\overline{Z_s} = \sqrt{\overline{R_s}^2 + \overline{X_s}^2}$

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Q A 25KVA 2200/220 V 50Hz single phase transformer has following resistance & leakage Reactance : $R_P = 0.8\Omega$, $X_P = 3.2\Omega$, $R_S = 0.09\Omega$, $X_S = 0.03\Omega$ Calculate (i) Eq resistance (ii) Eq reactance for Primary & Sec.

$\frac{N_P}{N_S} = 10$

Ans Primary

(1) Equivalent Resistance $\Rightarrow \overline{R_P} = R_P + \left(\frac{N_P}{N_S}\right)^2 \cdot R_S$

$= 0.8 + (10)^2 \cdot 0.09$

$= 9.8\Omega$.

(2) Eq Reactance $\Rightarrow \overline{X_P} = X_P + \left(\frac{N_P}{N_S}\right)^2 \; 0.03$

$= 12.2\Omega$.

Secondary

(1) Eqn Resistance $\Rightarrow \overline{R_S} = R_S + \left(\frac{1}{10}\right)^2 R_P$.

$= 0.09 + \frac{0.8 \times ()}{100}$

$\Rightarrow$

0.098Ω.

Eq Reactance $X_S + \left(\frac{N_S}{N_P}\right)^2 X_P$.

$= 0.03 \; \Omega$.

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Voltage Regulation ⇒ The voltage regulation of a transformer is defined as the net change in secondary terminal voltage from no load to full load expressed as % of its rated voltage for the same primary voltage.

$$\% VR = \frac{V_{snl} - V_{sfl}}{V_{sfl}} \times 100$$

nl → no load
fl → full load.

$$\% VR = \frac{I_s [R_s \cos\phi \pm X_s \sin\phi]}{V_s} \times 100 \quad \{\text{For Secondary}\}$$

$$\% V_R = \frac{I_P [R_P \cos\phi \pm X_P \sin\phi]}{V_P} \times 100 \quad \{\text{For Primary}\}$$

- \+ sign is used for lagging loads / inductive load / lagging power factor.
- \- sign is used for leading loads / capacitive load / leading power factor.

Losses in Transformer

Core (const losses) $\{P_i\}$
↓
Iron losses
↓ Hysteresis
↓ Eddy Current.

$\{P_c\}$ Copper (variable)
↓
winding (I^2R).
$= x^2 P_c$
↳ fraction of load
if loss = 50%
$x = 1/2$.

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Efficiency of a transformer.

Efficiency of a transformer is defined as the ratio of o/p power to i/p power

$$\% \eta = \frac{\text{O/P Power}}{\text{I/P Power}} \times 100$$

$$= \frac{\text{O/P Power}}{(\text{O/P Power} + \text{losses})} \times 100$$

$$= \frac{\text{O/P Power}}{(\text{O/P power} + \text{iron loss} + \text{Copper loss})} \times 100$$

$$\boxed{\% \eta = \frac{V_s I_s \cos\phi}{V_s I_s \cos\phi + P_i + P_c}}$$

⇒ if n is the fraction of full load at KVA then Efficiency at this fraction is given by

$$\% \eta = \frac{n V_s I_s \cos\phi}{n V_s I_s \cos\phi + P_i + n^2 P_c} \times 100$$

$$\boxed{\% \eta = \frac{n \, KVA \times 1000 \times \cos\phi}{n \, KVA \times 1000 \times \cos\phi + P_i + n^2 P_c} \times 100}$$

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Conditions.

for max Efficiency → The efficiency of a transformer at a given load & power factor is given by

$$\eta = \frac{V_s I_s \cos\phi}{V_s I_s \cos\phi + P_i + (I_s)^2 R_{es}}$$

The terminal voltage V_s is approx Constant. Thus for a given power factor, ~~is given by~~ η depends upon load Current I_s.

on Dividing Numr & Denr by I_s.

$$\eta = \frac{V_s \cos\phi}{V_s \cos\phi + \frac{P_i}{I_s} + I_s R_{es}} \quad \text{—— (1)}$$

from Eq (1) the numr is Const & eff will be max. if denominator will be min.

ie $\frac{d}{dI_s}\left[V_s \cos\phi + \frac{P_i}{I_s} + I_s R_{es}\right] = 0$

$$0 - \frac{P_i}{I_s^2} + R_{es} = 0.$$

$$I_s^2 R_{es} = \boxed{P_i = P_c} \quad \text{— (2)}.$$

$$\%\eta = \frac{V_s I_s \cos\phi}{V_s I_s \cos\phi + 2P_i} \times 100$$

Current at max Condition.

$$I_s = \sqrt{\frac{P_i}{R_{es}}}$$

Load at Max Condition.

$P_i = P_c$

$P_i = n^2 P_c$

$$n = \sqrt{\frac{P_i}{P_c}}.$$

Q) A 2 KVA 400/200 Volts 50Hz Single phase transformer has the following perimeter. as refer to primary side

$\overline{r_P} = 3\Omega$, $\overline{X_P} = 4\Omega$

determine the regulation of transformer when

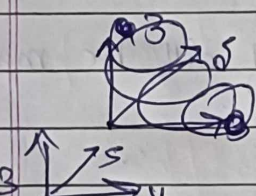
(I) full load with point at power factor lagging. 8.1

(II) " " " " leading. 0

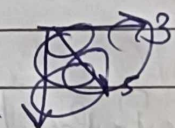
(III) Half load " " " " lagging. 3

Sol

$$\% VR = \frac{I_P\left[\overline{R_P}\cos\phi \pm \overline{X_P}\sin\phi\right] \times 100}{V_P}$$



$\cos\phi = \frac{4}{5}$, $\sin\phi = \frac{3}{5}$



$$= \frac{5 \times 100 \times VA}{\times 400}\left(3(0.8) + (0.6)4\right)$$

$$= 5(2.4 + 2.4)$$

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Q. in a 25 KVA 2000 by 200 Volt transformer have iron and copper losses of 350 watt and 400 watt respectivly, Calculate its Efficiency at unity P.f at (I) full load
(II) Half load.

$$\eta\% = \frac{V_s I_s \cos\phi}{} = \frac{n\,KVA \times 1000 \times \cos\phi}{n KVA \times 1000 \times \cos\phi + P_i + n^2 P_c}$$

unity P.f means $\cos\phi = 1$

full load $k = 1$.

$P_i = 350$, $P_c = 400$.

$$\Rightarrow \frac{25 \times 1000}{25000 + 350 + 400} \times 100 = 97.087\%$$

(II) At half load $n = \frac{1}{2}$

96.50 Ans

$$\eta\% = \frac{n KVA \times 1000 \times \cos\phi}{n KVA \times 1000 \times \cos\phi + P_i + n^2 P_c}$$

$$= \frac{\frac{1}{2} 25 \times 1000 \times 1}{\frac{25 \times 1000}{2} + 350 + 100} \Rightarrow 96.52\%$$

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Q. A 220 by 400 volt 10KVA 50Hz single phase transformer has a full load of Copper loss 120 watt. if its has a efficiency of 98% at full load and unity PF, determine the iron loss. (i) -

(ii) what would be η if at half load at Power factor lagging $\cos\phi = 0.8$. Ans 97.23.

(i) $98 = \dfrac{10\times1000}{10\times1000 + P_i + 120} \times 100$.

$10000 + P_i + 120 = \dfrac{10^6}{98}$.

$P_i = 84.08$ watt.

(ii) $\eta = \dfrac{\overset{5}{\cancel{10}}\times1000\times0.8}{0.8(5000) + 84.08 + \frac{120}{4}} = 97.22\%$

$98.77 = \dfrac{400\times1000\times0.8}{400\times1000\times0.8 + P_i + P_c}$

$P_i + P_c = -316760.14$.

$99.13 = \dfrac{\frac{1}{2}400\times1000}{200\times1000 + P_i + \frac{P_c}{4}}$.

$4P_i + P_c = -791929.78$.

$3P_i =$

$P_i = 131984$ 131 KW.

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Q. The Efficieny of 400 KVA single phase transformer is 98.77% when delivering full load at ~~pointed~~ 0.8 power factor and 99.13% at half load and unit powerfactor Calculate P_i & P_c.

⇒ Pointed Pf $\cos\phi = 0.8$

$$98.77 = \frac{200 \times 1000}{200\times1000 + x + y}$$

$$99.13 = \frac{200 \times 1000}{200 \times 1000 + x + \frac{y}{4}}$$

$$2\times10^5 + x + y = \frac{2\times10^5}{98.77}$$

⇒ $x + y = -197{,}975.0$

$$2\times10^5 + x + \frac{y}{4} = \frac{2\times10^5}{99.13}$$

$4x + y = -791929.7$

$3x = 593954.7$

$x = 197984.9$

$y =$

$P_i = 1.012$ Kw.

$P_c = 2.973$ Kw.

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Q. in a 50KVA the iron and Copperloss are 350 & 425 watt resp. Calculate efficiency at
(I) full load with unity PF
(II) Half —— " ——
(III) full load with 0.8 PF. Also determine max Efficiency and load at which Max Efficency occur.
(IV)

$$K = \sqrt{\frac{P_i}{P_c}} = \sqrt{\frac{350}{425}} = 0.907$$

load at which max Efficiency Occur $= \sqrt{K} \times$ full load in KVA
0.907 × 50 KVA
= 45.35 KVA

imp

= 98.31 %

(I) $\frac{50 \times 1000 \times 1}{50 \times 1000 + 350 + 425} = 99.84\%$

Ans = 98.48

(II) $\frac{25 \times 1000}{25 \times 1000 + 350 + \frac{425}{4}} = 98.556\%$

(III) $\frac{50 \times 1000 \times 0.8}{50 \times 1000 \times 0.8 + 350 + 425} = 99.80\%$

All day Efficiency

$$\%\eta_{Allday} = \frac{O/P \text{ in Kwh for 24 hours}}{I/P \text{ in Kwh for 24 hours}} \times 100.$$

$$\boxed{= \frac{O/P}{O/P + \text{losses}} \quad (\text{in Kwh for 24h})}.$$

Q A 20 KVA transformer on domestic load, which can be taken as has a full day efficiency of 95.3%, the copper loss them being twice of iron loss. Calculate its allday efficiency on following daily cycle (1) No-load for 10hr
(II) Half load for 8hr.
(III) full load for 6hr.

(1) full load at $O/P = 20 \times 1 = 20$ Kwh

$$\text{full load } I/P = \frac{O/P}{\eta} = \frac{20}{95.3} \times 100. = 20.986 \text{ Kw}.$$

Total losses $= P_i + P_c = IP - OP$

$$P_i + P_c = 0.986 \text{ Kw} \quad -(1)$$

given that $P_c = 2P_i$ —(2).

losses at full load. $P_i = 0.3287$ Kw $\quad P_c = 0.6574$ Kw.

now total $= 0 + (20 \times 8) + (1 \times 20 \times 6)$

$= 200$ Kwh.

iron Ko load se Kui farag nahi padte

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Ironloss in 24hrs $\Rightarrow$ 0.3287×24
$= 7.89\ Kwh$.

Culoss in 24hr in Kwh.

$\Rightarrow 0 + \left(\frac{1}{2}\right)^2 \times 0.6574 \times 8 + (1)^2 \times 0.6574 \times 6.$

$\Rightarrow 5.259\ Kwh$.

$\% \eta_{allday} = \frac{O/P}{O/P + losses}$ [for 24hr in kwh] $\times 100$.

$= \frac{200}{200 + 7.89 + 5.259} \times 100 = 93.83\%$

Q A transformer has max η of 98%. at 15 KwA at unity PF, it is loaded as follows (i) 12hr → 2Kw, 0.5Pf
(ii) 6hr → 12Kw, 0.8Pf
(iii) 6hr → 18Kw, 0.9Pf

Sol
Ans $P_i = .153 Kw$
$P_c = 1053 Kw$

Hr	load Kw	Pf	load (KVA) = Kw/PF.	fraction of load $k = \frac{\text{given load in Kw}}{\text{full load in KvA}}$
12	2Kw	0.5	$2/0.5 = 4KvA$	$k = \frac{4}{15} = 0.267$
6	12Kw	0.8	15 KvA	$= 1$
6	18Kw	0.9	20KvA	$= 1.33$ here transf. Can get damage

• Open circuit → Iron loss.
• closed circuit → Cu loss

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formula's

• No load Power factor $(\cos\phi) = \frac{W_0}{V_0 I_0}$.

• working Component ⇒ $I_w = \frac{W_0}{V_0}$

• Magnetising Component ⇒ $I_m = \sqrt{I_0^2 - I_w^2}$

• $R_0 = \frac{V_0}{I_w}$, $X_0 = \frac{V_0}{I_m}$

$W_c = I_{sc}^2 \cdot R_{es}$. I_{sc} = ammeter reading.

$V_{sc} = I_{sc} Z_{es}$.

$X_{es} = \sqrt{(Z_{es})^2 - (R_{es})^2}$

Q The following test data is obtained on a 5KVA 220 by 440 Volt single phase

OC test. → iron loss

220V, 2A, 100 watt. on low voltage side.

Sc test → Culoss

40V, 11.4, 200 watt on high voltage side.

determine %η at full load at 0.9 PF and regulation.

⇒ $\%\eta = \frac{n\,KVA \cos\phi}{n\,KVA + \text{iron loss} + \text{Cu loss}}$.

$$= \frac{(5\times1000 \times 0.9)}{\left(\frac{5\times1000}{0.9}\right) + 100 + 200} = 93.75\%$$

Q A 5KVA 400 by 200 volt 50Hz single phase transformer give following result. during no load and short circuit

No lod → 400V, 1A, 60 watt

SC → 15V, 12.5A, 150 watt. (Primary side)

Calculate (I) No load parameters R_0 & X_m

(II) Equivalent Resistance and reactance refer to primary

(III) Regulation at full load

(IV) Iron and Cu loss at full load

(V) Efficiency at full load and 0.8 PF.

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Q A 200 KVA 1000 by 250 Volt 50 Hz single phase transformer give following test result

SC Test 250V, 18 A, 1300 watt.

Calculate ~~1300~~ All day efficiency if the transformer is loaded

→ 8 hours full load at 0.8 PF

→ 10 h half load at 1 PF

→ 6 h no load.

⇒