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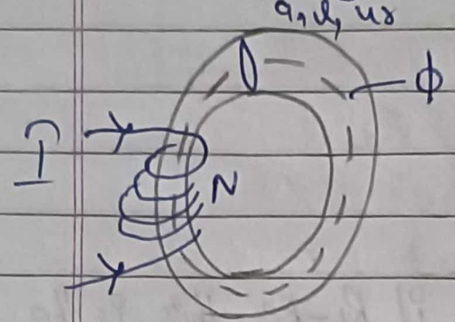
Unit-3

Magnetic Circuits



Consider a magnetic ring as shown in figure with n numbers of turns in wire. When current I is passed through solenoid, flux ϕ is set up in the core.

- flux density in the core $(B) = \phi/A$ (web/m² or T)

Mag Force $(H) = \frac{B}{\mu_0 \mu_r} = \frac{\phi}{a\mu_0\mu_r}$

According to work law, the work done in moving a unit pole once around the magnetic circuit is equal to the Amphere turns enclosed by the magnetic circuit.

H = magnetic intensity $\Rightarrow Hl = NI$ {mmf = magneto motive force} {unit = Amp turns}.

$\Rightarrow \frac{\phi}{a\mu_0\mu_r} \cdot l = NI \quad \Rightarrow \phi = \frac{NI \times a\mu_0\mu_r}{l}$

$$\boxed{\phi = \frac{NI}{l/a\mu_0\mu_r} = \frac{mmf}{Reluctance}}$$

Reluctance → The oposition offered to the magnetic flux by the magnetic circuit.

Rem

$\boxed{S = \frac{l}{a\mu_0\mu_r}}$ AT/web.

Permeance → it is a measure of easness by which flux can be set up in the material.

Permence (P) $= \frac{1}{S}$ unit = Henry or Web/AT.

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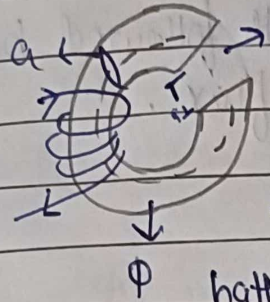
Reluctivity → it is a specific Reluctance of a magnetic material and Analogus to Resistivity.

* Leakage flux & fringing.



Consider a magnetic ring as shown in figure with n numbers of turns.

The flux which does not follow the intended path in a magnetic circuit is called leakage flux.

when current I flows through a solenoid as shown in figure, magnetic flux is produced by it. Most of this flux follows the intended path and passes through air gap. This flux is called useful flux ϕ_u.

However some of flux is just set up around the coil and it not utilized for any work. this flux is called Leakage flux ϕ_L.

$$\boxed{\phi_{Total} = \phi_u + \phi_L}$$

fringing → it is clear from the figure that useful flux when setup in the air gap, it tends to bulge outward at b & b'. This increase the effective area in the air gap and decreases flux density this effect is known as fringing. The fringing $\propto$ length of air gap.

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Comparision b/w Electric & Magnetic Circuits.

Similarities

Electric Circuit	Magnetic Circuit.
The closed path followed by electric current is called electric circuit.	Closed path followed by magnetic flux.
Current	flux
Emf	mmf
Resistance	Reluctance.
Conductance	Permeanance.
Resistivity	Reluctivity.
Current density	flux density
Electric intensity	magnetic intensity.

Differences

Electrical	Magnetic.
• Electric Current Actually flows in a circuit	• Magnetic flux does not flow, but it sets up in the magnetic circuit.
• for Electrical current their are large no of perfect insulator like glass, air etc. which does not allow current to pass through them under normal conditions	• for magnetic flux their is no perfect insulator, it can even be set up in non magnetic material like air rubber glass etc with reasonable mmf.
• The Resistance of an electric circuit is Almost Constant, as its value depends on ρ. which is Almost Constant. However the value ρ & R may vary slightly if temp changes.	• The Reluctance of magnetic circuit is not Constant rather it varies with the value of B. it is because the value of μ_R changes continuously in the change B.

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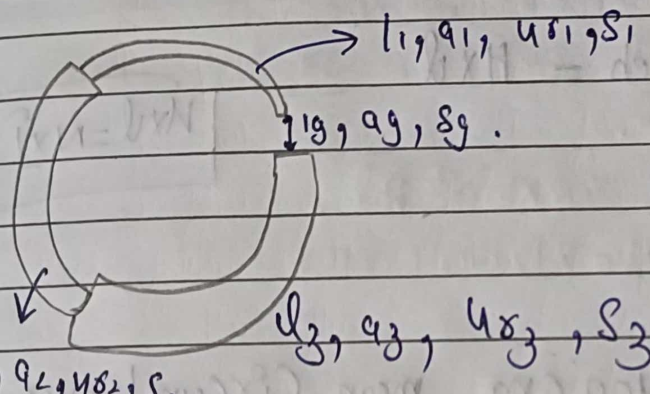
Energy is Expanded Continuously As long as the Current flows through an electric circuit. The Energy is dissipated in the form of Heat

Once the magnetic flux is set up in the magnetic circuit, no energy is expanded. However a small amount of energy is required at the time of set up of flux in the circuit.

Series magnetic circuit.



Total mmf $= \phi \times S$

$= S_1 + S_2 + S_3 + S_g$

$S = \frac{l}{a\mu_0\mu_r}$

$S_{net} = \frac{l_1}{a_1\mu_0\mu_{r1}} + \frac{l_2}{a_2\mu_0\mu_{r2}} + \frac{l_3}{a_3\mu_0\mu_{r3}} + \frac{l_g}{a_g\mu_0}$

Total Emf $= \phi \times \left[\frac{l_1}{a_1\mu_0\mu_{r1}} \cdots \frac{l_g}{a_g\mu_0}\right]$

$= \frac{\phi l_1}{a_1\mu_0\mu_r} - - - \frac{\phi l_g}{a_g\mu_0}$

We know that $B = \frac{\phi}{a}$

$S_0 = \frac{B_1 l_1}{\mu_0\mu_{r1}} + \frac{B_2 l_2}{\mu_0\mu_{r2}} \cdots + \frac{B_g l_g}{\mu_0}$

$= H_1 l_1 + H_2 l_2 + H_3 l_3 + H_g l_g$

Also we know that $H = \frac{B}{\mu_0\mu_r}$

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formula

- Total mmf $= \phi \times S = \phi \times \frac{l}{\mu_0 \mu_r a}$
- Total mmf $= N \times i$ {N → No of turns}
- So $\boxed{Ni = \phi \times \frac{l}{\mu_0 \mu_r a}}$
- Total Amp turns / web $= N \times I$
- Total Amp turns / web $= H \times l$ $\boxed{H \times l = N \times I}$
- $H = \frac{B}{\mu_0 \mu_r} = \frac{B}{\mu_0}$

Q An iron ring of 400 cm mean Circumfrance is made from round iron of Crossection 20 cm^2. its permeability is 500 if it is wound with 400 turns what Current would be required to produce a flux of 0.001 web.

⇒ $\mu_r = 500$

$$Ni = \phi \times \frac{l}{\mu_0 \mu_r a}.$$

$$i = \frac{1}{1000} \times \frac{400 \times 10^{-2}}{4\pi \times 500 \times 20 \times 10^{-4}}$$

$$\Rightarrow \frac{4}{\mu_0 \times 500 \times 2} = \frac{2}{500} = 3.183 \text{ Amp}$$

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Q. A flux density of 1.2 web/m² is required in 2mm air gap of an Electro magnetic having a iron path 1m long. Calculate its magnetising force and current required if the electromagnet has 1273 turns. Assume $\mu_r = 1500$.

=>

$$\frac{\phi}{A} \times \frac{l}{\mu_0 \mu_r} = Ni$$

$$\cancel{H \times l = N \times I}$$

$$\cancel{\frac{B}{\mu_0 \mu_r} \times l = N \times I}$$

$$\cancel{\frac{1.2 \times 1}{\mu_0 \times 1500} = 1273 \times i}$$

$l_g = 2 \times 10^{-3}$

$l = 1m$.

$$i = \frac{12}{10} \times \frac{1}{1500 \times \mu_0 \times 1273}$$

$$N \times I = \phi \left[\frac{l}{\mu_0 \mu_r a} + \frac{l_g}{\mu_0 a} \right]$$

$$N \times I = 1.2 \left[\frac{1}{} + \frac{2}{1000} \right]$$

$$I = \frac{12}{12730} \left[\frac{1}{\mu_0} + \frac{2}{1000} \right]$$

$$= 9.426 \times 10^{-4} \left[795774.7 \right]$$

$$H_i = \frac{B}{\mu_0 \mu_r} = 636.6A$$

$$H_g = \frac{B}{\mu_0} = 954900\ A$$

$H_i l_i = 636.66 \times 1 = 636.66$ + = Amp turns

$H_g l_g = 954900 \times \frac{2}{1000} = 1908.8$. = 2546.4 = $N \times I$

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Q. Estimate the no of Amp turns nesseary to produce a flux of 100000 lines round an iron ring of $6\,cm^2$ crossection and 20 cm mean diammeter, having a air gap of 2mm wide across it. μ_r of iron = 1200.

Relation 1web = 10^8 lines of force

$\Rightarrow$

$Hl = $

$Hl = \frac{\phi}{A \cdot \mu_0 \mu_r} \cdot l = $

$1web = \frac{10^8}{10^3}$

$\cancel{\frac{10^{-3}}{6\times10^{-4}\times\mu_0\times1200}} \cancel{\times 2\pi 10\times10^{-2}}$

Total length $= \pi d = \underline{20\pi}$ $\frac{2\pi}{10}$

iron $= \frac{2\pi}{10} - \frac{2}{1000} \Rightarrow \frac{2}{10}\left(\pi - \frac{1}{100}\right)$

$l_g = \frac{2}{1000}$

$H_i l_i = \frac{10^{-3}}{6\times10^{-4}\times\mu_0\times1200}\left[\frac{2}{10}\left(\pi - \frac{1}{100}\right)\right]$

$= 70.62$

$H_g l_g = \frac{10^{-3}}{6\times10^{-4}\times\mu_0} \times \frac{2}{1000} = 2652.5$

Amp tur. 2723.12 =

Ans - 3344.79AT

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Q Calculate the Relative permeability of an Iron ring when the exciting Current taken by 600 turn Coil is 1.2 Amp. and total flux = 1 milli web (10^{-3}) Circumfrance of the Ring is 0.5m and Area of Crossection is $10 cm^2$.

$\Rightarrow$

$$60 \times 12 = \frac{\Phi}{A \mu_0 \mu_r} \cdot l$$

$$60 \times 12 = \frac{10^{-3} \times \frac{1}{2}}{10 \times 10^{-4} \times \mu_0 \times \mu_r}$$

$$\mu_r = \frac{\cancel{10}}{\cancel{10} \times 2 \times \mu_0 \times 60 \times 12}$$

$$\mu_r = \frac{1}{2 \times \mu_0 \times 60 \times 12} = 552.6$$

Q An iron ring of mean length of 1m has an air gap of 1mm and a winding of 200 turns. if the $\mu_r = 500$. When a Current of 1 Amp flows through Coil find $\frac{\Phi}{A}$

$\Rightarrow$

$$200 = \frac{\Phi}{A \mu_0} \left[\frac{0.999}{500} + 0.001 \right]$$

$$200 = \frac{B}{\mu_0} \left[2.998 \times 10^{-3} \right]$$

$$\frac{200 \, \mu_0 \times 10^3}{2.998} = B \rightarrow 0.0838 \text{ web/m}$$

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Inductance

Expression for self inductance.

(1) $e = L \cdot \frac{di}{dt}$

$L = \frac{e\,dt}{di}$

(2) $L = \frac{N\phi}{I}$

(3) $L = \frac{N^2}{S}$

Expression for Mutual inductance.

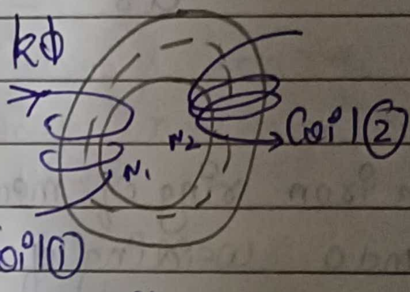
(1) $e_m = M \cdot \frac{dI_1}{dt}$

$M = \frac{e_m \cdot dt}{dI_1}$

(2) $M = \frac{N_2 \phi_{12}}{I_1} = \frac{N_1 \phi_{21}}{I_2}$

(3) $M = \frac{N_1 N_2}{S}$

Coefficient of Coupling.



$K = 0$

$K = 1$

when Current flows through one Coil it produces flux ϕ_1. The whole of this flux may not be linking with the other Coil Coupled to it as shown in figure it may be reduced because of leakage flux ϕ_1. by a fraction of K known as Cofficient of Coupling. thus the fraction of magnetic flux produced by Current in one Coil that links with the other is known as Cofficient of Coupling (K). if the flux produced by one Coil Completely links withother then the Value of K is 1 and Coil are said to be magnetically tightly Coupled.

if the flux produced by One Coil does not link at all with Other than the value of K is zero and Coil are said to be magnetically isolated.

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Consider the Ring as shown in figure when current I_1 flows through coil 1

$$L_1 = \frac{N_1 \phi_1}{I_1} \qquad M = \frac{N_2 \phi_{12}}{I_2} \qquad M = \frac{N_2 R \phi_1}{I_1} \quad \text{--- (1)}$$

$$L_2 = \frac{N_2 \phi_2}{I_2}, \quad M = \frac{N_1 \phi_{21}}{I_2} \qquad M = \frac{N_1 R \phi_2}{I_2} \quad \text{--- (2)}$$

on multiplying LHS & RHS.

$$M \times M = \frac{N_2 R \phi_1 \times N_1 R \phi_2}{I_1 \times I_2}$$

$$M^2 = L_1 L_2 R^2$$

$$M = R\sqrt{L_1 L_2}$$

$$\boxed{R = \frac{M}{\sqrt{L_1 L_2}}}$$

Q1 An air cort {$\mu_r = 1$} solenoid has 300 turns, its length is 25 cm and its cross section 3 cm^2 Calculate its self inductane in Henry.

$$L = \frac{N^2}{S} \Rightarrow \quad L = \frac{300 \times 30\cancel{0} \times 3 \times \cancel{10^{-4}} \times 1 \mu_0}{25 \times \cancel{10^{-2}}}$$

$$\frac{9 \times 3\cancel{00}}{\cancel{25}} \Rightarrow 1.357 \times 10^{-4}$$

$$\boxed{S = \frac{l}{\mu_0 \times \mu_r \times a}}$$

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~~Q2 A Coil wound on an Iron Core of permeability 500, has 200 turns and a Cross Sectional area of 8 cm². Calculate the inductance of Coil.~~

$\Rightarrow \cancel{L = \frac{N^2}{S} \Rightarrow 200\times 2}$

Q2 Calculate the inductance of toroid, 25 cm mean diatmer and 6.25 cm² cross section wound uniformly with thousand turns of wire. Calculate emf induced when Current in it increases at rate of 100 Amp per second. $l = \pi d$

$e = L \frac{di}{dt}$ $\quad e = \frac{N^2 \times 9 \times 40 \times 1}{l} \times 100 = 0.01$

Q3 Two Coils A and B of 600 & 1000 turns resp. Connected in series on same magnetic circuit of reluctance 2×10^6 Amp/turn. Assuming that their is no flux leakage, Calculate (i) self inductance of each Coil
(ii) Mutual " of two Coil.

$\Rightarrow \cancel{L = \frac{N^2 \times 9 \times 40}{4}} \Rightarrow \cancel{L = N^2}$

$L_1 = \frac{N^2}{S} = \frac{\cancel{60}\times\cancel{60}^{3}\times 100}{\cancel{2}\times 10^2} \Rightarrow 18\times 10^{-2}$

$L_2 = \frac{N^2}{S} = \frac{1000\times 1000}{2\times 10^6} \Rightarrow 0.5 \Rightarrow 50\times 10^{-2}$

$\frac{600\times 1000}{2\times 10^6} \Rightarrow \frac{6}{20} \Rightarrow \frac{3}{10} = 0.3$

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(vi) what would be the mutual inductance if the coff of coupling is 75%.

$$RM \Rightarrow 0.3 \times \frac{3}{4} = \underline{\underline{0.225}}.$$

Q The self inductance of a coil of 500 turn is .25 H if 60% of flux is linked with a second coil of 10,000 turns, calculate
(i) mutual inductance of two coil
(ii) Emf induced in a 2nd when current changes at rate of 100 Am/sec.

$\Rightarrow$ $L = 0.25$ $N_1 = 500$, $N_2 = 10000$

$$\cancel{M = N_2 K \frac{\phi_1}{I_1} - N_2 K \cdot L_1 = M = 10000 \times \frac{60}{100} \times \frac{25}{100}}$$

$$\cancel{250 \times 6 = M.}$$

$$\cancel{250 \times 6 = \frac{60}{100} \sqrt{\frac{25}{100} \times L_2}}$$

$$\cancel{\frac{2500 \times 2500}{25} \times 100 = L_2.}$$

$$L_1 = \frac{N \phi_1}{I_1}$$

$$\frac{25}{100} = 500 \times \frac{\phi_1}{I_1}$$

$$\frac{25}{5} \times 10^{-4} \Rightarrow \underline{\underline{5 \times 10^{-4}}} = \frac{\phi_1}{I_1}$$

(ii) $\cancel{250 \times 6}$

$$M = 10000 \times \frac{60}{100} \times 5 \times 10^{-4} \Rightarrow \frac{30}{10} \Rightarrow \underline{\underline{3H}}.$$

$$e = M \times \frac{di}{dt} \Rightarrow 3 \times 100 = \underline{\underline{300}}.$$

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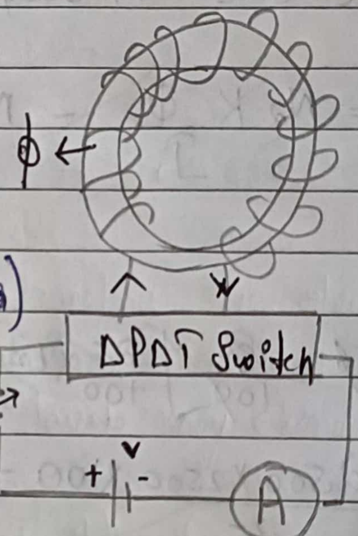
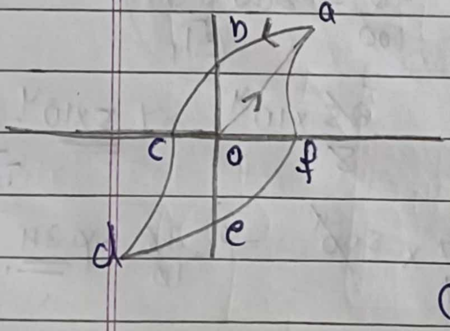
B-H Curve or Hystensis looh.

When a magnetic material is magnetise, first in one direction and then in other, it is found that flux density (B) logs behind applied magnetising force (H). This phenomenea is known as Hystensis.

Stensis is a term derived from greek word. ('hystereium') meaning to lag behind. To understand this consider a ring on which a solenoid is bound uniformly.



The solenoid is connected to DC source through a DPDT (Double Pole Double through) switch which is reversible.



When the field intensity (H) is increased gradually, by increasing current in the solenoid, the flux density (B) also increases. until saturation point a is reached and curves obtain is oa. If now the magnetising force is gradually reduced to zero by decreasing current in the solenoid, the flux density does not become zero. and curve so obtained is ab. When magnetising force (H) is zero, the flux density still has value ob.

Residual

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Residual magnetism & Retentivity.

The value of flux density ob retained by magnetic material is known a Residual magnetism of Power

To demagnatise the magnetic ring, the magnetising force (H) is reversed by reversing the direction of flow of current in the solenoid. this Can be Achive by changing the position of DPDT switch. when H is increased in reverse direction, the flux density starts decreassing and becomes zero and curve follows the path. vc. thus resudual magnetism of material is wiped of by applying magnetising force in opposite direction.

Cohhersive force

The value of magnetising force OC required to wipe off the residual magnetism is called Cohhersive force. To Complete the looh, the magnetising force (H) in increased in revere direction till saturation hoint reaches and followw th path cd.

Again H is ↑ in +ve direction by changing the position of dpdt switch and ↑ing the Current in the solenoid. The Curve follows the path efa and the loop is Completed.

Hence of is the total amount of Cohhersive force required to wipe of be amount of residual magnetism in one Complete Cycle of magnetization.

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losses in magnetic circuits

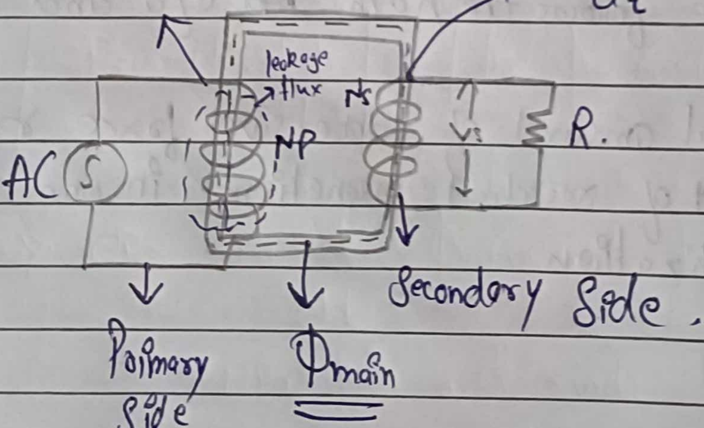
Hysteresis

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.

$EP = -NP.\frac{d\phi}{dt}$ $\quad$ $Ns.\frac{d\Phi}{dt} = Es$



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 material.
HR GO (Hot Rolled " ")

(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 observation 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.

(i) 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.
$V_s > V_P$ $V_P > V_s$.

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(3) on the basis of Core

(a) Shell → winding is surrounding the Core.

(b) Core → Core is surrounding the winding.

Use and throw

type. ~~Core 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 $\sin \omega t = 1$, $\omega t = 90°$

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

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

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. $\rightarrow \boxed{\dfrac{N_P}{N_s} = \dfrac{V_P}{V_s} = \dfrac{E_P}{E_s} = \dfrac{I_s}{I_P} = a}$

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) $\dfrac{E_P}{E_s} = \dfrac{N_P}{N_s}$ $\rightarrow$ 1200V

Why KVA is used and not on phase angle b/w Voltage and Current → As seen Cu loss of a transformer depends on Current and iron losses on voltage. Hence loss depends on VA i.e. Voltage Ampere. 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 in the core.

⇒ Primary Current at full load.

$$I_P = \frac{25KVA}{E_P} = \frac{25 \times 1000 \, VA}{3000 \, V}$$

$$8.33A$$

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

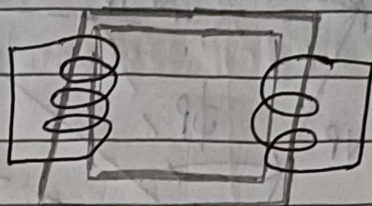
(II) Secondary Emf

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

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

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

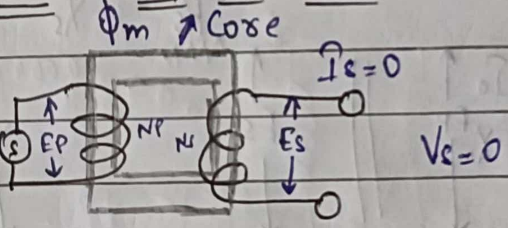
Transformer on DC

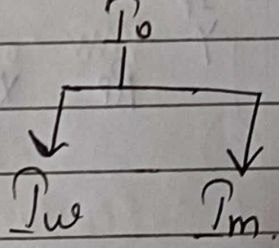


A transformer Can not work on dc supply. if a Rated DC Voltage is applied across the primary, a flux of Constant magnitude will be set up in the Core. Hence their will not be any self induced emf in the primary winding to oppose the applied voltage. The resistance of the primary winding is very low and 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.

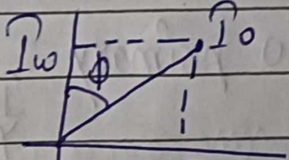




$I_w = I_o \cos\phi_o$

$I_m = I_o \sin\phi_o$

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

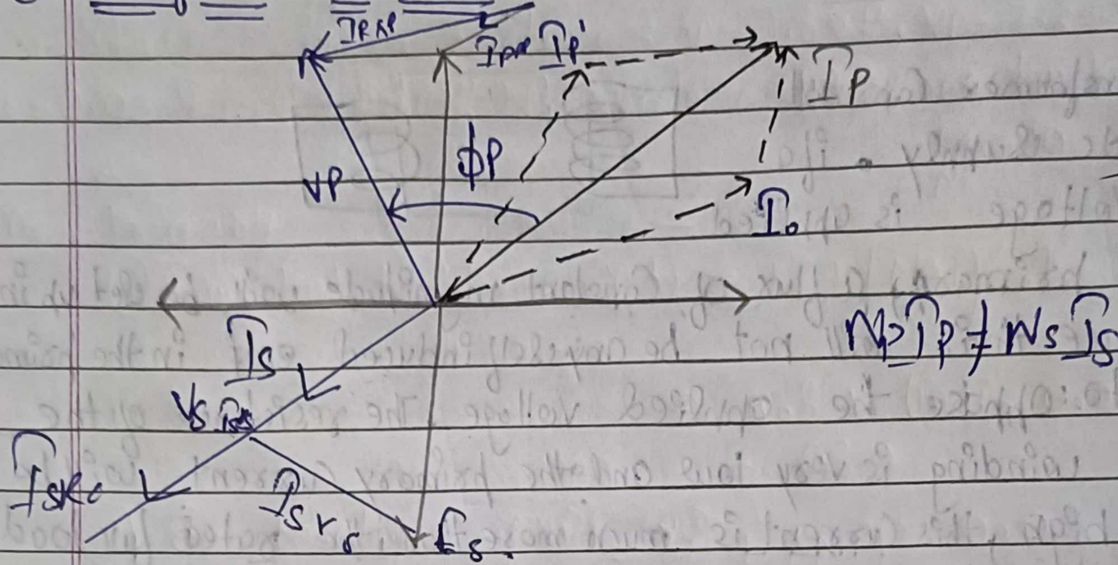


At Secondary Side no Current is drawn. So

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

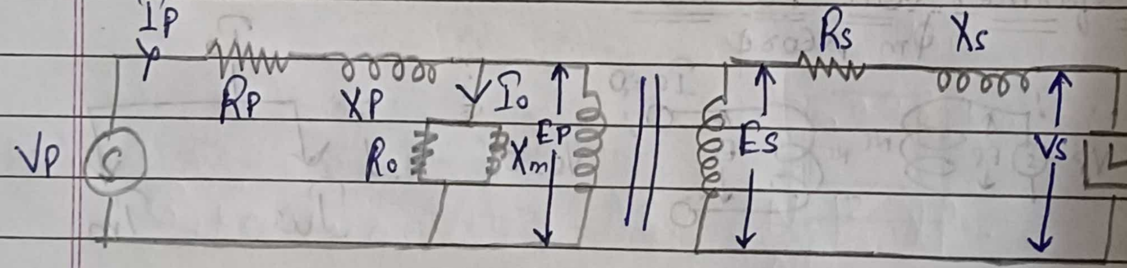
But flux is set up So Emf will be their.

② transformer on R-load.

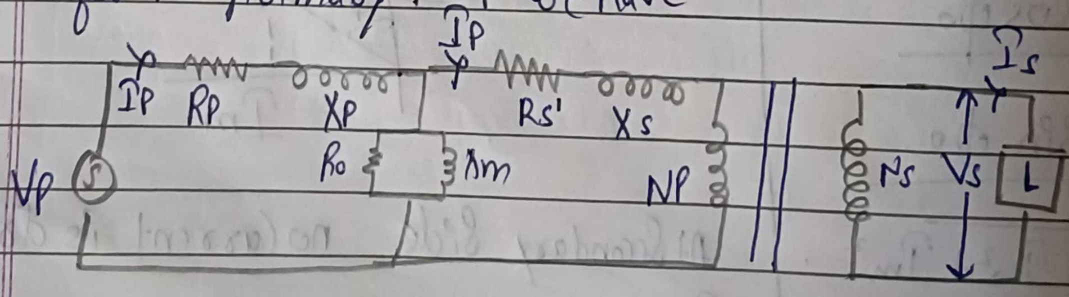


Equivalent Circuits of a transformer

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



* Refer to primary. we have.

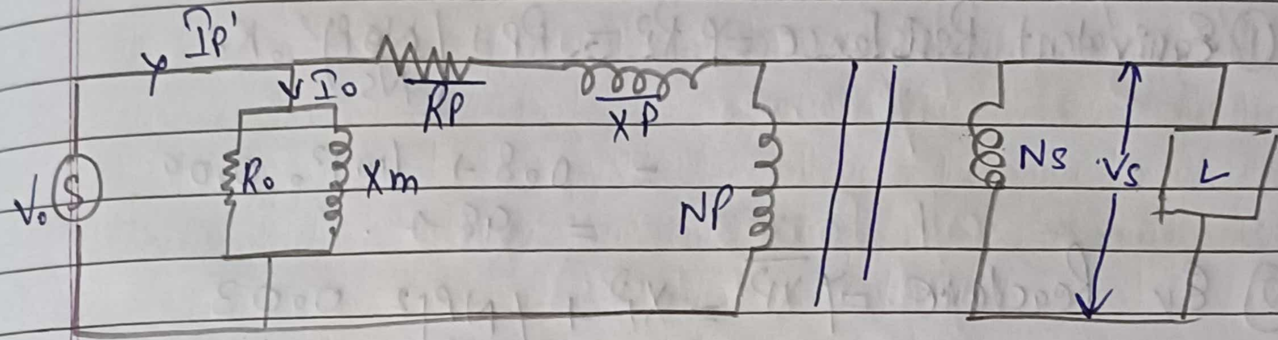


$$(I_s)^2 R_s = (I_p')^2 \cdot R_s'$$

$$\left(\frac{I_s}{I_p'}\right)^2 \cdot R_s = R_s'$$

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

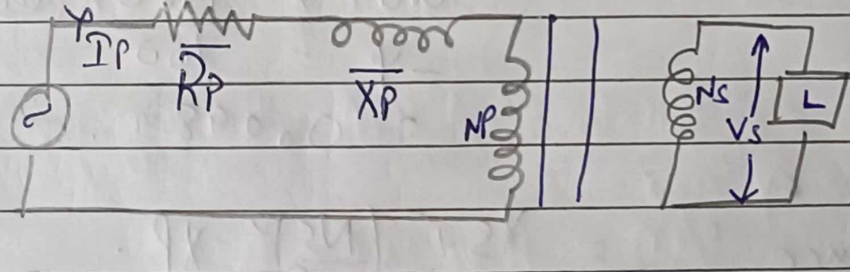
ie $$\boxed{X_s' = X_s \cdot \left(\frac{N_P}{N_S}\right)^2 = a^2 X_s}$$



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

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

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

$= 0.8 + (10)^2 \cdot 0.09$
$= 98\,\Omega$.

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

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

$\Rightarrow$

$0.098\,\Omega$.

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)

$= k^2 P_c$

↳ fraction of load.

if loss = 50%

$k = 1/2$

Efficiency of a transformer.

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

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

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

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

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

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

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

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

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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 Num^r & Den^r 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 num^r 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

$$\overline{rP} = 3\Omega , \quad \overline{XP} = 4\Omega$$

determine the regulation of transformer when

(i) Full load with point at power factor lagging. 8.1

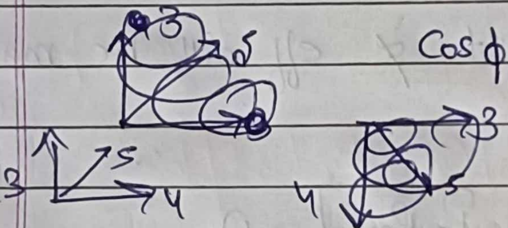
(ii) ,, ,, ,, ,, leading. 0

(iii) Half load ,, ,, ,, lagging. 3

Sol

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

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



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

$$\Rightarrow \frac{1}{5}(2.4 + 2.4).$$

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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 Pf means $\cos\phi = 1$

full load $n = 1$.

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

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

96.50 Ans

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

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

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

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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) $$98 = \frac{10 \times 1000}{10 \times 1000 + P_i + 120} \times 100$$

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

$$P_i = 84.08 \text{ watt}$$

(ii) $$\eta = \frac{5 \times 1000 \times 0.8}{0.8(5000) + 84.08 + \frac{120}{4}} = 97.22\%$$

$$98.77 = \frac{400 \times 1000 \times 0.8}{400 \times 1000 \times 0.8 + P_i + P_c}$$

$$P_i + P_c = -316760.14$$

$$99.13 = \frac{\frac{1}{2} 400 \times 1000}{200 \times 1000 + P_i + \frac{P_c}{4}}$$

$$4P_i + P_c = -791929.78$$

$$3P_i =$$

$$P_i = 131984$$

131 kw

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

$\Rightarrow$ Rated pf $\cos\phi = 0.8$

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

$$99.13 = \frac{400 \times 1000}{200 \times 1000 + x + \frac{y}{4}}$$

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

$\Rightarrow$ $x + y = -197,975.0$

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

$4x + y = -791929.7$

$3x = 593954.7$

$x = 197984.9$

$y =$

$P_i = 1.012$ Kw.

$P_c = 2.973$ Kw.

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Q. In a 50 KVA the iron and copper loss 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
(IV) and load at which Max efficiency occurs.

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

load at which max efficiency occur = $\sqrt{K}$ × full load in KVA
0.907 × 50 KVA
= 45.35 KVA.

= 98.21 %.

imp

(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

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

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

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 all day efficiency on following daily cycle (I) No-load for 10hr
(II) Half load for 8hr.
(III) full load for 6hr.

(1) full load at O/P = 20×1 = 20Kwh

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

Total losses = $P_i + P_c$ = IP − OP

$P_i + P_c = 0.986$ Kw − (1)

given that $P_c = 2P_i$ − (2).

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

now total = 0 + (20×8) + (1×20×6)
= 200 Kwh.

iron Ko load se Koi 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 KVA 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 $x = \frac{\text{given load in KVA}}{\text{full load in KVA}}$
12	2Kw	0.5	$2/0.5 = 4KVA$	$x = \frac{4}{15} = 0.267$
6	12Kw	0.8	15KVA	$= 1$
6	18Kw	0.9	20KVA	$= 1.33$ {here transfo. 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 ⇒ $I_m = \sqrt{I_0^2 - I_w^2}$

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

$W_c = I^2_{sc} \cdot R_{es}$. 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 → Cu loss

40V, 11.04, 200 watt on high voltage side.

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

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

$$\Rightarrow \left(\frac{(5 \times 1000 \times 0.9)}{\frac{5 \times 1000}{(0.9)} + 100 + 200} \right) = 493.45$$

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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 50Hz single phase transformer give following test result

SC Test 250V, 18A, 1300 watt.

Calculate 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.

⇒