B.Tech I Year

Regular Course Handbook

Subject Name: F. Electrical Engineering (Unit-3)

miet

BEE101 / BEE201: FUNDAMENTALS OF ELECTRICAL ENGINEERING

Content	Contact Hours
Unit -1: DC Circuits	6
Electrical circuit elements (R, L and C), Concept of active and passive elements, voltage and current sources, concept of linearity, unilateral and bilateral elements. Kirchhoff's laws, Mesh and nodal methods of analysis.	
Unit-2: : Steady State Analysis of Single Phase AC Circuits	6
Representation of Sinusoidal waveforms – Average and effective values, Form and peak factors. Analysis of single phase AC Circuits consisting R-L-C combination (Series and Parallel) Apparent, active & reactive power, Power factor. Concept of Resonance in series & parallel circuits, bandwidth and quality factor. Three phase balanced circuits, voltage and current relations in star and delta connections.	
Unit-3: Transformers	6
Magnetic circuits, ideal and practical transformer, equivalent circuit, losses in transformers, regulation and efficiency.	
Unit-4: Electrical machines	8
DC machines: Principle & Construction, Types, EMF equation of generator and torque equation of motor, applications of DC motors (simple numerical problems) Three Phase Induction Motor: Principle & Construction, Types, Slip-torque characteristics, Applications (Numerical problems related to slip only) Single Phase Induction motor: Principle of operation and introduction to methods of starting, applications. Three Phase Synchronous Machines: Principle of operation of alternator and synchronous motor and their applications.	
Unit-5: Electrical Installations	4
Introduction of Switch Fuse Unit (SFU), MCB, ELCB, MCCB, ACB. Types of Wires, Cables and Bus-bars. Fundamentals of earthing and lightning protection. Types of Batteries	

Course Outcomes:

	Course Outcome (CO)
CO 1	Apply the concepts of KVL/KCL and network theorems in solving DC circuits.
CO 2	Analyze the steady state behavior of single phase and three phase AC electrical circuits.
CO 3	Identify the application areas of a single phase two winding transformer as well as an auto transformer and calculate their efficiency. Also identify the connections of a three phase transformer.
CO 4	Illustrate the working principles of induction motor, synchronous machine as well as DC machine and employ them in different area of applications.
CO 5	Describe the components of low voltage electrical installations and perform elementary calculations for energy consumption.

Text Books:

1. Ritu Sahdev, "Basic Electrical Engineering", Khanna Publishing House, 2018.
2. P.V. Prasad, S.Sivanagaraju,"Electrical Engineering:Concepts and Applications" Cengage, 2018
3. D. P. Kothari and I. J. Nagrath, "Basic Electrical Engineering", Tata McGraw Hill, 2010.
4. D. C. Kulshreshtha, "Basic Electrical Engineering", McGraw Hill, 2009.

Reference Books:

1. E. Hughes, "Electrical and Electronics Technology", Pearson, 2010.
2. L. S. Bobrow, "Fundamentals of Electrical Engineering", Oxford University Press, 2011.
3. V. D. Toro, "Electrical Engineering Fundamentals", Pearson India, 1989.

Spoken Tutorial (MOOCs):

1. AC DC Circuit Analysis using NgSpice, Open Source Software (http://spoken-tutorial.org)

B.Tech First Year: Regular Course Lecture Plan Session 2022-23

Subject Name	Electrical Engineering

Unit No.	Unit Name	Syllabus Topics	Lecture No
1	DC CircuitS	Concepts of network, Active and passive elements, voltage and current sources. Concept of linearity and linear network, unilateral and bilateral elements. R, L and C as linear elements.	1
		Voltage source, Current source transformation, Kirchhoff's laws .	2
		Mesh analysis with Numericals	3
		Mesh analysis with Numericals	4
		Nodal analysis with Numericals	5
		Nodal analysis with Numericals	6
2	Steady State Analysis Of Ac Circuits	Concepts of AC fundamentals: r.m.s value and average value	7
		Form factor and peak factor of different waveforms	8
		Concept of phase & phasors, phasor representation of sinusoidally varying voltage and current wave	9
		Analysis of pure R, pure L and pure C circuit with power	10
		Analysis of Series RL, RC, RLC ckt and power traingle	11,12
		Resonance in series circuit, it's frequency & characteristics	13
		Bandwidth and quality factor	14
		Parallel Resonance and numericals on parallel R,L,C circuits	15,16
		Three phase star and delta connections	17,18
3	Transformers	Magnetic Circuits	19
		Single phase transformer: construction and working	20
		Ideal and Practical transformers with phasor and equivalent circuit	21
		Equivalent circuit of transformer with numericals	22
		Power losses in transformer	23
		Efficiency of transformer and numericals	24
		Maximum efficiency of transformer	25
		Voltage regulation of transformes at load	26

B.Tech First Year: Regular Course Lecture Plan Session 2022-23

Subject Name	Electrical Engineering	

Unit No.	Unit Name	Syllabus Topics	Lecture No
4	Electrical Machines	DC machines:Principle & Construction	27
		DC Generator-e.m.f equation,types ,applications	28
		DC Motor- Working,torque equation,back e.m.f	29
		DC Motor- Types, characteristics of series and shunt motors ,applications.	30
		Three Phase Induction Motor:Construction and working	31
		Slip, Slip-torque characteristics of three phase induction motor	32,33
		Single Phase Induction motor - Working & starting	34,35
		Synchronous motor - starting and working	36
5	Electrical Installation	LT Switchgears : Switch Fuse Unit (SFU), MCB	37
		LT Switchgears : ELCB, MCCB,ACB	38
		Types of Wires and Cables, fundamental of earthing & Lightning protection	39
		Types of Batteries,Bus bar	40

Signature	
Name of Subject Head	Mr. Ashok Kumar Rajput

MAGNETIC CIRCUIT

↳ Any current carrying conductor produces a magnetic field around the conductor. Magnetic field comprises the magnetic lines of forces which passes through the magnetic material in a closed path.

↳ The closed path followed by the magnetic lines of forces is called magnetic circuit. All electrical devices like as transformer, generator etc. work by the magnetic circuit.

* IMPORTANT TERMS RELATED TO MAGNETIC CIRCUIT:

1. Magnetomotive force [M.M.F] :-
Magnetic flux generator is called magnetomotive force. It is a some sort of magnetic pressure which set-up a magnetic flux in a magnetic circuit.
It depends upon the following factors :-
(a). No. of turns in a coil (N).
(b). Intensity of a current (I).

Hence, M.M.F. = NI Ampere-turn
M.M.F = NI AT.

2. Reluctance (S) :-
Resistance offered by magnetic circuit is called the reluctance. It opposes the magnetic flux in a magnetic flux circuit. Its unit is ampere-turns-weber^{-1}.
It depends upon the following factors :-
(a). Length of the core materials (l).
(b). Cross section area of the core (A).

Hence, Reluctance (S) = $\frac{l}{\mu \cdot A}$ AT/weber

$$S = \frac{l}{\mu_0 \mu_r A} \quad \because \mu = \mu_0 \mu_r$$

"Reluctance of the core can also be obtained by the ratio of m.m.f. to magnetic flux."

$$S = \frac{M.M.F}{\text{Magnetic flux}}$$

$$S = \frac{M.M.F}{\phi} \text{ AT/weber}$$

↳ Reluctance is analogous of resistance in an electric circuit.

(3). Permeance (P) :- Permeance is the reciprocal of reluctance of the material and it is measured in weber/AT.

Hence,

$$\text{Permeance (P)} = \frac{1}{\text{Reluctance}}$$

$$P = \frac{1}{S} \text{ weber/AT}$$

$$P = \frac{A \mu_0 \mu_r}{l} \text{ weber}$$

Permeance is the analogous of the conductance in an electric circuit.

(4). Magnetic flux (ϕ) :- Number of magnetic line of force passes through any cross-section is called magnetic flux. It's unit is weber. Hence,

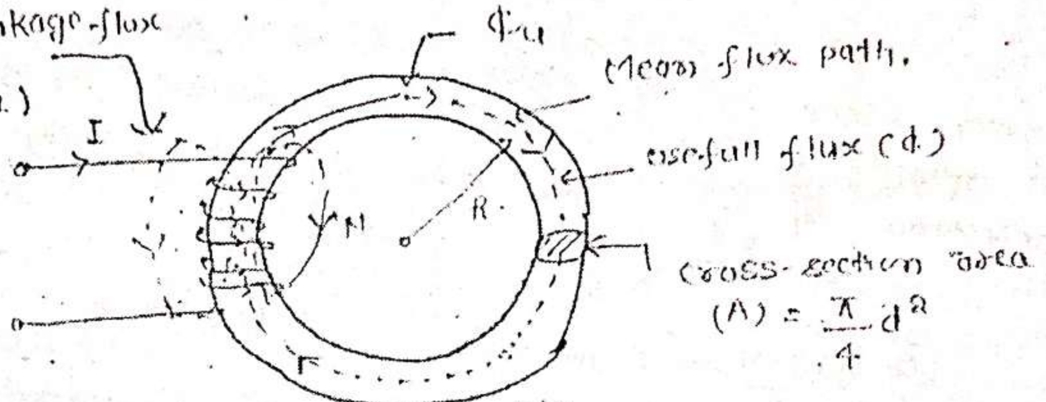
$$\text{magnetic flux} (\phi) = B \cdot A \text{ weber}$$

$$\phi = B \cdot A. \text{ weber.}$$

Where, B = Magnetic field (in Tesla).

A = Cross-section area (in metre^2)

b. Let us consider a toroidal ring of ferromagnetic material of mean radius R and circular cross-section of diameter d. The core of the ring is excited by a coil with N turns carrying a current I. Magnetic flux is established in the core & forms a closed path.



Fig

Let, l = mean length of the magnetic circuit in metre $= 2\pi R$

A = Cross section area of the core $= \pi \frac{d^2}{4}$ metre^2

μ_r = relative permeability of the core.

due to the ampere's law $\oint B \cdot dl = \mu NI$

$$B \cdot l = \mu NI$$

$$B = \frac{\mu NI}{l} \qquad \because \mu = \mu_0 \mu_r$$

$$B = \frac{\mu_0 \mu_r NI}{l}$$

Flux density in the core material, $B = \frac{\text{flux}}{\text{cross-section area}}$

$$B = \frac{\phi}{A}$$

Comparing above two equations, hence $\qquad \because NI = \text{mmf}$

$$\frac{\phi}{A} = \frac{\mu_0 \mu_r NI}{l}$$

$$\phi = \frac{NI}{\frac{l}{\mu_0 \mu_r A}}$$

$$\phi = \frac{M.M.F}{\text{Reluctance of magnetic path}}$$

$$\phi = \frac{NI}{S} \text{ weber.}$$

⇒ from above it is clear that
(i) intensity of flux is inversely proportional to the reluctance of the core related material, Hence,

$$\phi \propto \frac{1}{S}$$

$$\phi = \frac{NI}{S} \quad \{\text{analogous to ohm's law}\}$$

⇒ In magnetic circuit, total flux (ϕ_T) produced by the toroidal ring is categorised into two parts

1) Linkage flux or useful flux
2) Leakage flux.

⇒ Linkage flux or useful flux :- Linkage flux is that flux which is linked with the magnetic core i.e ϕ_u

⇒ Leakage flux :- The magnetic flux which does not follow the intended path in a magnetic circuit is called leakage flux i.e ϕ_L.

$$\left[\phi_T = \phi_u + \phi_L\right]$$

↳ Leakage coefficient or Leakage factor :-
The ratio of total flux produced to the useful flux is called leakage coefficient or leakage factor. It is indicated by λ. Hence,

$$\text{Leakage factor } (\lambda) = \frac{\text{Total flux}}{\text{useful flux}} = \frac{\phi_T}{\phi_u}.$$

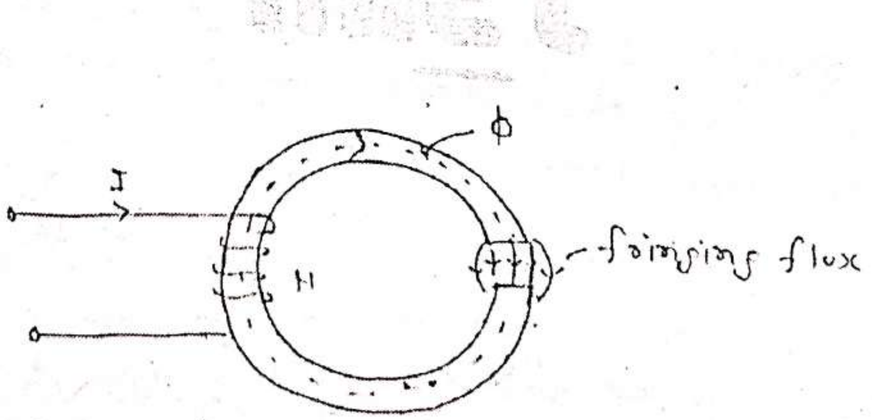
→ The value of leakage factor is always greater than unity. Practically, it will lie b/w 1.12 to 1.25.

Hence $1.12 < \lambda < 1.25$

↳ fringing :- Air gaps are provided in many practical magnetic circuit. Consider a ring provided with an air gap. as shown in the fig. below.

When the flux lines cross the air gaps. They tend to spreading at the edges of the air gap, So, the effective area of the air gap increases & flux density decreases.

This effect is called fringing.



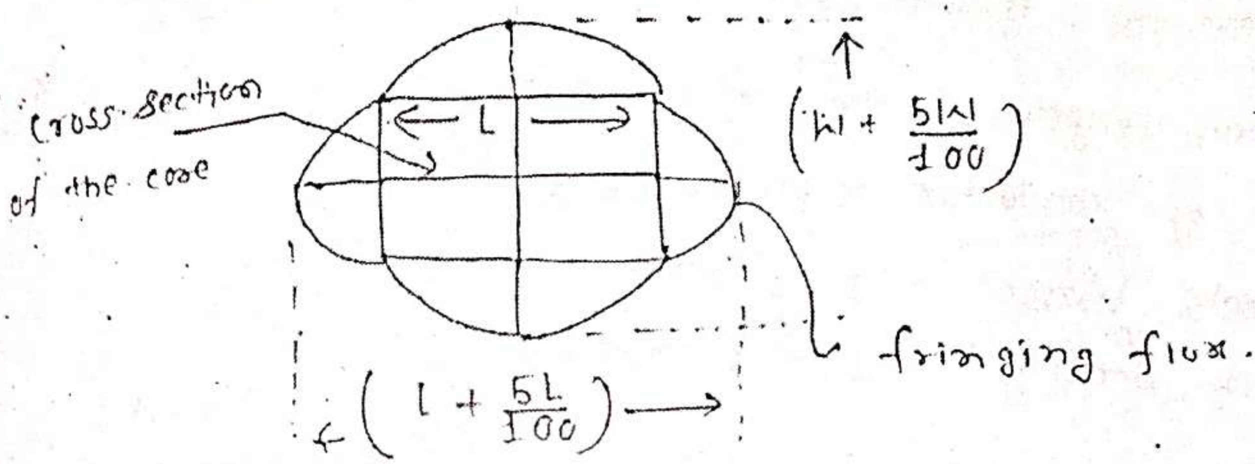
⇒ If the air gap is small as possible then we will assume, fringing flux is neglected.

If it is not neglected then effective cross-section area will increase.

Hence, cross-section of the air-gap will be,

$$A_g = (L + 5\% \text{ of } L) \times (W + 5\% \text{ of } W)$$

$$= \left(L + \frac{5L}{100}\right) \times \left(W + \frac{5W}{100}\right)$$



* Approximate area of the air gap if the fringing Not Neglected.

* comparison between Magnetic & Electric circuit.

↳ Magnetic circuit & electric circuit both are analogous to each other. A comparison of the two circuit is given.

Magnetic circuit	Electric circuit
The closed path for magnetic flux is called magnetic circuit	The closed path for electric current is called electric circuit.
flux is setup in the magnetic circuit.	current flowing in the electric circuit
$\text{flux } (\phi) = \frac{\text{m.m.f}}{\text{Reluctance } (S)}$	$\text{current } (i) = \frac{\text{emf } (E)}{\text{Resistance } (R)}$
3. MMF is the generator of flux in Amperes turn.	emf is the generator of current in volts.
4. Reluctance (S) opposes the flux	Resistance (R) opposes the current.

→ continued.–

Magnetic circuits	Electric Circuit
5. Reciprocal of reluctance is called permeance. $P = \frac{1}{S}$	Reciprocal of resistance is called conductance
6. Permeability of the magnetic core is μ.	conductivity of electric wire is σ.
7. flux density i.e $B = \frac{\phi}{A} \frac{\text{weber}}{\text{metre}^2}$.	current density i.e J $J = \frac{I}{A} \frac{\text{amp}}{\text{metre}^2}$
8. The reluctance (S) of magnetic circuit is not constant.	The resistance (R) of an electric circuit is is almost constant
9. Magnetic flux is set-up in a magnetic circuit, no energy is expanded	Energy is expanded continuously, as long as current flows through an electric circuit

⇒ Combination of Magnetic Circuits :-

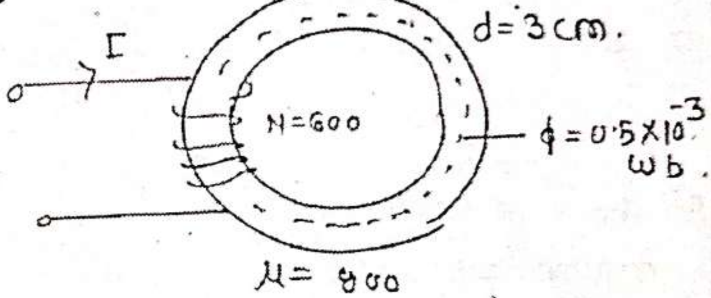
There are two combinations are used which are:-

1. Series magnetic circuit.
2. Parallel magnetic circuit.

Ques:- A cast steel ring has a circular cross-section of 3cm in diameter & a mean length of 80cm The ring is uni-formly wound with a coil of 600 turns. Estimate the current required to produce a flux of 0.5 mWb in the ring. Neglect the leakage flux & fringing. Assume relative permeability of ring as 800.

Given $d = 3\times10^{-2}$ m $\quad l_T = 80\times10^{-2}$ m $\quad N = 600$ Turns

$\phi = 0.5\times10^{-3}$ wb $\quad \mu_r = 800$



To find:- value of I ?

we know that

$A = \frac{\pi d^2}{4}$ $\quad A = \frac{\pi (3\times10^{-2})^2}{4}$

$\Rightarrow A = 0.0007\ m^2$

$\Rightarrow$ From the identity of mmf, we know that

$MMF = \phi . S = NI$

Magnetic Reluctance $\quad S = \frac{l}{A\mu_0\mu}$ $\quad S = \frac{80\times10^{-2}}{(0.0007)(4\pi\times10^{-7})\times(800)}$

$S = 1136821.022$ AT/weber.

$\phi S = NI$ $\Rightarrow$ value of supply current can be given as.

$\Rightarrow I = \frac{\phi S}{N}$ $\quad I = \frac{0.5\times10^{-3}\times 1136821.022}{600}$

$\Rightarrow I = 0.947$ Amp

↳ Numerical on series magnetic circuit →

Ques:- An iron ring of mean length 80 cm is uniformly wound with 500 turns of conductor wire. When a current of 1A is supplied to the coil, it produces a magnetic flux density of 1.1 Tesla in the core. Calculate the relative permeability of magnetic path.

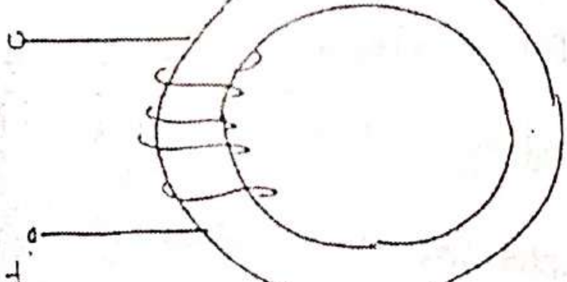
⇒ Given, length of the iron ring, $l_i = 80\,cm = 80 \times 10^{-2}\,m$.

⇒ No. of conductor turn, $N = 500$

⇒ Supply current $I = 1$ Amp.

⇒ flux density $B = 1.1$ Tesla.

To find the value of μ_r



We know that

$$B = \mu_0 \mu_r H.$$

$$H = \frac{NI}{l}. \quad \therefore H = \frac{500 \times 1}{80 \times 10^{-2}\,m}.$$

$$H = 625\ AT/m.$$

$\because B = \mu H.$

or $B = \mu_0 \mu_r H.$

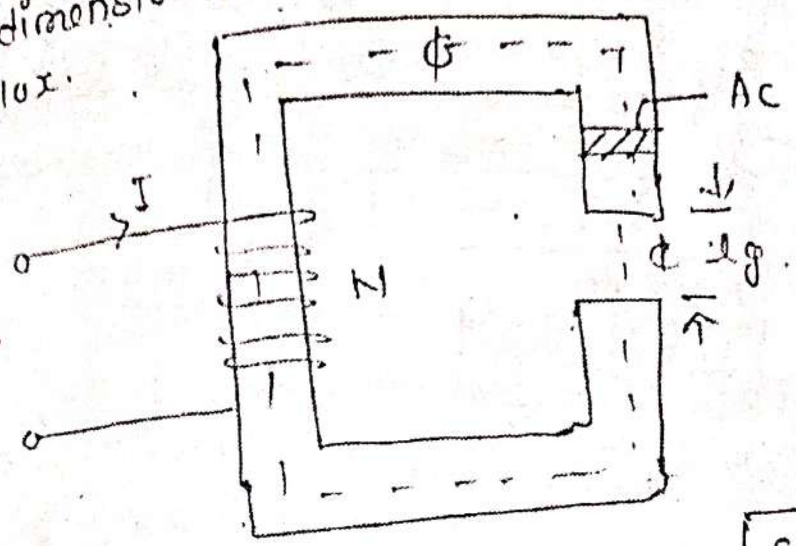
$\mu_0 = 4\pi \times 10^{-7}$

$$\mu_r = \frac{B}{\mu_0 H} = \frac{1.1}{(4\pi \times 10^{-7}) \times 625}$$

$$\boxed{\mu_r = 1400.563} \text{ Ans.}$$

Magnetic Circuit :-

(1). Series magnetic circuit has a number of parts of different dimensions & material carrying the same magnetic flux.



total reluctance of the magnetic circuit $\boxed{S = S_c + S_g}$.

where S_c = Reluctance of core S_g = Reluctance of air gap.

$$S_c = \frac{l_c}{\mu_0 \mu_r A_c} \ \frac{AT}{weber}.$$

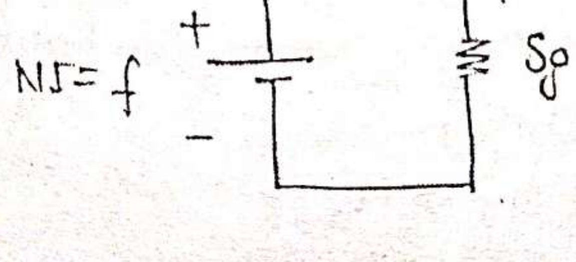
$$S_g = \frac{l_g}{\mu_0 A_g} \cdot \frac{AT}{weber}.$$

Substuting the values of S_c & S_g

$$S = S_c + S_g = \frac{l_c}{\mu_0 \mu_r A_c} + \frac{l_g}{\mu_0 A_g}.$$

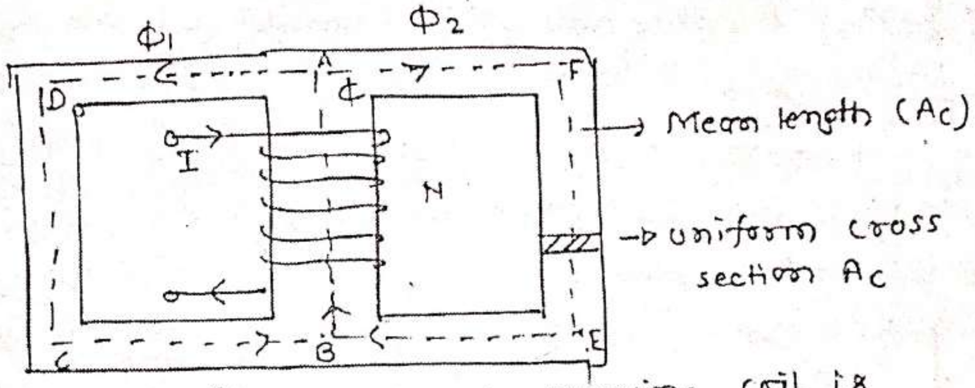
total m.m.f can be obtained by following expression

[mmf = ϕ x total reluctance (S).]



⇒ Parallel Magnetic circuit →.

In parallel magnetic circuit, two or more magnetic path are connected in such a manner that the magnetic flux is different in each magnetic path. Parallel magnetic circuits is shown below.



In the above circuit, a current carrying coil is wound on the central limb AB. The coil sets-up a magnetic flux ϕ in the central limb which is further divided into two paths i,e;

(i) Flux ϕ_1 flows in the path of ABCD.

(ii). Flux ϕ_2 flows in the path of ABEF.

** what is Hysteresis ? (IMP) [2016-17] ODD & EVEN [AKTU]

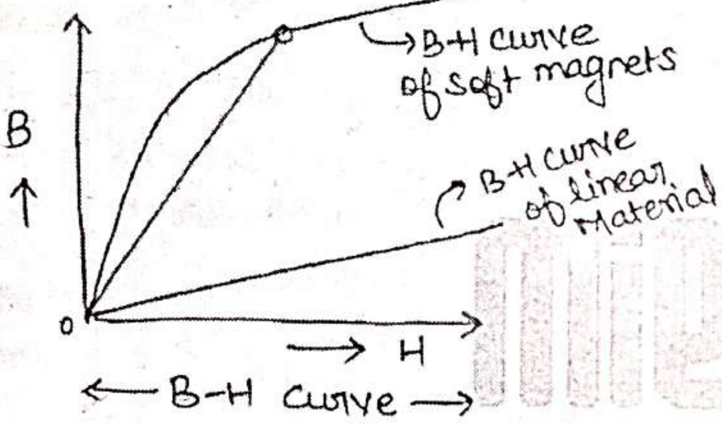
→ Hysteresis is the common property of ferromagnetic substances.

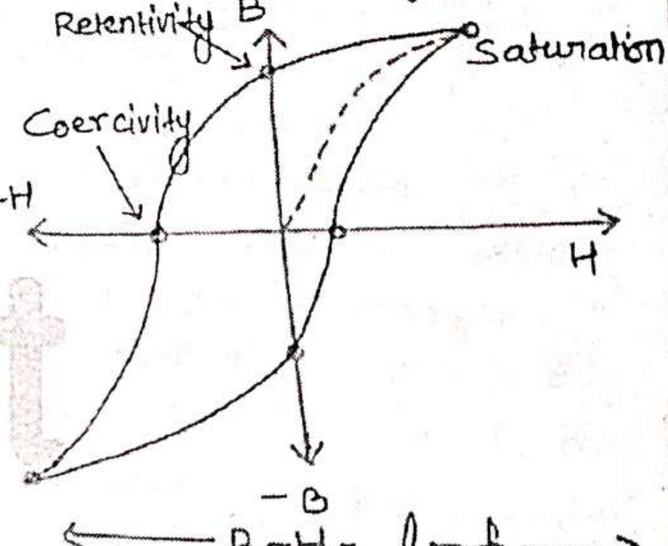
→ When the magnetization of ferromagnetic materials lags behind the magnetic field, this effect can be described as the hysteresis effect.

→ Hysteresis is characterized as a lag of magnetization intensity (B) behind the magnetic field intensity (H).

** B-H Curve :-

If an alternating magnetic field is applied to the material, its magnetization will trace out a loop called a hysteresis loop or B-H curve.





B → Magnetic flux density

H → Magnetizing force.

a) Coercivity :- It is the minimum external electric field required to destroy the residual magnetism is called Coercivity.

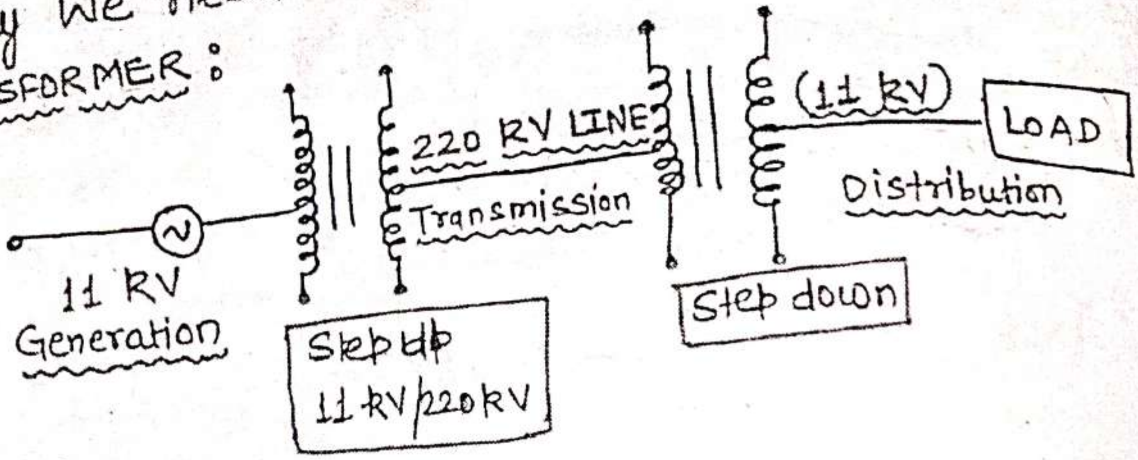
b) Retentivity :- It is the value of intensity of magnetisation retained by the ferromagnetic substance when the magnetising field is switched off.

* Materials used to make permanent magnets should have high value of retentivity and coercivity.

* Material used to make electromagnets have high retentivity and low coercivity.

Why We need TRANSFORMER ??

⇒ TRANSFORMER :



Now, Three phase power $= \sqrt{3} V_L I_L \cos\phi$

$I_L \propto \frac{1}{V_L}$ {as P and $\cos\phi$ are constant} if $V_L \uparrow$, $I_L \downarrow$

If $I_L \downarrow \longrightarrow I^2R$ loss low, size of conductors in transmission line are small, efficiency will increase, Voltage drop in line reduces.

Define Transformer or Explain Transformer ? [2014-

Transformer is a static device i.e no rotating part or no moving part, which transfers electrical energy from electrical circuit to another one with the desired change in voltage and current via magnetic flux and without change in frequency.

What is the working principle of Transformer? [20 (2019-20)

Transformer works on the principle of mutual Induction which states that "when two coils are inductively coupled and if current in one coil is changed uniformly then an E.M.F gets induced in the other coil."

1. Transformer has two windings (Primary (N_1 turns) winding and secondary (N_2 turns) winding)
2. For step up transformer $(N_2 > N_1)$
3. For Step down transformer $(N_1 > N_2)$

----Continue

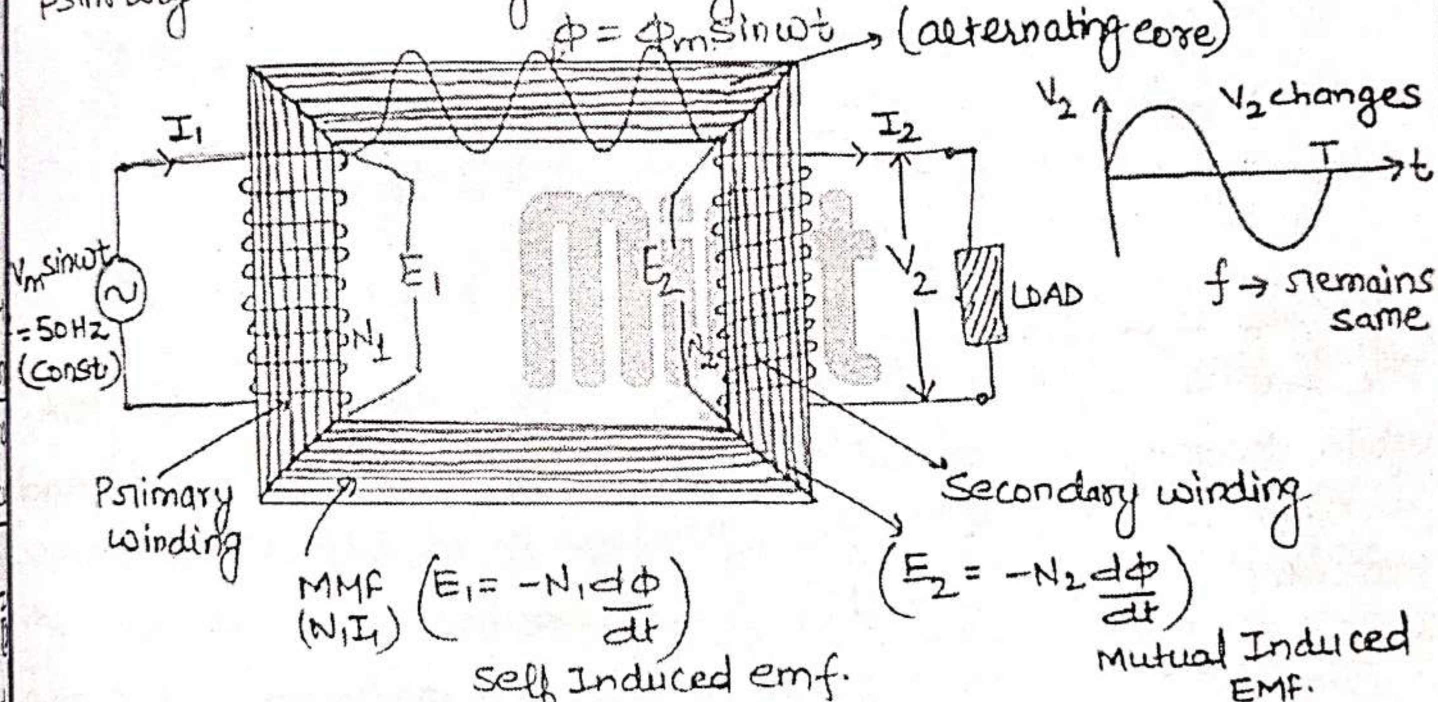
Explain the working of a Transformer? [M·IMP] SURESHOT [2013-14, 15-16, 17-18, 19-20]

WORKING OF A TRANSFORMER:

When primary winding is excited by an A.C. Voltage, due to current I_1 & N_1 an MMF (N_1I_1) is produced which circulates flux (ϕ) in the core.

Due to alternating current, flux changes at primary and an EMF (Statically) gets induced in the primary by faraday's law of Electromagnetic Induction.

The flux is alternating in nature and it links with the secondary so, due to mutual Induction an emf gets induced in the secondary winding. There is no electrical connection between the primary and secondary windings.



Ques:- What will happen, if Transformer provides/operate on DC? [2013-14, 2017-18]

ANS:- * Transformer cannot work on DC, because in DC supply flux produced in the core is not alternating.

* Flux is of constant Nature.
* As there is no change in flux so, no EMF is induced.
* If forcefully DC is given to the primary, core saturates and it will draw excessively large current which may burn the winding.

For DC primary winding Impedance ⇒ $Z = R + jX_L (\Omega)$

$\{X_L = 2\pi f L \ \Omega, \ f = 0 \text{ (DC)}\}$ $X_L = 0$ for DC, $Z = R_1$ (Min)

$\boxed{I = V/R}$ ↑ very large.

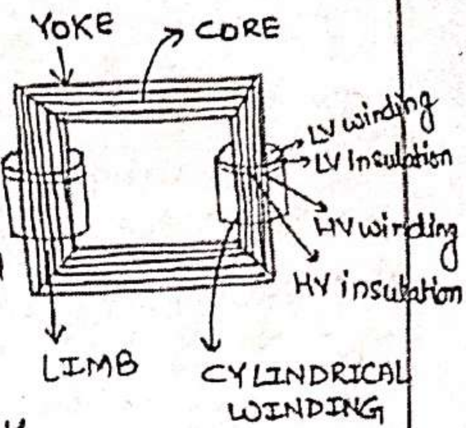
Imp:

** Explain the construction and Types of Transformer :

[2014-15] AKTU

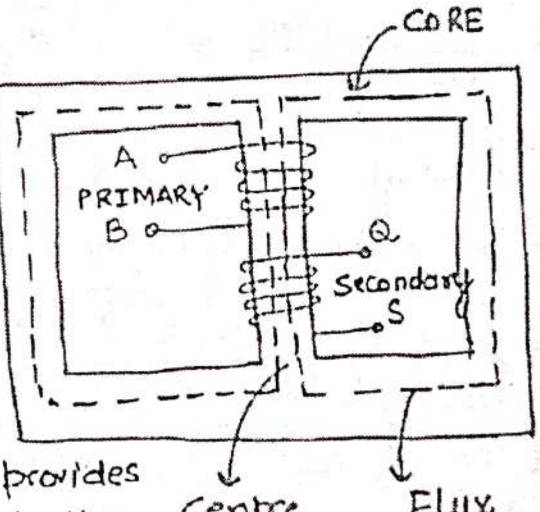
EXPLANATION:- Various types of Transformers are core type Transformer and shell type Transformer. [2014-2015]

1. CORE TYPE TRANSFORMER :



* Core of this transformer is in the form of rectangular frame and made up of laminations to reduce eddy current loss.
* Core is made up of high grade silicon steel to minimize hysteresis loss.
* Laminated rectangular core provides a single magnetic circuit. The primary and secondary windings are uniformly distributed on two limbs of the core.
* Low voltage winding is placed near the core so that less insulation is required.
* Better cooling as more surface is exposed to the atmosphere.
* The coils can be easily removed by removing the laminations of the type yoke for maintenance.
* It is used for low voltage transformer as well as for high transformers in power system.

2. SHELL TYPE TRANSFORMER :



* The Primary and secondary windings are placed on the central limb of the core.
* The high voltage and low voltage windings are of sandwich-type, which are in the form of interleaved -pancakes.
* This type of core provides double magnetic circuit. This type of core provides a better mechanical support and protection for the windings.
* The core surrounds the windings, cooling is not very effective. For removing any winding for maintenance, large no. of laminations are required to be removed.
* This construction is used for very high voltage transformers.

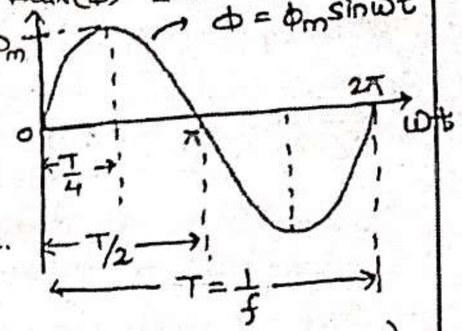
** Derive the EMF Equation of a Transformer :- [M.IMP][2013-14, 15-16, 17-18, 18-19]

Let ϕ = flux in the core of a transformer

ϕ_m = maximum value of flux (wb)

f = supply frequency (Hz)

$T = \frac{1}{f}$ = Time period (sec.)



E_1 = RMS value of the primary induced emf.

E_2 = RMS value of the secondary induced emf.

N_1 = No. of turns on primary B_m = Max. flux density (wb/m²)

N_2 = No. of turns on secondary

According to Faraday's law of Electromagnetic Induction, the average EMF induced in each turn is proportional to the average rate of change of flux.

Average EMF per turn $\propto \frac{d\phi}{dt}$

$$\because \frac{d\phi}{dt} = \frac{\text{Change in flux}}{\text{Time required for change in flux.}}$$

Consider $\frac{1}{4}^{th}$ cycle ϕ changes from 0 to ϕ_m.

$$\therefore \frac{d\phi}{dt} = \frac{(\phi_m - 0)}{(T/4)} = \frac{\phi_m}{(1/4f)}$$

$\therefore$ Average EMF per turn $= 4 f \phi_m$ ——— (1)

For sinusoidal quantity. Form Factor $= \frac{\text{RMS Value}}{\text{Average value}} = 1.11$

$\therefore$ RMS value = 1.11 × Average Value.

$\because$ Primary winding has N_1 no. of turns and secondary has N_2 no. of turns, so R.M.S value of primary and secondary induced EMF is,

$$\boxed{E_1 = 4.44 f \phi_m N_1} \longrightarrow (2)$$

$$\boxed{E_2 = 4.44 f \phi_m N_2} \longrightarrow (3)$$

From equation (2) and (3), for Ideal Transformer

* Voltage Ratio :- $\boxed{\frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{N_2}{N_1} = K}$ (K - Voltage transform ratio) where $\left(K = \frac{N_2}{N_1}\right)$

Thus, 1. If $N_2 > N_1$ i.e $K > 1$, $E_2 > E_1$ → Step up Transformer

If $N_2 < N_1$ i.e. $K < 1$, $E_2 < E_1$ → Step down Transformer

If $N_2 = N_1$ i.e $K = 1$, $E_2 = E_1$ → Isolation or 1:1 Transformer

* Current Ratio :-

For an Ideal Transformer, there are no losses. So Input (VA) equal to the output (VA)

$$\therefore V_1 I_1 = V_2 I_2$$

$$\therefore \boxed{\frac{V_2}{V_1} = \frac{I_1}{I_2} = \frac{E_2}{E_1} = \frac{N_2}{N_1} = K}$$

* Rating of Transformer :-

The rating of transformer is in Volt-ampere or KVA|MVA. while designing the transformer, there is no idea about load and its nature so its rating is expressed in VA|KVA|MVA. Moreover, Cu loss $\propto I^2$ and Coreloss $\propto$ Vsupply. These losses doesn't depend on load power factor. So rating of transformer is in VA|KVA|MVA not in KW|MW.

* Full load currents :-

$$\boxed{\text{KVA rating of transformer} = \frac{V_1 I_1}{1000} = \frac{V_2 I_2}{1000}}$$

$$\boxed{(I_1)_{f.L} = \frac{(KVA)\text{rating} \times 1000}{V_1}}$$

$$\boxed{(I_2)_{f.L} = \frac{(KVA)\text{rating} \times 1000}{V_2}}$$

where I_1 and I_2 are the full primary and secondary current. It is the safe maximum value of current which transformer can bear.

...merical: A 3300 V | 200 V, 50 Hz, 100 KVA transformer has its low ...ltage winding with 80 turns. Calculate :- [2018-19] AKTU

... The currents in both windings.

... No. of turns of high Voltage winding.

... Maximum value of flux. Transformer is fully loaded.

...ution:- 3300/200 V, 100 KVA, f = 50 Hz, $N_2 = 80$

... Primary current $(I_1)_{FL} = \dfrac{KVA \times 1000}{V_1} = \dfrac{100 \times 10^3}{3300} = 30.303\,A.$

Secondary current $(I_2)_{FL} = \dfrac{KVA \times 1000}{V_2} = \dfrac{100 \times 10^3}{200} = 500\,A.$

... $\dfrac{V_2}{V_1} = \dfrac{N_2}{N_1} = \dfrac{E_2}{E_1} = K$ $\therefore N_1 = \dfrac{V_1}{V_2} \times N_2 = \dfrac{3300}{200} \times 80$

$$\boxed{N_1 = 1320}$$

...i) As, $E_1 = 4.44\, f\, \phi_m N_1$ $\therefore \phi_m = \dfrac{E_1}{4.44 f_1 N_1} = \dfrac{3300}{4.44 \times 50 \times 1320}$

$$\phi_m = 11.26\ mwb$$

...ues:- For a single phase transformer having Primary and ...econdary turns of 440 and 880 respectively, Determine the transformer KVA rating if half load secondary current is 7.5 A and maximum value of core flux is 2.25 mwb.

...olution:- Given :- $N_1 = 440$, $N_2 = 880$, $(I_2)_{H.L} = 7.5\,A$

$$\phi_m = 2.25 \times 10^{-3}\ Wb.$$

As, $E_2 = 4.44\, f\, \phi_m N_2$

$\therefore E_2 = 4.44 \times 50 \times 2.25 \times 10^{-3} \times 880$

$$\boxed{E_2 = 439.56\,V}$$

$(I_2)_{FL} = \dfrac{(KVA)\ rating \times 1000}{E_2}$, $(I_2)_{FL} = 7.5 \times 2 = 15\,A$

$\boxed{KVA = 6.5934\ KVA}$ |ANS|

*Ideal Transformer :- [2013-2014]

What do you understand by the term "ideal transformer" [2013-2014]

Definition :- A transformer that doesn't have any losses like copper and core is known as an ideal Transformer.

① No losses (Iron and copper) ② Primary and secondary winding resistances are zero. ③ Leakage flux is zero i.e. 100% flux produced by primary links with the secondary.

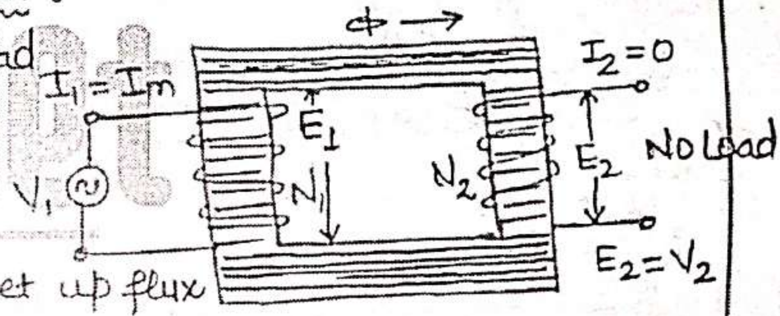
④ Permeability of the core is so high. ⑤ Efficiency (η) = 100%

⑥ As, R_1 and R_2 are zero. So, $V_1 = E_1$ and $E_2 = V_2$.

$$\left\{ K_r = \frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} \right\}$$

* Ideal Transformer on No Load :-

For Ideal Transformer on no load



* I_2 will be zero ($I_2 = 0$)
* No core loss, No cu loss
* Primary draws a current which is just necessary to set up flux in the core.
* $I_1 = I_m$ = Magnetising current (Sets up flux in the core)

As $R_1 = 0$, $R_2 = 0 \Rightarrow (V_1 = E_1)$ and $E_2 = V_2$

E_1 opposes $V_1 \Rightarrow$ By Lenz's Law (Induced E.M.F)

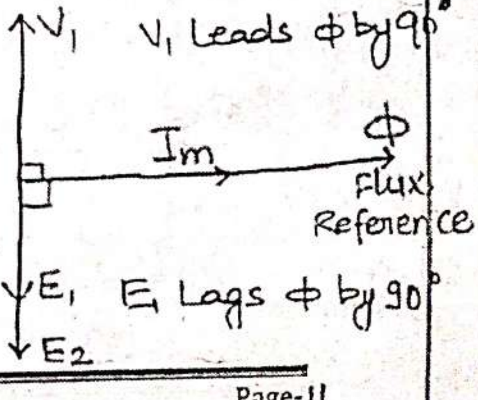
* Phasor diagram of Ideal Transformer on No-Load :- [V. Imp.]

* Take ϕ as reference

Im sets up ϕ, so is in phase with ϕ.

Im lags V_1 by 90° as winding is purely Inductive.

E_1 and E_2 are induced emfs. (in same phase) but oppose V_1 (Lenz's Law)



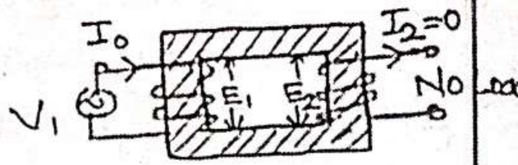
$P_{in} = V_1 I_m \cos 90° = 0$, $P_{in} = P_{out} = 0$

PRACTICAL TRANSFORMER [2014-2015] AKTU

A Practical transformer will differ from an ideal transformer in following aspects : 1- Core material (finite permeability) 2- Losses will occur 3- Leakage fluxes 4. finite winding resistance

*** Practical Transformer on NO-LOAD :- [Imp.]**

* On no, Load, In a practical transformer has iron Losses i.e hysteresis Loss and eddy current loss.



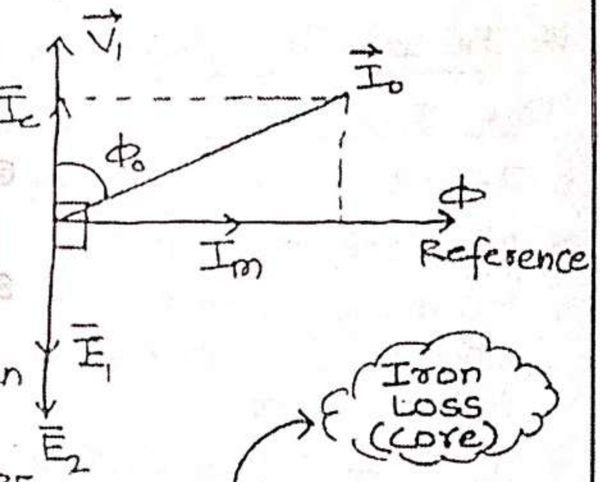
* The no load current (I_0) has two components :

a) I_m - Magnetising component → sets up flux in the core.

b) I_c - Active component → supplies for core loss.

I_m → Magnetising component lags V_1 by 90°

I_c → Core Loss component which is in phase with V_1



$\boxed{I_m = I_0 \sin\phi_0}$ $\boxed{I_C = I_0 \cos\phi_0}$

$\boxed{I_0 = \sqrt{I_c^2 + I_m^2}}$ ϕ_0 → angle between I_0 and V_1

$\cos\phi_0$ → No load P.F.

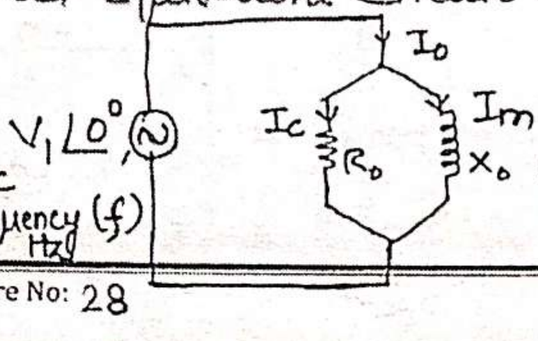
Iron Loss (Core)

*Total power Input on no-load ⇒ $\boxed{W_0 = V_1 I_0 \cos\phi_0 = V_1 I_c}$ (Watt)

IMP:- * No load current (I_0) is very small ≈ 3 to 5 % of full load rated current.

AKTU [2014-15] * Due to small I_0, the primary Cu Loss is negligibly small and only core Loss is obtained under no load.

* No-load Equivalent circuit :-



IMPORTANT

$\bar{I_0} = \bar{I_c} + \bar{I_m}$, $I_C = I_0 \cos\phi_0$

$I_m = I_0 \sin\phi_0$ $R_0 = \dfrac{V_1}{I_c}$

$X_0 = \dfrac{V_1}{I_m}$ $W_0 = V_1 I_0 \cos\phi_0 = V_1 I_c$

Numericals :- Ques-1: A 25 KVA, 3300/230V, 50Hz, 1-Phase transfo-mer draws a no Load current of 15 A when excited on load Voltage side and consumes 350 watt. Calculate two components of current. [2017-18] AKTU

Solution :- $W_0 = 350$ watt, $I_0 = 15A$, $V_0 = 230V$, $f = 50Hz$

$W_0 = V_0 I_0 \cos\phi_0$, $\cos\phi_0 = \frac{350}{15 \times 230} = \underline{0.1014 \text{ (Lag)}}$

$\sin\phi_0 = \underline{0.9948}$, $I_c = I_0 \cos\phi_0 = 15 \times 0.1014 = \underline{1.521 \text{ AMP.}}$

$I_m = I_0 \sin\phi_0 = 15 \times 0.9948 = \underline{14.922 \text{ AMP.}}$ |ANS|

Ques-2 :- A Voltage $V = 200 \sin 314t$ is applied to the transformer primary in a no-load test. The resulting current is found to be $i = 3 \sin(314t - 60°)$. Determine the core loss and no-load equivalent circuit parameters.

Solution :- No load current $I_0 = \frac{I_{max}}{\sqrt{2}} = \frac{3}{\sqrt{2}} = \underline{2.12 \text{ amp.}}$

$\Rightarrow$ Core loss $W_0 = V_1 I_0 \cos\phi_0 = \frac{200}{\sqrt{2}} \times \frac{3}{\sqrt{2}} \cos 60° = \underline{150 \text{ watt.}}$

$\because V_{1RMS} = \frac{V_{max}}{\sqrt{2}}$ and $\phi = 60°$ as i Lags v by $60°$

Active Component $\Rightarrow I_c = I_0 \cos\phi_0 = \frac{3}{\sqrt{2}} \cos 60° = \underline{1.06 \text{ AMP.}}$

Magnetising Component $I_m = I_0 \sin\phi_0$ or $\sqrt{I_0^2 - I_c^2} = \sqrt{(2.12)^2 - (1.06)^2}$

$\Rightarrow I_m = \underline{1.836 \text{ Amp.}}$, No load resistance $\Rightarrow R_0 = \frac{V_1}{I_c} = \frac{200/\sqrt{2}}{1.06} = \underline{133.4}$

No load Reactance $\Rightarrow X_0 = \frac{V_1}{I_m} = \frac{200}{\sqrt{2}} / 1.836 = \underline{77\Omega}$

|ANS|

Ques-3 :- The no-load current of a transformer is 4.0 A at 0.25 PF when supplied at 250 V, 50 Hz. The number of turns on the primary winding is 200. Calculate :-
(i) Flux in the core (ii) Core loss (iii) Magnetising current

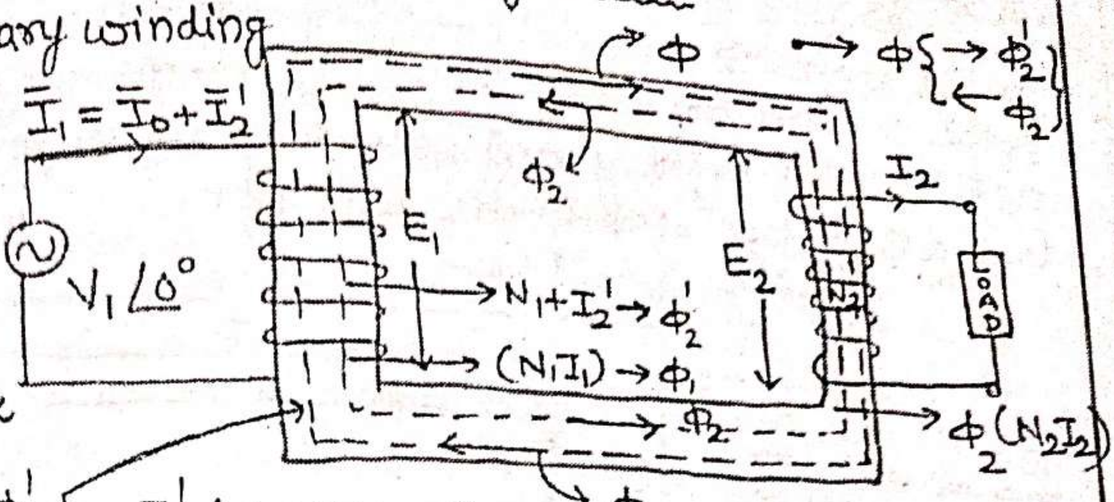
Solution :- (i) $E_1 = 4.44 f \phi_m N_1 \Rightarrow \phi_m = \frac{E_1}{4.44 f N_1} = \frac{250}{4.44 \times 50 \times 200}$

$\phi_{max} = \underline{5.63 \text{ mWb}}$

(ii) Core loss $= V_1 I_0 \cos\phi_0 = 250 \times ...$

TRANSFORMER ON LOAD (M.M.F Balancing on Load)

Primary and secondary winding resistance and leakage reactance are Negligible.



ϕ → Main flux

ϕ_2 → Secondary flux

$\phi \rightarrow \leftarrow \phi_2$ $\quad \phi_2'$ by I_2' (Additional)

Additional flux by I_2' is $\phi_2' \rightarrow$ $\quad \left\{ \begin{matrix} \rightarrow \phi_2 \\ \leftarrow \phi_2' \end{matrix} \right\} \leftarrow \phi$

$\phi_2' \longrightarrow \quad \longleftarrow \phi_2$ (Now, $\phi \rightarrow$ Constant)

When transformer is loaded, I_2 flows in secondary winding. The magnitude and phase of I_2 is determined by the load.

If load is Inductive, I_2 Lags V_2 by ϕ_2. If load is capacitive I_2 leads V_2 by ϕ_2. If load is resistive, I_2 is in phase with V_2. $\phi_2 = 0$

Due to the secondary winding MMF $(N_2 I_2)$, I_2 sets up its own flux ϕ_2. Main flux ϕ is produced by I_m.

ϕ_2 opposes ϕ. Hence, $N_2 I_2$ is demagnetising ampere-turns.

The flux ϕ_2 momentarily reduces the main flux, due to which the primary induced EMF E_1 also reduces. Hence, the vector difference $\bar{V}_1 - \bar{E}_1$ increases due to which primary draws more current from the supply to neutralize ϕ_2.

This additional current drawn by primary I_2' is due to which and it sets up its own flux ϕ_2' which opposes ϕ_2 and helps the main flux ϕ. So, the ampere turns $N_1 I_2'$ balances the ampere turns $N_2 I_2$. Hence the net flux in the core is again maintained at constant level.

* The load component I_2' always neutralizes the changes in the load (I_2). As practically flux in the core is constant, the core loss is also constant for all the loads. Hence the transformer is called a constant flux machine.

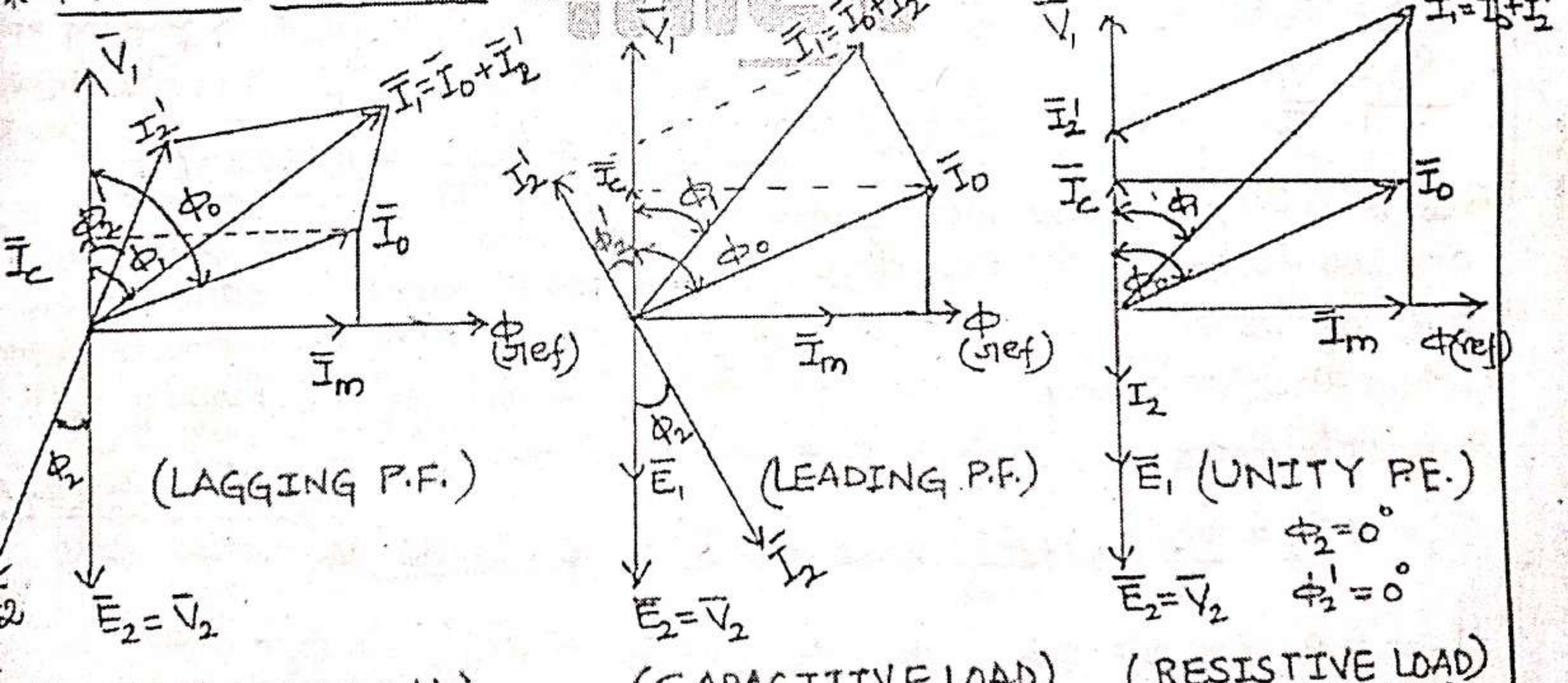
$N_2 I_2 = N_1 I_2'$ {MMF Balancing} $I_2' = \frac{N_2}{N_1} . I_2 \Rightarrow \boxed{I_2' = K I_2}$ **

So, when transformer is loaded, I_1 has two component

1. I_0 (No load current, lags V_1 by ϕ_0)
   - I_c (active component → supplies core loss
   - I_m (Magnetising component) → sets up flux in the core
2. I_2' (Load component, antiphase with I_2 (Phase of I_2 decided by load)

$\therefore$ * $\boxed{I_1 = I_0 + I_2'}$ $\Rightarrow$ * $\boxed{I_2' = K I_2}$ * $\boxed{\bar{I}_0 = \bar{I}_c + \bar{I}_m}$ $\left\{ \begin{array}{l} I_c = I_0 \cos\phi_0 \\ I_m = I_0 \sin\phi_0 \end{array} \right\}$

* PHASOR DIAGRAM OF TRANSFORMER ON LOAD ($R=0$, $Z=0$)



(INDUCTIVE LOAD) (CAPACITIVE LOAD) (RESISTIVE LOAD)

$\left\{ \begin{array}{ll} \phi_2 = \bar{I}_2 \wedge \bar{V}_2 & \phi_1 = \bar{I}_1 \wedge \bar{V}_1 \\ \phi_0 = \bar{I}_0 \wedge \bar{V}_1 & \phi_2' = \bar{I}_2' \wedge \bar{V}_1 \end{array} \right\}$ As $R_1 = 0$, $X_1 = 0$, $R_2 = 0$, $X_2 = 0$ i.e. Primary and secondary winding resistances and leakage reactances are zero. So, $\bar{V}_1 = -\bar{E}_1$ and $\bar{E}_2 = \bar{V}_2$.

Numericals :-

Ques: A single phase 440V/110 V, transformer takes a no-load current of 4 A at 0.2 P.F. If the secondary supplies a current of 100 A at a power factor of 0.8 lagging. Determine :- (i) The current drawn by the primary winding. (ii) The magnetising reactance and resistance representing core loss.

Solution :- $I_0 = 4$ AMP, $\cos\phi_0 = 0.2$, $\phi_0 = \cos^{-1}(0.2) = 78.463^\circ$

$I_0 = 4\angle{-78.463^\circ}$ amp. $I_2 = 100$ A, $\cos\phi_2 = 0.8$, $\phi_2 = \cos^{-1}(0.8) = 36.86$

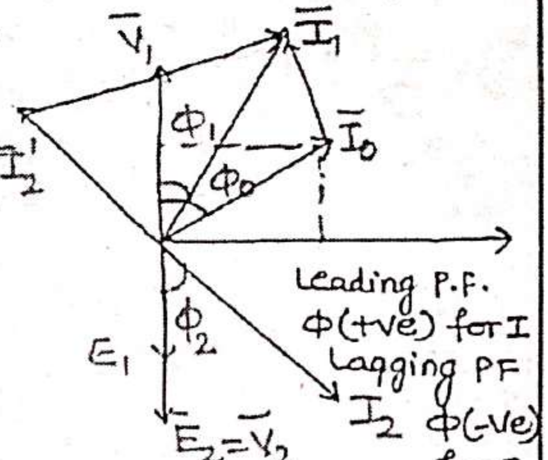
$I_2 = 100\angle{-36.86^\circ}$ amp. $K = \frac{N_2}{N_1} = \frac{110}{440} = 0.25$

$I_2' = K I_2 = \frac{1}{4} \times 100 = 25$ amp $\Rightarrow I_2' = 25\angle{-36.86^\circ}$ amp.

$\bar{I}_1 = \bar{I}_0 + \bar{I}_2' = 4\angle{-78.463^\circ} + 25\angle{-36.86^\circ}$

$= (0.80 - j3.919) + (20 - j15)$

$\bar{I}_1 = 28.1170\angle{-42.28^\circ}$



$\underline{I_C} = I_0 \cos\phi_0 = 4 \times 0.2 = \underline{0.8\,A}$

$\underline{I_m} = I_0 \sin\phi_0 = 4\sqrt{1-\cos^2\phi_0} = \underline{3.9191\,A}$

$\underline{R_0} = \frac{V_1}{I_c} = \frac{440}{0.8} = \underline{550\,\Omega}$, $\underline{X_0} = \frac{V_1}{I_m} = \frac{440}{3.9191} = \underline{112.2706\,\Omega}$

Ques:- A single phase transformer has 100 turns on the primary and 200 turns on the secondary. The no load current is 3amp at a p.f. of 0.2 lagging. Calculate the primary current and power factor when the secondary current is 280 A at a p.f. of 0.8 lagging.

Solution :- $\cos\phi_2 = 0.8$ (Lag) $\phi_2 = \cos^{-1}(0.8) = +36.86^\circ$ $\underline{I_2 = 280\angle{-36.86^\circ}\,A}$

$I_2' = K I_2 = \frac{N_2}{N_1} \cdot I_2 = \frac{200}{1000} \times 280 \Rightarrow I_2' = 56\angle{-36.86^\circ}$ A.

$I_0 = 3A$, $\cos\phi_0 = 0.2$, $\phi_0 = \cos^{-1}(0.2) = 78.5^\circ$, $\underline{\sin\phi_0 = 0.98}$

$\bar{I}_1 = \bar{I}_0 + \bar{I}_2' = [3\angle{-78.5^\circ} + 56\angle{-36.86^\circ}]$

$= [3(0.20 - j0.98) + 56(0.80 - j0.60)] = \underline{45.4 - j36.54}$

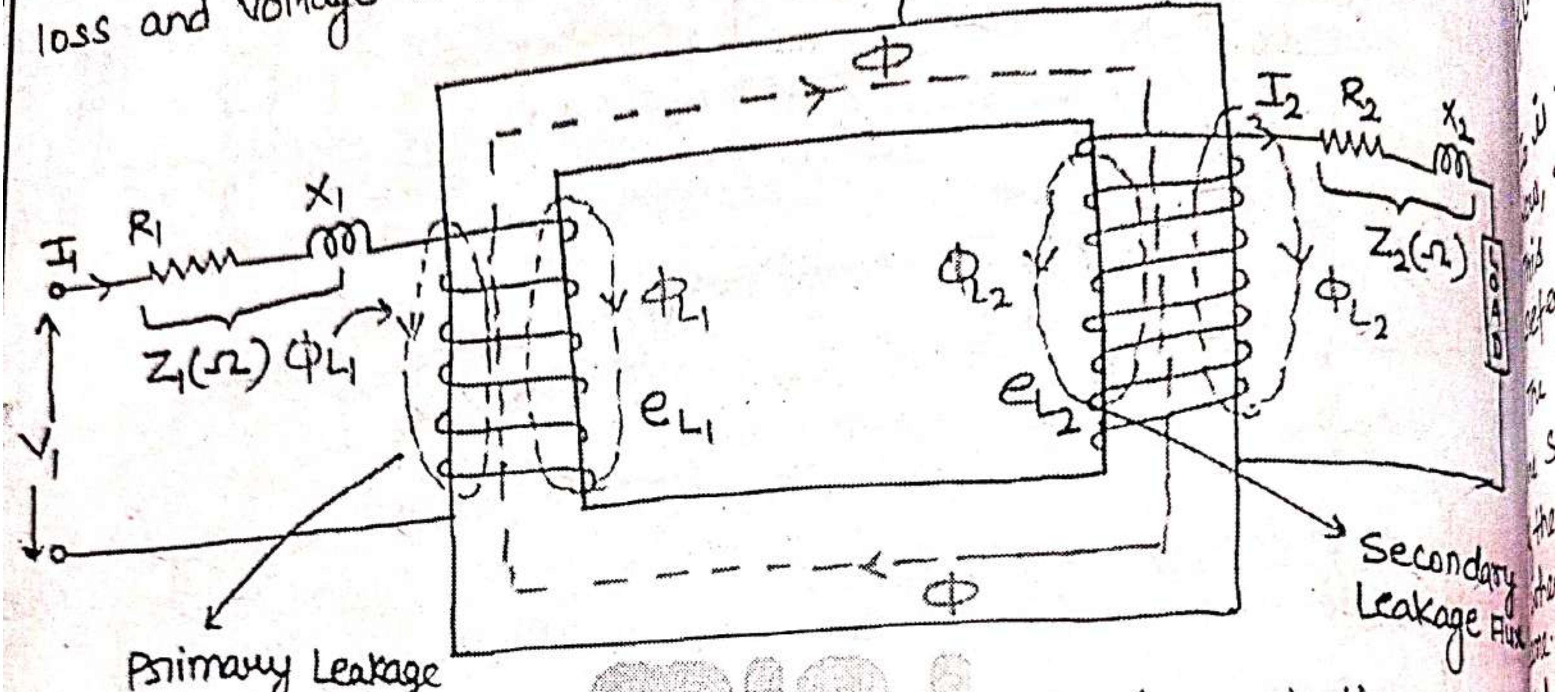
$\bar{I}_1 = 58.3\angle{-38.86^\circ}$, $\phi_1 = +38.86^\circ$(Lag) $\underline{\cos\phi_1 = 0.778\text{(Lag)}}$

|ANS|

(V.Imp)

⊛ Draw and Explain the equivalent Circuit diagram of Transformer. [2014, 2015, 2016]

As we know, an Ideal transformer is supposed to posses no resistance. But in actual transformer there is always some resistance of primary and secondary winding which causes a copper loss and voltage drop in the windings.

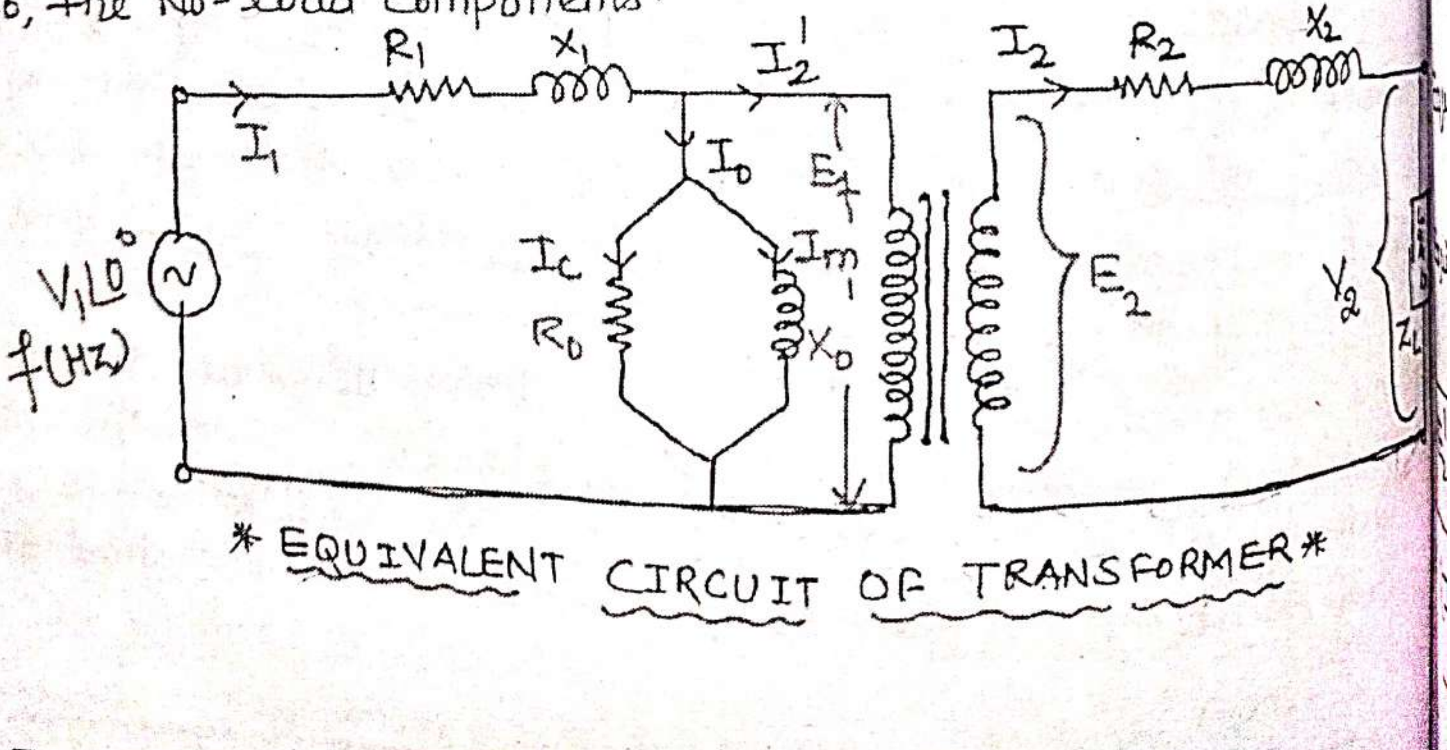


$R_1 \rightarrow$ Primary winding resistance, $R_2 \rightarrow$ Secondary winding resistance

$X_1 \rightarrow$ Primary Leakage reactance, $X_2 \rightarrow$ Secondary Leakage reactance

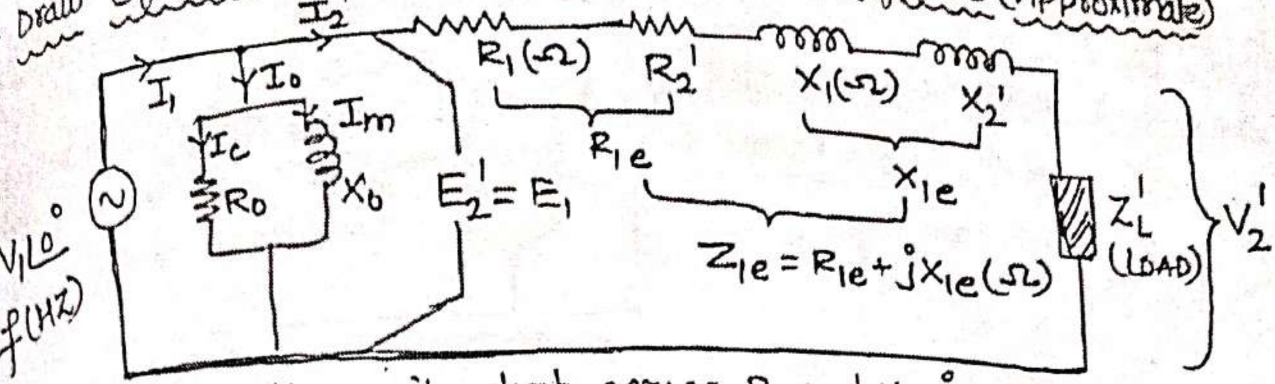
** Equivalent Circuit of Transformer :-

- It has primary and secondary winding resistance and Leakage reactance.
- Also, the No-load components.



* EQUIVALENT CIRCUIT OF TRANSFORMER *

* Draw Equivalent circuit Referred to primary side (Approximate)



- I_0 is very small so its drop across R_1 and X_1 is neglected.
- Now, shift the no-load branch to the left of R_1 and X_1.
- This is called approximate equivalent circuit of Transformer referred to primary side.
- The resistance of the two windings can be transferred to any one side either primary or secondary without affecting the performance of the transformer.
- when resistances are transferred to either side copper loss remains same.

Total Cu loss $= I_1^2 R_1 + I_2^2 R_2 = I_1^2\left[R_1 + \left(\frac{I_2}{I_1}\right)^2 \cdot R_2\right] = I_1^2 \underbrace{\left[R_1 + \frac{R_2}{K^2}\right]}_{R_{1e}(\Omega)}$

$(P_{Cu}) = I_1^2 R_{1e}$ watt

So, $R_2' = \frac{R_2}{K^2}$ and $X_2' = \frac{X_2}{K^2}$ and $X_2' = \frac{X_2}{K^2}$

Equivalent Resistance referred to primary

$$R_{1e} = R_1 + R_2' = \left(R_1 + \frac{R_2}{K^2}\right)\ \Omega$$

Equivalent Reactance referred to primary

$$X_{1e} = X_1 + X_2' = \left(X_1 + \frac{X_2}{K^2}\right)\ \Omega$$

Equivalent Impedance referred to primary

$$Z_{1e} = (R_{1e} + jX_{1e})\ \Omega \quad \text{or} \quad Z_{1e} = \frac{Z_{2e}}{K^2}\ (\Omega)$$

**
$I_2' = KI_2$
$Z_2 = R_2 + jX_2(\Omega)$
$Z_2' = \frac{Z_2}{K^2}$ $R_2' = \frac{R_2}{K^2}$
$X_2' = \frac{X_2}{K^2}$ $Z_L' = \frac{Z_L}{K^2}$

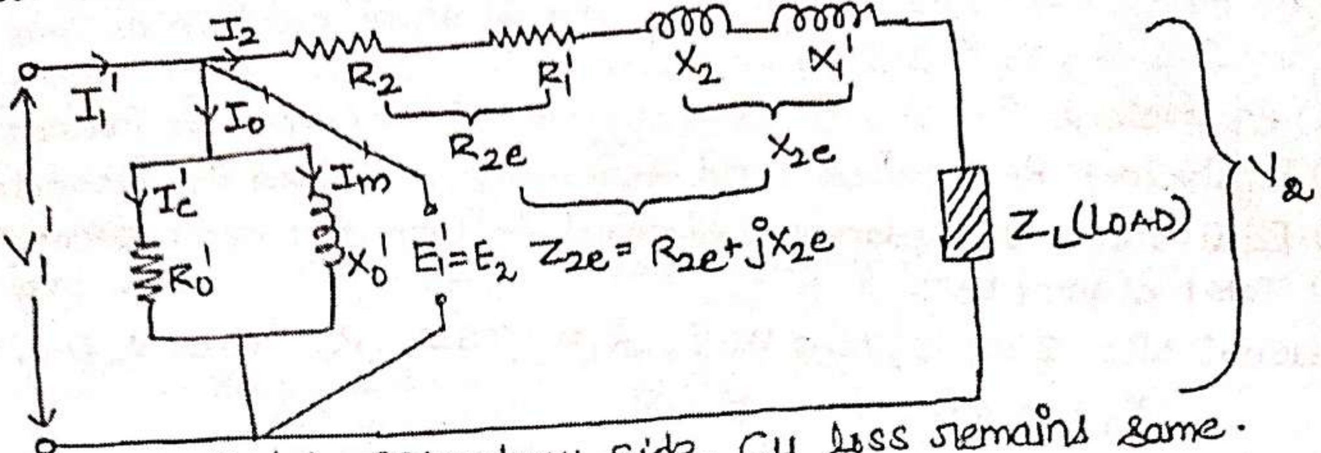
$\boxed{E_2' = \frac{E_2}{K}}$ $\boxed{V_2' = \frac{V_2}{K}}$

Low voltage side → High current → $Z\downarrow$
High voltage side → Low current → $Z\uparrow$

** $\boxed{K = \frac{V_2}{V_1} = \frac{N_2}{N_1}}$

$(I_1)_{f.L} = \frac{KVA \times 1000}{V_1}$ amp. $(I_2)_{f.L} = \frac{KVA \times 1000}{V_2}$ amp.

* Draw Approximate equivalent circuit referred to secondary :-



→ When R_1 is shifted to secondary side, Cu loss remains same.

→ Total Cu loss $= I_1^2 R_1 + I_2^2 R_2 = I_2^2\left[\left(\frac{I_1}{I_2}\right)^2 \cdot R_1 + R_2\right] = I_2^2[\underbrace{K^2 R_1 + R_2}_{R_{2e}}]$

→ $(P_{cu})_{Total} = I_2^2 \cdot R_{2e}$ (Watt)

→ Equivalent resistance referred to secondary side

$$R_{2e} = R_2 + R_1' = (R_2 + K^2 R_1)\ \Omega$$

→ Equivalent reactance referred to secondary side

$$X_{2e} = X_2 + X_1' = (X_2 + K^2 X_1)\ \Omega$$

→ Equivalent Impedance referred to secondary side

$$Z_{2e} = (R_{2e} + jX_{2e})\ \Omega \quad \text{or} \quad (Z_{2e} = K^2 Z_{1e})\ \Omega$$

$\boxed{R_1' = K^2 R_1}$ $\boxed{X_1' = K^2 X_1}$ $\boxed{Z_1 = (R_1 + jX_1)\ \Omega}$ $\boxed{Z_1' = K^2 Z_1}$

$\boxed{R_0' = K^2 R_0}$ $\boxed{X_0' = K^2 X_0}$ $\boxed{I_1' = \frac{I_1}{K}}$ $\boxed{E_1' = KE_1}$ $\boxed{I_0' = \frac{I_0}{K}}$ $\boxed{V_1' = KV_1}$

$\boxed{I_c' = \frac{I_c}{K}}$ $\boxed{I_m' = \frac{I_m}{K}}$ $I_{1(f.L)} = \frac{KVA \times 1000}{V_1}$ $I_{2(f.L)} = \frac{KVA \times 1000}{V_2}$

Total Copper loss $P_{(cu)f.L} = I_1^2 R_1 + I_2^2 R_2$ (Watt)

OR

$I_1^2 R_{1e}$ or $I_2^2 R_e$ watt

$I_1 \rightarrow$ Primary Full load current

$I_2 \rightarrow$ Secondary Full load current.

Numericals:- Ques- A 15 KVA, 2200/110V single phase transformer has $R_1 = 1.75\Omega$, $R_2 = 0.0045\Omega$. The leakage reactances are $X_1 = 2.6\Omega$, $X_2 = 0.0075\Omega$. Calculate-

a) Equivalent Resistance and Reactance referred to Primary.
b) Equivalent Resistance and Reactance referred to Secondary.
c) Equivalent Impedance referred to primary and secondary
d) Total Copper Loss.

Solution: $V_1 = 2200\,V$, $V_2 = 110V$, $R_1 = 1.75\Omega$, $R_2 = 0.0045\Omega$, $X_1 = 2.6\Omega$
$X_2 = 0.0075\Omega$ $\quad K = \frac{V_2}{V_1} = \frac{110}{2200} = \underline{0.05}$

$$R_{1e} = R_1 + R_2' = R_1 + \frac{R_2}{K^2} = 1.75 + \frac{0.0045}{(0.05)^2} = \underline{3.55\,(\Omega)}$$

$$X_{1e} = X_1 + X_2' = X_1 + \frac{X_2}{K^2} = 2.6 + \frac{0.0075}{(0.05)^2} = \underline{5.6\,(\Omega)}$$

$$R_{2e} = R_2 + R_1' = R_2 + K^2R_1 = 0.0045 + (0.05)^2 \times 1.75 = \underline{0.00887\,(\Omega)}$$

$$X_{2e} = X_2 + X_1' = X_2 + K^2X_1 = 0.0075 + (0.05)^2 \times 2.6 = \underline{0.014\,\Omega}$$

$$Z_{1e} = R_{1e} + jX_{1e} = (3.55 + j5.6), \; |Z_{1e}| = \underline{6.6304\,(\Omega)}$$

$$Z_{2e} = R_{2e} + jX_{2e} = (0.00887 + j0.014), \; |Z_{2e}| = \underline{0.01657\,(\Omega)}$$

$$(P_{cu})_{Total} = I_1^2R_1 + I_2^2 \cdot R_2 = (6.81)^2 \times 1.75 + (136.36)^2 \times 0.0045 = \underline{165.027\,W}$$

$$\text{OR} = I_1^2R_{1e} = (6.81)^2 \times 3.55 = \underline{165.027\,(\text{Watt})}$$

$$\text{OR} = I_2^2R_{2e} = (136.36)^2 \times 0.00887 = \underline{165.027\,(\text{Watt})}$$

$$(I_1)_{fL} = \frac{KVA \times 1000}{V_1} = \frac{15 \times 10^3}{2200} = \underline{6.8181\text{ amp.}}$$

$$(I_2)_{fL} = \frac{KVA \times 1000}{V_2} = \frac{15 \times 10^3}{110} = \underline{136.3636\text{ amp.}}$$

Ques:- The ohmic values of the circuit parameters of a transformers having a turn ratio of 5 are $R_1 = 0.5\Omega$, $R_2 = 0.021\Omega$, $X_1 = 3.2\Omega$, $X_2 = 0.12\Omega$, $R_0 = 350\Omega$, referred to primary and $X_0 = 98\Omega$ referred to primary. Draw the approximate equivalent circuit of the transformer referred to secondary. Show the numerical values of the ckt. Parameters

Solution:- Turns Ratio $\frac{N_1}{N_2} = 5$, $K = \frac{N_2}{N_1} = \frac{1}{05} = 0.2$

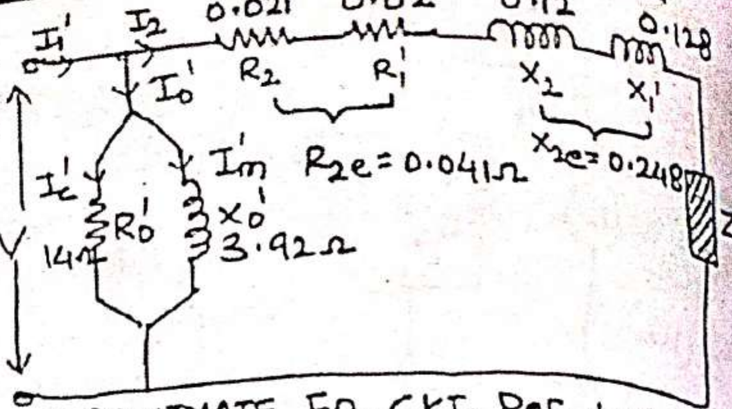
$$R_1' = K^2R_1 = (0.2)^2 \times 0.5 = 0.02\,\Omega \qquad X_1' = K^2X_1 = (0.2)^2 \times 3.2 = 0.128\,\Omega$$

$R_{2e} = R_2 + R_1' = R_2 + K^2 R_1 = \underline{0.041\,\Omega}$

$X_{2e} = X_2 + X_1' = X_2 + K^2 X_1 = \underline{0.248\,\Omega}$

$R_0' = K^2 R_0 = (0.2)^2 \times 350 = \underline{14\,\Omega}$

$X_0' = K^2 X_0 = (0.2)^2 \times 98 = \underline{3.92\,\Omega}$



APPROXIMATE EQ. CKT. Ref. to Sec. Side

Ques: A 20 KVA, 2000V/200V, single phase 50 Hz transformer has a primary resistance of 1.5Ω and a reactance of 2Ω. The secondary resistance and reactance are 0.015Ω and 0.02Ω respectively. The no Load current of transformer is 1 A at 0.2 P.F. Find :-
i) Equivalent resistance, reactance, Impedance referred to primary
ii) supply current (iii) Total copper Loss (iv) Draw approximate equivalent circuit referred to primary.

solution :- (i) $R_{1e} = R_1 + \frac{R_2}{K^2} = 0.1 + \frac{0.004}{(0.2)^2} = \underline{0.2\,\Omega}$

$X_{1e} = X_1 + \frac{X_2}{K^2} = 0.3 + \frac{0.012}{(0.2)^2} = \underline{0.6\,\Omega}$

$R_{2e} = R_2 + K^2 R_1$
$= 0.004 + (0.2)^2 \times 0.1$
$= \underline{0.008\,\Omega}$

$X_{2e} = X_2 + K^2 X_1 = 0.012 + (0.2)^2 \times 0.3 = \underline{0.024\,\Omega}$ |ANS|

(ii) $Z_{1e} = (R_{1e} + jX_{1e}) = (0.2 + j0.6) = 0.6325\ (\Omega)$

$Z_{2e} = (R_{2e} + jX_{2e}) = (0.008 + j0.024) = 0.0253\ (\Omega)$ |ANS|

(iii) $Z_1 = R_1 + jX_1 = (0.1 + j0.3) =$

$Z_2 = R_2 + jX_2 = (0.004 + j0.012) =$

$(I_1)_{f.L} = \frac{KVA \times 1000}{V_1} = \frac{100 \times 10^3}{1100} = \frac{1000}{11}$ AMP.

Equivalent resistance drop referred to primary $= I_1 R_{1e} = \frac{1000}{11} \times 0.2 = 18.1$

Equivalent reactance drop referred to primary $= I_1 X_{1e} = \frac{1000}{11} \times 0.6 = 54.5$

% Resistance drop $= \frac{I_1 R_{1e}}{V_1} \times 100 = \frac{18.18}{1100} \times 100 = 1.653\%$

% Reactance drop $= \frac{I_1 X_{1e}}{V_1} \times 100 = \frac{54.54}{1100} \times 100 = 4.96\%$

|ANS|

Ques: A 100 KVA, 1100/220 V, 50 Hz, Single phase transformer has a leakage impedance of $(0.1+j0.4)\Omega$ for HV winding and $(0.006+j0.015)\Omega$ for L.V. winding. Find the equivalent winding resistance, reactance and impedance referred to the H.V and L.V. sides.

Solution: Turn ratio $= \frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{1100}{220} = 5$, Transformation ratio $K = \frac{N_2}{N_1} = \frac{1}{5} = \underline{0.2}$

$[R_1 = 0.1\Omega,\ X_1 = 0.4\Omega,\ R_2 = 0.006\Omega,\ X_2 = 0.015\Omega]$

$Z_1 = (0.1+j0.4)\Omega \qquad Z_2 = (0.006+j0.015)$

$\quad R_1 + jX_1 \qquad\qquad R_2 + jX_2$

Referred to HV side:-

$R_{1e} = R_1 + \frac{R_2}{K^2} = 0.1 + \frac{0.006}{(0.2)^2} = \underline{0.25\Omega}$ $\Big\}$ $X_{1e} = X_1 + \frac{X_2}{K^2} = 0.4 + \frac{0.015}{(0.2)^2} = \underline{0.775\Omega}$

$Z_{1e} = R_{1e} + jX_{1e} = (0.25 + j0.775) = \underline{0.8143\Omega}$ |ANS|

Referred to L.V. side:

$R_{2e} = R_2 + K^2R_1 = 0.006 + (0.1)(0.2)^2 = \underline{0.01\Omega}$

$X_{2e} = X_2 + K^2X_1 = 0.015 + (0.2)^2(0.4) = \underline{0.031\Omega}$

$Z_{2e} = R_{2e} + jX_{2e} = (0.01 + j0.031)\Omega = \underline{0.0326\Omega}$

Question :- Classify the losses in transformer. [2020-2021]
List the various losses occuring in transformer [2015-16]

* LOSSES in TRANSFORMER *

1. CORE LOSS (Iron Loss) Constant Loss
2. COPPER LOSS (Variable loss) (I^2R Loss) directly proportional to I^2

(a) → Hysteresis Loss $\{W_h = K_h B_m^{1.6} f V\}$
(b) → Eddy current Loss $\{W_e = K_e B_m^2 f^2 t^2 V\}$

1. CORE LOSS (IRON LOSS) → When core is subjected to A.C. supply.
→ Depends on supply voltage which is constant.
→ Therefore these are constant losses.

a) Hysteresis Loss :- When the magnetic core is subjected to an alternating flux so due to the magnetisation and demagnetisation of magnetic core, it don't follow a linear and similar path. Hence some energy gets wasted in every cycle, which is represented by the area of the B-H curve. It is therefore preferred to use material having thinner B-H curve.

* The power loss due to hysteresis is given by —

$$\boxed{W_h = K_e B_m^{1.6} f V}$$, where K_e - constant, B_m → max. flux density. (wb/m²)
f → supply freq. (Hz)
V → Volume of the core (m^3)

$$\boxed{W_h \propto B_m^{1.6} f}$$

→ It can be minimized by using steel of high silicon content.

b) Eddy current Loss :- when the magnetic core is subjected to an alternating flux then due to magnetization and de-magnetization the magnetic dipoles in it reverse their orientation 50 times in a secon
→ Magnetic core is also a good conductor of electricity. So emf gets induced in iron itself.
→ In random movement of dipoles inside the core, small loops of edd currents gets induced. These tinny eddy currents loops randomly and temporarily keep developing in various possible planes in the

-core. These currents lead to small I^2R loss due to them.

→ The power loss due to eddy currents is given by :-

* $\boxed{W_e = K_e B_m^2 f^2 t^2 V}$ K_e - constant, B_m - Flux density (Max.) of core (wb/m²)

Eddy current Loss

f - supply frequency (Hz)

t → thickness of core (m²)

Joules/sec OR Watt

V → Volume of core (m³)

* $\boxed{W_e \propto B_m^2 f^2}$

→ In order to reduce eddy current loss, the core is laminated.

→ Thin insulated sheets (called lamina) of core material are stacked together to form the core.

→ This arrangement reduces the possible number of planes for development of eddy currents.

Hence, the eddy currents and eddy current loss get reduced.

(ii) COPPER LOSS (I^2R LOSS) :-

→ These losses occur due to the ohmic resistances of the primary and secondary windings.

→ If I_1 and I_2 are the full load primary and secondary currents respectively and R_1 & R_2 are the primary and secondary winding resistances.

→ R_{1e} - equivalent resistance referred to the primary side.

→ R_{2e} - equivalent resistance referred to the secondary side

then - Full load Cu loss when windings are taken seperately

$$(P_{cu})_{F.L} = I_1^2 R_1 + I_2^2 R_2 \quad \text{(watt)}$$

Full load Cu loss when parameters are referred to secondary -

$$(P_{cu})_{F.L.} = I_2^2 R_{2e} \quad \text{(watt)}$$

Full load Cu loss when parameters are referred to Primary -

$$(P_{cu})_{F.L} = I_1^2 R_{1e} \quad \text{(watt)}$$

As, I is variable so, these losses are variable losses

Ques:- In a 25 KVA, 2000V/200V transformer the iron and copper losses are 200 W and 400 watts respectively. Calculate the efficiency at half-full load and 0.8 power factor lagging. Determine also the maximum efficiency and the corresponding load. [2016-17, 2017-18, 18-19] AKTU [IMPORTANT]

Ans:- Full load copper loss, $P_c = 400\,W = 0.4\,KW$

Iron loss, $P_i = 200\,W = 0.2\,KW$

output at half load and 0.8 pf $= \frac{1}{2} \times 25 \times 0.8 = 10\,KW$

copper losses at half load $= \left(\frac{1}{2}\right)^2 \times (0.4)\,kW = 0.1\,KW$

So efficiency at half-full load and 0.8 pf.

$$\eta = \frac{P_{out}}{P_{in}} \times 100 = \frac{10}{10+0.1+0.2} \times 100$$

$$= 97.087\,\% \quad |ANS|$$

Load Corresponding to maximum efficiency ⇒

$$\text{Rated KVA} \times \sqrt{\frac{P_i}{P_c}} = 25 \times \sqrt{\frac{0.2}{0.4}}$$

$$= 17.68\,KVA \quad |ANS|$$

Maximum efficiency, assuming power factor unity ⇒

$$\frac{17.68 \times 1.0}{17.68 + 0.2 + 0.2} \times 100 = 97.788\,\% \quad |A$$

Ques: A transformer is rated at 100 kVA, at full load its copper loss, 1400 watt and iron losses are 940 watt. Calculate (i) the efficiency at full load, unity power factor (ii) The efficiency at half load, the same power factor (iii) The load kVA at which maximum efficiency will occur. [2018-19] AKTU [2015-2016]

Ans: Copper loss at full load, $P_c = 1400\,W = 1.4\,kW$

Iron loss, $P_i = 940\,W = 0.94\,kW$

(i) At Full load Unity Power Factor

Transformer output = Rated kVA × $\cos\phi$ = 100 × 1.0 = 100 kW

Transformer input = output + $P_i + P_c$ = 100 + 0.94 + 1.4

= 102.34 kW.

Transformer efficiency, $\eta = \dfrac{\text{output}}{\text{Input}} \times 100 = \dfrac{100}{102.34} \times 100$

= 97.714 % |ANS|

(ii) At Half-Load Unity Power factor

Transformer output = $\frac{1}{2}$ × rated kVA × $\cos\phi$ = $\frac{1}{2}$ × 100 × 1.0

= 50 kW.

Transformer input = output + iron loss + copper loss

$= 50 + 0.94 + \left(\frac{1}{2}\right)^2 \times 1.400 = 51.29$ kW

Transformer efficiency, $\eta = \dfrac{\text{output}}{\text{Input}} \times 100 = \dfrac{50}{51.29} \times 100$

= 97.485 % |ANS|

(iii) Load at which maximum efficiency will occur

$= \text{Rated kVA} \times \sqrt{\dfrac{P_i}{P_{cu}}} = 100 \times \sqrt{\dfrac{0.94}{1.4}} = 81.94$ kVA

** What is Voltage Regulation of Transformer? [IMP.] [2018-19]

$$\% \text{ Voltage Regulation} = \frac{E_2 - V_2}{V_2} \times 100$$

The ratio $\boxed{\frac{E_2 - V_2}{V_2}}$ is called per unit regulation.

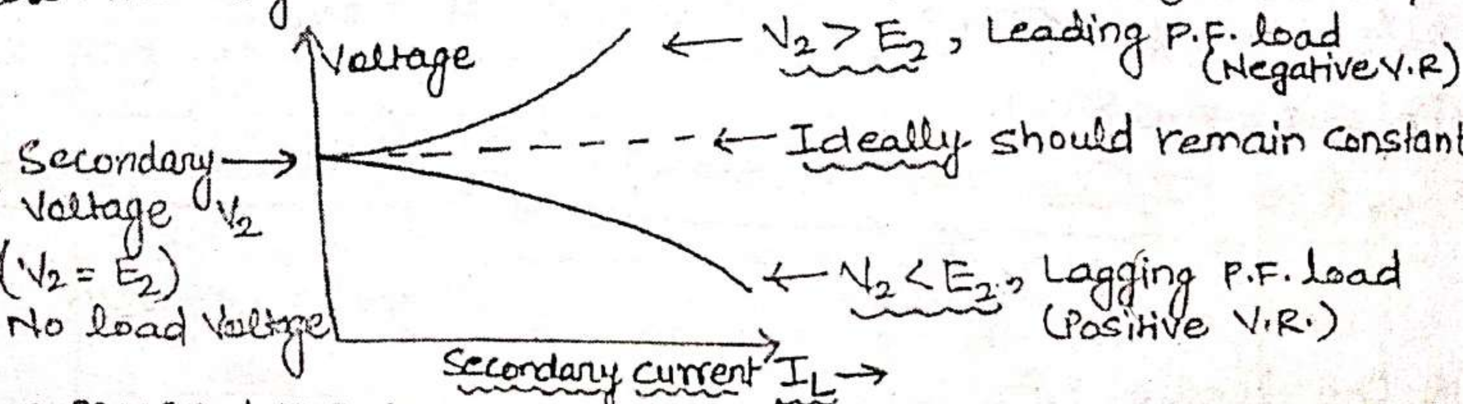
Because of the voltage drop across the primary and secondary impedances, it is observed that the secondary terminal voltage drops from its no load value (E_2) to load value (V_2) as load and load current increases.

"The decrease in secondary terminal voltage expressed as a fraction of the no load secondary terminal voltage is called regulation of the transformer".

E_2 = Secondary terminal voltage on no-load.
V_2 = Secondary terminal voltage on load.

V_2 → depends on I_2 and as well as on power factor of the load. As load current increases, the voltage drops tend to increase and V_2 drops more and more.
For lagging power factor → $V_2 < E_2$, → Positive regulation.
For leading power factor → $E_2 < V_2$, → Negative regulation.

NOTE:- The voltage drop should be as small as possible. Hence, less the regulation better is the performance of the transform[er]



* EXPRESSION FOR VOLTAGE REGULATION →

** $\boxed{\% R = \frac{E_2 - V_2}{V_2} \times 100} = \boxed{\frac{\text{Total Voltage drop}}{V_2} \times 100}$ **

Numerical on Voltage Regulation :-

Question :- A 250 V/125 V, 5 KVA single phase transformer has primary resistance of 0.2 Ω and reactance of 0.75 Ω. The secondary resistance is 0.05 Ω and reactance is 0.2 Ω.

Determine : (i) It's regulation while supplying full load on 0.8 leading p.f.

(ii) The secondary terminal voltage on full load and 0.8 leading p.f.

(iii) Determine % resistive and reactive drops.

Solution :- Given $R_1 = 0.2\Omega$, $X_1 = 0.75\Omega$, $R_2 = 0.05\Omega$, $X_2 = 0.2\Omega$

$\cos\phi = 0.8$ (lead)

$$(I_2)_{F.L} = \frac{KVA}{V_2} = \frac{5\times10^3}{125} = 40\,A.$$

$$K = \frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{125}{250} = 0.5$$

For leading p.f. $E_2 < V_2$.

$$R_{2e} = R_2 + K^2 R_1 = 0.05 + (0.5)^2 \times 0.2 = 0.1\,\Omega$$

$$X_{2e} = X_2 + K^2 X_1 = 0.2 + (0.5)^2 \times 0.75 = 0.3875\,\Omega$$

(i) $\cos\phi = 0.8$

$$\%R = \frac{I_2[R_{2e}\cos\phi - X_{2e}\sin\phi]}{V_2}\times 100 = \frac{40[0.1\times0.8 - 0.3875\times0.6]\times100}{125}$$

$$\%R = -4.88\%$$

(ii) For leading p.f.

$$E_2 = V_2 + I_2R_{2e}\cos\phi - I_2X_{2e}\sin\phi$$

$$V_2 = E_2 - I_2R_{2e}\cos\phi + I_2X_{2e}\sin\phi$$

$V_2 = 125 - 40[0.1\times0.8 - 0.3875\times0.6] \Rightarrow V_2 = 125 - 40[-6.1] \Rightarrow \boxed{V_2 = 131.1\,V}$

5 Year's

University Paper Questions

(AKTU Question Bank)

B. Tech I Year [Subject Name: F. of Electrical Engineering]

S. No.	5 Years AKTU University Examination Questions Questions	Unit-III Transformers Session	Lec. No.
1.	Explain different types of Magnetic materials with examples. [10]	2018-19	19-26
2.	Explain B-H loop for magnetic circuit. [3]	2016-17	19-26
3.	Deduce analogy between electric circuits and magnetic circuits. Also explain B-H curve and discuss its effect on hysteresis loss [7]	2016-17	19-26
4.	Define the following terms as applied to magnetic circuit: (i) MMF (ii) Flux density (iii) Reluctance (iv) Permeability. [10]	2013-14	19-26
5.	Derive an E.M.F expression of power transformer. Also draw an equivalent circuit of it. [10]	2013-14	19-26
6.	What will happen if the primary of a transformer is connected to dc supply? [2]	2019-20, 17-18, 14-15, 13-14	19-26
7.	Why transformer is not used on DC? [2]	2017-18, 13-14	19-26
8.	Discuss the principle of operation of a single phase transformer. Derive EMF equation for a single phase transformer. [10]	2018-19, 17-18, 15-16, 13-14	19-26
9.	Why transformer rated in VA? Explain in brief. [2]	2014-15	19-26
10.	Write EMF equation of single phase transformer. [2]	2015-16	19-26
11.	What is transformer? Explain the constructional features of different types of transformer. [5]	2014-15	19-26
12.	What do you understand by the term "ideal transformer "? [2]	2013-14	19-26
13.	Draw and explain the no load and full load phasor diagrams for a single phase transformer. [10]	2019-20	19-26
14.	An 1100/110V, 22 KVA, single phase transformer has primary resistance 4Ω and reactance 6Ω respectively. The secondary resistance and reactance are 0.04Ω and 0.065Ω respectively. Calculate: (i) Equivalent resistance and reactance of secondary referred to primary. (ii) Total resistance & reactance referred to primary. (iii) Equivalent resistance and reactance of primary referred to secondary. (iv) Total copper loss [10]	2018-19	19-26
15.	A 400 V/200 V single phase transformer has primary winding resistance 1.0 ohm and secondary winding resistance 0.2 ohm. What will be the total resistance of transformer referred to the primary side? [2]	2015-16	19-26
16.	Draw equivalent circuit diagram of single phase transformer. [2]	2014-15	19-26
17.	Derive and explain the equivalent circuit of a transformer. Define efficiency of a transformer. Find condition for maximum efficiency of transformer. [10]	2014-15	19-26
18.	Classify the losses in transformer. [2]	2020-21	19-26

19.	Write detailed note on Hysteresis loss and Eddy current loss in magnetic circuit and also state how to reduce the eddy current loss considerably. [5]	2016-17, 2014-15	19-26
20.	Derive the EMF equation of single phase transformer. A single phase 100kVA, 6.6kV/230V, 50 Hz, transformer has 90% efficiency at 0.8 lagging power factor both at full load and also at half load. Determine iron and copper loss at full load for transformer. [10]	2020-21, 14-15	19-26
21.	Classify the losses in transformer. [2]	2020-21	19-26
22.	A transformer is rated at 100 KVA. At full load its copper loss is 1200W and iron losses are 960W. Calculate: (i) Efficiency at full load, unity pf (ii) Efficiency at half load, 0.8 pf lagging. (iii) Efficiency at 75% full load, 0.7 pf lagging (iv) The load kVA at which maximum efficiency occurs (v) The maximum efficiency at 0.85 pf lagging. [10]	2018-19	19-26
23.	A 25 KVA, 2000/200V transformer has full load copper & iron losses are 1.8 kW & 1.5 kW respectively. Find: (i)The efficiency at half the rated kVA & at unity power factor (ii) The efficiency at full load & at 0.8 power factor lagging. (iii) kVA load for maximum efficiency & value of maximum efficiency. [7]	2017-18	19-26
24.	What do you understand by the efficiency of a transformer? Deduce the condition for maximum efficiency. [3]	2016-17	19-26
25.	In a 25 KVA, 2000V/200 V transformer the iron and copper losses are 200W and 400W respectively. Calculate the efficiency of half load and 0.8 pf. lagging. Also determine the maximum efficiency and corresponding load. [7]	2016-17	19-26
26.	List the various losses occurring in transformer & the condition for maximum efficiency. In a 25 KVA, 2000/200V transformer the iron & copper losses are 200W & 400W respectively. Calculate the efficiency at half load and 0.8 power factor lagging. Determine also the maximum efficiency & the corresponding load. [10]	2015-16	19-26
27.	A single phase 250 kVA transformer has an efficiency of 96 % on full load at 0.8 power factor and on half (i) Iron loss (ii) Full load copper loss. [10]	2013-14	19-26
28.	A single phase 250 kVA transformer has an efficiency of 96 % on full load at 0.8 power factor and on half (i) Iron loss (ii) Full load copper loss. [10]	2013-14	19-26
29.	The maximum efficiency of a 100 KVA, 1100/440 V, 50 Hz transformer is 96%, This occurs at 75% of full load at 0.8 p.f. lagging. Find the efficiency of transformer at half load at 0.6 p.f. leading. [10]	2018-19	19-26
30.	In a 25KVA, 2000V/200 V transformer the iron and copper losses are 200W and 400W respectively. Calculate the efficiency of half load and 0.8 pf. lagging. Also determine the maximum efficiency and corresponding load. [7]	2017-18	19-26
31.	A 50 KVA transformer has a core loss of 400 W and a full load copper loss	2015-16	19-26

	of 800 W. The power factor of the load is 0.9 losing. Calculate: (i) Full load efficiency (ii) The maximum efficiency and the load at which maximum efficiency occurs. [10]		
32.	Explain the condition for maximum efficiency in a single phase transformer. [2]	2014-15	19-26
33.	Define voltage regulation of a transformer. [2]	2019-20	19-26
34.	What is voltage Regulation in a single Phase Transformer? What should be its value for an ideal transformer? [10]	2018-19	19-26
35.	(i) Explain single phase Auto transformer and give its application. [10] (ii) In a 25 kVA, 2000/200 V transformer, the constant and variable losses are 350 W and 400 W respectively. Calculate the efficiency on unity power factor at (i) full load and (ii) half load.	2019-20	19-26
36.	What are the advantages of auto-transformer over two winding transformer? [2]	2018-19	19-26
37.	What is an Auto Transformer? What are the advantages and disadvantages of using an Auto Transformer? Explain (without derivation) how the efficiency varies when a normal two winding transformer is converted into an Auto Transformer. [10]	2018-19, 16-17	19-26
38.	What are the various three phase transformer connections? Name them. [2]	2018-19	19-26
39.	Explain single phase auto transformer and give its two applications. [5]	2015-16	19-26
40.	Explain the working principle of auto-transformer and also prove that as compared to single phase two winding transformer there is copper saving in auto-transformer. [10]	2014-15	19-26
41.	Discuss in brief about autotransformer. [5]	2013-14	19-26