ELECTRICAL ENGINEERING

ELECTRICAL MACHINES

Comprehensive Theory
with Solved Examples *and* Practice Questions

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Electrical Machines

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CHAPTER

1

Magnetic Circuits

Introduction

The electromagnetic system is an essential element of all rotating electric machinery, electromechanical devices and static devices like the transformer. The role of electro-magnetic system is to establish and control electromagnetic fields for carrying out conversion of energy, its processing and transfer. Electromechanical energy conversion takes place via the medium of a magnetic field or electrical field, but most practical converters use magnetic field as the coupling medium between electrical and mechanical systems. In transformers, the electrical energy is transferred from one electrical circuit to another electrical circuit via the medium of a magnetic field as the coupling medium between two electrical circuits. This is due to fact that the energy storing capacity of magnetic field is much greater than that of the electric field.

1.1 MAGNETIC CIRCUITS

- The complete closed path followed by the lines of flux is called a magnetic circuit. In low power electrical machines, magnetic field is produced by permanent magnets. But in high-power electrical machinery and transformers, coupling magnetic field is produced by electric current.
- In a magnetic circuit, the magnetic flux is due to the presence of a magnetomotive force same as in an electric circuit, the current is due to the presence of a electromotive force.

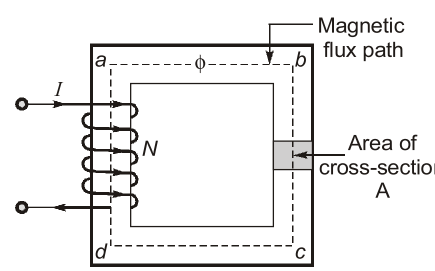


Fig.: Magnetic circuit

- The mmf is created by a current flowing through one or more turns.

$$MMF = \text{Current} \times \text{Number of turns in the coil}$$

$$f = MMF = NI \text{ (ampere-turns) or (ATs)}$$

- The magnetic flux ϕ may be defined as the magnetomotive force per unit reluctance.

$$\phi = \frac{\text{MMF}}{\text{Reluctance}}$$

where reluctance in magnetic circuit is similar as resistance in electric circuit.

- The opposition offered to the magnetic flux is called reluctance,

$$Rl = \frac{l}{\mu A} \text{ AT/wb}$$

where, l = length of the magnetic path; A = area of cross-section normal to flux path, m^2.

$\mu = \mu_0 \cdot \mu_r$ = permeability of the magnetic material

μ_r = relative permeability of magnetic material; μ_0 = permeability of free space = $4\pi \times 10^{-7}$ H/m.

The permeance of a magnetic circuit is the reciprocal of its reluctance.

$$P = \frac{1}{R_l}$$

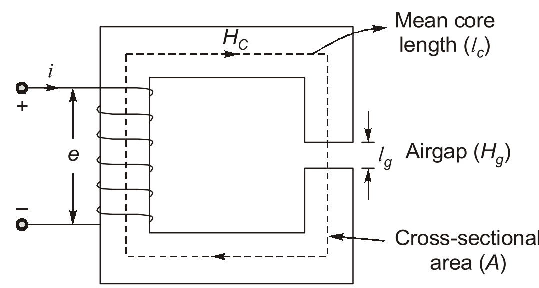
Reluctances in a magnetic circuit obey the same rules as resistances in an electric circuit. The equivalent reluctance of a number of reluctances in series is the sum of the individual reluctances :

$$R_{l_{eq}} = R_{l_1} + R_{l_2} + R_{l_3} + \,.....$$

Permeances in series and parallel obey the same rules as electrical conductances.

1.1.1 Core with Air-Gap

A typical magnetic circuit with an air-gap is shown below in the figure. It is assumed that the air-gap is narrow and the flux coming out of the core passes straightly through the air-gap, such that the flux density in the air-gap is the same as in the core and core permeability μ is regarded as constant (linear magnetization). But in reality the flux in the air-gap fringes out so that the air-gap flux density is somewhat less that of the core (fringing effect).



MMF Ni is now given as : $\quad \text{Ni} = H_c l_c + H_g l_g = \dfrac{B_c}{\mu_c} l_c + \dfrac{B_g}{\mu_o} l_g$

Assuming that all the core flux passes straight down the air-gap (it means no fringing),

$$B_c = B_g$$

$\therefore$ $$\phi = B_c A = B_g A$$

$\therefore$ $$N_i = \phi\left(\frac{l_c}{\mu_c A}\right) + \phi\left(\frac{l_g}{\mu_o A}\right) \Rightarrow N_i = \phi(R_{l_c} + R_{l_g})$$

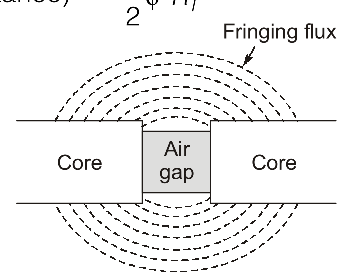
where, $R_{l_c} = \dfrac{l_c}{\mu_c \cdot A}$ = core reluctance ; $\quad R_{l_g} = \dfrac{l_g}{\mu_o A}$ = air-gap reluctance

The magnetic energy stored in the air-gap and the iron core is given as

$$W = \frac{1}{2} L I^2 = \frac{1}{2}\left(\frac{N^2}{\text{Reluctance}}\right) \times I^2 = \frac{1}{2 \times \text{Reluctance}} \times (\phi \times \text{Reluctance})^2 = \frac{1}{2}\phi^2 R_T$$

where R_T is total reluctance that is $R_T = R_{l_c} + R_{l_g}$.

1.1.2 Fringing



At an air-gap in a magnetic core, the flux fringes out into neighbouring paths as shown in figure. The result is non-uniform flux density in the air-gap, enlargement of the effective air-gap area and a decrease in the average air-gap flux density.

If area of air-gap increases, then total area of core with consideration of air gap increases. Then average flux density gets reduced. It is possible to partially offset these inherent sources of error by using a "corrected" or "effective" mean path length and the cross-sectional area instead of actual physical length and area in the calculations. Satisfactory results may be achieved with this approximate method.

(c) $$Ni = \frac{B_c}{\mu_o \mu_r} l_c + \frac{B_g}{\mu_o} l_g$$

$$i = \frac{B_c}{\mu_o N}\left(\frac{l_c}{\mu_r} + l_g\right) = \frac{1.2}{4\pi \times 10^{-7} \times 600}\left(\frac{40}{6000} + 0.06\right) \times 10^{-2} \quad (\because B_g = B_c)$$

$$= 1.06 \text{ A}$$

$$L = \frac{\lambda}{i} = \frac{1.152}{1.06} = 1.09 \text{ H}$$

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OBJECTIVE BRAIN TEASERS

Q.1 A cast steel electromagnet has an airgap of length 2 mm and an iron path of length 30 cm. The number of ampere turns necessary to produce a flux density of 0.8 Wb/m^2 in the gap is _____. Neglect leakage and fringing. (For 0.8 Wb/m^2 cast steel requires 750 AT/m).

Q.2 A cast steel ring has a circular cross-section 3 cm in diameter and a mean circumference of 80 cm. The ring is uniformly wound with 600 turns.

(a) The current required to produce a flux of 0.5 m Wb in the ring is _____ A.

(b) If a saw cut 2 mm wide is made in the ring, then approximately the flux produced by the current found in (a) is _____ mWb.

(c) The current value which will give the same flux as in (a), after the air gap of 2 mm is made in the ring is _____ A.

Assume the gap density to be the same as in the iron and neglect fringing.

(For 0.705 Wb/m^2 cast steel requires 670 AT/m).

Q.3 An iron ring of mean length 50 cm has an air gap of 1 mm and a winding of 200 turns. If the permeability of the iron is 300 and a current of 1 A flows through the coil, then the flux density is _____.

Q.4 Why the transformer stampings are varnished before being used to build the core?

(a) To increase air-gap between stampings

(b) To reduce hysteresis loss

(c) To reduce eddy current loss

(d) To provide strength to the core

Q.5 Maximum flux established in an AC excited iron core is influenced by

(a) frequency only

(b) voltage only

(c) both voltage and frequency

(d) reluctance of the core

Q.6 A circular iron core has an air-gap cut in it and is excited by passing direct current through a coil wound on it. The magnetic energy stored in the air-gap and the iron core is

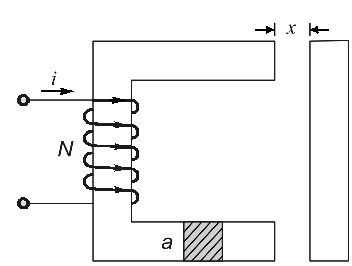
(a) in inverse ratio of their reluctance

(b) in direct ratio of their reluctances

(c) equally divided among then

(d) energy resides wholly in the iron core

Q.7 In the electromagnetic relay of given figure below the reluctance of the iron path is negligible. The coil self-inductance is given by the expression



(a) $\mu_0 N^2 a/x$ (b) $\mu_0 N/2\,ax$

(c) $\mu_0 N^2 a/2x$ (d) $\mu_0 N^2/2\,ax$

Q.8 An iron-cored choke with 1 mm air-gap length, draws 1 A when fed from a constant voltage AC source of 220 V. If the length of air-gap is increased to 2 mm, the current drawn by the choke would

(a) become nearly one half
(b) remain nearly the same
(c) become nearly double
(d) become nearly zero

Q.9 The unit of inductance is

(a) Wb T/A (b) V s/A
(c) H-turns^2 (d) All are equivalent

Q.10 Building steel core out of stampings reduces eddy current loss because,

(a) it increases core resistivity.
(b) it increases the effective length of eddy current paths thereby increasing effective resistance to the flow of eddy currents.
(c) it increases core permeability.
(d) it reduces the effective length of eddy current path, thereby reducing effective resistance to the flow of eddy currents.

Q.11 In a 4-pole dynamo, the flux/pole is 15 mWb. The average emf induced in one of the armature conductors, if armature is driven at 600 rpm

(a) 2.5 V (b) 0.6 V
(c) 9 V (d) 0.9 V

ANSWER KEY

1.	(1498.24)			**2.**	(Sol)	**3.**	(Sol)
4.	(c)	**5.**	(c)	**6.**	(b)	**7.**	(c)
8.	(c)	**9.**	(d)	**10.**	(b)	**11.**	(b)

HINTS & EXPLANATIONS

1. (1498.24)

Length of iron path,

$$l_i = 30 \text{ cm} = 30 \times 10^{-2} \text{ m}$$

Length of air gap = 2 mm = 2×10^{-3} m

$$B = NI \times \frac{\mu_o \mu_r}{l}$$

$$NI = \frac{Bl}{\mu_o \mu_r}$$

$$NI_{\text{air}} = \frac{0.8 \times 2 \times 10^{-3}}{4\pi \times 10^{-7}} = 1273.24 \text{ AT}$$

$$NI_{\text{cast steel}} = 750 \text{ AT/m} \times l_i$$

$$= 750 \times 30 \times 10^{-2} = 225 \text{ AT}$$

$$NI_{\text{Total}} = NI_{\text{cast steel}} + NI_{\text{air}}$$

$$= 1498.24 \text{ AT}$$

2. (Sol)

(a) The cross-sectional area

$$= \frac{\pi d^2}{4} \times 10^{-4} = \frac{\pi \times 9}{4} \times 10^{-4}$$

$$= 7.068 \approx 7.1 \times 10^{-4} \text{ m}^2$$

The flux density,

$$B = \frac{\phi}{A} = \frac{0.5 \times 10^{-3}}{7.1 \times 10^{-5}} = \frac{5}{7.1}$$

$$= 0.705 \text{ Wb/m}^2$$

$\therefore$ AT required = 670 × 0.8 = 536

$\therefore$ The current required

$$= \frac{AT}{N} = \frac{536}{600} = 0.89 \text{ A}$$

(b) Flux without air gap = 0.5 mWb

$$\phi = \frac{NI}{S_i}$$

$$0.5 \times 10^{-3} = \frac{600 \times 0.8933}{S_i}$$

S_i = Reluctance of iron (steel) = 1072000

S_a = Reluctance of air

$$= \frac{2 \times 10^{-3}}{4\pi \times 10^{-7} \times \left(\pi \times \frac{d^2}{4}\right)} = 2251581.9$$

S_T = Total reluctance

$$= S_i + S_a = 3323581.9$$

ϕ_{new} = new flux with air gap

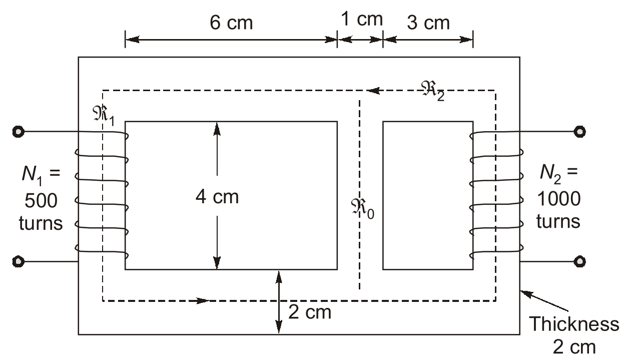
$$\phi_{new} = \frac{536}{3323581.9} = 0.16127 \text{ mWb}$$

(c) Ampere turn required = NI

$$= \phi \times S_T \text{(Flux} \times \text{Total Reluctance)}$$

CONVENTIONAL BRAIN TEASERS

Q.1 For the magnetic circuit of figure find the self and mutual inductances between the two coils. Core permeability = 1600.



1. (Sol)

$$l_1 = (6 + 0.5 + 1) \times 2 + (4 + 2) = 21 \text{ cm}$$

$$l_2 = (3 + 0.5 + 1) \times 2 + (4 + 2) = 15 \text{ cm}$$

$$l_0 = 4 + 2 = 6 \text{ cm}$$

$$R_1 = \frac{21 \times 10^{-2}}{4\pi \times 10^{-7} \times 1600 \times 2 \times 2 \times 10^{-4}} = 0.261 \times 10^6$$

$$R_2 = \frac{15 \times 10^{-2}}{4\pi \times 10^{-7} \times 1600 \times 2 \times 2 \times 10^{-4}} = 0.187 \times 10^6$$

$$R_0 = \frac{6 \times 10^{-2}}{4\pi \times 10^{-7} \times 1600 \times 1 \times 2 \times 10^{-4}} = 0.149 \times 10^6$$

(i) Coil 1 excited with 1 A :

$$R = R_1 + R_0 \parallel R_2 = 0.261 + 0.1871 \parallel 0.149 = 0.344 \times 10^6$$

$$\phi_1 = \frac{(500 \times 1)}{(0.344 \times 10^6)} = 1.453 \text{ mWb}$$

By flux division (similar to current division) :

$$\phi_{21} = \phi_2 = \frac{1.453 \times 0.149}{(0.149 + 0.187)} = 0.64 \text{ mWb}$$

$$L_{11} = N_1\phi_1 = 500 \times 1.453 \times 10^{-3} = 0.7265 \text{ H}$$

$$M_{21} = N_2\phi_{21} = 1000 \times 0.649 \times 10^{-3} = 0.64 \text{ H}$$

(ii) Coil 2 excited with 1 A :

$$R = R_2 + \frac{(R_0R_1)}{(R_0R_1)} = \frac{0.187 + (0.149 \times 0.281)}{(0.149 + 0.281)} \times 10^6 = 0.284 \times 10^6$$

$$\phi_2 = \frac{(1000 \times 1)}{(0.284 \times 10^6)} = 3.52 \text{ mWb}$$

$$L_{22} = N_2\phi_2 = 1000 \times 3.52 \times 10^{-3} = 3.52 \text{ H}$$

$$M_{12} = M_{21} \text{ (bilateral)} = 0.65 \text{ H}$$

CHAPTER

2 Transformer

Introduction

The transformer is a static device for transferring electrical energy from one alternating current circuit to another without a change in frequency. A transformer may receive energy at one voltage and deliver it at a higher voltage, in which case it is called a **step-up** transformer. When the energy is received at a higher voltage and delivered at a lower voltage, it is called a **step-down** transformer.

A transformer has no rotating parts; therefore, it requires little attention and its maintenance cost is low; its efficiency is much higher when compared to other electrical machines. Their sizes, range from very small ones such as pulse transformer and transformer used in radio, TV and other communication sets to some of the largest single units of electrical equipment ever manufactured, like power transformers for transmitting thousands of MVA power over large distances.

2.1 TRANSFORMER CONSTRUCTION

The magnetic core is a stack of thin silicon-steel laminations about 0.35 mm thick for 50 Hz transformers. An alloy of iron and steel containing 0–65% of Silicon (Si) is used. The presence of silicon significantly increases the resistivity of the steel, thereby helping in reducing the eddy current losses. The hysteresis loop is narrowed.

Cold-rolled grain-oriented sheet steel (C.R.G.O.) is used in manufacturing magnetic cores of transformers C.R.G.O. has better magnetic properties (μ) and lesser core losses when the alternating flux is made to flow along the direction of rolling because grain orientation in the rolling direction, increases the magnetic flux density attained by the core.

Insulators like japan varnish, impregnated paper, oxide paints are used in lamination. The sheet lamination is coated with tough enamel insulation which is resistant to hot transformer oil (mineral oil) and electromagnetic stresses. In high-frequency transformers, magnetic cores have either simple air core or ferrite core.

2.1.1 Types of Transformers

Generally, there are two types of transformers, the core type and shell type.

In core type the windings surround a considerable part of steel core as shown in fig. (a). In the shell type, the steel core surrounds a major part of the windings as shown in fig. (c). The vertical portions of the core are usually called limbs or legs and top and bottom portions are called the yoke. It means for single phase transformers core type has two-legged core whereas shell type has three-legged core.

In core type transformer leakage flux is reduced by placing half of LV winding over one leg and other half over the second leg. For the HV winding over one leg and other half over the second leg. LV is placed adjacent to steel core and HV winding outside in order to minimise the amount of insulation required, as shown in fig. (b). In shell type transformer LV and HV windings are wound over central limb and are interleaved or sandwiched as shown in fig. (d).

In core type flux has one path around the legs, while in shell type flux in central limb divides equally and returns through the two limb.

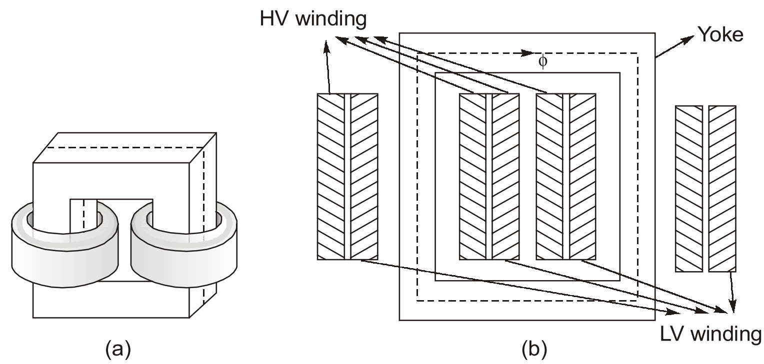


***Fig. :** Constructional Details of Core Type*

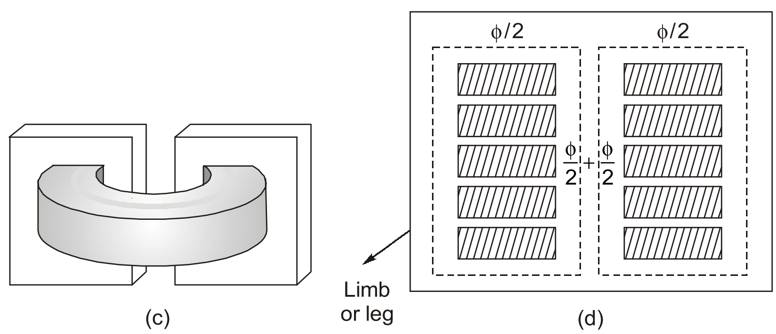


***Fig. :** Constructional Details of Shell Type*

***Table :** Comparison between core type and shell type transformers*

Core-type transformers	Shell-type transformers
• Core-type transformers, the coils encircle the core. • These transformers involve high leakage flux and leakage reactance. • They are easy to fabricate and repair. • They provide poor regulation. • It requires less iron but more conductor materials. • These are less costly. • These are preferred for low voltage, low power levels.	• In these transformers, the core encircle the coils. • These transformers have low leakage flux and leakage reactance. • They are difficult to fabricate and repair. • They provide better regulation. • It requires more iron but less conductor materials. • These are more costly. • These are preferred for high voltage, high power levels.

2.1.2 Types of Transformer Windings

(a) Cylindrical Windings : The windings are in the form of cylindrically wounded coils. There are multiple layers in these windings and each layer consists of several conductors. Paper insulation is provided between each layer of conductors.

(b) Disk Winding : In shell-type winding, sandwiched disk windings are used. The low-voltage and high voltage windings are arranged in multiple disk form sandwiching each other. However, on the top and

OBJECTIVE BRAIN TEASERS

Q.1 A 4 kVA, 400/200 V, 1-phase transformer has leakage impedance of 0.02 + j0.04 per unit. This leakage impedance in ohms, when referred to hv side is $x + jy$ the value of x is ______.

Q.2 A 100 MVA, 230/115 kV Δ–Δ, 3-ϕ power transformer has a resistance of 0.02 per unit and a reactance of 0.055 per unit. The transformer supplies a load of 80 MVA at 0.85 p.f. lagging. The percentage voltage regulation of the transformer is _____ %.

Q.3 A 1-ϕ, 5 kVA, 440/220, 50 Hz transformer is connected for short circuit test, it has following constants :

$$r_p = 0.5\ \Omega,\ r_s = 0.20\ \Omega$$
$$x_p = 0.6\ \Omega,\ x_s = 0.15\ \Omega$$
$$r_0 = 600\ \Omega,\ x_0 = 200\ \Omega$$

The short circuit voltage V_{SC} is _____ V.

Q.4 There is some suitable tapping on an auto-transformer starter for an induction motor required to start the motor with 40 per cent of full-load torque. The short-circuit current of the motor is 5 times the full load current and full-load slip is 0.035. The current drawn from the mains as a fraction of full-load current is _____ times.

Common Data for Questions (5 and 6):

A 500 kVA transformer has 95 % efficiency at full load and also at 60 % of full load both at unity p.f.

Q.5 Sum of iron loss and copper loss at full load is ______ kW.

Q.6 Transformer efficiency at 75 % full load and unity power factor is _______ %.

Q.7 Two transformers connected in open delta supplies a 400 kVA balanced load operating at 0.866 p.f. (lag). The load voltage is 440 V. What is the kW supplied by each transformer?

(a) 200 KW and 300 kW
(b) 200 kW and 115.5 kW
(c) 115 kW and 400 kW
(d) 115.5 kW and 300 kW

Q.8 An auto-transformer having 1250 turns is connected across a 250 V supply. If a tap is taken at 800th turn, the secondary voltage will be obtained as ____ V.

Q.9 A 3-phase transformer has its primary connected in delta and secondary in star. It has an equivalent resistance of 1% and equivalent reactance of 6%. The primary applied voltage is 6600 V. _____ be the ratio of transformation in order that it will deliver 4800 V at full load current and 0.8 power factor lag.

Q.10 At 400 V and 50 Hz the total core loss of a transformer was found to be 2400 W. When the transformer is supplied at 200 V and 25 Hz, the core loss is 800 W. The eddy current loss at 400 V and 50 Hz is _____ W.

Q.11 Two single-phase transformers in parallel connection, supplies a load of 500 A, at 0.8 p.f. lagging and at 400 V. Their equivalent impedances referred to secondary winding are (2 + j3) ohms and (2.5 + j5) ohms respectively. The kVA supplied by transformer-I is _____ kVA.

Q.12 A 500 kVA, 11 kV/0.43 kV, 3-phase delta/star connected transformer has HV copper loss of 2.5 kW and LV copper loss of 2 kW on rated load. The ohmic value of the equivalent resistance on the delta side is _____ Ω/ph.

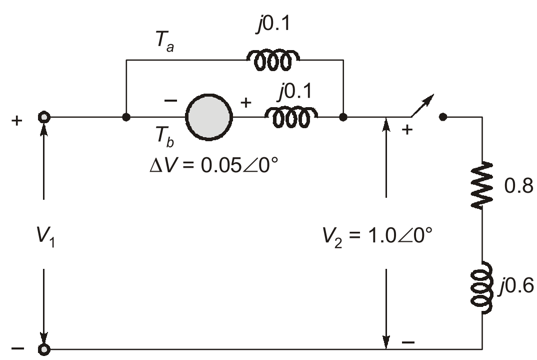
Q.13 A 5 kVA, 400/80V transformer has R_{eq}(HV) = 0.25 Ω and X_{eq} (HV) = 5 Ω and a lagging load is being supplied by it resulting in the following meter readings (meters are placed on the HV side).

I_1 = 16 A, V_1 = 400 V, P_1 = 5 kW. For this condition the reading of the voltmeter if connected across the load terminals is _____ V. (Assume the exciting current to be zero).

Q.14 Find the percentage loading at which maximum efficiency occurs in a given transformer with full load iron and copper losses as 3 kW and 8 kW respectively

(a) 50%
(b) 61.2%
(c) 70.7%
(d) 37.5%

Q.15 Open circuit test was done on a transformer with rated voltage and rated frequency in order to find out core losses. If this open circuit test now conducted on the double of rated voltage and double of the rated frequency, then

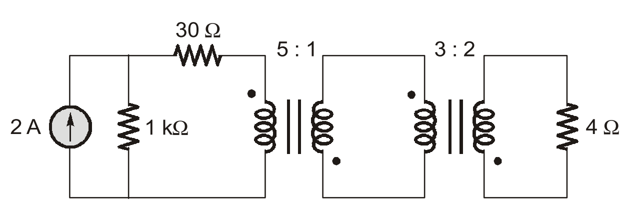


Transformer T_a has a voltage ratio equal to the ratio of the base voltages on the two sides of the transformer. This transformer has an impedance of j0.1 p.u. on the appropriate base. The second transformer T_b also has an impedance of j0.1 p.u. on the same base but has a step up toward the load of 1.05 times that of T_a (secondary windings on 1.05 tap). Figure shows transformer T_b represented by its impedance and the insertion of the voltage ΔV.

The complex power transmitted to the load through each transformer is

(a) $S_{T_a} = 0.4\angle 7.1°$p.u.; $S_{T_b} = 0.68\angle 54°$ p.u.
(b) $S_{T_a} = 0.6\angle 8.2°$p.u.; $S_{T_b} = 0.42\angle 54°$ p.u.
(c) $S_{T_a} = 0.7\angle 4.2°$p.u.; $S_{T_b} = 0.68\angle 54°$ p.u.
(d) $S_{T_a} = 0.4\angle 7.1°$p.u.; $S_{T_b} = 0.61\angle 72°$ p.u.

Q.35 The power dissipated by 4 Ω resistor in the circuit is _______ W.



ANSWER KEY

1. (0.8) 2. (3.7) 3. (20.1) 4. (2.28)
5. (26.32) 6. (95.15) 7. (231, 115.5) 8. (160)
9. (0.44) 10. (800, 1600) 11. (121.8)
12. (6.53) 13. (70.4) 14. (b) 15. (b) 16. (a)
17. (a) 18. (c) 19. (b) 20. (a) 21. (a)
22. (b) 23. (b) 24. (b) 25. (d) 26. (c)
27. (b) 28. (c) 29. (c) 30. (d) 31. (c)
32. (0) 33. (10392.304) 34. (a)
35. (568.80)

HINTS & EXPLANATIONS

1. (0.8)

$$\text{Base impedance} = \frac{400}{\left(\frac{4000}{400}\right)} = \frac{400\times 400}{4000}$$
$$= 40\ \Omega$$

leakage impedance referred to hv side

$$= (0.02 + j\,0.04) \times 40 = 0.8 + j1.6$$
$$x = 0.8$$

2. (3.7)

$$I_{S(\text{base})} = \frac{100}{\sqrt{3}\times 115} = 502 \text{ A}$$

Since the transformer supplies a load of 80 MVA at 0.85 pf lagging, so secondary line current of the transformer is

$$I_S = \frac{80}{\sqrt{3}\times 115} = 402 \text{ A}$$

$$(I_S)_{pu} = \frac{402}{502}\angle -\cos^{-1}(0.85) = 0.8\angle -31.8°$$

per unit no load voltage of this transformer is

$$V_{NL} = V_S + \vec{I}\,\vec{Z}$$
$$= 1\angle 0° + (0.8\angle -31.8°) \times (0.02 + j0.055)$$
$$= 1.037\angle 1.6°$$

$$\text{V.R.} = \frac{1.037-1}{1} \times 100\,\% = 3.7\,\%$$

3. (20.1)

$$I_{SC} = \frac{5000}{440} = 11.36 \text{ A}$$
$$V_{SC} = I_{SC} \times Z_{eq}$$
$$= 11.36\,[\{0.5 + (2)^2 \times 0.2\} + j\{0.6 + (2)^2 \times 0.15\}]$$
$$= 11.36[1.3 + j1.2]$$
$$= 11.36 \times 1.77\angle 42.70°$$
$$= 20.1\angle 42.70° \text{ V}$$

$$I_{circulating} = \frac{0.05}{j0.2} = -j0.25 \text{ p.u.}$$

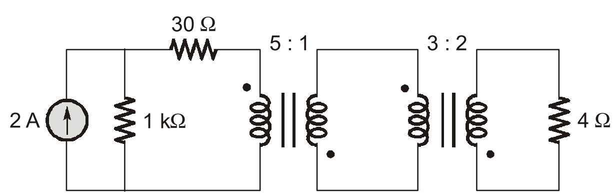
The current in each path is half the load current after switch is closed.

$$I_{Ta} = 0.4 - j0.3 - (-j0.25)$$
$$= 0.4 - j0.05 \text{ p.u.}$$
$$I_{Tb} = 0.4 - j0.3 + (-j0.25)$$
$$= 0.4 - j0.55 \text{ p.u.}$$

So, $S_{Ta} = VI_{T_a}^* = 0.4\angle 7.1°$ p.u.

$S_{Tb} = VI_{T_b}^* = 0.68\angle 54°$ p.u.

35. (568.8)



Refer all resistors to primary circuit

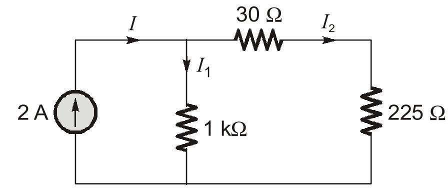
4 Ω referred to second loop primary

$$= 4\times\left(\frac{3}{2}\right)^2 = 9\ \Omega$$

9 Ω referred to primary again

$$= 9\times\left(\frac{5}{1}\right)^2 = 225\ \Omega$$

Now the circuit will become,



$$I_2 = 2\times\frac{1\text{k}\Omega}{1\text{k}\Omega+225+30} = 1.59 \text{ A}$$

As 225 Ω in the referred resistance of 4 Ω on the primary side, hence power dissipated in 225 Ω is the power dissipated in 4 Ω resistor.

$$\therefore P_{4\,\Omega} = I_2^2 \times R = 225 \times (1.59)^2 = 568.8 \text{ W}$$

(This can also be verified by referring current to 4 Ω resistance and then calculating power in it).

■■■■

CONVENTIONAL BRAIN TEASERS

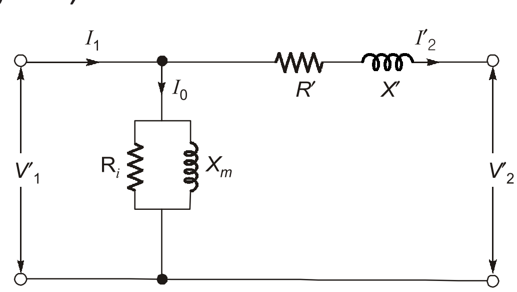
Q.1 Calculate voltage at the secondary terminals and primary input current when supplying full load secondary current at power factor (a) unity (b) 0.8 lag, for 4 kVA, 230/460 V single phase transformer. The following are test results :

Open circuit with 230 V applied to LV side – 0.6 A, 75 W

Short circuit with 20 V applied to HV side – 10 A, 60 W

1. (Sol)

Open circuit test (primary side) :



Referred to primary side