SETSQUARE ACADEMY

Degree Engineering (Mumbai University)

F.E. Semester - I

Previous Year Paper Solutions
(December 2007 - May 2016)

Basic Electrical Engineering

Common for all Branches

Chapter 4 : TRANSFORMER

Theory Questions

(1) What are assumptions (characteristics) for an Ideal Transformer? **[D-13][4],[May 09][4],[May 08][**

Solution:

Assumptions for an ideal transformer are:

(i) There are no losses in the core

(ii) No copper losses

(iii) Leakage flux is assumed negligible. Therefore all the flux produced by the primary winding is coupl to the secondary.

(iv) The primary and secondary winding resistances are negligible.

(v) Voltage regulation is 0%.

(vi) Efficiency is 100%.

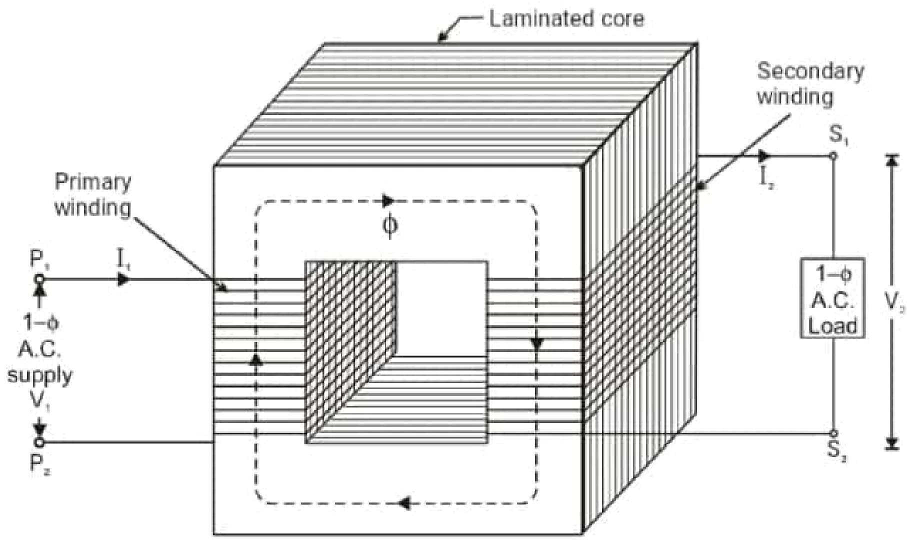
(2) Explain the principle of working for a single phase transformer and derive the e.m.f. equation for the same. **[M-15][4],[D-14][6],[M-13][4],[D-12][4],[M-08][8]**

Solution:

Working Principle of a Transformer.

A transformer is a static (or stationary) electrical apparatus by means of which electric power in one circuit transformed into electric power of the same frequency in another circuit. It can raise or lower the voltage i a circuit but with a corresponding decrease or increase in current. The physical basis of a tranformer is mutual induction between two coils linked by a common magnetic flux. In its simplest form it consists of tw inductive coils which are electrically separated but magnetically linked through a path of low reluctance as shown in Fig. The two coils possess high mutual inductance. If one coil is connected to a source of alternating voltage, an alternating flux is set up in the laminated core, most of which is linked with the other c in which it produces mutually induced emf (according to Faraday's Laws of Electromagnetic Induction

$|e_M| = M\frac{dI_1}{dt}$). If the second coil circuit is closed, using a load then a current flows in it and so electric ener is transferred (entirely magnetically) from the first coil to the second coil. The first coil, in which electric ener is fed from the a.c. supply, is called primary winding and the other from which energy is taken out, is calle secondary winding.



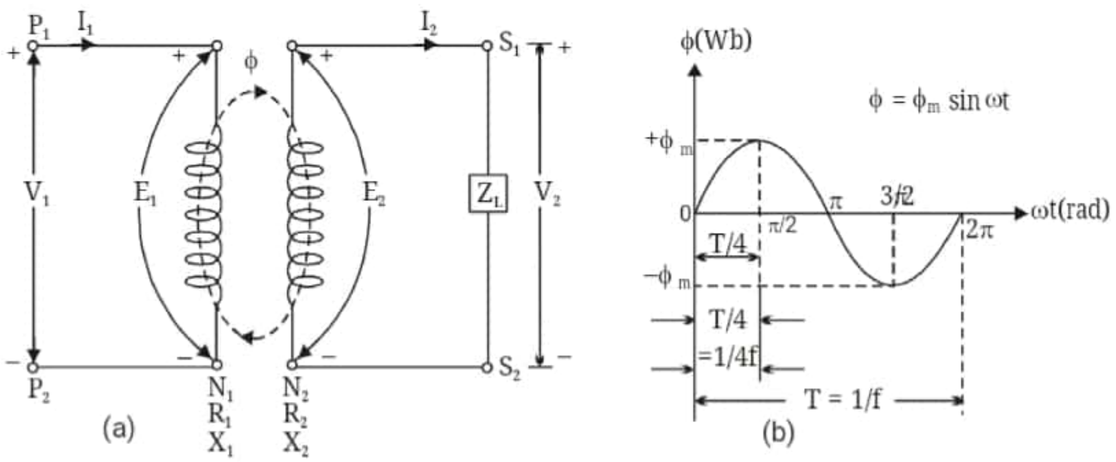
EMF Equation

Let N_1,$I_1$$R_1$ and X_1 be the number of primary turns, primary current, primary resistance and primary leaka reactance respectively. Also let N_2, I_2, R_2 & X_2 be the corresponding secondary quantities.

Let V_1 & V_2 be the primary & secondary terminal voltages.

Further let E_1 & E_2 be the primary self induced emf & secondary mutually induced emf respectively.

Assumption: Though the flux ϕ varies sinusoidally, it is assumed that it varies uniformly i.e. linearly varies fro the initial value of zero to the the final value ϕ_m in the time dt = T/4.



From Fig. (b), clearly $d\phi = \phi_m$

The above flux links with the stationary primary turns N_1 during the time $dt = \frac{1}{4f}$.

$\therefore$ As per Faraday's 2nd law of EMI, the magnitude of the average emf induced in the primary will be

$$E_{1av} = N_1 \frac{d\phi}{dt} = N_1 \frac{\phi_m}{1/4f} = 4f\, N_1\phi_m$$

$\therefore$ The rms value of the emf will be E_1 = Form Factor $\times E_{1av} = 1.11 \times 4f\, N_1\phi_m$

($\because$ for a sinusoidaly varying and alternating voltage, Form Factor = $\frac{\text{RMS value}}{\text{Average value}} = 1.11$)

$\therefore \qquad E_1 = 4.44\, f\, N_1\phi_m$ ......(i)

Similarly for secondary, we get $E_2 = 4.44\, f\, N_2\phi_m$ ......(ii)

Equations (i) and (ii) above are called emf equations of a transformer.

(3) What is the transformation ratio of an idal transformer? **[Dec 07][2]**

Solution:

For an ideal transformer, neglecting very small potential drops in the primary and secondary as the windi resistances are assumed zero

$$E_1 \approx V_1 \text{ and } V_2 \approx E_2$$

$$\therefore \frac{E_2}{E_1} = \frac{V_2}{V_1} = K$$

This ratio is known as the transformation ratio of an ideal transformer.

(4) What are the losses in the transformer? Explain why the rating of transformer in KVA not in KW.
[M-14][4],[D-11][5],[D-10][5

Solution:

Losses in a transformer

A transformer being static electrical apparatus, there are no friction or windage losses. Hence, the only losse occurring are:

Core or Iron Loss:

It includes both hysteresis loss and eddy current loss. Since the flux in the core remains almost constant for a loads, the core loss is constant.

Hysteresis loss, $W_h = \eta f B_m^{1.6} V$ watts;

Eddy current loss, $W_e = K_e f^2 t^2 B_m^2 V$ watts

Where, η = Hysterisis constant, B_m = max. flux density in the core, t = thickness of the core, f = frequency of the AC supply, K_e = eddy current constant, V = volume of the core material.

These losses are minimized by using steel of high silicon content for the core and by using very thin lamination which are interleaved to reduce the air gap. Iron or core loss is found from the O.C. test.

Copper loss:

This loss is due to the ohmic resistance of the transformer windings.

$$\text{Total Cu loss} = (I_1^2R_1 + I_2^2R_2) = I_1^2R_{01} = I_2^2R_{02}$$

Cu loss is proportional to $(\text{current})^2$ and hence $(\text{kVA})^2$. Copper losses are found from S.C. test.

Rating of Transformer in KVA and not in KW

The rated transformer output is limited by heating and hence losses in the transformer, i.e. copper loss an iron loss. These losses depend upon the voltage and current, and are almost unaffected by the power facto of the load. Therefore transformer rated output is expressed in KVA and not in KW.

(5) Derive condition for maximum efficiency of a transformer. Also derive equation for load at maximum efficiency. **[D-13][8**

Solution:-

Condition for maximum Efficiency :

$$\eta = \frac{\text{ouput power}}{\text{input power}} = \frac{\text{Input power} - \text{losses}}{\text{input power}}$$

Let copper loss; $W_{cu} = I_1^2 R_{01}$ or $W_{Cu} = I_2^2 R_{02}$

Iron (core) loss $= W_i$ Input power $= V_1 I_1 \cos\phi$

$$\text{So, } \eta = \frac{V_1 I_1 \cos\phi - I_1^2 R_{01} - W_i}{V_1 I_1 \cos\phi} = 1 - \frac{I_1 R_{01}}{V_1 \cos\phi} - \frac{W_i}{V_1 I_1 \cos\phi}$$

$$\text{for } \eta_{max,}\ \frac{d\eta}{dI_1} = 0 \Rightarrow \frac{d\eta}{dI_1} = 0 - \frac{R_{01}}{V_1 \cos\phi} + \frac{W_i}{V_1 I_1^2 \cos\phi} = 0 \Rightarrow \frac{W_i}{V_1 I_1^2 \cos\phi} = \frac{R_{01}}{V_1 \cos\phi}$$

$$\therefore W_i = I_1^2 R_{01} \text{ or } W_i = I_2^2 R_{02}$$

Thus, the condition to achieve maximum efficiency is Iron loss = Copper loss

Load at η_{max} :

Let at 'X' times full load, the efficiency is max.

So copper loss at η_{max}, $= X^2 \times [W_{cu}]_{FL}$

But at η_{max}, iron (or core) loss = copper loss

$$W_i = X^2 [W_{Cu}]_{FL} \Rightarrow X = \sqrt{\frac{W_i}{[W_{Cu}]_{FL}}}$$

$$\%\eta_{max} = \frac{X \text{ x fullload KVA x pf}}{(X \text{ x fullload KVA x pf}) + 2W_i} \text{x}100$$

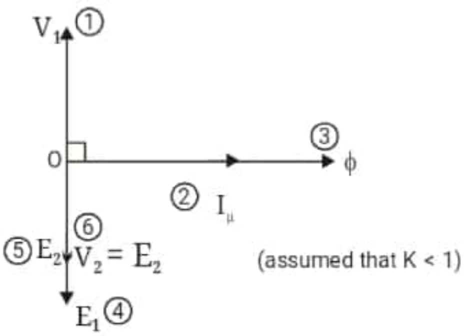
$\therefore$ load corresponding to maximum efficiency

$$[kVA]_{max} = \left(\sqrt{\frac{W_i}{(W_{Cu})_{FL}}}\right) x (kVA)_{FL}$$

(6) Draw the phasor diagram of a transformer on no load and explain the various currents and vottages in it. **[May 15][4],[May 15][6],[Dec 09][4]**

Solution:

Phasor diagram of an ideal transformer with no load



An ideal transformer is one which has no iron and copper losses.

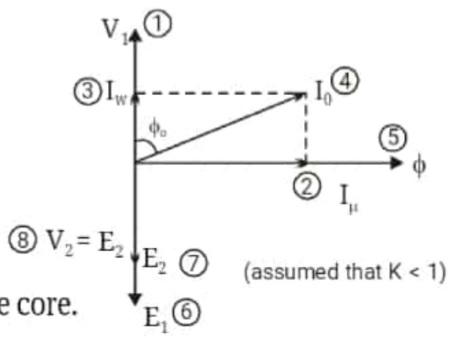
When the sinusoidally varying alternating supply voltage V_1 is applied acorss the primary, the sinusoidally varying alternaing magnetising current I_μ starts flowing through primary, setting up flux ϕ (which is also sinusoidally varying and alternating) in the core. Since the primary coil is highly inductive, I_μ lags V_1 by 90°. We also know that the flux ϕ is in phase with I_μ ($\because \phi \propto I$).

An emf E_1 is induceed in the primary according to Faraday's first law of EMI and is called as primary emf self inductance. It is in phase opposition to V_1 according to Lenz's law i.e. $E_1 \approx -V_1$.

As secondary is in the vicinity of primary, an emf of mutual inductance i.e. E_2 is induceed in secondary whi is in phase opposition to the very cause producing it i.e. V_1 and finally we get at the secondary terminals, tl terminal voltage V_2 which is also opposite to the very cause producing it i.e. V_1.

Thus we find that E_1, E_2 and V_2 are in phase with each other and they are in phase opposition to V_1 i.e. tl very cause producing them.

Phasor diagram of a practical transformer with no load



In a practical transformer with no load, the losses are

(a) Magnetic losses in the core and

(b) Very very small copper losses in the primary winding.

Now the no load current I_0 will be drawn from supply. It will consist of two components.

(i) The magnetising component I_μ responsible for setting up flux in the core.
It is lagging V_1 by 90° since the primary coil is highly inductive.

(ii) The loss component I_w which is responsible mainly for the iron loss and very small primary Cu loss. It is phase with V_1. This component is also called as active, working or iron loss component.

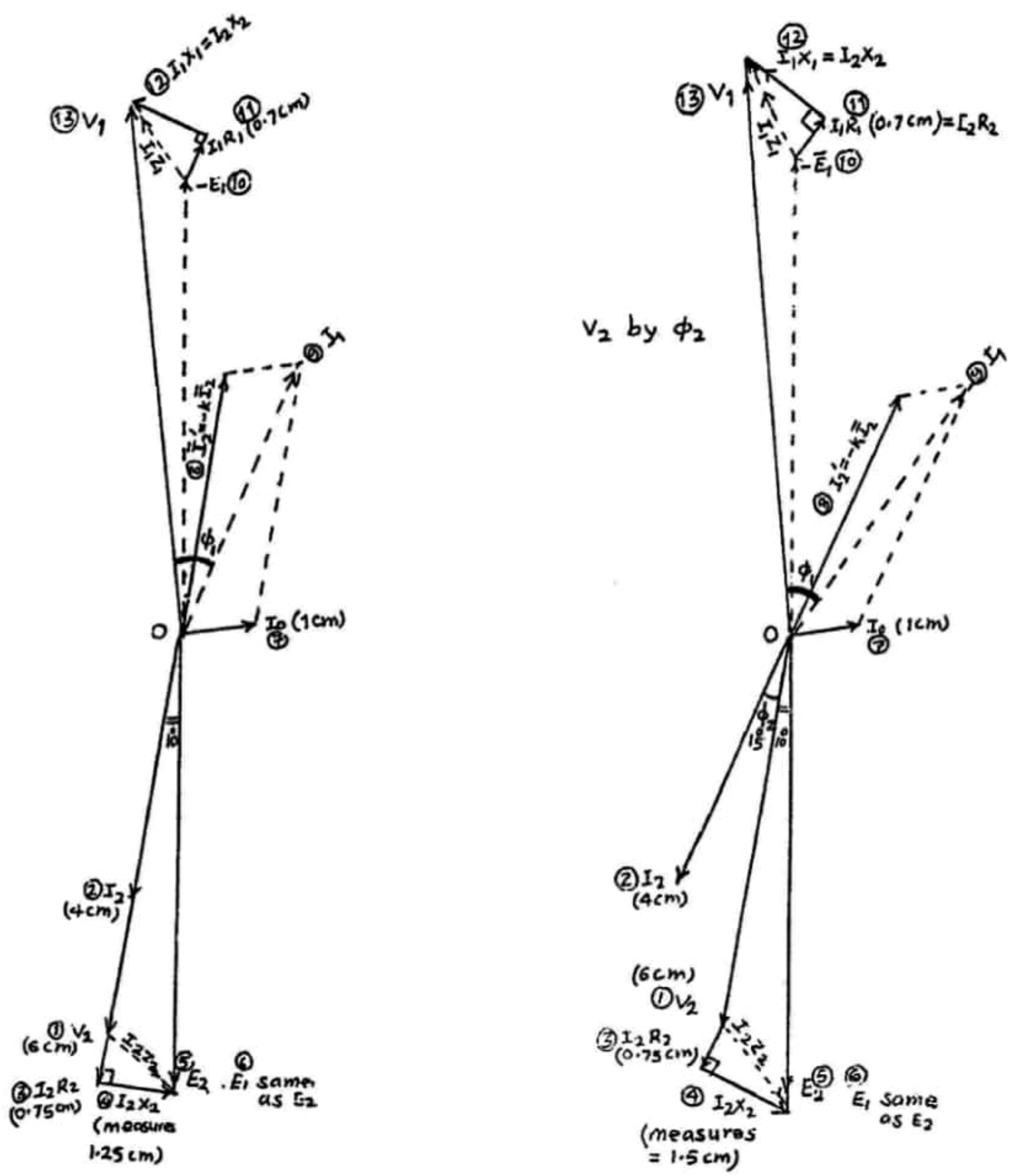
Usually I_0 is kept very small as compared to full load primary current $I_{1_{FL}}$ so as to have higher efficiency of t transformer. I_{00} is comparatively larger than I_w.

E_2 is the emf induced in the secondary due to mutual induction while $V_2 = E_2$ is the terminal voltage across t secondary.

(7) Draw phasor diagram of single phase transformer on resistive load [Unity power factor] and inductiv load [lagging power factor]. **[M-14][6],[D-12][6]**

Solution:

Case I: Resistive load i.e. upf. **Case II:** Inductive load i.e. lagging p.f.



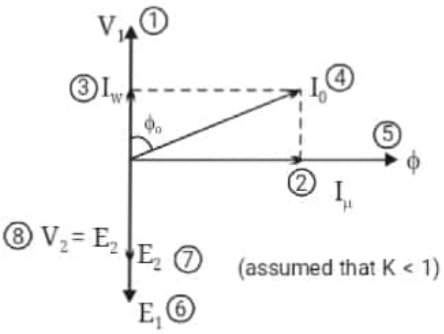
Note: It is observed that $E_2 > V_2$ for u.p.f & lagging p.f.

(8) Draw and explain phasor of 1-phase pratical tranformer when **[D-13][6],[May 09][8],[Dec 08][4]**

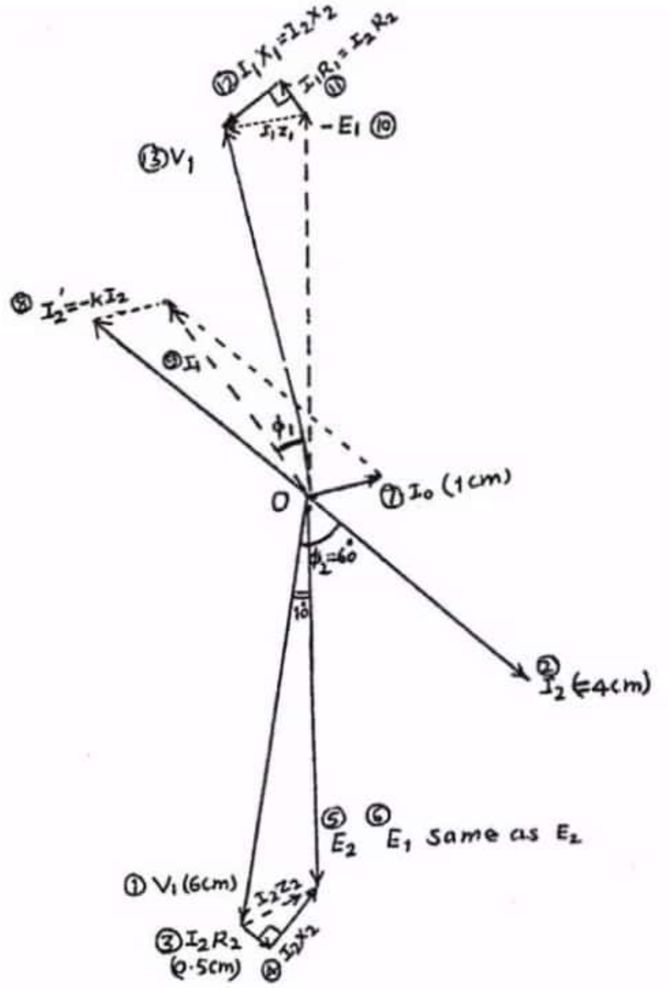
(i) On no load (ii) Leading power factor load

Solution:

(i) No load



(ii) Leading p.f



Note: It is observed that $E_2 < V_2$ for a leading p.f.

(9) Develop the approximate equivalent circuit of a transformer. How it helps in deciding the Regulation of transformer. **[Dec 10][12]**

Solution:

Equivalent Circuit of a Transformer

Let us develop the equivalent circuit of a transformer w.r.t. primary with the usual notations.

(I) Following Fig. (a) shows a 1 - ϕ transformer diagrammatically

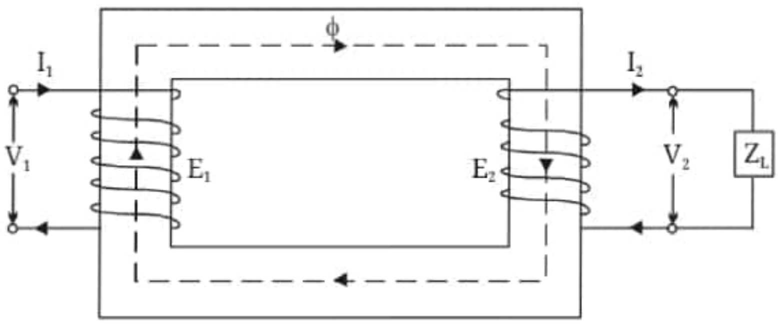


Fig. (a)

(II) In Fig. (b) below is shown the circuit of a transformer in which the resistances and reactance are shown external to the windings

$R_0 = \dfrac{E_1}{I_w}$ is called excitation resistance which is responsible for no load losses.

$X_0 = \dfrac{E_1}{I_\mu}$ is called excitation reactance which is responsible for setting up the flux in the core.

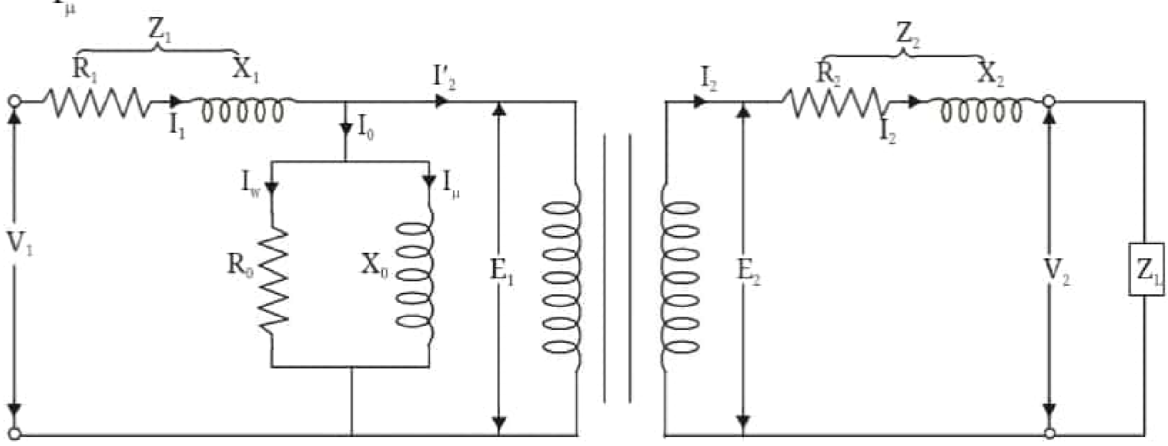


Fig. (b)

(III) Transferring the secondary quantities on the primary side, we get following circuit as shown in Fig. (c) belo

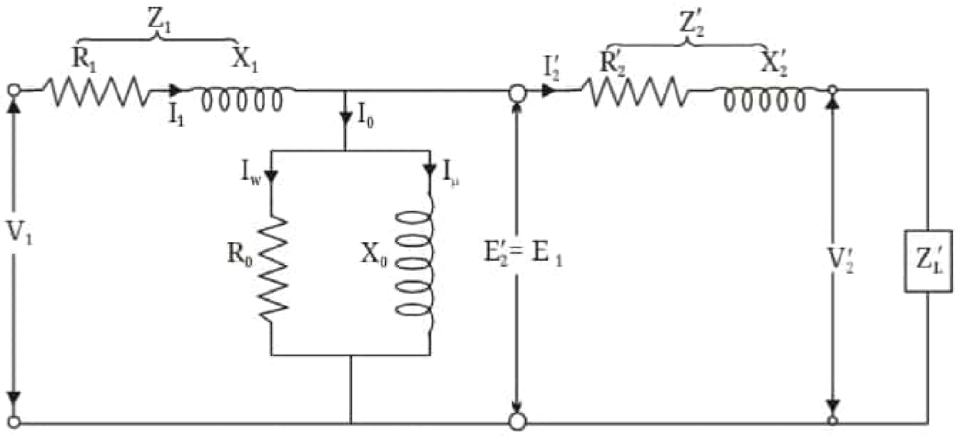


Fig. (c)

(IV) $\because$ I_0 is very small compared to the full load primary current $I_{1_{FL}}$ $\therefore$ neglecting very small I_0R_1 and I_0X_1 potential drops i.e. assuming that $E_1 \simeq V_1$, we can transfer the parallel combination of R_0 and X_0 on the extrem left ie directly across V_1 $\therefore$ We get following circuit as shown in Fig. (d) below :

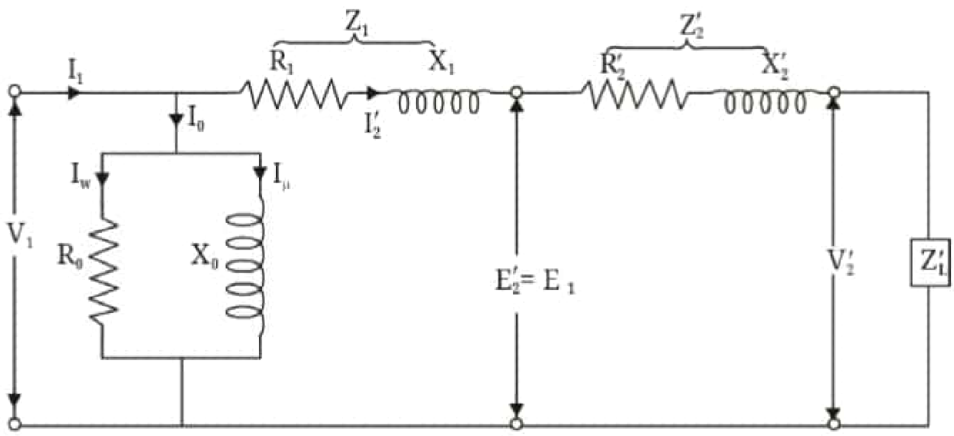


Fig. (d)

(V) Finally, we get the following simplified circuit of the tranformer as referred to primary shown in Fig. (e), where $R_{01} = (R_1 + R'_2)$ and $X_{01} = (X_1 + X'_2)$

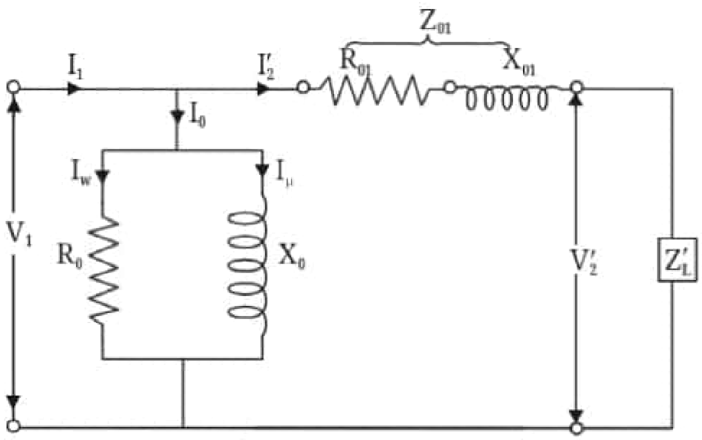


Fig. (e)

Voltage Reguation of a transformer:

(i) The terminal voltage across the load is $\overline{V_2} = \overline{E_2} - \overline{I_2 Z_2}$.
Clearly, at no load, $I_2 = 0 \therefore V_2 = E_2$ and is the highest, however, as I_2 increases, I_2Z_2 drop increases a therefore V_2 decreases. Voltage regulation takes care of this drop in the terminal voltages as load changes

(ii) General mathematical expression of voltage regulation.

$$\% \text{ Voltage Regulation} = \frac{V_{2NL} - V_{2L}}{V_{2NL}} \times 100 = \frac{E_2 - V_{2L}}{E_2} \times 100$$

(iii) Like efficiency, voltage regulation is also specified at two factors viz load and the load p.f.

(iv) Ideally the voltage regulation should be zero. However, for upf and lagging pf, depending upon the load, it varies between +2% to +5%, while for a leading pf it varies between –1% to –3%.

(v) As mentioned above, regulation for upf and lagging pf is positive $\because E_2 > V_2$ however for leading pf it is negative $\because E_2 < V_2$

(10) With the help of a neat diagram explain how short circuit test is conducted on a single phase transformer
[M-15][6],[May-11][6]

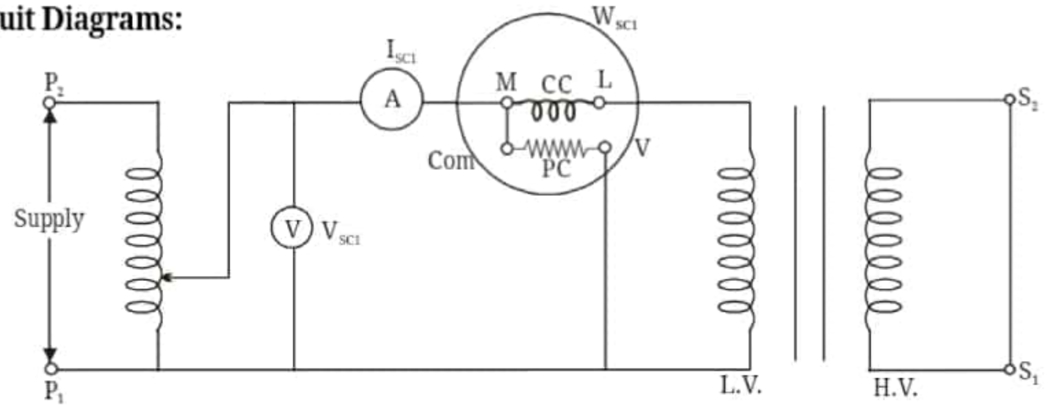
Solution:

Short Circuit or Impedance test

Procedure:

The connections are made as shown in circuit diagram. Either of the sides HV or LV whichever is convenie (but preferably LV) is solidly short circuited and meters are connected to the other side. The supply is give through a continuously variable auto-transformer and the voltage is carefully and gradually increased till full load rated current flows through the short circuited winding and hence as well as through the metering side. It is generally observed that 5 to 10% the rated voltage is required to circulate the full load rated current through the windings. Now the readings of the instruments are noted.

Circuit Diagrams:



Note that here the transformer we have considered is of step-down type for the sake of convenience only ∵ secondary is LV. it is shorted & meters are connected on primary here i.e. here short circuit test meterin side (abbreviated as SCTMS) is primary.

Theory and Explanation:

As mentioned above since one of the sides is short circuited, it offers the least impedance to the current flov ∴ it is seen that very small voltage of about 5 to 10% is required to be applied on the other side (i.e. meterin side) for circulating the rated current. And the wattmeter reading indicates copper losses. This can be explaine as follows.

As the applied voltage is very less, it is clear that the flux set up is also less since $V_1 = 4.44\, f N_1 \phi_m$.
∴ $\phi_m \propto V_1$ and therefore B_m is also very less. Thus the iron losses can be neglected.

∵ $W_h \propto B_m^{1.6}$. and $W_e \propto B_m^2$ will be very small.

The current flowing through the short circuited winding and hence through the metering side is the rated or fu load current and therefore the wattmeter represents copper losses, $W_{Cu_{FL}}$

Thus, from these two reasons we can say that the wattmeter reading during short circuit or impedance te represents copper loss.

Calculations :

Assuming here that, the metering side is primary, for the sake of convenience only, following calculations a made:

(i) $Z_{01} = \dfrac{V_{SC_1}}{I_{SC_1}}$; Thus Z_{01} can be calculated.

(ii) $W_{SC_1} = I_{SC_1}^2 R_{01} \Rightarrow R_{01} = \dfrac{W_{SC_1}}{I_{SC_1}^2}$ and can be calculated.

(iii) ∴ $X_{01} = \sqrt{(Z_{01})^2 - (R_{01})^2}$ is known.

However, if the metering side is secondary, then we can modify the above calculations as:

(i) $Z_{02} = \dfrac{V_{SC2}}{I_{SC2}}$, Thus Z_{02} can be calculated.

(ii) $W_{SC2} = I_{SC2}^2 R_{02} \quad \Rightarrow R_{02} = \dfrac{W_{SC2}}{I_{SC2}^2}$ and can be calculated

(iii) $X_{02} = \sqrt{Z_{02}^2 - R_{02}^2}$ is known.

(11) With the help of a neat diagram explain how open circuit test is conducted on a single phase transformer. [D-14][6],[M-11][6]

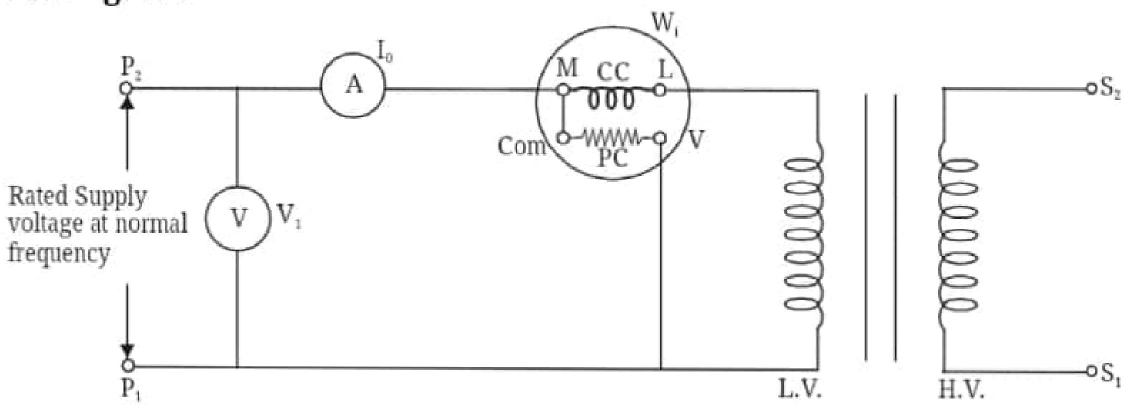
Solution:

Open Circuit or no load test:

Procedure:

In this test, either of the sides HV or LV of the transformer, whichever is convenient, is left open (but usual HV) and rated supply voltage at the normal frequency is applied to the other side. Ammeter, voltmeter and wattmeter are connected on this side, the readings of which are carefully noted.

Circuit Diagram:



Note that here the transformer we have considered is of step up type for the sake of convenience only ∵ primary is LV, meters are connected on primary i.e. here open circuit test metering side (abbreviated as OCTMS) is primary.

Theory and Explanation

In a transformer the main losses are:

Constant iron losses (W_i) consisting of

(a) Hysteresis losses, $W_h = \eta f B_m^{1.6} V$ watts (b) Eddy current losses $W_e = K_e f^2 t^2 B_m^2 V$ watts

Variable copper losses in primary ($I_1^2 R_1$) and secondary ($I_2^2 R_2$)

When the transformer is on no load, the current drawn from the supply by the transformer is called "No load current" I_0 and is very small. And the wattmeter reading indicates constant iron losses W_i during the test.

Calculations:

Assuming that primary is LV here, i.e. metering side is primary for the sake of convenience only, following calculations are made:

(i) Wattmeter reading say $W_i = V_1 I_0 \cos\phi_0$

Since W_i, V_1 and I_0 can be read from the respective instruments, the no load power factor $\cos\phi_0 = \frac{W_i}{V_1 I_0}$ can easily be determined.

(ii) ∴ $I_\mu = I_0 \sin\phi_0$ and $I_w = I_0 \cos\phi_0$ can now be determined.

(iii) ∴ $X_0 = \frac{V_1}{I_\mu}$ & $R_0 = \frac{V_1}{I_w}$ can also be found out. [Note that $R_0 > X_0$ ∵ $I_w < I_\mu$]

However, if the metering side is secondary then we can modify the above calculations as:

(i) $W_i = V_2 I'_0 \cos\phi'_0$ ∴ $\cos\phi'_0$ and $\sin\phi'_0$ can be found

(ii) $I'_\mu = I'_0 \sin\phi'_0$ and $I'_w = I'_0 \cos\phi'_0$ can now be determined

(iii) $X'_0 = \frac{V_2}{I'_\mu}$ and $R'_0 = \frac{V_2}{I'_W}$ are found.

Numerical Problems

Type I : Basic Sums

(1) A 5 kVA, 240/2400 V, 50 Hz single phase transformer has the maximum value of flux density as 1.2 Tesla. If the e.m.f. per turn is 8 V. Calculate the number of primary and secondary turns and the primary and secondary current at full load. **[D-14][4]**

Solution:-

$$E_1 = 4.44\, f\, \phi_m\, N_1 \qquad \therefore\ N_1 = \frac{E_1}{4.44 f\, \phi_m} = \frac{240}{4.44\times 50\times 1.2} = 0.9 \cong 1$$

$$E_2 = 4.44\, f\, \phi_m\, N_2 \qquad \therefore\ N_2 = \frac{E_2}{4.44 f\, \phi_m} = \frac{2400}{4.44\times 50\times 1.2} = 9.009 \cong 9$$

$$I_{1FL} = \frac{\text{KVA rating}}{V_1} = \frac{5\text{KVA}}{240} = 20.833\text{A}$$

$$I_{2FL} = \frac{\text{KVA rating}}{E_2} = \frac{5000\text{VA}}{2400} = 2.083\text{A}$$

(2) A 3000/200 V, 50 Hz single phase transformer has a cross sectional area of 150 cm² for the core. If the number of turns on the low voltage winding is 80, determine number of turns on the high voltage winding and maximum value of flux density in the core. **[M-13][6]**

Solution:-

Given: $E_1 = 3000\text{V}, \quad f = 50\text{Hz}, \quad E_2 = 200\text{V}, \quad N_2 = 80\text{turns}, \quad A = 150\,\text{cm}^2$

To find: $N_1 = ? \qquad B_m = ?$

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} \Rightarrow N_1 = N_2 \times \frac{E_1}{E_2} = 80\times\frac{3000}{200} = 1200$$

$$\therefore E_1 = 4.44 f\, \phi_m\, N_1 = 4.44 f\, B_m\, A N_1 = 4.44\times 50\times B_m \times 150\times 10^{-4}\times 1200$$

$$\therefore B_m = \frac{3000}{4.44 \text{x} 50 \text{x} 150 \text{x} 10^{-4} \text{x} 1200} = 0.75\ \text{Weber}/\text{m}^2 = 0.75\text{T}$$

(3) A 50 KVA, 2200/440V, 50 Hz single phase transformer has primary turns of 200. **[May 12][5]**
Determine: (i) flux in core (ii) Secondary turns (iii) rated primary current (iv) rated secondary current

Solution:

Given: kVA = 50, V_1 = 2200 V, V_2 = 440 V, f = 50 Hz, N_1 = 200

1. Flux in core: $V_1 = 4.44\, f\, N_1\, \phi_m \ \Rightarrow 2200 = 4.44\times 50\times 200\times \phi_m \ \Rightarrow \phi_m = 0.04954$ Wb

2. Secondary turn: $N_2 = \dfrac{V_2}{V_1}\times N_1 = \dfrac{440}{2200}\times 200 = 36.36$

3. Rated Primary current: $I_1 \text{ rated} = \dfrac{\text{kVA}\times 10^3}{V_1} = \dfrac{50\times 10^3}{2200} = 22.73$ Amp.

4. Rated Secondary current: $I_1 \text{ rated} = \dfrac{\text{kVA}\times 10^3}{V_2} = \dfrac{50\times 10^3}{440} = 113.64$ Amp.

Type II : O.C., S.C., Efficiency and Regulation of a Transformer

(1) A 5kVA. 1000/200V, 50 Hz, single phase transformer gave the following test results.

O.C. test (hv. side) :	1000V	0.24 A	90 W
S.C. test (hv. side) :	50V	5A	110 W

Calculate the equivalent circuit parameters of the transformer and draw the equivalent circuit diagram.
[M-16][8],[D-15][6],[M-15][8]

Solution:-

5 KVA, 1000/200 V, 50 Hz

Open circuit Test: $V_1 = 100\,V,\ I_0 = 0.24\,A,\ W_0 = 90\,W$

$$\cos\phi_0 = \frac{W_0}{V_1 R_0} = 0.375 \quad \therefore \quad \phi_0 = 67.98^0;\ \sin\phi_0 = 0.927$$

$$R_0 = \frac{V_1}{I_0 \cos\phi_0} = \frac{1000}{0.24 \times 0.375} = 11.1111\,k\Omega$$

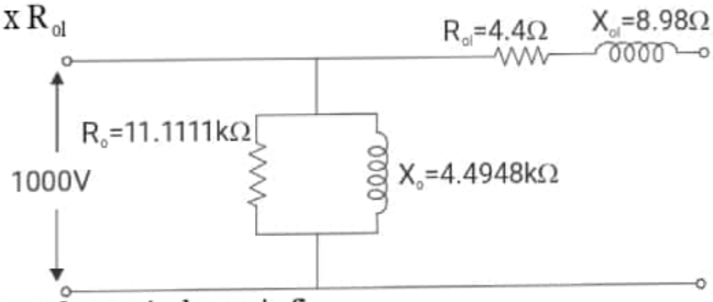
$$X_0 = \frac{V_1}{I_0 \sin\phi_0} = \frac{1000}{0.24 \times 0.927} = 4.4948\,k\Omega$$

Short circuit Test: $W = I_1^2 . R_{ol} \Rightarrow 110 = 5^2 \times R_{ol}$

$\therefore R_{ol} = 4.4\Omega$

$$Z_{ol} = \frac{V_{sc}}{I_1} = \frac{50}{5} = 10\,\Omega$$

$$X_{ol} = \sqrt{Z_{ol}^2 - R_{ol}^2} = \sqrt{10^2 - 4.4^2} = 8.98\,\Omega$$



Equivalent circuit reference to primary side of transformer is shown in fig.

(2) A 30 kVA, 2400/120V, 50Hz transformer has high-voltage winding resistance of 0.1 Ω and leakage reactance of 0.22Ω. The low voltage winding resistance is 0.035Ω and leakage reactance is 0.012Ω. Calculate equivalent resistance as referred to primary and secondary, equivalent reactance as referred to primary and secondary, equivalent impedance as referred to primary and secondary. Copper loss at full load and at 75% of full load. **[D-14][8],[M-13][8][D-12][8**

Solution:-

$E_1 = 2400V,\quad E_2 = 120V,\ R_1 = 0.1\Omega,\ R_2 = 0.035\Omega,\ X_1 = 0.22\Omega,\ X_2 = 0.012\,\Omega$

$$\therefore K = \frac{E_2}{E_1} = \frac{120}{2400} = 0.05, \qquad I_1 = \frac{30 \times 1000}{2400} = 12.5\,Amp, \qquad I_2 = \frac{30 \times 1000}{120} = 250\,Amp$$

Equivalent resistance as referred to both primary & secondary.

$$R_{01} = R_1 + \frac{R_2}{K^2} = 0.1 + \frac{0.035}{(0.05)^2} = 14.1\Omega$$

$$R_{02} = K^2 R_{01} = (0.05)^2 \times 14.1 = 0.03525\,\Omega$$

Equivalent Reactance as referred to both primary & secondary.

$$X_{01} = X_1 + \frac{X_2}{K^2} = 0.22 + \frac{0.012}{0.05^2} = 5.02\,\Omega$$

$$X_{02} = K^2 X_{01} = (0.05)^2 \times 5.02 = 0.0125\,\Omega$$

Equivalent Impedance as referred to both primary & secondary.

$$Z_{01}=\sqrt{R_{01}{}^2+X_{01}{}^2}=14.1\Omega \quad \text{and} \quad Z_{02}=\sqrt{R_{02}{}^2+X_{02}{}^2}=5.02\Omega$$

Copper loss at full load

$$\therefore W_{Cu}=I_2^2\,R_{02}=(250)^2 \times 0.03525=2203.25\text{ watt}=2.203\text{ KW}$$

At 75% full load, x = 0.75

$$W_{Cu}=x^2 \times W_{CuFl}=1.2393\text{kW}$$

(3) A 5 KVA 200/400 volts, 50Hz single phase transformer gave the following rest results.

O.C test [LV side]	200V	0.7A	60W;
S.C test [HV side]	22V	16V	120W

(i) Draw the equivalent circuit of the transformer referred to LV side insert all parameter values.

(ii) Efficiency at 0.9 power factor leading if operating at rated load.

(iii) Currents at which efficiency is maximum, also find load kVA at max.η.

[M-14][6],[Dec-11][10][Dec-10][12

Solution:-

Given : 5 kVA, 200/400 volt, 50Hz

$$V_1=200\text{V}, \qquad I_0=0.7\text{ A}, \qquad \omega_i=60\text{ w}$$

$$V_{SC}=22\text{V}, \qquad I_2=10\text{ A}, \qquad \omega_{SC}=120\text{ w}$$

From OC test :

$$\therefore \quad W_1=V_1I_0\cos\phi_0 \Rightarrow \cos\phi_0=\frac{\omega_i}{V_1I_0}=\frac{60}{200 \times 0.7}=0.4285$$

$$\therefore \quad \phi_0=64.62^{\circ} \quad \text{and} \quad \sin\phi_0=0.9$$

$$\because \quad I_\omega=I_0\cos\phi_0 \qquad I_\omega=0.7 \times 0.4285=0.2999\text{ Amp.}$$

$$\therefore \quad I_\mu=I_0\sin\phi_0=0.7 \times 0.9=0.63\text{ Amp.}$$

$$\therefore \quad R_0=\frac{V_1}{I_\omega}=\frac{200}{0.2999}=666.89\Omega \quad \text{and} \quad X_0=\frac{V_1}{I_\mu}=\frac{200}{0.63}=317.46\Omega$$

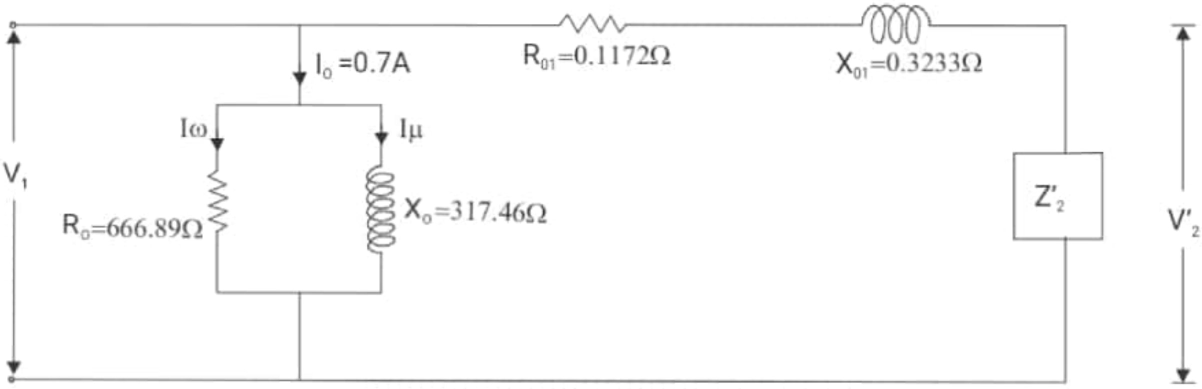
Form SC test:

$$\therefore \quad \omega_{SC}=I_2^2\,R_{02} \quad \therefore \quad R_{02}=\frac{\omega_{SC}}{I_2^2}=\frac{120}{16^2}=0.4687\,\Omega$$

$$\therefore \quad Z_{02}=\frac{V_{SC}}{I_2}=\frac{22}{16}=1.375\Omega \quad \text{and} \quad X_{02}=\sqrt{Z_{02}^2-R_{02}^2}=\sqrt{(1.375)^2-(0.4687)^2}=1.2926\Omega$$

$$\text{Now,} \quad K=\frac{E_2}{E_1}=\frac{400}{200}=2$$

$$\therefore \quad R_{01}=\frac{R_{02}}{K^2}=\frac{0.4687}{2^2}=0.1172\,\Omega \quad \text{and} \quad X_{01}=\frac{X_{02}}{K^2}=\frac{1.2926}{2^2}=0.3232\,\Omega$$



$$(I_2)_{FL} = \frac{\text{kVA rating x1000}}{E_2} = \frac{5\text{x}1000}{400} = 12.5\text{ A} \quad \text{and} \quad I_2 = 16\text{ A}$$

$$[W_{Cu}]_{FL} = \left(\frac{12.5}{16}\right)^2 \text{x}120 = 73.24\text{ watt}$$

Now $pf = 0.9 \;\; X = 1....\text{rated load}$

$$\therefore \quad \%\eta = \frac{\text{X x full load kVA x pf}}{(\text{X x full load kVA x pf}) + \omega_i + X^2\,\omega_{Cu}} \text{x}100 = \frac{1\text{x}5\text{x}0.9}{(1\text{x}5\text{x}0.9) + (0.06) + (1)^2\text{ x}0.07324} \text{x}100$$

$$\%\eta = 0.9712\text{x}100 \;\; = 97.12\%$$

$$\therefore \quad \eta = 0.9712$$

(4) A 50KVA, 4400/220 volt transformer has R_1 = 3.45Ω, R_2 = 0.009Ω. The reactance are X_1 = 5.2Ω and X_2 = 0.015Ω. Calculate for the transformer,

(i) Full load currents on primary and secondary side,

(ii) Equivalent resistance, rectances, impedance, referred to primary side and secondary side,

(iii) Total copper lose using individual resistance and equivalent resistances. **[M-14][8]**

Solution:-

Given : 50kVA, 4400/220 volt transformer i.e.

$E_1 = 4400V$, $\quad R_1 = 3.45\,\Omega$, $\quad X_1 = 5.2\,\Omega$

$E_2 = 220\,V$, $\quad R_2 = 0.009\,\Omega$, $\quad X_2 = 0.015\,\Omega$

$$k = \frac{E_2}{E_1} = 0.05$$

$$I_1 = \frac{\text{KVArating x1000}}{E_1} = \frac{50\text{x}1000}{4400} = 11.364\text{ Amp.}$$

$$I_2 = \frac{\text{KVA rating x1000}}{220} = 227.273\text{ Amp}$$

Refer to the primary side

$$\text{Resistance, } R_{01} = R_1 + R_2^1 = R_1 + \frac{R_2}{K^2} = 3.45 + \frac{0.009}{0.05^2}$$

$$\therefore\ R_{01} = 7.05\,\Omega$$

Resistance, $X_{01} = X_1 + X_{2'} = X_1 + \frac{X_2}{K^2} = 5.2 + \frac{0.015}{0.05^2}$

$$\therefore\ X_{01} = 11.2\,\Omega$$

Impedance, $Z_{01} = \sqrt{R_{01}{}^2 + X_{01}{}^2} = 13.23\,\Omega$

Refer to secondary side,

Resistance, $R_{02} = R_2 + R_1{}' = R_2 + K^2\,R_1 = 0.009 + (0.05)^2 \text{ x } 3.45 = 0.017625\,\Omega$

Resistance, $X_{02} = X_2 + X_1{}' = X_2 + K^2\,X_1 = 0.015 + (0.05)^2 \text{ x } 5.2 = 0.028\,\Omega$

Impedance, $Z_{02} = \sqrt{R_{02}{}^2 + X_{02}{}^2} = 0.033\,\Omega$

Total copper loss,
Using individual resistances,

$$W_{cu} = I_1{}^2 R_1 + I_2{}^2 R_2 = 11.364^2 \text{ x } 3.45 + 227.273^2 \text{ x } 0.009$$

$$W_{cu} = 910.412 \text{ watt}$$

Using equivalent resistance,

Using R_{01}, $W_{cu} = I_1{}^2 R_{01} = 11.364^2 \text{ x } 7.05$

$$W_{cu} = 910.44 \text{ watt}$$

Using R_{02}, $W_{cu} = I_2{}^2 R_{02} = 227.273^2 \text{ x } 0.017625$

$$W_{cu} = 910.38 \text{ watt}$$

(5) The following results were obtained on a 40 KVA, 2400/120 V transformer.
O.C.Test: 120V, 9.65A and 396W (on L.V. side)
S.C.Test: 92V, 20.8A and 810W (on H.V. side)
Calculate the parameter of approximate equivalent circuit referred to H.V. side. **[D-13][6],[May 09][**

Solution:-

Given: 40 kVA, 2400/120 V transformer
S.C. test is carried out on H.V. side i.e. primary side in given problem

$\therefore\ W_{SC_1} = 810\,W$, $\quad I_1 = 20.8\,A \quad V_{SC} = 92\,V$

$$\therefore\ W_{SC_1} = I_1^2\,R_{01} \Rightarrow R_{01} = \frac{W_{SC_1}}{I_1^2} = \frac{810}{(20.8)^2} = 1.8722\,\Omega$$

$$\therefore\ Z_{01} = \frac{V_{SC_1}}{I_1} = \frac{92}{20.8} = 4.42\,\Omega$$

$$\therefore\ X_{01} = \sqrt{Z_{01}{}^2 - R_{01}{}^2} = 4\,\Omega$$

(6) A 5kVA, 1000/200 V, 50 Hz, single phase transformer gives following test results:

OC test (LV side)	200V	1.2A	90W
SC test (HV side)	50V	5A	110 W

Determine efficiency as half load at 0.8 p.f. lagging. **[M-13][6]**

Solution:-

Given: KVA Rating = 5 KVA, E_1 = 1000V, E_2 = 200V, f =50Hz

From OC test (LV side i.e. secondary side)

W_i =90W = 0.09 KW

From SC test (HV side i.e. primary side)

W_{SC} =110W = 0.11KW

$$\text{Full load current} = \frac{\text{KVA rating x1000}}{E_1} \Rightarrow I_1 = \frac{5\text{x}1000}{1000} = 5\text{Amp}$$

$$W_{cu} = W_{SC} = 0.11\text{kW}$$

Efficincy at half load & 0.8 pf lagging

$\therefore X = 0.5$ and $pf = 0.8$

$$\%\eta = \frac{\text{X x full load KVA x pf}}{\text{X x full load KVA x pf x } W_i + X^2\, W_{Cu}}\text{x}100$$

$$= \frac{0.5\text{x}5\text{x}0.8}{0.5\text{x}5\text{x}0.8 + 0.09 + (0.5)^2\text{x}0.11} = 94.45$$

(7) A 230/110V, single phase transformer takes an input of 350 VA at no load and at rated voltage. The core loss is 110 W. Find (i) The iron loss component of no load current (ii) magnetizing component of no load current and (iii) No load power factor. **[D-12][6]**

Solution:-

V_1 = 230V, V_2 = 110V, KVA rating = 350 VA

(I) W_i =110W

$$W_i = V_1 I_0 \cos\phi_0 \Rightarrow 110 = 230\, I_0 \cos\phi_0$$

$$\therefore \text{Iorn loss component, } I_w = I_0 \cos\phi_0 = \frac{110}{230} = 0.478\text{A}$$

(II) N.L.Input =350 VA = $V_1 I_0$ = 230 I_0

I_0 =1.521A

(III) Now $I_w = I_o \cos\phi_o \Rightarrow 0.478 = 1.521\text{x}\cos\phi_o$

$$\therefore \text{N.L.P.F.} = \cos\phi_0 = \frac{0.478}{1.521} = 0.3142 \text{ lagging}$$

(IV) Magnetizing component

$$I_\mu = I_o \sin\phi_o = I_o[\sqrt{1-\cos\phi_o I}] = 1.521[\sqrt{1-(0.3142)^2}] = 1.488\text{ A}$$

(8) A 5 KVA, 400/200 V, 50 Hz, single phase transformer gave the following results during open and short circuit tests.

O.C. Test : 400V 1A 60 W .... (H. V. Side)

S.C. Test : 15V 12.5A 50 W .... (H. V. Side)

Calculate:

(i) No. load parameters R_0 and X_0.

(ii) Equivalent resistance and reactance referred to high voltage side

(iii) Regulation at full load and 0.8 pf lagging.

(iv) Iron and copper losses at full load.

(v) Efficiency at half load and 0.8 pf lagging. **[M-12][10]**

Solution:

Given: kVA = 5, V_1 = 400 V, V_2 = 200 V, K = 0.5, f = 50 Hz, V_1 = 400 V, I_0 = 1A, W_0 = 60W, V_{SC} = 15V, I_{SC} = 12.5 A, W_{SC} = 50W.

It is seen that $I_{SC} = I_1$ rated = 12.5 Amp.

(i) No load parameters R_0 and X_0:

From to OC test results,

$$\cos\phi_0 = \frac{W_0}{V_1 I_0} = \frac{60}{400\times 1} = 0.15 \Rightarrow \phi_0 = 81.37^\circ$$

$$\therefore \sin\phi_0 = 0.9886$$

$$\therefore R_0 = \frac{V_1}{I_0\cos\phi_0} = \frac{400}{1\times 0.15} = 2.667\,k\Omega$$

$$\therefore X_0 = \frac{V_1}{I_0\sin\phi_0} = \frac{400}{1\times 0.9886} = 404.61\Omega$$

(ii) Equivalent resistance and reactance referred to H.V. side:

From the SC test,

$$R_{1T} = \frac{W_{SC}}{I_{SC}^2} = \frac{50}{(12.5)^2} = 0.32\Omega$$

$$Z_{1T} = \frac{V_{SC}}{I_{SC}} = \frac{15}{12.5} = 1.2\Omega$$

$$\therefore X_{1T} = \left(Z_{1T}^2 - R_{1T}^2\right)^{1/2} = [(1.2)^2 - (0.32)^2]^{1/2} = 1.16\ \Omega$$

(iii) Regulation at full load and 0.8 PF lagging:

$\cos\phi = 0.8$, $\therefore \sin\phi = 0.6$

$$\%\text{ Regulation} = \frac{[I_1 R_{1T}\cos\phi + I_1 X_{1T}\sin\phi]}{V_1}\times 100 = \frac{[(12.5\times 0.32\times 0.8)+(12.5\times 1.16\times 0.6)]}{400}\times 100$$

$$\therefore \%\text{ Regulation} = 2.975\%$$

(iv) Iron and copper losses at full load:

Iron losses $P_i = W_0$ = 60W

$$\text{Full load current } I_{1(FL)} = \frac{5\times 10^3}{400} = 12.5\text{ Amp.}$$

Since $I_{1(FL)} = I_{SC}$, the value of W_{SC} represents the full load copper loss

$\therefore\ P_{cu(FL)} = W_{SC} = 50W$

(v) Efficiency at half load and cos ϕ = 0.8:

$$\%\eta_{HL} = \frac{0.5 \times kVA \times 10^3 \times \cos\phi}{(0.55 \times kVA \times 10^3 \times \cos\phi) + P_1 + P_{cu(HL)}} \times 100$$

But $$P_{cu(HL)} = \frac{1}{4} \times P_{cu(HL)} = \frac{1}{4} \times 50 = 12.5W$$

$$\%\eta_{HL} = \frac{0.5 \times 5000 \times 0.8}{(0.5 \times 5000 \times 0.8) + 60 + 12.5} \times 100 = 96.5\%$$

(9) In a 50 KVA, 1100/220 V transformer, the iron and copper losses at full load are 350 W and 425 W respectively. Calculate the efficiency at

(i) Full load with unity power factor

(ii) Half load with unity power factor

(iii) Full load with 0.8 pf lagging.

Also determine the maximum efficiency and the load at which maximum efficiency occurs assuming the load to be resistive. **[M-12][10]**

Solution:

Given: kVA = 50, V_1 = 1100 V, V_2 = 220V, P_i = 350 W $P_{cu(FL)}$ = 425 W

(i) Efficiency at full load and cos ϕ = 1 :

$$\%\ \eta_{FL} = \frac{kVA \times 10^3 \times \cos\phi}{(kVA \times 10^3 \times \cos\phi) + P_i + P_{cu(FL)}} \times 100 \quad = \frac{50 \times 10^3 \times 1}{(50 \times 10^3 \times 1) + 350 + 425} \times 100$$

$$\therefore\ \eta_{FL} = 98.47\%$$

(ii) Efficiency at half load and cos ϕ = 1 :

$$P_{cu(HL)} = \frac{1}{4} \times P_{cu(FL)} = \frac{1}{4} \times 425 = 106.25\,W$$

$$\%\ \eta_{HL} = \frac{0.5 \times KVA \times 10^3 \times \cos\phi}{(0.5 \times kVA \times 10^3 \times \cos\phi) + P_i + P_{cu(HL)}} \times 100 \quad = \frac{0.5 \times 50 \times 10^3 \times 1}{(0.5 \times 50 \times 10^3 \times 1) + 350 + 106.25} \times 100$$

$$\therefore\ \eta_{HL} = 98.21\%$$

(iii) Efficiency at half load and cos ϕ = 0.8 :

$$\%\ \eta_{HL} = \frac{0.5 \times 50 \times 10^3 \times 0.8}{(0.5 \times 50 \times 10^3 \times 0.8) + 350 + 106.25} \times 100$$

$$\therefore\ \eta_{HL} = 97.77\,\%$$

(10) A 100 kVA, 1000/10,000V, 50Hz 1-phase transformer has iron losses of 1100 watts the copper loss with 5A in high voltage winding is 400 watts. Calculate the efficiency at 25% of full load at: (i) UPF (ii) 0.8 lagging pf, the output being maintained at 10,000 V **[M-11][10]**

Solution:

Given: A transformer 100 kVA 100/10,000 Volts, Iron loss P_i = 1100 Watts

Copper loss P_{cu} with 5 A at 1000 Volts = 400 Watts

To find: Efficiency at 25% load at (a) unity p.f. (b) 0.8 p.f. lagging

Step 1: Find current at 25% load:

Output at 25% load = 25 kVA

corresponding current $= \dfrac{25 \times 1000}{10000} = 2.5\,A$

Step 2: Find current loss and total loss at 2.5 Amp:

$\therefore$ Current loss = $400 \times \left(\dfrac{2.5}{5}\right)^2 = 100$ Watt

$\therefore$ Total loss = 1100 + 100 = 1200 Watt = 1.2 kW

Step 3: Find output at 25% load unity pf and efficiency:

Output at 25% load unity pf = 25 × 1 = 25 kW

$$\therefore \eta \text{ at 25\% load unity pf} = \frac{\text{output}}{\text{output} \times \text{Losses}} \times 100 = \frac{25}{25+1.2} = \frac{25}{26.2} \times 100$$

$\therefore$ η at 25% load unity pf = 95.42%

Step 4: Find output at 25% load 0.8 p.f. lagging and efficiency:

Output = 25 × 0.8 = 20 kW

$$\therefore \eta \text{ at 25\% load unity pf} = \frac{\text{output}}{\text{output} \times \text{Losses}} \times 100 = \frac{20}{20+1.2} \times 100 = \frac{20}{21.2} \times 100$$

$\therefore$ η at 25% load unity pf = 94.34%

(11) Obtain the equivalent circuit of a 200/400 volts 50 Hz single phase transformer from the following tests.

O.C. test :	200V	0.7A	70 W	on L. V. side
S.C. test :	15V	10A	85 W	on H. V. side

Calculate the secondary voltage when delivering 5 kw, 0.8 p.f. lagging the primary voltage being 200V. **[Dec 09][10]**

Solution:-

Given : V_{oc} = 200V , I_0 = 0.7 A, W_0 70W, V_{sc} =15 V, I_{sc} = 10A, W_{sc} = 85 W, V_1/V_2 = 200/400

To Find : Equivalent circuit , Secondary voltage for P_2 = 5 kW, $\cos\phi_2 = 0.8$ and V_1 = 200 V.

Part I : Equivalent Circuit

Step 1 : Find $R_0, X_0, R_{2T}, X_{2T}, R_1, R_{1T}$

From the O.C test, $\cos\phi_0 = \dfrac{W_0}{V_{oc} I_0} = \dfrac{70}{200 \times 0.7} = 0.5$ $\therefore$ $\phi = 60^0$

$\therefore \sin\phi_0 = 0.866$

$$\therefore \; R_o = \frac{V_{oc}}{I_o \cos\phi_o} = \frac{200}{0.7 \times 0.5} = 571.43\Omega$$

$$\therefore \; X_o = \frac{V_{oc}}{I_o \sin\phi_o} = \frac{200}{0.7 \times 0.866} = 329.92\,\Omega$$

From the S.C test $W_{sc} = I^2_{sc} \times R_{2T}$

$$\therefore \; R_{2T} = \frac{W_{sc}}{I^2_{sc}} = \frac{85}{(10)^2} = 0.85\,\Omega \;\text{ and }\; Z_{2T} = \frac{V_{sc}}{I_{sc}} = \frac{15}{10} = 1.5\,\Omega$$

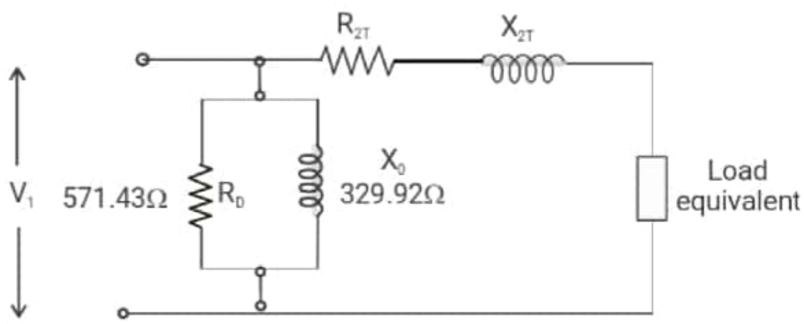
$$\therefore \; X_{2T} = \sqrt{Z^2_{2t} - R^2_{2T}} = \sqrt{(1.5)^2 - (0.85)^2} = 1.24\Omega$$

Transformation ratio $k = \frac{V_2}{V_1} = \frac{400}{200} = 2$

$$\therefore \; R_{1T} = \frac{R_{2T}}{k^2} = \frac{0.85}{4} = 0.2125\Omega \;\text{ and }\; \therefore \; X_{1T} = \frac{X_{2T}}{k^2} = \frac{1.24}{4} = 0.31\Omega$$

Step 2 : Draw the equivalent circuit :

The equivalent circuit with respect to the primary (low voltage) winding is as shown in fig



Part II : Secondary Voltage

Given : $V_1 =$ 200 V, Cos $\phi_2 = 0.8$, P_2 5kW

The secondary induced voltage $E_2 = kV_1 = 2 \times 200 = 400$ V

$P_2 = E_2 I_2 \cos\phi_2$

$$\therefore \; I_2 = \frac{5 \times 10^3}{400 \times 0.8} = 15.625 \text{ Amp}$$

$\therefore$ Load voltage $V_2 = E_2 - I_2[\,R_{2T}\cos\phi_2 + X_{2T}\sin\phi_2]$

$\cos\phi_2 = 0.8$, $\therefore \phi = 36.87^0$ $\therefore$ $\sin\phi = 0.6$

$\therefore$ $V_2 = 400 - 15.625[0.85 \times 0.8 + 1.24 \times 0.6]$

$\therefore$ $V_2 = 399$ volts

(12) A 20 KVA, 2000/200 V, transformer has primary resistance and reactance of 2.3 Ω and 4.2 Ω respectively. Corresponding secondary values are 0.025 Ω and 0.04 Ω. Open circuit loss is 200 watts. Determine-

(i) Equivalent resistance and reactance referred to primary and secondary

(ii) Full load regulation and efficiency at 0.8 power factor lagging. **[M-08][8]**

Solution :

Given:- kVL = 20, V_1 = 2000V, W_O = 200W, R_1 = 2.3 Ω, R_2 = 0.025 Ω, X = 0.04 Ω

To find:- R_{1T}, X_{1T}, R_{2T}, X_{2T}, η_{FL}, % R

Equivalent resistances and reactance:

$$K = \frac{V_2}{V_1} = 200/2000 = 0.1$$

R_{1T} and X_{1T} (primary) :

$$R_{1T} = R_1 + \frac{R_2}{K^2} = 2.3 + \frac{(0.025)}{(0.1)^2} = 4.8\Omega \text{ and } X_{1T} = X_1 + \frac{X_2}{K^2} = 4.2 + \frac{(0.04)}{(0.1)^2} = 8.2\Omega$$

R_{2T} and X_{2T} (secondary) :

$$R_{2T} = R_2 + K^2R_1 = 0.025 + (0.1)^2 \text{ x } 2.3 = 0.048\Omega$$

$$X_{2T} = X_2 + K^2X_1 = 0.04 + (0.1)^2 \text{ x } 24.2 = 0.082\,\Omega$$

Full load efficiency :

$$\text{Full load secondary current } I_{2(FL)} = \frac{V_A}{V_2} = \frac{20\times10^3}{200} = 100\text{ A}$$

$$\therefore \text{ Full load copper loss } P_{cu(FL)} = I^2_{2(FL)} \text{ x} R_{2T} = 100^2 \text{ x } 0.048 = 480 \text{ W}$$

$\therefore$ Iron loss = 200 W

$$\eta_{FL} = \frac{kVA\times1000\times\cos\phi}{kVA\times1000\times\cos\phi + P_i + P_{cu(FL)}} = \frac{20\times1000\times0.8}{(20\times1000\times0.8)+200+480}$$

$$\therefore \eta_{FL} = 0.9592 \text{ or } 95.92\%$$

Regulation :

$V_{2(FL)}$ = 200V

$$E_2 = V_2 + I_{2FL}\,[R_{2T}\cos\phi + X_{2T}\sin\phi]$$

But $\cos\phi = 0.8$ $\quad\sin\phi = 0.6$

$$\therefore E_2 = 200 + 100\,[(0.048 \text{ x } 0.8) + (0.082 \text{ x } 0.6)] = 208.76 \text{ V}$$

$$\text{Percentage Regulation} = \frac{E_2 - E_1}{E_2}\text{x}100 = \frac{208.76 - 200}{208.76}\text{x}100$$

$$= 4.196\%$$

(13) Calculate the (a) Full load efficiency at 0.8 p.f. (lag) (b) Terminal voltage when supplying full load at 0.8 p.f. (lag) for an input voltage of 500V. The result of O.C. and S.C. test on 5 KVA, 500/250 V, 50 Hz, 1-ϕ transformer are as follows: **[D-07][8]**

O.C. :	500V	1A	50W
S.C. :	15V	6A	21.6W

Solution :

Given : V_{SC} = 15V, I_{SC} = 6A, W_{SC} = 21.6W, V_O = 500 V, I_O = 1A, W_O = 50 W

Form S.C test find R_{2T}, X_{2T}, and Z_{2T}:

$$Z_{2T} = \frac{V_{SC}}{I_{SC}} = 15/6 = 2.5\,\Omega \qquad \left(\text{But } W_{SC} = I_{SC}^2 \text{ x } R_{2T}\right)$$

$$\therefore R_{2T} = \frac{W_{SC}}{I_{SC}^2} = \frac{21.6}{6^2} = 0.6\,\Omega$$

$$\therefore X_{2T} = \sqrt{Z_{2T}^2 - R_{2T}^2} = \sqrt{(2.5)^2 - (0.6)^2} = 2.43\Omega$$

Calculate full load copper and iron loss :

$$I_{2(FL)} = VA/V_2 = (5 \text{ x } 1000)/250 = 20A$$

$$P_{cu} = W_{SC} \text{ at } 6\text{ A} = 21.6\text{ W at } 6\text{ A}$$

$$\therefore P_{cu} \text{ at } 6\text{ A} = \left(\frac{6}{20}\right)^2 \text{ x } P_{cu}$$

$$P_{cu(FL)} = \left(\frac{20}{6}\right)^2 \text{ x } P_{cu} \text{ at } 6\text{ A} = \left(\frac{6}{20}\right)^2 \text{ x } 21.6$$

$$\therefore P_{cu(FL)} = 240\text{ W}$$

Iorn loss $P_i = W_O = 50$ W ....from O.C test

Calculate η at F.L :

$$\eta_{FL} = \frac{kVA \times 1000 \times P.f}{(kVA \times 1000 \times P.f) + \left[P_i + P_{cu(FL)}\right]} = \frac{5 \times 1000 \times 0.8}{(5 \times 1000 \times 0.8) + [50 + 240]}$$

$$= 0.9324 \text{ or } (93.24\%)$$

Terminal voltage :

$$\cos\phi = 0.8 \Rightarrow \phi = 36.87^\circ \Rightarrow \sin\phi = 0.6$$

$$\therefore \text{Terminal voltage} = E_2 - I_{2FL}\left[R_{2T}\cos\phi + X_{2T}\sin\phi\right]$$

$$= 250 - 20\left[(0.6 \text{ x } 0.8) + (2.43 \text{ x } 0.6)\right] = 211.24\text{ V}$$

(14) A transformer has its maximum efficiency of 98% at 15 kVA at UPF. During the day it is loaded as follows:

	12 hrs :	2 kW at 0.5 p.f.
	6 hrs :	12 kW at 0.8 p.f.
	6 hrs :	18 kW at 0.9 p.f.

Find the all-day efficiency. **[D-07][8]**

Solution:-

Step 1: To find the Iorn and full load copper loss :

$$\eta_{max} = \frac{kVA\,x10^3\,x\,PF}{(kVA\,x10^3\,x\,PF) + P_i + P_{cu}}$$

$$\text{But } P_i = P_{cu}\ (\text{for } \eta_{max}) \Rightarrow P_i + P_{cu} = 2P_i$$

$$\therefore 0.98 = \frac{15\,x10^3 x1}{(15\,x10^3 x1) + 2P_i} \Rightarrow P_i = 153W$$

Assuming kVA full load $= \frac{18}{0.9} = 20kVA$ from the given data

$$\therefore \text{kVA for maximum efficiency = Full load kVA} \sqrt{\frac{\text{Iron loss}}{\text{Full load copper loss}}}$$

$$\therefore 15kVA = 20kVA\sqrt{\frac{0.153kW}{P_{cu(FL)}}}$$

$$\therefore P_{cu(FL)} = 0.272kW \text{ or } 272W$$

Step 2 : To calculate total loss :

$$P_{cu} \text{ at full load } (20kVA) = 272W$$

$$P_{cu} \text{ at } 15\,kVA = 153W$$

$$P_{cu} \text{ at } 4kVA = \left(\frac{4}{20}\right)^2 x\,272 = 10.88W$$

$$\therefore \text{Total Cu loss} = (272W\,x\,6h) + (153W\,x6h) + (10.88W\,x\,12h) = 2680.56\,Wh$$

$$\text{Total iron loss} = 153W\,x\,24h = 3672Wh$$

$$\therefore \text{Total loss} = 2680.56 + 3672 = 6352.56Wh$$

Step 3 : To calcuate energy output :

$$\text{Output} = (2kW\,x12h) + (12kW\,x6h) + (18kW\,x\,6h) = 204\,kWh$$

Step 4 : All day effciency :

$$\eta_{allday} = \frac{\text{Output}}{\text{Output + loss}} = \frac{204\,x10^3}{(204\,x10^3 + 6352.56)} = 0.9698 \text{ or } 96.98\%$$