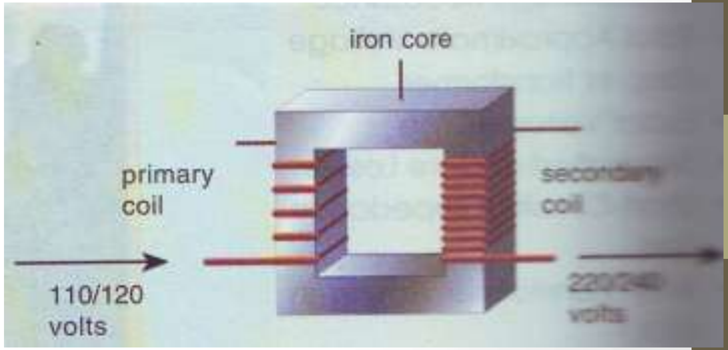
UNIT- III

LECT -40

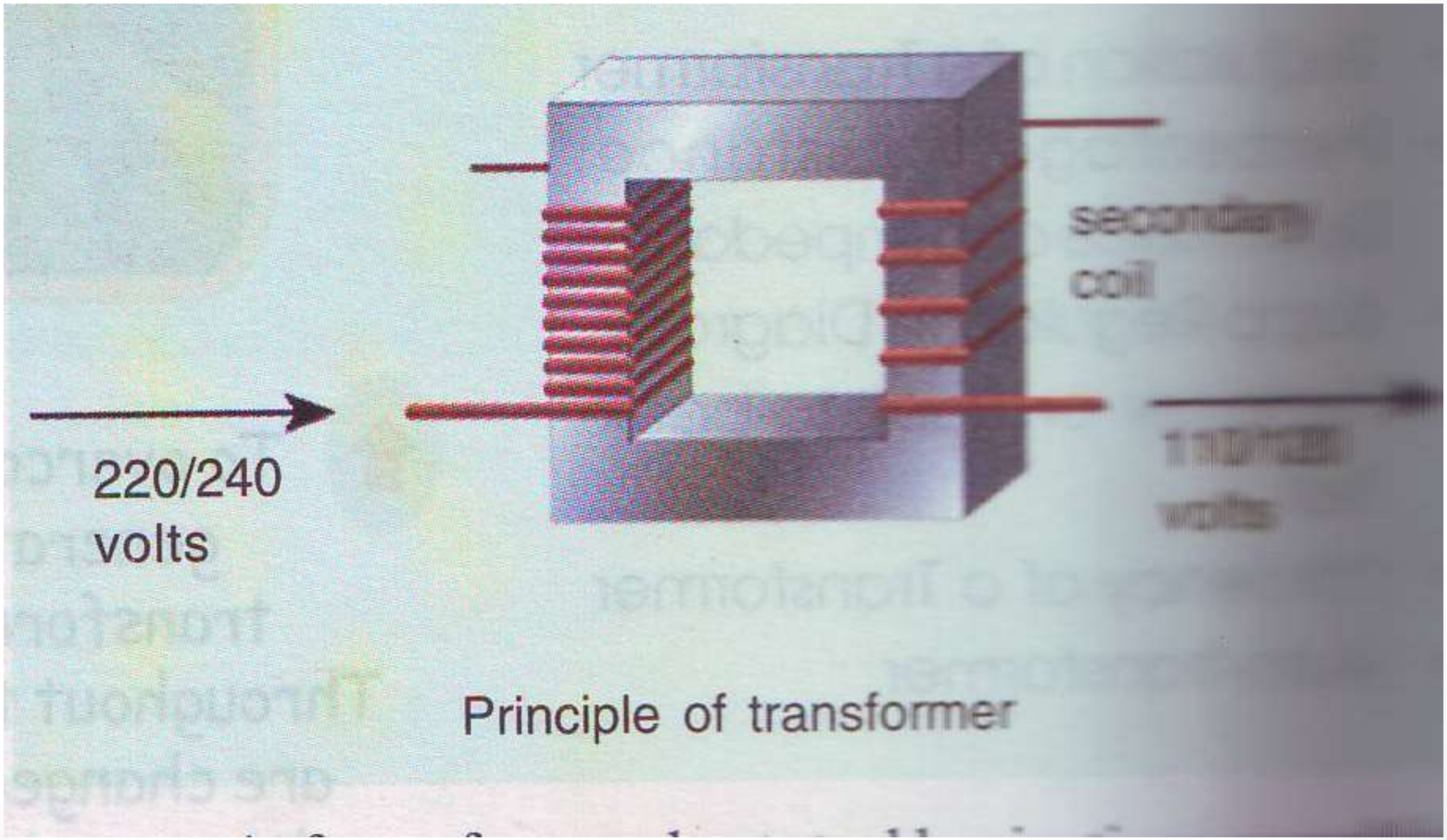
CONSTRUCTION & WORKING OF TRANSFORMER

TRANSFORMERS

- **1.WORKING PRINCIPLE OF A TRANSFORMER-**
- **The transformer is a static device, or a machine, that transfers electrical energy from one electrical circuit to another electrical circuit through the medium of magnetic field without a change of frequency.**
- **The electric circuit which receives energy from the supply mains is called primary winding and other circuit which delivers electric energy to the load is called secondary winding.**



TRANSFORMERS



Principle of transformer

TRANSFORMERS

- **The transformer is an electromagnetic energy conversion device, since the energy received by the primary is first converted to magnetic energy and it is then reconverted to useful electrical energy in the other circuit. Thus primary and secondary windings of a transformer are not connected electrically, but are coupled magnetically. This coupling magnetic field allows the transfer of energy in either direction, from high voltage to low voltage circuits or low voltage to high voltage circuits.**

TRANSFORMERS

- **If secondary winding has more turns than primary winding, then secondary voltage is higher than the primary voltage and transformer is called step-up transformer. In case secondary winding has less turns than primary winding, then secondary voltage is lower than the primary voltage and transformer is called step-down transformer. Therefore, when referring to the winding of a particular transformer, the term HV winding and LV winding should be used instead of primary and secondary windings.**
- **The physical basic of transformer is mutual induction between two circuits linked by a common magnetic flux.**

TRANSFORMERS

- If one winding connected to source of alternating voltage, an alternating flux is set up in the laminated core, most of which is linked with the other winding in which it produces mutually-induced e.m.f. according to Faraday's Law Of Electromagnetic Induction

  ($e= M\, dI/dt$). If second winding circuit is close, a current flows in it and so electrical energy is transferred from one winding to another winding.
- In general, important tasks performed by transformers are :
- Transfers electric power from one circuit to another.
- It dose so without a change of frequency.
- It accomplishes this by electromagnetic induction.
- Where the two electric circuits are in mutual inductive influence of each other.

TRANSFORMERS

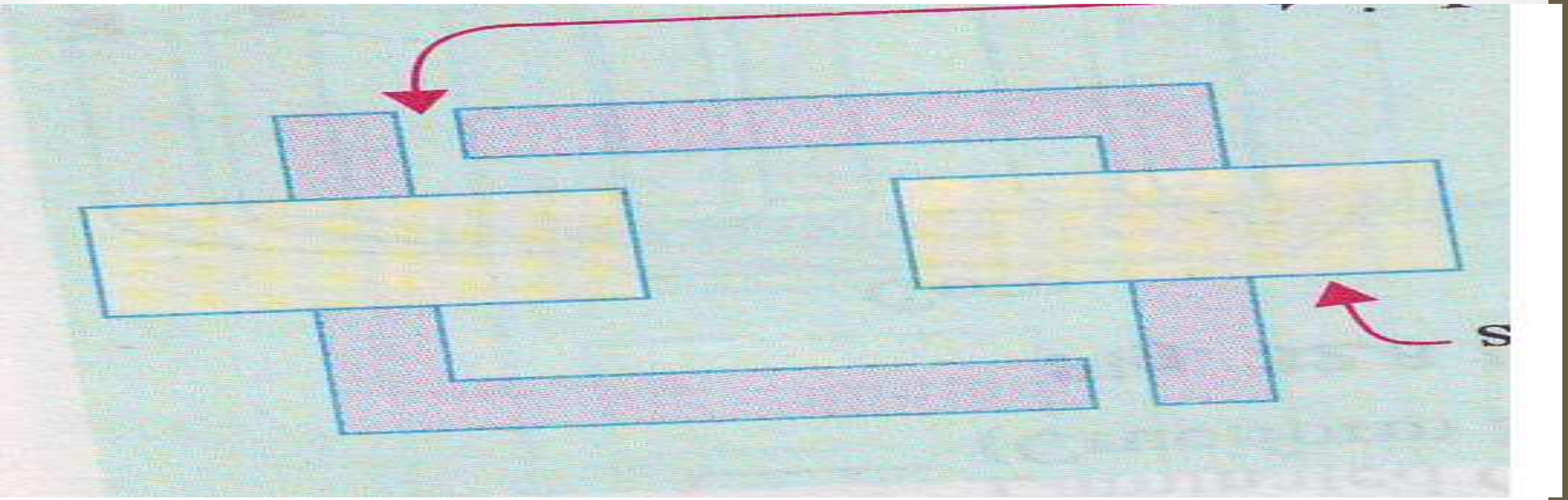
- **2.TARNSFORMER CONSTRUCTION**

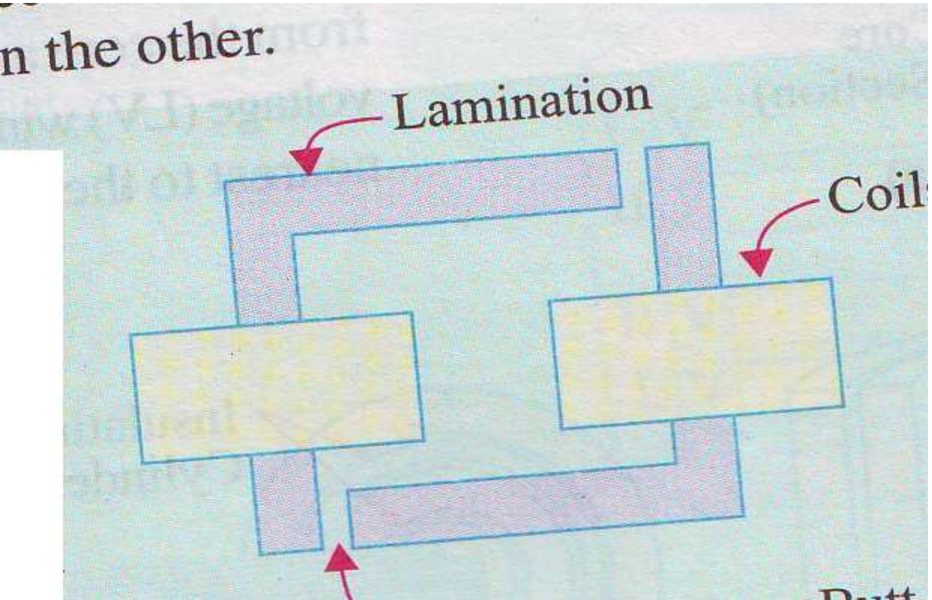
- **The simple elements of a transformer consist of two windings having mutual inductance and a laminated steel core. The two winding are insulated from each other and the steel core. Other necessary parts are some suitable container for the assembled core and windings ; a suitable medium for insulating the core and its winding from the container ; suitable porcelain, oil filled or capacitor bushing for insulting and bringing out the terminals of windings from tank.**

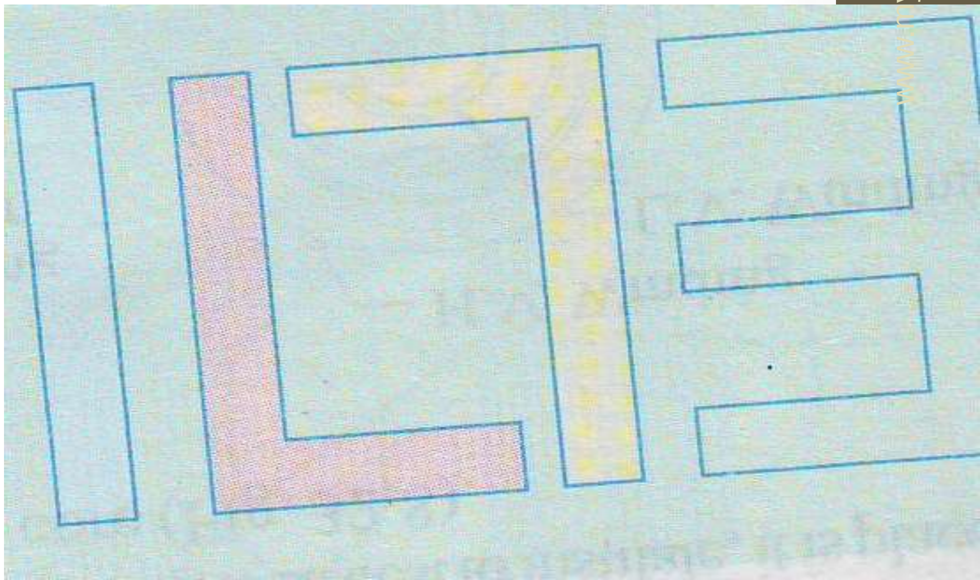
TRANSFORMERS

- **In all types of transformers, the core is a stack of thin silicon-steel laminations assembled to provide a continuous magnetic path with minimum of air-gap included. The steel used is of high silicon contain, sometimes heat treated to produce a high permeability and low hysteresis loss at the usual operating flux densities. The eddy current loss is minimized by laminating the core, the laminations being insulated from each other by a light coat of core-plate varnish.**
- **Constructionally, the transformers are of two general types core type and shell type. These two types differ from each other by the manner in which the windings wound around the core.**

TRANSFORMERS

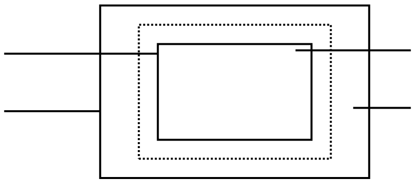




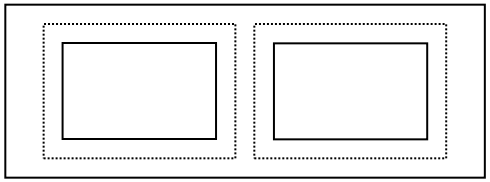


TRANSFORMERS

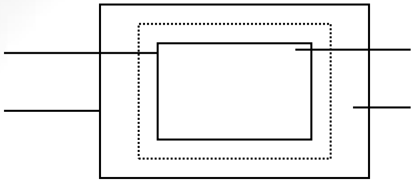
- 1.CORE TYPE :- In the core type transformer windings surrounded a considerable part of the core.
- 2.SHELL TYPE :- in shell type transformer core surrounded a considerable part of the windings

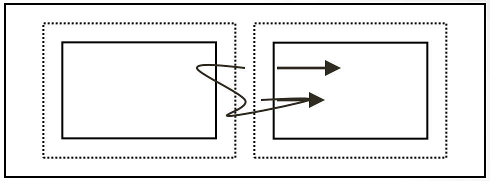


1.CORE TYPE



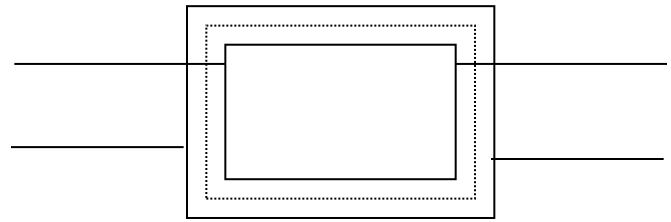
2.SHELL TYPE





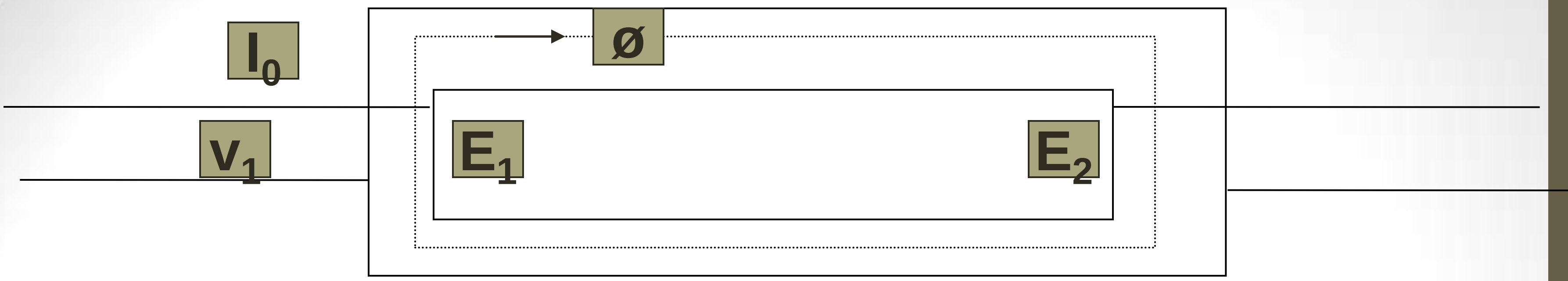
CORE TYPE	SHELL TYPE
Winding surround a considerable part of the core	**Core surround a considerable part of the winding**
Flux has one magnetic path	**Flux has two magnetic path**
Two legs core	**Three legs core**
Concentric winding are used	**Interleaved windings are used**

- **3.PRINCIPLE OF TRANSFORMER ACTION-**
- **A transformer workers on the principle of electromagnetic induction. According to this principle, an e.m.f. is induced in a coil if it links a changing flux.**



The primary winding P is connected to an alternating voltage source and secondary winding is open circuited, therefore, an alternating no-load current I_0 starts flowing through N_1 turns. The alternating mmf N_1I_0 sets up alternating flux ϕ which is confined to the high permeability iron path. The alternating flux, induces voltage E_1 known as self induced voltage in primary winding and E_2 in secondary winding known as mutual induced voltage.

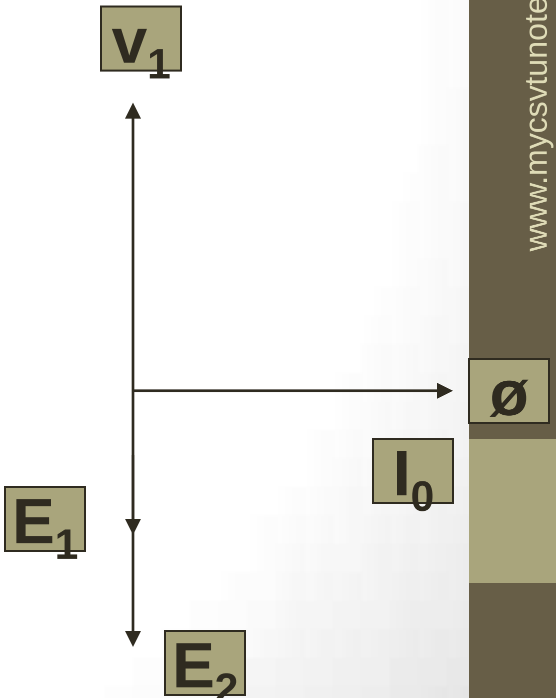
- **4.ELEMENTARY THEORY OF AN IDEAL TRANSFORMER -**
- **A transformer to be an ideal one, the various assumptions are as follows:**
- **Windings resistances are negligible.**
- **All the flux set up by the primary links the secondary windings.**
- **The core losses (hysteresis and eddy current losses) are negligible.**
- **The core has constant permeability.**
- **In other words, an ideal transformer consists of two purely inductive coils wound on a loss free core. It may, however, be noted that it is impossible to realize such a transformer in practice, yet for convenience, we will start with such a transformer and step by step approach an actual transformer**



- **Consider an ideal transformer shown in above Fig. whose secondary is open and whose primary is connected to sinusoidal alternating voltage V_1. This potential difference causes an alternating current to flow in the primary. Since the primary coil is purely inductive and there is no output (secondary being open) the primary draws the magnetising current Iμ only. The function of this current is merely to magnetise the core, it is small in magnitude and lags V_1 by 90 .This alternating current $I\mu$ produces an alternating flux ϕ which is , at all times. Proportional to the current (assuming permeability of the magnetic circuit to be constant) and . hence, is in phase with it.**

- This changing flux is linked both with the primary and the secondary windings. Therefore, it produces self-induced e.m.f. in the primary . This self-induced e.m.f. E_1 is, at every instant, equal to and on oppsition to V_1.It is also known as counter e.m.f. of the primary. Similarly, thereis produced. In the secondary an induced e.m.f. E_2 which is known as mutually induced e.m.f. This antiphase with V_1 and its magnitude is proportional to the rate of change of flux and the number of secondary turns.

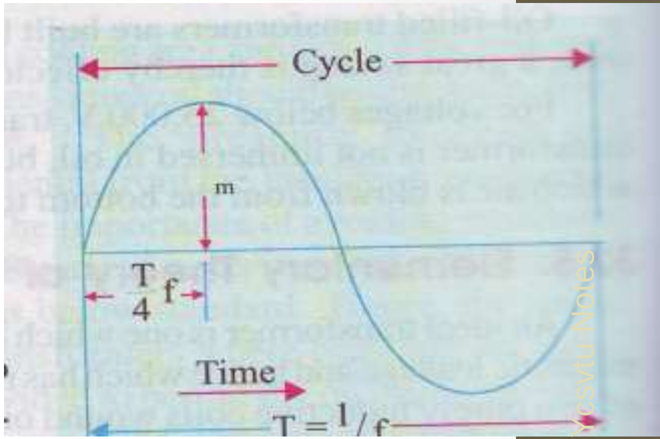
\The instantaneous values of applied voltage, induced e.m.f.s, flux and magnetising current are shown by sinusoidal waves in Fig. show the vectorial representation of the effective values of the above quantities.



LECT -41

EMF EQUATION
OF
TRANSFORMER

E.M.F. EQUATION OF A TRANSFORMER-



- Let N_1=No. Of turns in primary
- N_2=No. Of turns in secondary
- ϕ_m = max. flux in core in wb
- = B_m*A
- f = frequency of a.c. input in Hz
- As shown in Fig flux increases from its zero value to maximum value ϕ_m in one quarter of the i. e. in 1/4f second
- Average rate of change of flux = $\phi_m/(1/4f)$
- = $4f\phi_m$ Wb/s or volt
- Now rate of change of flux per turn means induced e.m.f.

- $\therefore$ average e.m.f./turn $=4f\phi_m$ Wb /s or volt
- If flux ϕ varies sinusoidally, then r.m.s. Value of induced e.m.f. is obtained by multiplying the average value with form factor.
- Form factor =r.m.s. value/average value=1.11
- $\therefore$ r.m.s. Value of e.m.f. /turn $=1.11*4f\phi_m$
- $=4.44f\phi_m$ volt
- Now, r.m.s.value of the induced e.m.f. in the whole of primary winding
- =(induced e.m.f./turn)*No. of primary turns
- $E_1 = 4.44f\, N_1\, \phi_m = 4.44f\, N_1 B_m\, A$ ....(i)
- Similarly, r.m. s. Value of the e.m.f. Induced in secondary is,
- $E_2 = 4.44f\, N_2\, \phi_m = 4.44f\, N_2 B_m\, A$ ......(ii)

- It is seen from (i) and (ii) that $E_1/N_1=E_2/N_2=4.44f\,\phi_m$.
- It means that e.m.f. /turn is the same in both the primary and secondary windings.
- In an ideal transformer of no-load,
- $E_1 = V_1$ and $E_2 = V_2$
- Or $V_2/V_1 = E_2/E_1$ ...(iii)

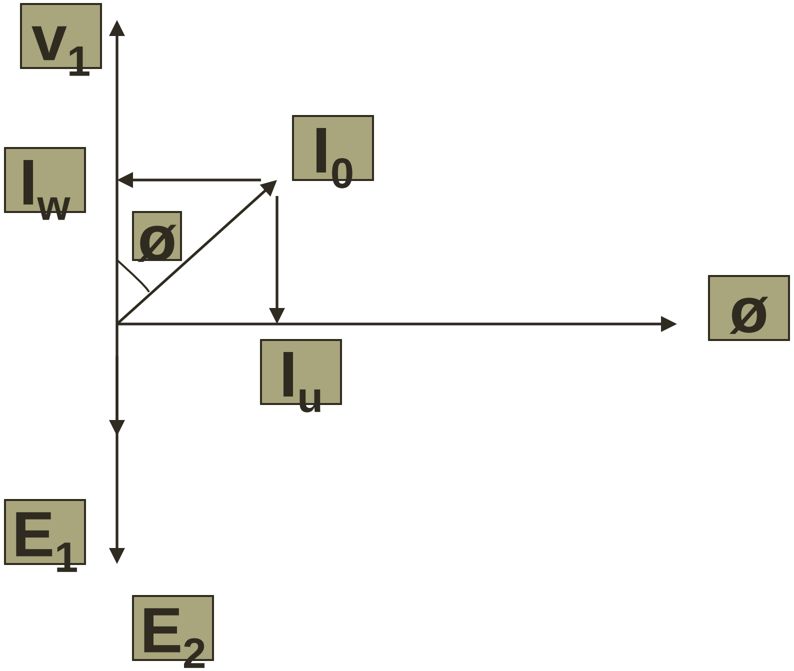
- **6.VOLTAGE TRANSFORMATION RATIO (K)-**
- From equations (i) and (ii), we get
- $E_2/E_1=N_2/N_1$.......(iii)
- In transformer input power = output power
- Then $V_1I_1 = V_2I_2$
- Or $V_2 / V_1 = I_1 / I_2$ ....(iv)
- From eq. (i) to (iv)
- $V_2 / V_1 = E_2/E_1=N_2/N_1 = I_1 / I_2 = K$
- This constant K is known as transformation ratio.
- (i) If $N_2 > N_1$ i.e. $K > 1$, transformation is known as step-up transformer
- (ii)If $N_2 < N_1$ i.e. $K<1$, then transformeris known as step-down transformer

LECT -42

PHASOR DIAGRAM
OF
TRANSFORMER

- **TRANSFORMER ON NO-LOAD**
- *An ideal transformer i.e. one in which there were no core losses and copper losses. But practical conditions an actual transformer is put on load, there is iron loss in the core and copper loss in the windings (both primary and secondary) and these losses ate not entirely negligible.*
- **Even when the transformer is on no-load, the primary input current is not wholly reactive. The primary input current under no-load conditions has to supply**
- **(i) iron losses in the core i.e. hysterias is loss and eddy current loss and**
- **(ii) a very small amount of copper loss in primary (there being no Cu loss in secondary as it is open). Hence, the no load primary input current I_0 is not at 90° behind V_1 but lags it by an angle**
- **$\phi_0 < 90°$.**

- **No-load input power**
- **$W_0 = V_1 I_0 \cos\phi_0$**
- **Where $\cos\phi_0$ is primary power factor under no-load conditions. No-load condition of an actual transformer is shown vectorially in fig.**



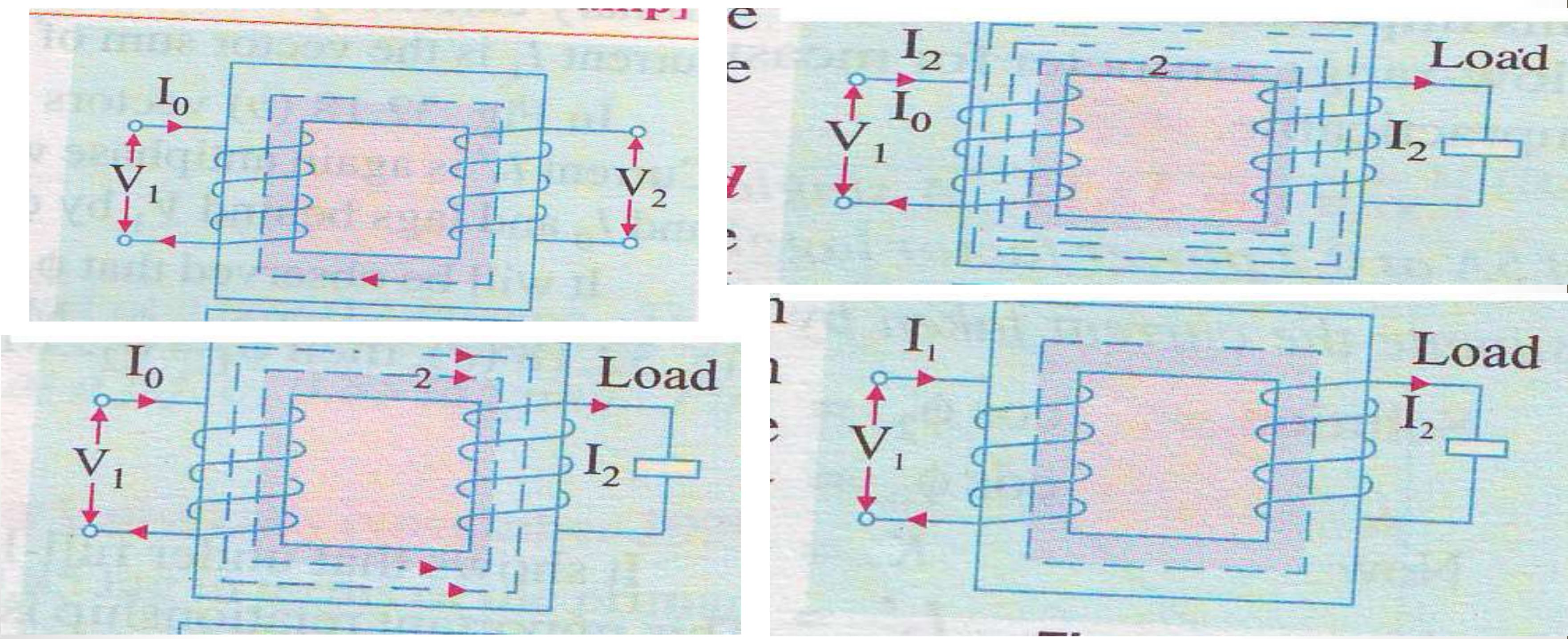
- As seen from fig, primary current I_0 has two components
- (i) One in phase with V_1. This is known as active or working or iron loss component I_w because it mainly supplies the iron loss plus small quantity of primary Cu loss.
- $$I_w = I_0 \cos\phi_0$$
- (ii) The other component is in quadrature with V_1 and is known as magnetising component I_μ because its function is to sustain the alternating flux in the core. It is wattless.
- $$I_\mu = I_0 \sin\phi_0$$
- Obviously, I_0 is the vector sum of I_w and I_μ ,hence $I_0 = \sqrt{(I_\mu^2 + I_w^2)}$.

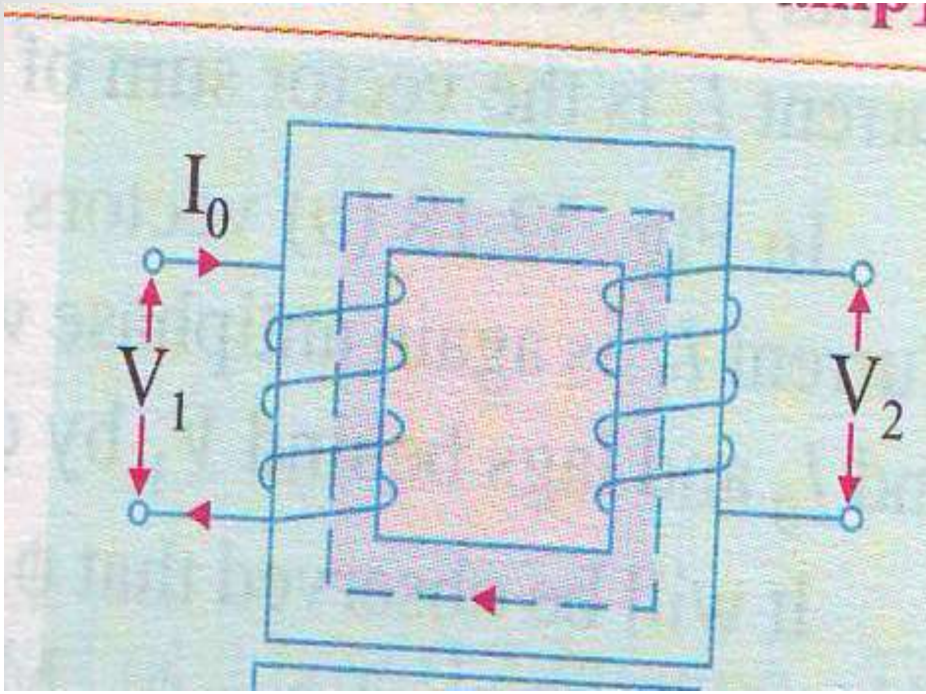
- The following points should be noted carefully:
- 1.The no-load primary current I_0 is very small as compared to the full-load primary current.
- It is about 1percent of the full-load current.
- Owing to the fact that the permeability of the core varies with the instantaneous value of the exciting current, the wave of the exciting or magnetising current is not truly sinusoidal.
- 2. As I_0 is very small, the no-load primary Cu loss is negligibly small which means that no-load primary input is practically equal to the iron loss in the transformer.
- As it is principally the core-loss which is responsible for shift in the current vector , angle ϕ_0 is known as hysteresis angle of advance.

8. TRANSFORMER ON LOAD-

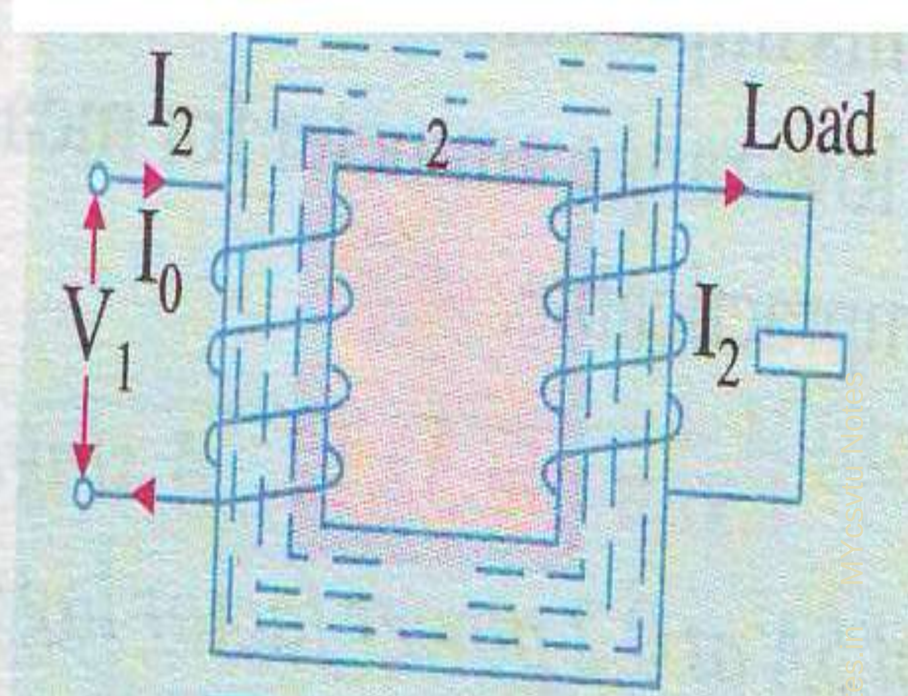
- When the secondary is loaded the secondary current I_2 is set up. The magnitude and phase of I_2 with respect to V_2 is determined by the characteristics of the load. Current I_2 is in phase with V_2 if load is non-inductive, it lags if load is inductive and it leads if load is capacitive.
- The secondary current sets up its own m.m.f. ($=N_2 I_2$) and hence its own flux ϕ_2 which is in opposition to the main primary flux ϕ which is due to I_0. The secondary ampere-turns N_2I_2 are known as demagnetizing amp-turns. The opposing secondary flux ϕ_2 weakens the primary flux ϕ momentarily, hence primary back e.m.f. E_1 tends to be reduced. For a moment V_1 agains the upper hand over E_1 and hence causes more current to flow in primary.

- **Let the additional primary current be I'_2. It is known as *load component of primary current*. This current is antiphase with I_2 .The additional primary m.m.f. $N_1 I'_2$ sets up its own flux ϕ'_2 which is in opposition to ϕ_2 (but is in the same direction as ϕ) and is equal to it in magnitude. Hence ,the two fluxes cancel each other out So, we find that the magnetic effects of secondary current I_2 are immediately neutralized by the additional primary current I'_2 which is brought into existence exactly at the same instant as I_2 . The whole process is illustrated in below fig.**

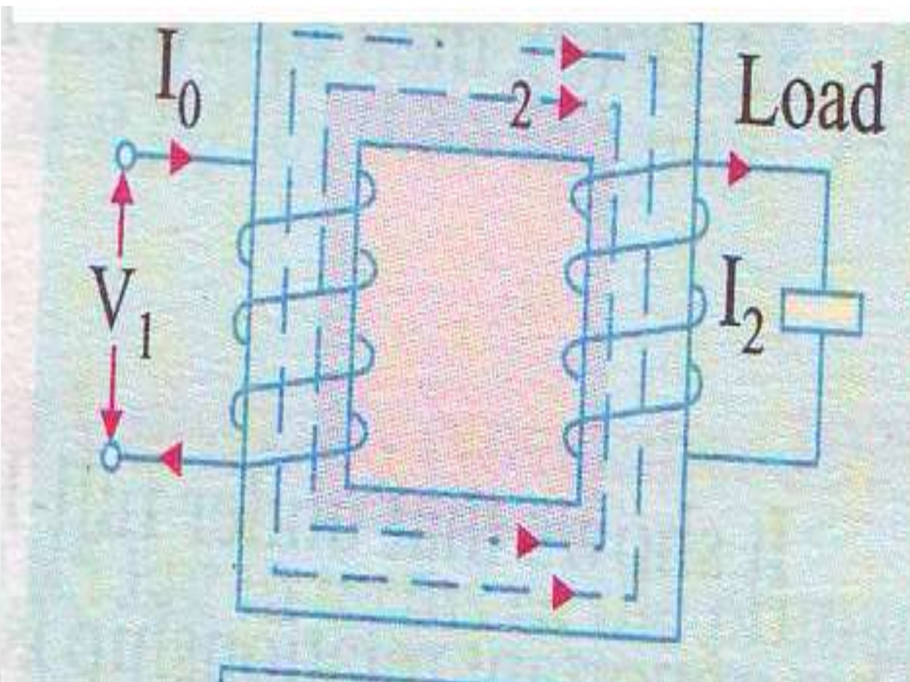




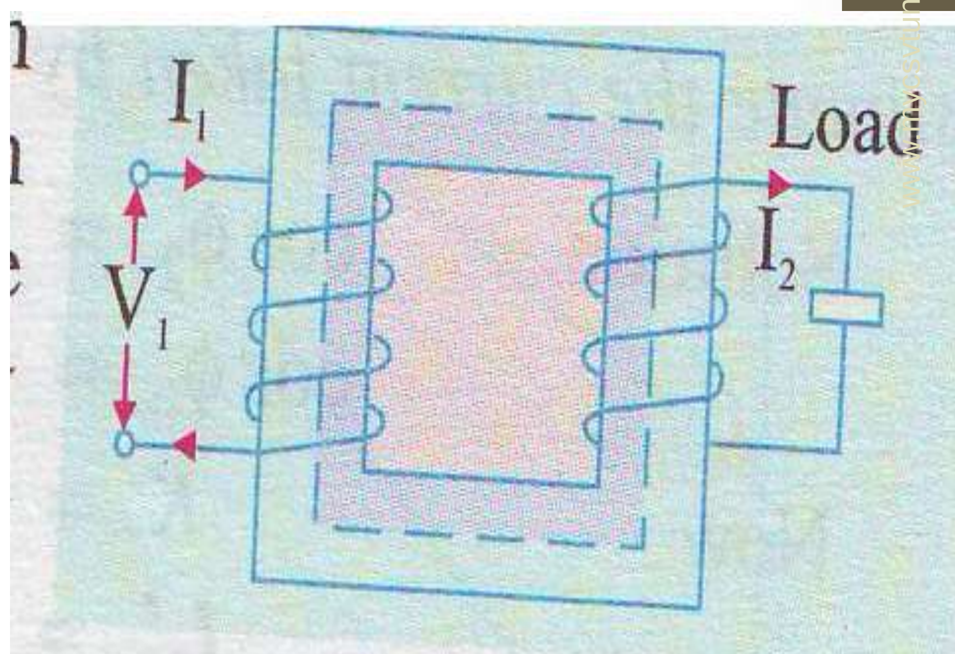
I0
V1
V2



I2
I0
V1
2
Load
I2

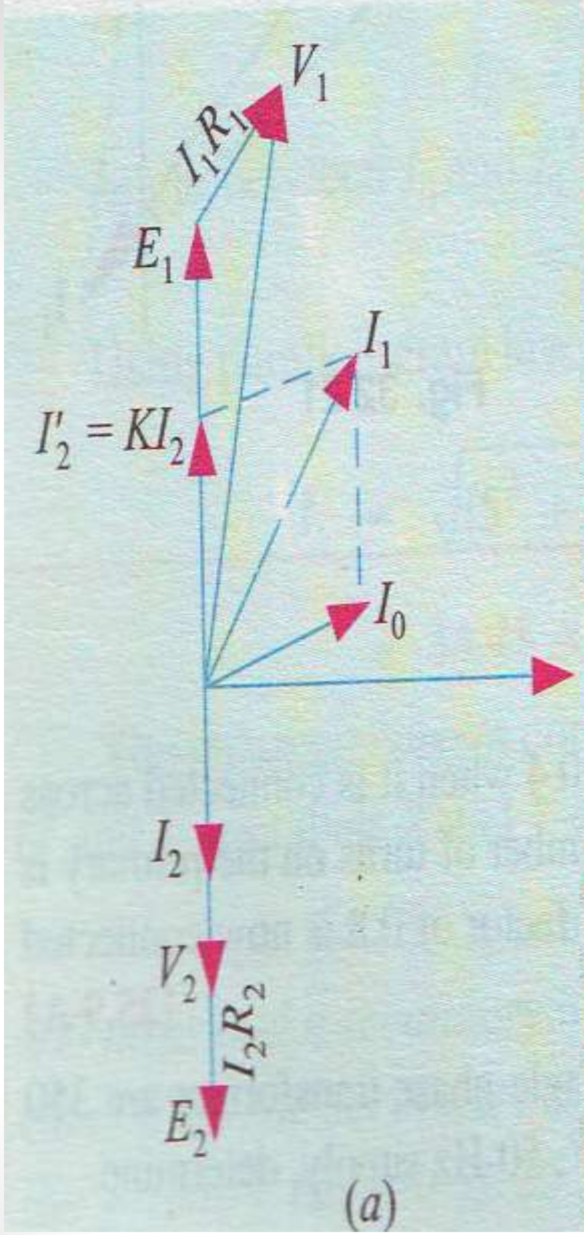


I0
V1
2
Load
I2

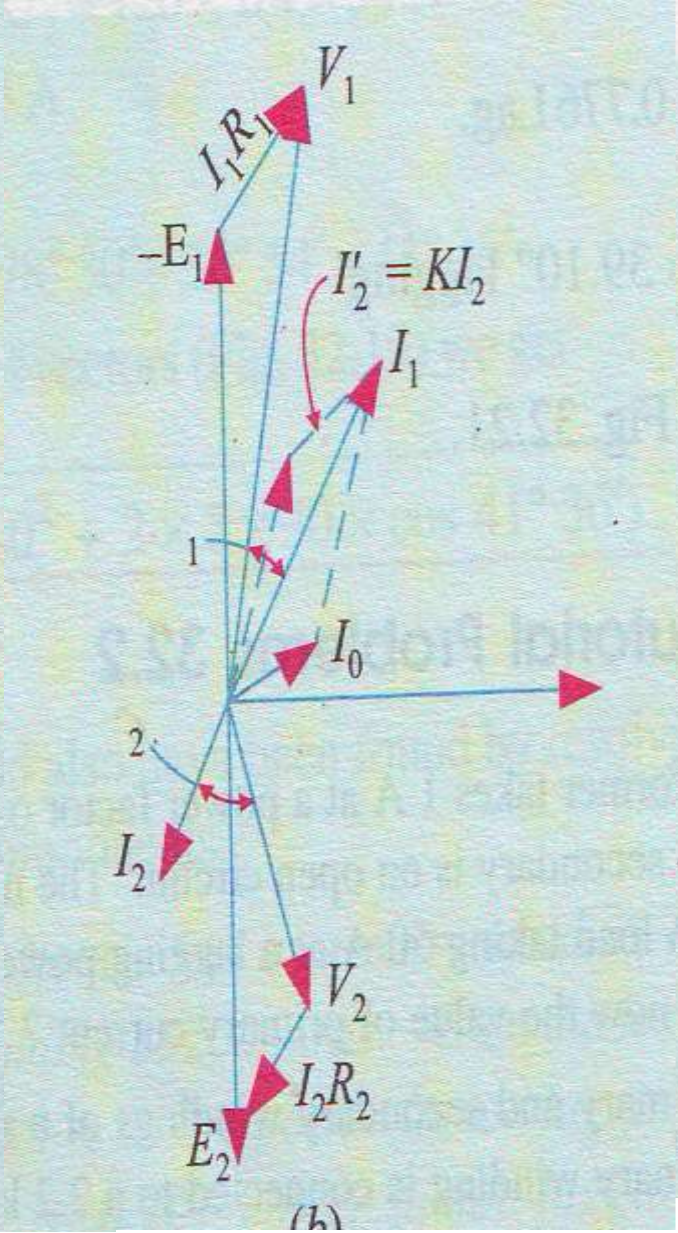


I1
V1
Load
I2

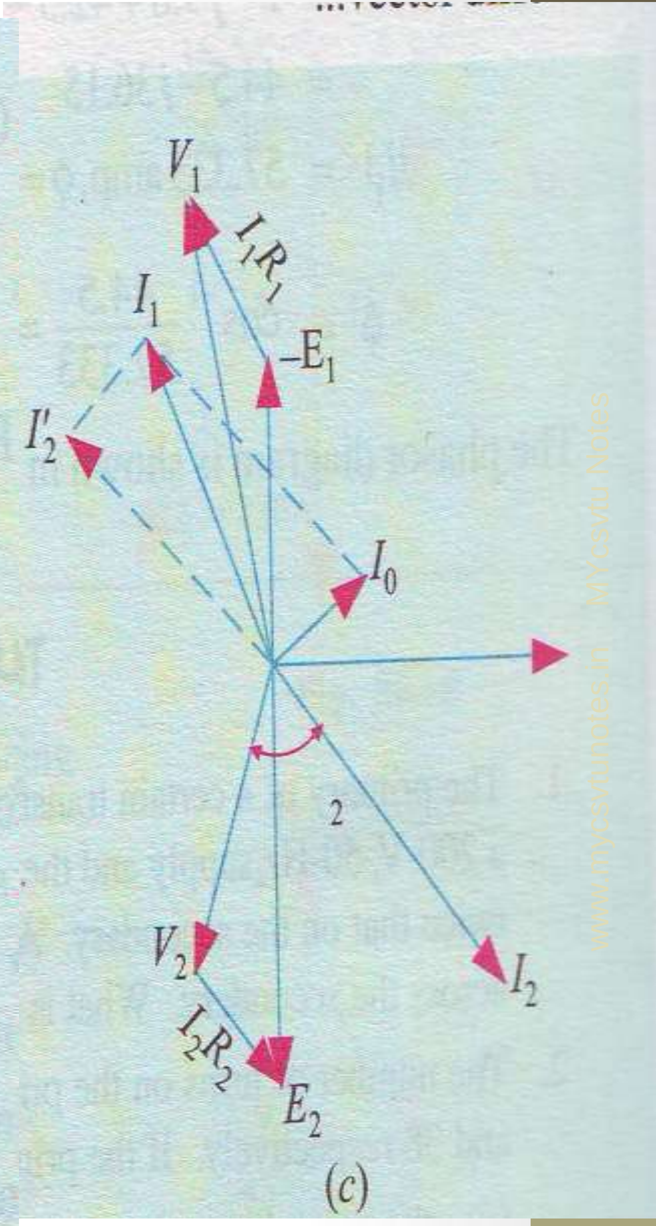
- **Hence whatever the load conditions, *the net flux passing through the core is approximately the as at***
- ***no-load* therefore *the core loss is also practically the same under all load conditions.***
- **As $\phi_2 = \phi'_2$**
- **so $N_2 \; I_2 = N_1 \; I'_2$ and hence $I'_2 = N_1 / N_2 \; * \; I'_2$**
- **Hence , when transformer is on load , the primary winding has two currents no-load current I_0 and I'_2 which is anti-phase with I_2 and K times in magnitude. *The total primary current is the vector sum of I_0 and I'_2***



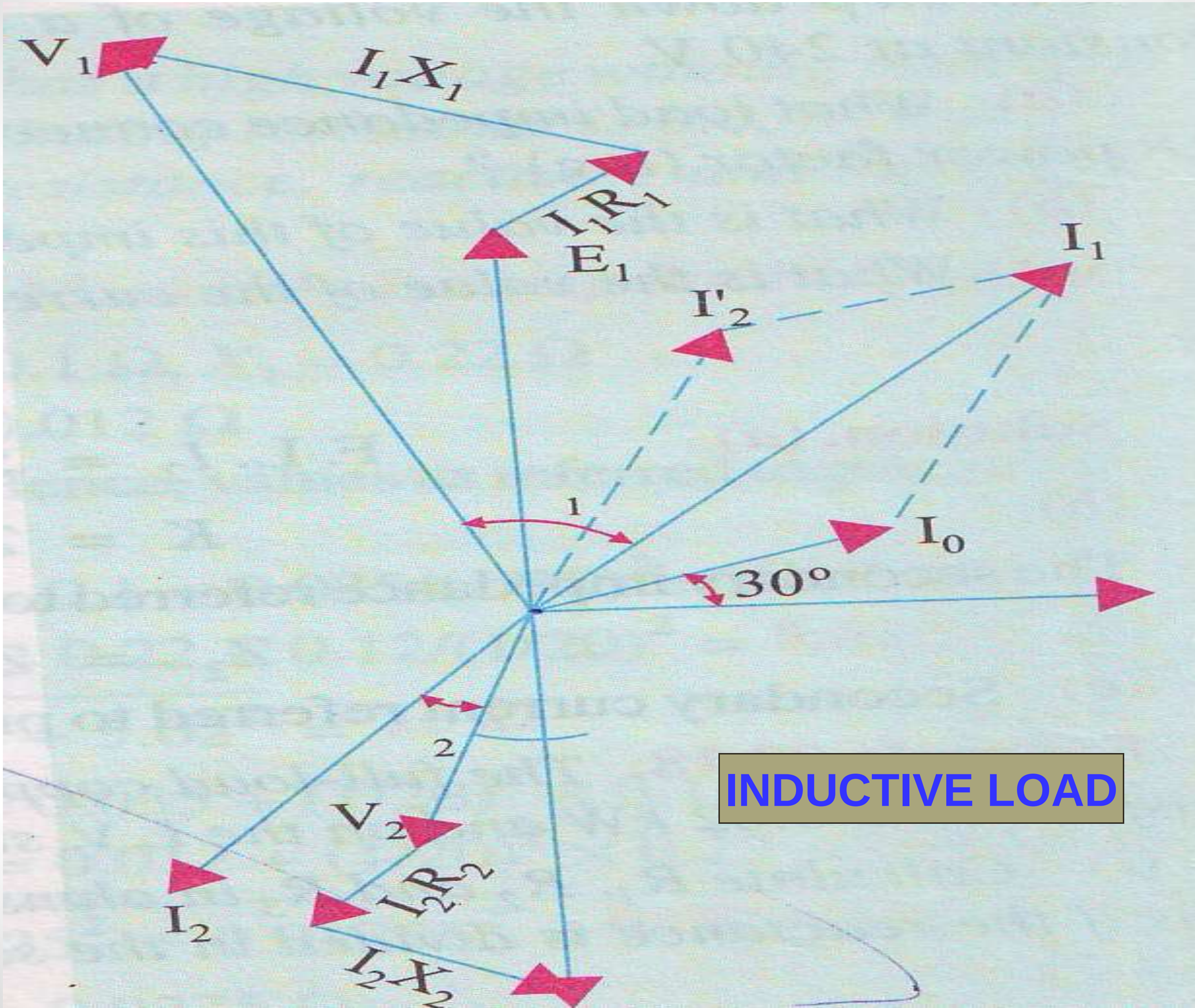
RESISTIVE LOAD



INDUCTIVE LOAD



CAPACITIVE LOAD



INDUCTIVE LOAD

LECT -43

PROBLEMS OF TRANSFORMER

- PROB 1.
- The maximum flux density in the core of a 250/3000 V , 50 Hz transformer is 1.2 Wb/m^2 if emf per turn is 8 V find (I) N_1,N_2 (2) area of core
- Solu: Given $E_1=V_1=250$ v
- $E_2= V_2= 3000$ v
- $E_1= N_1$*emf /turn
- $N_1= 250/8= 32$ and $N_2= 3000/8 = 375$
- $E_2= 4.44 *f*N_2* Bm*A$
- 3000 =4.44*50*375*1.2*A
- A = 0.03 m^2

- PROB 2.
- 1-phase tran has 400 primary turn and 1000 secondary turn. Net area of the core is 60 cm2 if primary winding is connected to a 50 Hz 520 v supply. Find max value of flux density and secondary induced voltage.
- Solu Given N_1=400
- N_2= 1000
- A=60 cm2=60*10-4m^2
- F =50 Hz
- V_1=520 V
- $N_2/N_1=E_2/E_1=V_2/V_1=K$
- $K=N_2/N_1$=1000/400=2.5
- $V_1=E_1$
- $E_2=KE_1$=2.5*520=1300V
- E_1= 4.44 *f*N_1* Bm*A
- 520 =4.44*50*400*Bm*60*10-4
- Bm = 0.976Wb/m^2

- PROB 3
- A 25-kVA tran has 500 turn on primary and 50 turn on secondary. The primary is connected 3000-v, 50 Hz supply. Find full load primary and secondary current, secondary emf and max flux in the core
- Solu :-Given KVA OUTPUT 25 KVA
- $N_1=500$
- $N_2=50$
- $V_1=3000$ V
- $N_2/N_1=E_2/E_1=V_2/V_1=K$
- $V_1=E_1$
- $K=N_2/N_1=50/500=0.1$
- $E_2=KE_1=0.1*3000=300V$
- I_1=KVA OUTPUT*1000/V_1=25*1000/3000=8.33 A
- I_2=KVA OUTPUT*1000/V_2=25*1000/300=83.3 A
- $E_1=4.44 f \phi N_1$
- $\phi = E_1/4.44f N_1 = 3000/4.44*50*500=27$ mWb

1. The number of turns on the primary and secondary windings of a 1ϕ transformer are 350 and 35 respectively. If the primary is connected to a 2.2kV,50.Hz supply, determine the secondary voltage on no-load.

   [220V]
2. A 3000/200-v, 50-Hz,1-phase transformer is built on a core having an effective cross sectional area of 150cm2 and has 80 turns in the LV winding. Calculate B and HV turns.
   (0.75 Wb/m^2 ,1200)
3. A 3300/230-v, 50-Hz,1-phase transformer is to be worked at a max flux density 1.2 Wb/m^2 in the core having an effective cross sectional area of 150cm2. Calculate LV and HV turns.
   (58,830)
4. A 40 kVA 3300/240-v, 50-Hz,1-phase transformer has 600 turns on primary calculate.N_2 , max flux , I_1 & I
   (48, 22.5 mwb, 12.1A & 166.7 A)

5 A double wound 1-phase, 10 kva transformer is to be worked at a max flux density 1.2 Wb/m2 in the core is required to step down from 1900v to 240v,50Hz.It is to be 1.5 v /turn. Calculate N1 ,N2, I1,I2 and area of core. (1267, 160, 41.75 A, 5.27 A , 56.4cm2)

6 The no-load voltage ratio of a 1phase 50 Hz tran is 1200/440 calculate N ,N if max flux is 0.075 Wb. [24 and 74]

7 A 1-phase tran has number of turns on the primary and secondary windings are 500 and 1200 respectively.If effective cross sectional area of core is 75cm2 and the primary is connected to a 400v,50.Hz supply, determine max flux density and the secondary voltage on no-load. [0.48 Wb/m2,60V]

8 A 10 kVA 1-phase tran has turn ratio 300/23 primary is connected to 1500 v 60 Hz supply find V2, I1,I2 AND max valu of flux. [115 V , 6.67 A ,87 A, 11.75 mwb]

9 A 100 kVA 3300/400-v, 50-Hz,1-phase transformer has 110 turns on secondary calculate.N1,max flux , I1 & I2 (907, 16.4 mwb, 30.3A & 250 A)

1 A 2200/200-v, 50-Hz,1-phase transformer a no-load primary current of 0.6 A and absorb 400 watts. Find magnetizing and iron loss current.

- Solu :- iron loss current = no-load input watt/primary voltage
- =400/2200 =0.182 A
- $I20=I2w + I2\mu$
- $I\mu = (\sqrt{I20-I2w})$
- $I\mu = (\sqrt{0.62-0.1822})$ =0.572 A

2 A 2200/250-v, 50-Hz,1-phase transformer takes 0.6 A at Pf 0.3 on open circuit . Find magnetizing and working component of no load current.

- Solu . I0= 0.6 A $\cos\phi$= 0.3
- Iw = I0* $\cos\phi$= 0.5 *0.3= 0.15 A
- $I\mu = (\sqrt{I20-I2w})$
- $I\mu = (\sqrt{0.62-0.1822})$ =0.476 A

3 The number of turns on the primary and secondary windings of a 1-transformer are 350 and 35 respectively. If the primary is connected to a 2.2kV, 50.Hz supply, determine the secondary voltage on no-load.

4 A 3000/200.V, 50-Hz, 1-phase transformer is built on a core having an effective cross-sectional area of 150 cm2 and has 80 turns in the low-voltage winding. Calculate the value of the maximum flux density in the core the number of turns in the high-voltage winding.

[(a) 0.75Wb/m2 (b) 1200]

5 A 3,300/230.V 50-Hz, 1-phase transformer is to be worked at a maximum flux density of 1.2 Wb/m2 in the core. The effective cross/sectional area of the transformer core is 150 cm2. Calculate suitable values of primary and secondary turns.

[830;58]

6 A 40-k VA, 3,300/240-V, 50-Hz, 1-phase transformer has 660 turns on the primary. Determine the number of turns on the secondary (b) the maximum value of flux in the core the approximate value of primary and secondary full-load currents. Internal drops in the windings are to be ignored.

[(a)48 (b)22.5 mWb (c)12.1A;166.7A]

7 A double-wound, 1-phase transformer is required to step down from 1900 V to 240 V, 50-Hz. It is to have 1.5 V per turn. Calculate the required number of turns on the primary and secondary windings respectively. The peak value of flux density is required to be not more than 1.2 Wb/mw. Calculate the required Cross-sectional area of the steel core. If the output is 10 kVA, calculate the secondary current.

[1,267;160;56.4 cm2;41.75 A]

8 The no-load voltage ratio in a 1-phase, 50-Hz, core-type transformer is 1,200/440. Find the number of turns lin each winding if the maximum flux is to be 0.75 Wb .

[24 and 74 turns]

9 A 1-phase transformer has 500 primary and 1200secondaryturns. The net cross-sectional area of the core is 75 cm2. If the primary winding be connected to a 400-V, 50 Hz supply, calculate the peak value of flux density in the core and (ii) voltage induced in the secondary winding.

[0.48Wb/m2;60V]

10 A 10-kVA, 1-phase transformer has a turn ratio of 300/23. The primary is is connected to a 1500/V, 60Hz supply. Find the secondary volts on open-circuit and the approximate values of the currents in the two Windings on full-load. Final also the maximum value of the flux.

[115V;6.67A;87A; 11.75mWb]

11 A 100-k VA, 3300/400. V, 50.Hz, 1-phase transformer has 110 turns on the secondary. Calculate the approximate values of the primary and secondary full/load currents, the maximum value of flux in the core and the number of primary turns. How does the core flux vary with load ?

[30.3 A; 250 A; 16.4 mWb; 907]

12 The no/load current of a transformer is 5.0 A at 0.3 power factor when supplied at 230-V,50-Hz. The number of turns on the primary winding is 200. Calculate (I) the maximum value of flux in the core (ii) the core loss (iii) the magnetising current.
[5.18 mWb; 345W; 4.7A]

13 The no-load current of a transformer is 15 A at a power factor of factor of 0.2 when connected to a 460-V, 50-Hz supply. If the primary winding has 550 turns, calculate the magnetising component of no/load current (b) the iron loss (c) the maximum value of the flux in the core.
[(a) 14.7A (b)1,380 W (c) 3.77 mWb]

14 The no/load current of a transformer is 4.0 A at 0.25 p.f. when supplied at 250-V, 50-Hz. The number of turns on the primary winding is 200. Calculate the r.m.s. value of the flux in the core (assume sinusoidal flux) (ii) the core loss (iii) the magnetising current.
[(I) 3.98 mWb

(ii) 250 W (iii) 3.87 A]

- 1. A single-phase transformer with a ratio of 440/110-V takes a no load
- Current of 5 A at 0.2 power factor lagging. If the secondary supplies a current of 120 A at a p.f. of 0.8
- Lagging, estimate taken by the primary.
- SOLUTION : - cos ϕ2 = 0.8, ϕ2=cos-1 (0.8) = 36.54°
- cos ϕ0 = 0.2, ϕ0=cos-1 (0.2) =78.30°
- Now K=V2/V1 = 110/440 = 1/4
- I2'=KI2=120x1/4 =30 A
- I0=5 A.
- Angle between I0 an I2'
- = 78°30'-36.54°= 41°36'
- Using parallelogram law of vectors (fig.27-19) we get
- I1=√ (52+302+2x5x30xcos 41°36')
- = 34.45 A
- The resultant current could also have been found by resolving I2' and I0 into their X-and
- Y-components.

- A transformer has a primary winding of 800 turns and a secondary winding of 200 turns. When the load current on the secondary is 80 A at 0.8 power factor lagging, the primary current is 25 A at 0.707 power factor lagging. Determine graphically or otherwise the no-load current of the transformer and its phase with respect to the voltage.
- SOLUTION : - Here
- K= 200/800=1/4; I2'=80x1/4=20A
- ϕ2=cos-1 (0.8) = 36.54°
- ϕ1=cos-1 (0.707) =45°
- As seen from fig. 27.20, I1 is the vector sum of I0 and I2'. Let I0 lag behind V1 by an angle ϕ0
- I0 cos ϕ0 +20 cos 36.9=25 cos 45
- I0 cos ϕ2=25x 0.707-20x0.8 =1.675 A
- I0 sin ϕ0 +20 sin 36.9=25 sin 45
- I0 sin ϕ2=25x 0.707-20x0.6 =5.675 A
- tanϕ0 = 5.675/1.675=3.388
- ϕ0 =73.3
- Now, I0 sin ϕ0 =5.675
- I0 =5.675/sin 73.3=5.93 A

3 The primary of a certain transformer takes 1 A at a power factor of 0.4 when it is connected across a 200-V, 50-Hz supply and the secondary is on open circuit. The number of turns on the primary is twice that on the secondary. A load taking 50 A at a lagging power factor of 0.8 is now connected across the secondary. What is now the value of primary current ?

[25.9A]

4 The number of turns on the primary and secondary windings of a single/phase transformer are 350 and 38 respectively. If the primary winding is connected to a 2.2kV, 50-Hz supply, determine the secondary voltage on no-load.The primary current when the secondary current is 200 A at 0.8 p.f. lagging, if the no-load current is 5 A at 0.2 p.f. lagging.The power factor of the primary current.
[239 V; 25.65A; 0.715 lag]

5 A 400/200-V, 1-phase transformer is supplying a load of 25 A at a p.f. of 0.866 lagging. On no-load, the current land power factor are l2 A and 0.208 respectively. Calculate the current taken from the supply.
[13.9A lagging V1 by 36.10]

6 A transformer takes 10 A on no-load at a power factor of 0.1. The turn ratio is 4:1 (step down). If a load is supplied by the secondary at 200 A and p.f. of 0.8, find the primary current and power factor (internal voltage drops in transformer are to be ignored)
[57.2A; 0.717 lagging]

- (7) A 1-phase transformer is supplied at 1,600 V on the h.v. side and has a turn ratio of 8:1. The transformer supplies a load of 20 kW at a power factor of 0.8 lag and takes a magnetizing current of 2.0 A
- A at a power factor of 0.2 Calculate the magnitude and phase of the current taken from the h.v. supply.
- [17.15A; 0.753 lag]
- (8) A 2,200/200-V transformer takes 1 A at the H.T. side on no-load at a p.f. of 0.385 lagging. Calculate the iron losses.
- If a load of 50 A at a power of 0.8 lagging is taken from the secondary of the transformer, calculate the actual primary current and its power factor. [847 Wl;5.44A; 0.74 lag]
- (9) A 400/200-V, 1-phase transformer is supplying a load of l50 A at a power factor of 0.866 lagging. The
- no-load current is 2 A at 0.208 p.f. lagging. Calculate the primary current and primary power factor.
- [26.4A; 0.838 lag]

LECT -44

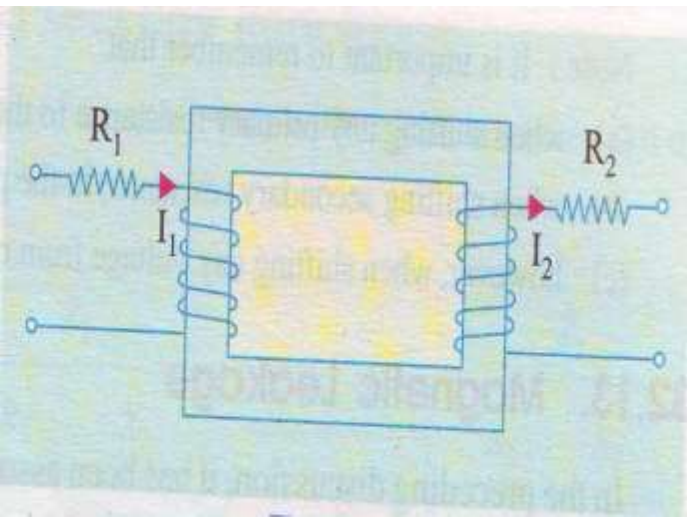
EQUIVALENT CIRCUIT

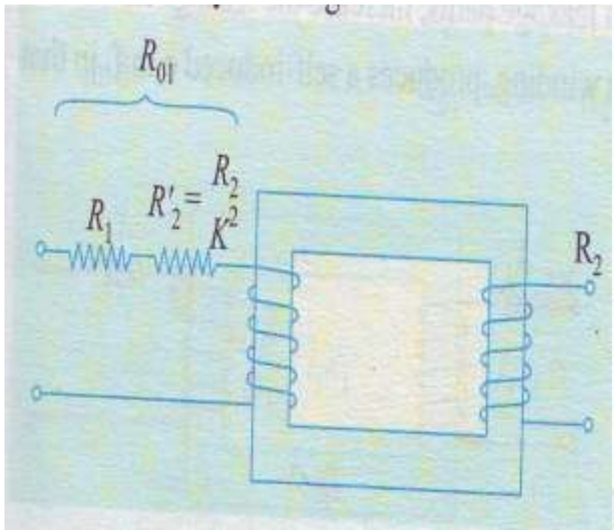
OF

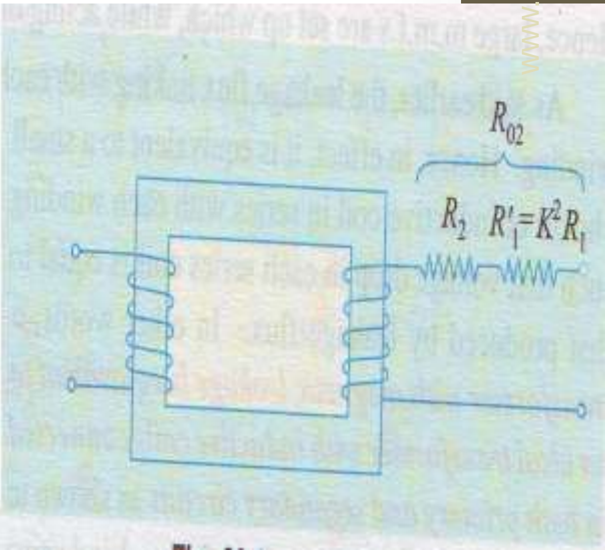
TRANSFORMER

EQUIVALENT RESISTANCE

- **In a transformer whose primary resistance R_1 and secondary resistance is R_2**
- **This resistance is external to the winding and transferred to any one of the two windings. The advantage of the resistance in one winding is that it makes calculation very simple and easy.**
- **The cu loss in secondary is $I_2^2 R_2$. this loss is supplied by primary which takes a current I1 . Hence, if R'_2 is the *equivalent resistance in primary which would have caused the same loss as* R_2 in secondary, then**
- **$I_1^2 R'_2 = I_2^2 R_2$**
- **$R'_2 = (I_2^2 / I_1^2) R_2$**







- **If neglect no load current I_0 then (I_2 / I_1) hence $R'_2 = R_2/K^2$, similarly, equivalent primary resistance as referred to the secondary $R'_1 = K^2 R_2$**
- **In below fig secondary resistance has been transferred to primary side having secondary circuit resistance less.** ***The resistance $R_1 + R'_2 = R_1 + R_2/K^2$ is known as the equivalent or effective resistance of the transformer as referred to primary*** **and represented by $R_{01} = R_1 + R'_2 = R_1 + R_2/K^2$**

A resistance of R_2 in secondary is equivalent to R_2/K^2 in primary. Hence it is ***called the equivalent secondary resistance as referred to primary i.e. R'_2.***

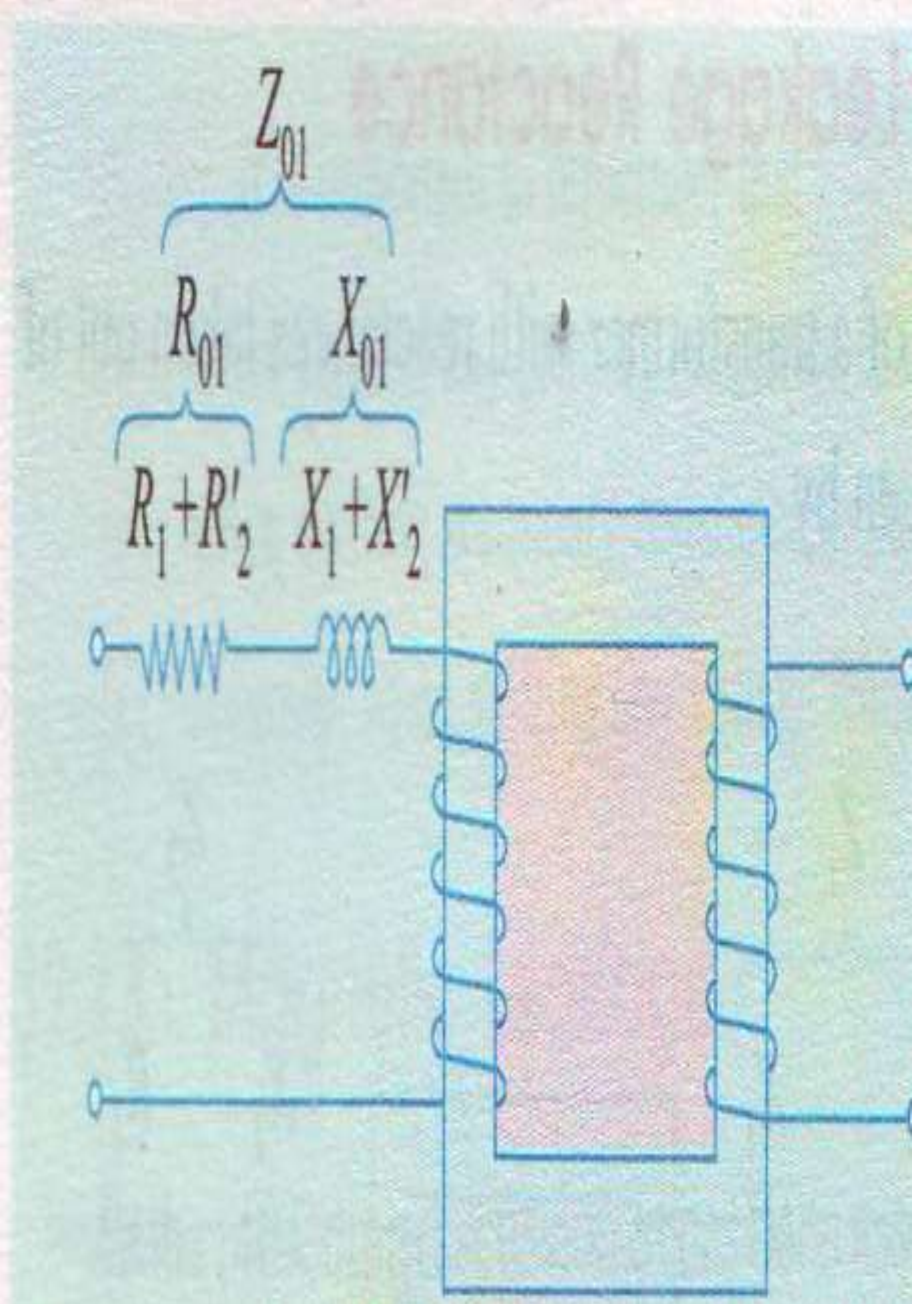
- **(3) Total or effective resistance of the transformer as referred to primary is**

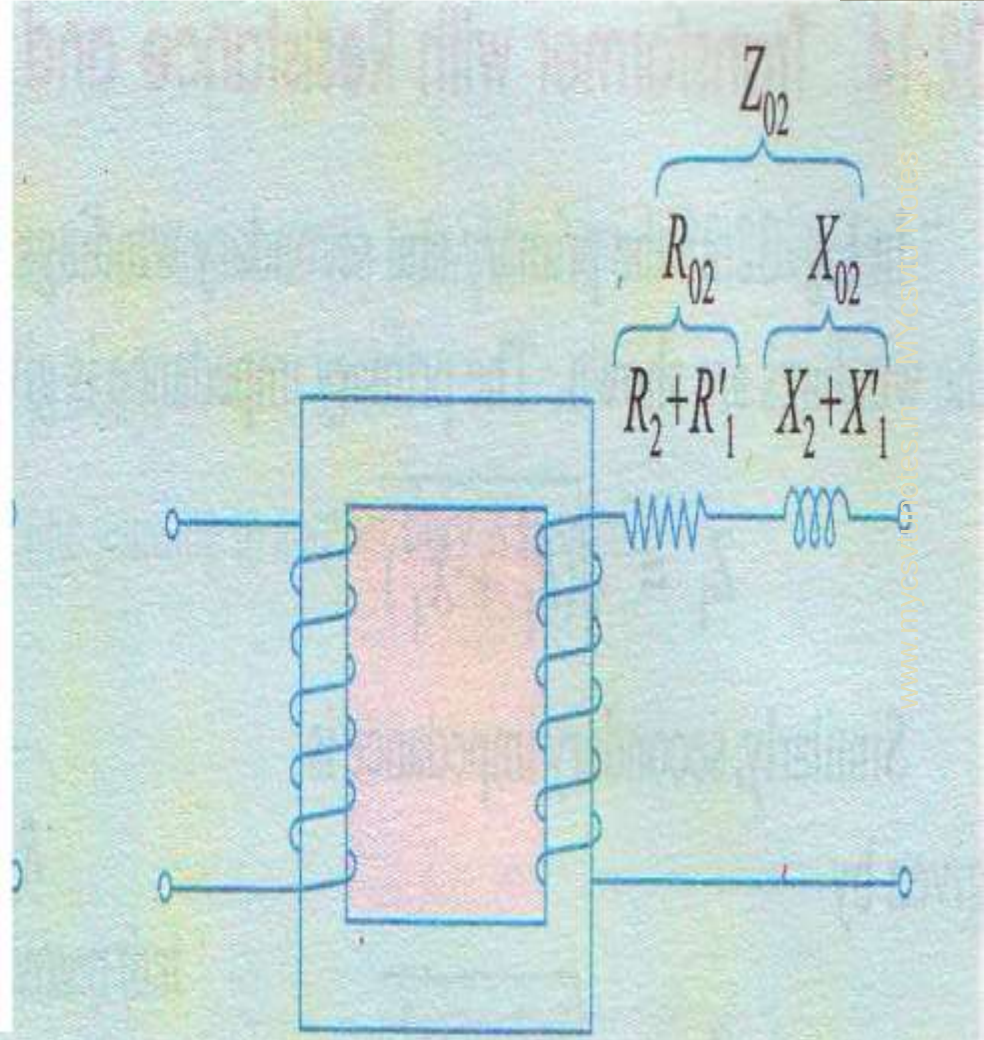
$$R_{01} = R_1 + R'_2 = R_1 + R_2/K^2$$

Total or effective resistance of the transformer as referred to secondary is

-
$$R_{02} = R'_1 + R_2 = K^2 R_1 + R_2$$

- **Similarly primary and secondary leakage reactance can also transferred from one winding to the other in the same way as resistance.**
- **$X'_2 = X_2 / K^2$ and $X'_1 = K^2 X_1$**
- **And $X_{01} = X_1 + X'_2 = X_1 + X_2 / K^2$**
- **and $X_{02} = X'_1 + X_2 = K^2 X_1 + X_2$**
- **It is obvious that total impedance of the transformer as primary and secondary is given by**
- **$Z_{01} = \sqrt{[(R_{01})^2 + (X_{01})^2]}$ and**
- **$Z_{02} = \sqrt{[(R_{02})^2 + (X_{02})^2]}$**

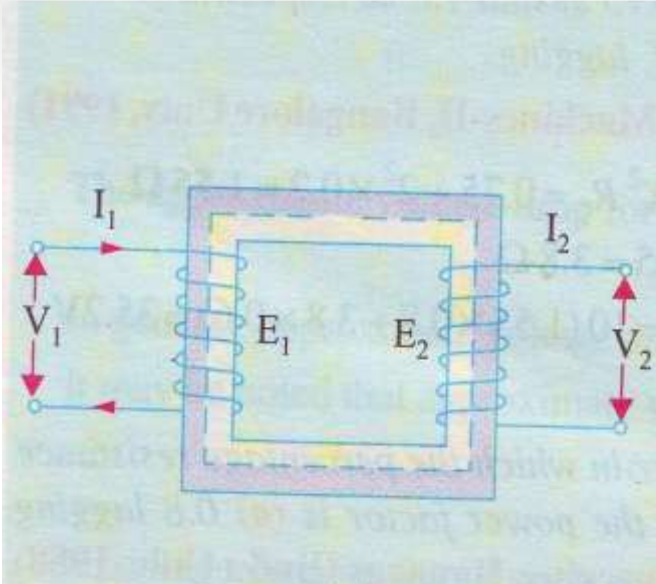

Z_{01}
R_{01}
X_{01}
$R_1+R'_2$
$X_1+X'_2$

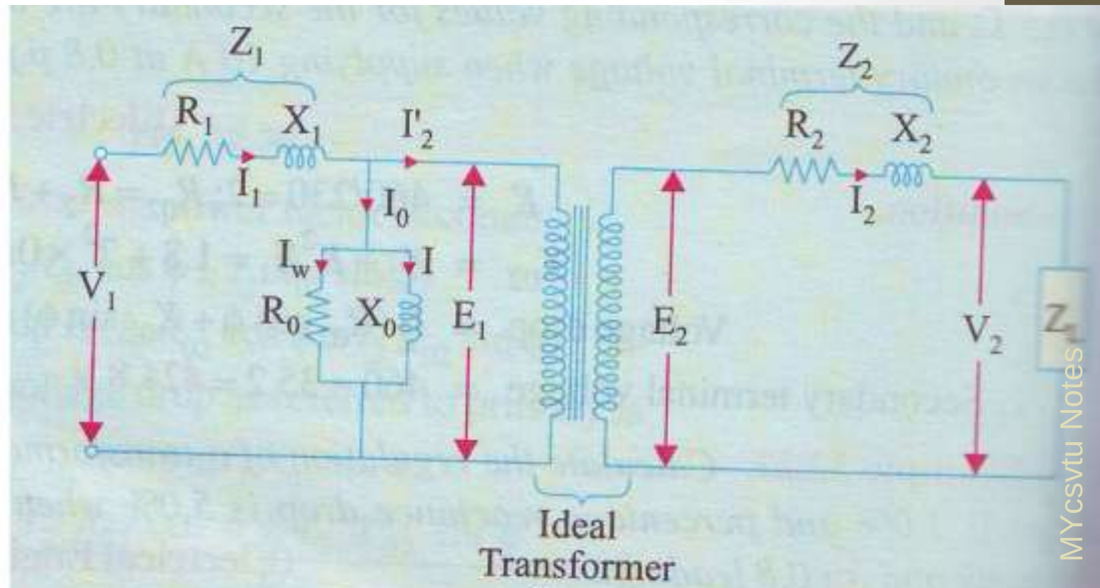

Z_{02}
R_{02}
X_{02}
$R_2+R'_1$
$X_2+X'_1$

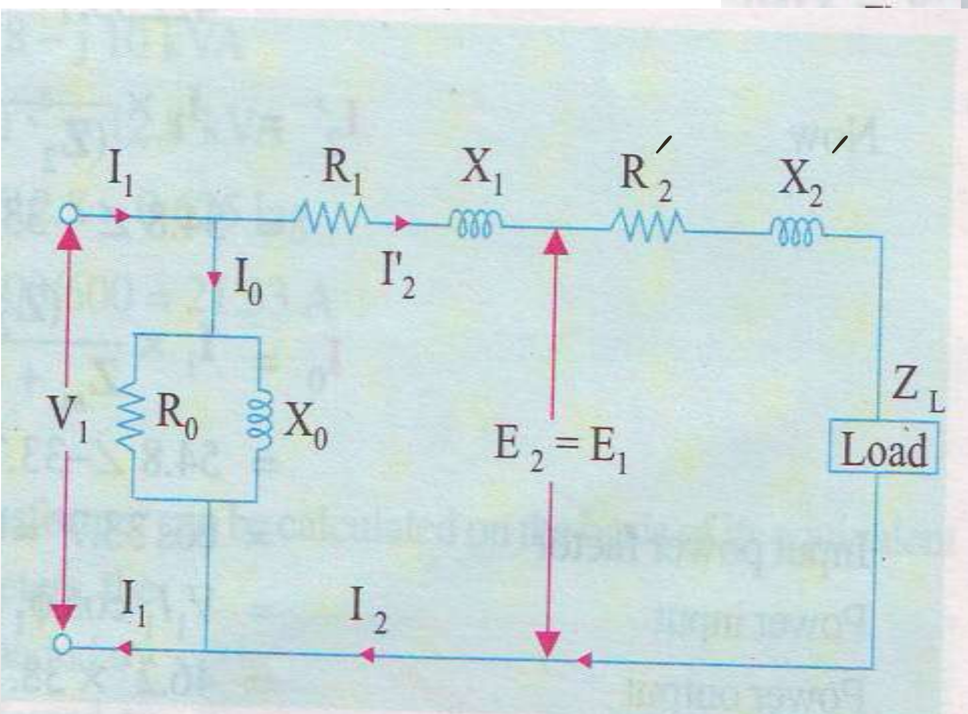
- EQUIVALENT CIRCUIT

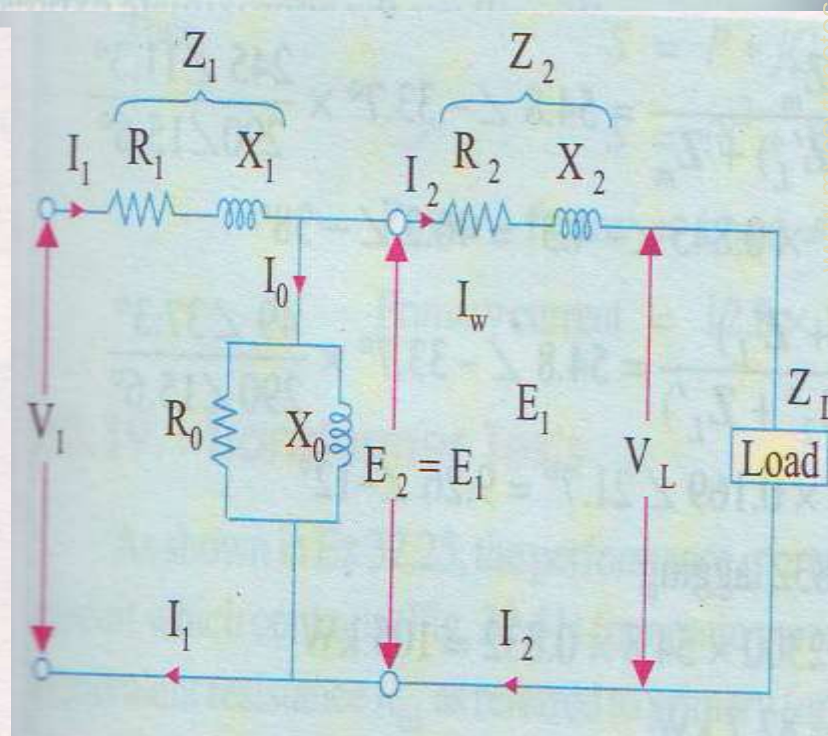
- The transformer shown diagrammatically in below fig can be resolved into an equivalent circuit in which the resistance and leakage reactance of the transformer are imagined to be external to the winding whose only function then is to transform the voltage. The no-load current I_0 is simulated by pure inductance X_0 taking the magnetizing component $I\mu$ and a non inductive resistance R_0 taking the working component I_w connected in parallel across primary circuit. The value E_1 is obtained by subtracting vectorially
- $I_1 Z_1$ from V1 . The value of $X_0 = E_1 / I\mu$ and
- $R_0 = E_1 / Iw$ it is clear $E_2/E_1 = K$

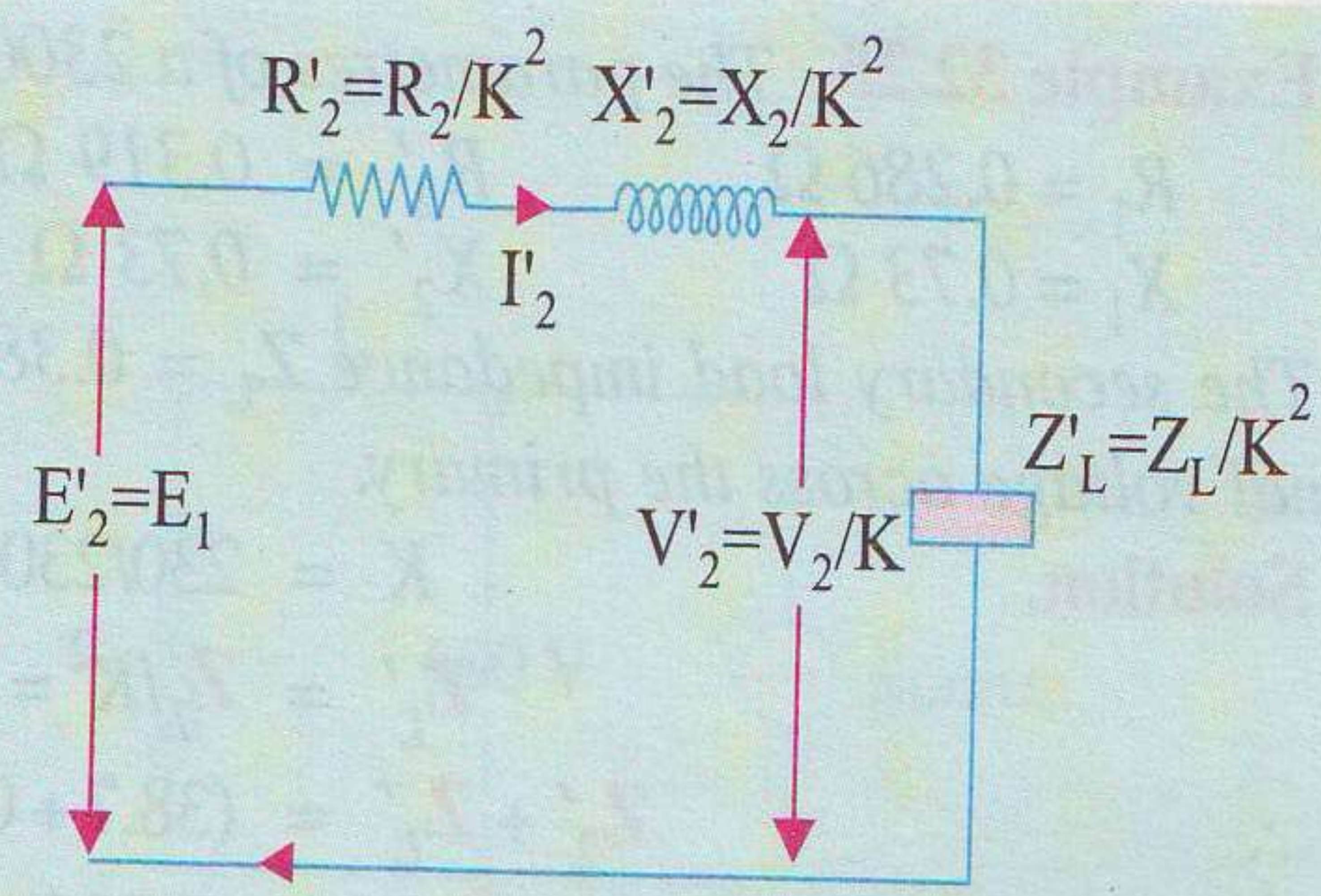
- Make transformer calculation easier simpler, it is preferable to transfer V,I,and Z either primary or to be secondary.
- Hence primary equivalent of the secondary induced voltage E'_2 = $E_2/K = E1$
- primary equivalent of the secondary output voltage
- $V'_2 = V_2/K = V1$
- primary equivalent of the secondary current
- $I'_2 = KI_2$
- and $R'_2 = R_2/K^2$, $X'_2 = X_2/K^2$ and $Z'_2 = Z_2/K^2$
- the same relationship is used for shifting an external load impedance to the primary.
- The secondary circuit and its equivalent primary values are shown in below fig.
- The total equivalent circuit of the transformer is obtained by adding in the primary impedance as shown in below fig.


I1
I2
V1
E1
E2
V2
(a)


Z1
R1
X1
I'2
I1
I0
Iw
I
R0
X0
V1
E1
E2
Z2
R2
X2
I2
V2
Ideal
Transformer
(b)


I1
R1
X1
R2′
X2′
I0
I'2
V1
R0
X0
E2 = E1
ZL
Load
I1
I2


Z1
Z2
I1
R1
X1
I2
R2
X2
I0
Iw
V1
R0
X0
E2 = E1
E1
VL
ZL
Load
I1
I2



(b)

LECT -45

REGULATION OF TRANSFORMER

- **REGULATION OF A TRANSFORMER**
- **When a transformer is loaded with constant primary voltage due to internal resistance and reactance the secondary voltage decreased (inductive load i.e. lagging pf) or increased (capacitive load i.e. leading pf)**
- **Let secondary terminal voltage at no-load**
- **$= V_{02} = E_2 = KE_1 = KV_1$**
- **secondary terminal voltage at full-load $= V_2$**
- **The change in secondary terminal voltage from no-load to full-load $= V_{02} - V_2$**

- Regulation is define in two ways
- REGULATION DOWN :-The change in secondary terminal voltage from no-load to full-load is divided by V_2 is known as *regulation down.*
- % Regulation down = $[(V_{02} - V_2)/ V_2] \times 100$
-
- REGULATION UP :-The change in secondary terminal voltage from no-load to full-load is divided by V_{02} is known as *regulation up.*
- % Regulation up = $[(V_{02} - V_2)/ V_{02}] \times 100$

- Regulation is to be taken as always *regulation down*
- Lesser the value of regulation better the transformer, because a good transformer should keep its secondary terminal voltage as constant as possible under all conditions of load.
- Regulation may also be explained in terms of primary values
- % Regulation $= (V_1 - V'_2)/V_1 \times 100$
- where V_1 is secondary no-load terminal voltage as referred to primary $E'_2 = E_2/K = E_1 = V_1$
- V'_2 is the secondary full-load voltage as referred to primary is $V'_2 = V_2/K$
- Regulation is also define in this way
- % regn $= (I_1 R_{01} \cos\phi + I_1 X_{01} \sin\phi) / V_1 \times 100$
- $= V_r \cos\phi + V_x \sin\phi$
- where $V_r = (I_1 R_{01} * 100) / V_1$
- $V_x = (I_1 X_{01} * 100) / V_1$

PERCENTAGE RESISTANCE, REACTANCE AND IMPEDANCE

- **Percentage resistance at full-load**
- $\%R = (I_1R_{01} * 100) / V_1 * 100 = (I^2{}_1R_{01} * 100) / V_1 * I_1 100$
- $\%R = (I^2{}_2R_{02} * 100) / V_2 * I_2 100$ = % cu loss at full-load
- $\%R = Vr$ = % cu loss at full-load.
- **Percentage reactance at full-load**
- $\%X = (I_1X_{01} * 100) / V_1 * 100 = = (I_2X_{02} * 100) / V_2 * 100 = Vx$
- **Percentage impedance at full-load**
- $= \%Z = (I_1Z_{01} * 100) / V_1 * 100 = = (I_2Z_{02} * 100) / V_2 * 100$
- $\%Z = \sqrt{(\%R^2 + \%X^2)}$

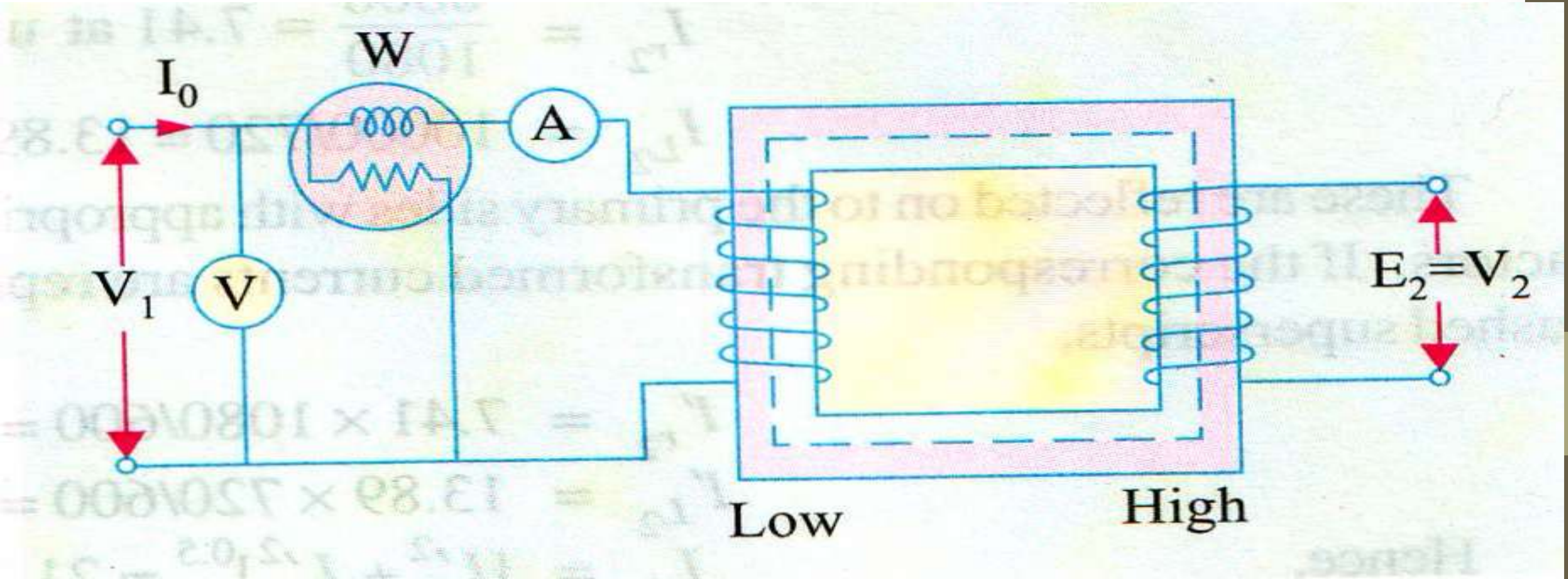
LECT -46

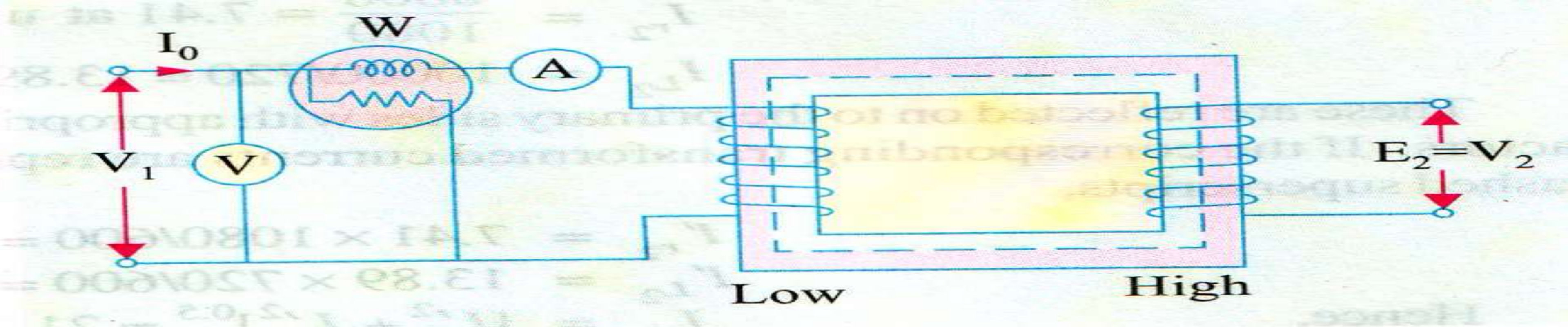
OC/SC TEST ON TRANSFORMER

- TRANSFORMER TESTS

- The performance of a transformer can be calculated on the basis of its equivalent circuit which contain four main parameters
- The equivalent resistance R_{01} (or R_{02})
- The equivalent reactance X_{01} (or X_{02})
- No-laod component (R_0 and X_0)
- This parameters can be easily determined by two test
- OPEN-CIRCUIT OR NO-LOAD TEST
- SHORT-CIRCUIT OR LOAD TEST

- **OPEN-CIRCUIT OR NO-LOAD TEST :-**
- **The purpose of the test is to determine no load loss or core loss and no-load current I_0 which helpful in finding R_0 and X_0 .**
- **One winding usually HV winding left open and other is connected to supply of normal voltage and frequency**



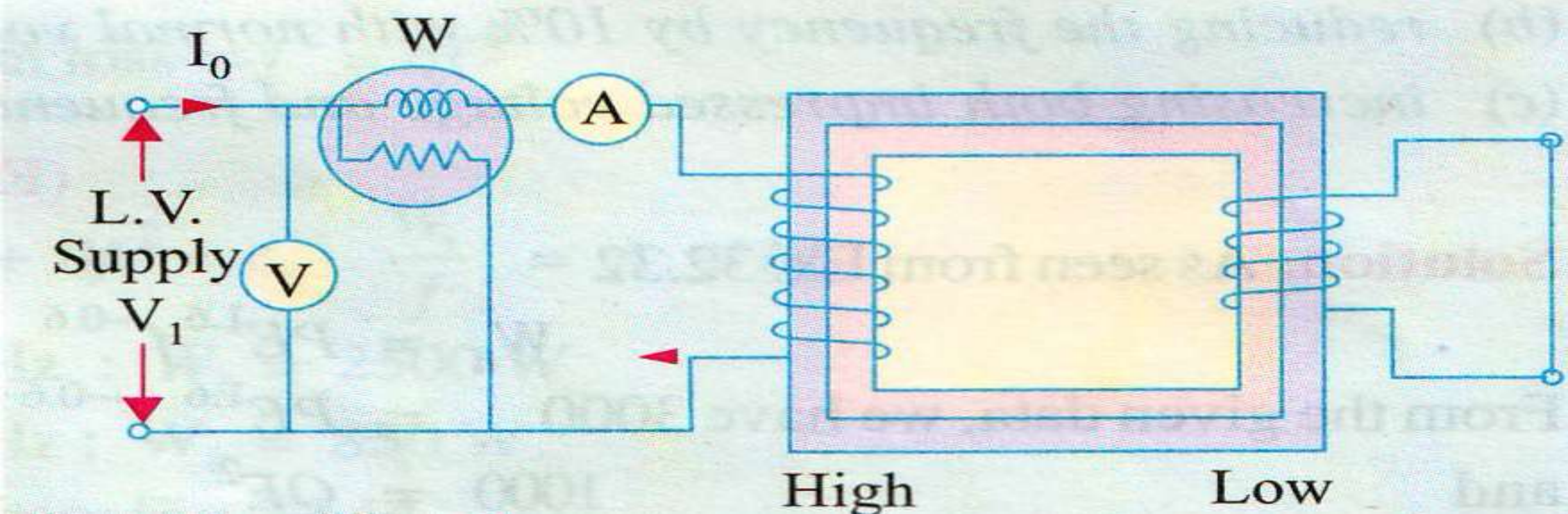


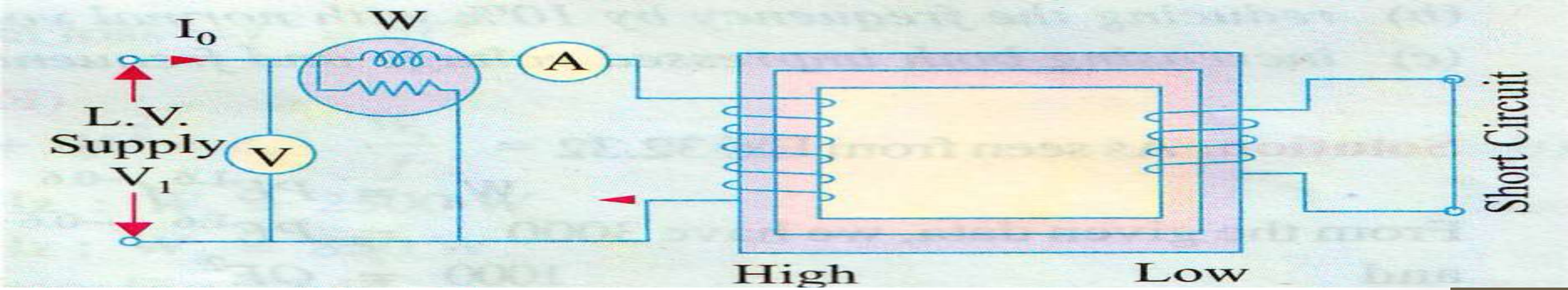
- In above fig a wattmeter, voltmeter and an ammeter are connected to primary (LV) winding and secondary open. With normal voltage applied to the primary, normal flux set up in the core, hence normal iron loss will occur which are recorded in wattmeter. As the primary no-load current I_0 (as measured by ammeter) is small (2 to 10% of rated load current), cu loss is negligibly small in primary and nil in secondary . Hence wattmeter reading represents practically the core loss under no-load condition (which is same for all loads).
- Sometimes, a high resistance voltmeter is connected to the secondary for measurement of E_2 = this help to find transformation ratio K.

- If Wattmeter reading = W
- Voltmeter reading = V_1
- Ammeter reading = I_0
- $W = V_1 I_0 \cos\phi_0$
- $\cos\phi_0 = W / (V_1 I_0)$
- and $I_W = I_0 \cos\phi_0$
- $I\mu = I_0 \sin\phi_0$
- and $X_0 = V_1 / I\mu$
-
- $R_0 = V_1 / I_W$

- SEPARATION OF CORE LOSSES
- The core loss of a transformer depends upon the frequency and the maximum flux density when the volume and thickness of the core laminations are given. The core loss is made up of two parts
- Hysteresis loss $W_h = P\,B^2_{max}\,f$ as given by Steinmetz's empirical relation
- Eddy current loss $We = Q\,B^{1.6}_{max}\,f^2$
- Where P and Q are constant
- The total core loss is given by
- $Wi = We + Wh$
- $= P\,B^2_{max}\,f + Q\,B^{1.6}_{max}\,f^2$

- **SHORT-CIRCUIT OR IMPENDANCE TEST**
- **The purpose of the test is to determine**
- **(i) Equivalent impendanceZ_{01} ,resistance R_{01} and leakage reactance X_{01} .**
- **(ii) Cu loss at full load.**
- **(iii) Total voltage drop in the transformer and hence regulation.**
- **In this test one winding usually LV winding short circuited by thick conductor.**





- A low voltage(5 to 10% of normal primary voltage) at correct frequency is applied to the primary and cautiously increased till
- full-load currents are flowing both in primary and secondary. Applied voltage is a small percentage of the normal voltage, flux produced is also small percentage of its normal value hence, core loss are very small with result that the wattmeter reading represents the full-load cu loss

- If Wattmeter reading $= W$
- Voltmeter reading $= V_{sc}$
- Ammeter reading $= I_1$
- $W = I^2{}_1 R_{01}$
- $R_{01} = W/I^2{}_1$
- and $X_{01} = \sqrt{(Z^2{}_{01} - R^2{}_{01})}$

LECT -47

LOSSES & EFFICIENCY

OF

TRANSFORMER

- **LOSSES IN A TRANSFORMER**
- Transformer is a static device there is no friction and windage losses. Hence transformer has only two losses .
- Core or iron loss :- core loss includes both hysteresis and eddy current loss this loss is practically constant at all loads.
- Hysteresis loss $W_h = P B^2_{max}$ f watt as given by Steinmetz's empirical relation
- Eddy current loss $We = Q B^{1.6}_{max} f^2$ watt
- Where P and Q are constant
- These loss is minimized by using steel high silicon content for the core and by using very thin laminations.
- Copper loss :- This loss is due to ohmic resistance of the transformer winding.
- Total cu loss $= I^2_1R_1 + I^2_2R_2 = I^2_1R_{01} = I^2_2R_{02}$ It is clear that Cu loss is proportional to to $(current)^2$or $(KVA)^2$.
- cupper loss depend on current and iron loss depend on voltage hence transformer rating is in VA OR KVA.

- EFFICIENCY OF A TRANSFORMER
- Efficiency of any machine is defined as
- Efficiency = Output/Input
- Input = Output + losses
- Since transformer has two losses, Cu loss and Core loss
- Hence , Input = Output + Cu loss + Core loss
- Efficiency = Output / (Output + Cu loss + Core loss)
- In other words
- Output = Input - Cu loss - Core loss = Input – losses
- Efficiency = (Input – losses) / Input
- Efficiency = 1 – (losses / Input)

- <u>Condition for maximum efficiency</u>
- Cu loss = $I^2_1R_{01}$ = $I^2_2R_{02}$ = Wcu
- Iron loss = Hysteresis loss + Eddy current loss = Wh + We = Wi
- Considering primary side
- Primary input = $V_1 I_1\cos\phi$
- Efficiency = $(V_1 I_1\cos\phi - \text{losses}) / (V_1 I_1\cos\phi)$
- $= 1- (\text{Losses} / V_1 I_1\cos\phi)$
- $= 1 - Wi / V_1 I_1\cos\phi - Wcu / V_1 I_1\cos\phi$
- $= 1 - Wi / V_1 I_1\cos\phi - I^2_1R_{01} / V_1 I_1\cos\phi$
- $= 1 - Wi / V_1 I_1\cos\phi - I_1R_{01} / V_1 \cos\phi$
- for η is maximum $d\eta/dI_1 = 0$
- now differentiating both sides wrt I_1
- $d\eta/dI_1 = d/dI_1 (1 - Wi / V_1 I_1\cos\phi - I_1R_{01} / V_1 \cos\phi)$
- $= 0 + [Wi /(V_1 \cos\phi I^2_1)] - [R_{01} / V_1 \cos\phi] = 0$
- $[Wi /(V_1 \cos\phi I^2_1)] = [R_{01} / V_1 \cos\phi]$
- $Wi = I^2_1R_{01}$
- Iron loss = CU loss
- The output current corresponding to maximum efficiency is
- $I^2 = \sqrt{(Wi / R_{02})}$
- Load corresponding to maximum efficiency
- = full load X $\sqrt{(Wi / \text{Cu loss at full load})}$

- Some important point
- If x = actual load / full load
- Actual load = x * full load
- Cu loss at actual load = x^2 *full load cu loss
- And iron is same for all load condition
- Efficiency at any load is given
- Efficiency =

$$\frac{x \cdot \text{Output in KW or W}}{x \cdot \text{Output in KW or W} + x^2 \cdot \text{full load cu loss KW or W} + \text{Core loss in KW or W}}$$

LECT -48

ALL DAY EFFICIENCY

OF

TRANSFORMER

ALL- DAY EFFICIENCY :-

- All day efficiency of transformer is the ratio of output in kwh to the input in kwh for 24 hours
- η all-day = output in kwh / input in kwh (for 24 hrs)
- This efficiency is always less than the commercial efficiency of a transformer
- The performance of transformer should be judge by all-day (also called energy, operational) efficiency which is computed on the basic of energy consumed during a certain period, usually a day of 24 hrs.

- 1. A 30-kVA,, 2400/120-V, 50-Hz transformer has a high voltage winding residhance of 0.1
- And a leakage reactance of 0.22 . The lowl voltage winding resistance is 0.035 and the leakage reactance is 0.012 . Find the equivalent winding resistance, reactance and impedance referred to the (I)
- High voltage side and (ii) the low-voltage side
- Solution :- K=120/2400 = 1/20; r1=0.1 Ω , X1 =0.22 Ω
- R2 = 0.035 Ω and X2 = 0.012 Ω
- Here, high-voltage side is, obviously, the primary side. Hence, values as referred to primary side are
- R01=R1+R2’=R1+R2/K2=0.1+0.035/(1/20)2=14.1Ω
- X01=X1+X2’=X1+X2/K2=0.22+0.012/(1/20)2=5.02Ω
- Z01=√ R01+x012 = √14.12=5.022=15
- R02=R2+R1’=R2+K2 R1=0.035+(1/20)2=0.1=0.03525Ω
- X02=X2+X1’=X2+K2X1= 0.012+(1/20)2 x0.22=0.01255Ω
- Z02= √R022+X022= √0.035252+0.012552=0.0374Ω
- (or Z02= K2Z01=(1/20)2x15=0.0375Ω

- 1. A 50/kVA, 4,400/220-V transformer has R1=345Ω, R2=0 009Ω. The values of reactances are X1=5.2 Ω and X2=0.015Ω. Calculate for the transformer (I) equivalent resistance as referred to primary (ii) equivalent resistance as referred to secondary (iii) equivalent reactance as referred to both primary and secondary (iv) equivalent impedance as referred to both primary and secondary (v) total Cu loss, first using individual resistances of the two windings and secondly, using equivalent resistances as referred to each side.
- Solution : Full-load I1=50,000/4,400=11.36A (assuming 100% efficiency)
- Full/load I2=50,000/220 = 227 A; K=220/4,400=1.20
- R01=R1+R2/K2 =3.45+0.009/(1/20)2 = 3.45+3.6 =7.05Ω
- R02= R2+K2R1=0.009+(1/20)2x3.45 = 0.009 + 0.0086 =0.0176 Ω
- Also, R02=K2R01=(1/20)2x 7.05 =0.0176Ω (check)
- (iii) X01=X1+X2'=X1+X2/K2=5.2+0.015/(1/20)2=11.2Ω
- X02=X2+X1'=X2+K2X1= 0.015+5.2/202 =0.028Ω
- Also X02 = K2X01=11.2/400 = 0.028Ω (check)
- Z01= √(R012+X012)= √(7.052+11.22)=13.23Ω
- Z02= √(R022+X022)= √(0.01762+0.0282)=0.0331Ω
- Z02= K2Z01=13.23/400 =0.0331Ω(check)
- (v) Cu loss= I12 R1 +I22 R2=11.36 2 x3.45+227 2 x0.009=910W
- Also Cu loss = I12 R01 =11.362 x7.05= 910 W
- I22 R02 =2272 x0.0176=910W

- .2. The parameters of a 2300/230/230-V, 50-Hz transformer are given below :
- R1 = 0.286 ohm R2 ‘=0.319 ohm R0 ‘=250 ohm
- X1 =0.73 ohm X2 ‘=0.73 ohm X0 =1250 ohm
- The secondary loadl impedance Zl =0.387+ I 0.29. Solve the exact equivalent circuit with normal
- Voltage across the primary.
- Solution : K= 230/2300 =1/10; Zl =0.l387+ I 0.29
- Zl ‘ = Zl /K2 = 100 (0.387+I 0.29) = 38.7+I 29 = I 29 = 48.4 ∠ 36.8°
- Z2 ‘= 0.319 +j0.73
- Z2 ‘+ZL ‘= (38.7+0.319)+j (29+0.73)=39.02+j29.73=49.0/37/37.3°
- Ym = (0.004-j0.0008)’ Zm =1/ Ym =240 + j48 = 245∠ 11.3°
- Zm + (Z2’+ZL’)=(240+j48)+39+j29.7)+ =290 ∠15.6°
- I1 = V1/(Z1 +[Zm (Z’2 +Z’L)/ (Zm +Z’2 +Z’L)]
- = 2300 ∠0/(0.286+j0.73+41.4 ∠33
- = 2300∠0/42∠33.7 = 54.8∠- 33.7
- I’2 = I1 X Zm / (Zm +Z’2 +Z’L) =54.8∠-33.7 x 245∠11.3/290∠15.6
- =54.8∠-33.7 x0.845∠-4.3 = 46.2∠-38
- I0 = I1 X (Z’2 +Z’L)/(Zm +Z’2 +Z’L) =54.8∠-33.7 x 49∠37.3/290∠15.6
- =54.8∠-33.7 x0.169∠21.7 = 9.26∠-12
- Input power factor = cos 33.7 = 0.832 lagging
- Power input = V1I1 cos ϕ 1 = 2300x 54.8x0.832 = l105 kW
- Power output = 46.22x38.7=82.7 kW
- Primary Cu loss = 54.82x0.286 =860 W
- Secondary Cu loss = 46.22x0.319 = 680 W; Core loss = 0.262x 240 = 20.6 kW
- η= (92.7/105)x100=78.8%; V’2=I’2Z’1 = 46.2x48.4=2,240 V
- Regulation = 2300-2240/2240 x 100=2.7%

- **Prob1**:-In a test for the determination of the losses of a 440-V, 50 Hz transformer, the total iron losses were found to be 2500 W at normal voltage and frequency. When applied voltage and frequency were 220V and 25Hz, the iron losses were found to be 850 W. calculate the eddy current loss at normal frequency and voltage
- **Solu** : flux density is remain constant in both cases and voltage and frequency is half in second.
- Hence eddy curent loss We $\propto$ f2 hence We= Af2 and hysteresis loss Wh $\propto$ f hence Wh=Bf
- Where A,B are constant
- Total iron losses Wi = We+Wh =Af2 +Bf = f(Af +B)
- Af+B = Wi/f (1)
- A*50 + B = 2500/50 = 50
- A*25 + B = 850/25 = 34
- A = 0.64 AND B = 18
- We = A f2 = 0.64*502 = 1600 W
- Wh = Bf = 18*50 = 900 W

- **Prob2**:- When a transformer is connected to a 1000-V, 50 Hz supply, the core loss is 1000W, of which 650 is hysteresis and 350 is eddy current loss. If the applied voltage is raised to 2000 v and the frequency 100Hz, find the new losses.
- **Solu** : flux density is remain constant in both cases and voltage and frequency is half in second.
- Hence eddy curent loss We $\propto$ f2 hence We= Af2 and hysteresis loss Wh $\propto$ f hence Wh=Bf
- Where A,B are constant
- **For 1000V at 50 Hz**
- Wh = Af =A*50
- A = Wh/f = 650/50 =13
- We =Bf2
- B = 350/50*50 = 7/50
- **For 2000V at 100 Hz**
- We = B f2 = (7/50)*1002 = 1400 W
- Wh = Af = 13*100 = 1300 W
- New core loss is 1300+1400=2700W

- A transformer with normal voltage impressed has a flux density 1.4 Wb/m2 and , the core loss consisting 1000 W eddy current loss and 3000 is hysteresis loss. What do these losses become under following conditions :
- Increasing the applied voltage by 10% at rated frequency.
- Reducing the frequency by 10% with normal voltage.
- Increasing both voltage and frequency by 10%.
- **solu**
- since voltage eq. is E = 4.44 f NBm A
- Bm ∝ E/f
- Hysteresis loss Wh =PBm1.6f and We = Q Bm2f 2
- Wh = P(E/f)1.6f and We = Q (E/f)2f 2
- 3000 = PE1.6f -6 and 1000 = Q E2 …….. eq 1
- where E and f are the normal values of primary voltage and frequency
- here voltage becomes = E +10% E =1.1E ……..eq2
- The new Hysteresis loss Wh =P(1.1E)1.6f -6f
- From eq 1 and 2 Wh/3000 = (1.1E)1.6 Wh = 3000 * 1.165 = 3495 W
- New eddy –current loss is We = Q (1.1E)2
- Hence We/1000 = (1.1)2
- We =1000 * 1.21=1210 W
- when frequency change eddy current loss would not be effected. The new hysteresis loss
- Wh = PE1.6(0.9f)-6
- Wh/3000 = (0.9)-6 = 3000 * 1.065 =3196 W
- In this case both E and f are increased by 10%. The new losses becomes
- Wh = PE1.6(0.9f)-6 therefore Wh/3000 = (1.1)1.6(0.9)-6
- Wh = 3000 * 1.165 * 0.944 = 3299 watt
- As We is unaffected by changes in frequency but affected by voltage changes and its value same in case (a) i.e.1210W

- **Prob3**:-A 30-kV A,6000/230-V single-phase transformer has the following parameters:-
- Primary winding ressitance=10Ω
- Secondery winding ressitance referred to primary =10.8Ω
- Primary winding leakage reactance=16Ω
- Secondery winding leakage reactance referred to primary =18Ω
- Calculate, neglecting no-load current, the voltage to be applied to the primary to circulate full-load current when the secondery is short-circuited. What is the power factor on short- circuit?
- **Solution.**
- R01=r1+r2=10+10.8=20.8Ω; X01=X1+X2=16+18=34Ω
- Z01= √(R201+ X201)=√(20.82+342)=39.8Ω
- F.L. secondery current,I2=30x103/230=130.4A;K=230/6000=23/600
- F.L. primaery current I1=I'2=KI2=(23/600)x130.4=5A
- Vsc=I1Z01=5x39.8=**199V**
- Short circuit p.f.=cosϕ0=R01/Z01=20.8/39.8=**0.675**

- **Prob4:-** Obtain the equilant circuit of a 200/400-V,50-Hz,1-phase transformer from the following data:-
- O.C. test :200V,0.7A,70W -on l.v. side
- S.C. test :15V,10A,85W -on h.v.side
- Calculate the secondery voltage when delivering 5kW at 0.8p.f. Langging, the primary voltage being 200V.
- **Solution.**
- **From O.C. Test**
- $V_1 I_0 \cos\phi_0 = W_0$
- $\therefore 200 \times 0.7 \times \cos\phi_0 = 70$
- $\therefore \cos\phi_0 = 0.5$ and $\sin\phi_0 = 0.866$
- $I_w = I_o \cos\phi_0 = 0.7 \times 0.5 = 0.35A$
- $I_u = I_o \sin\phi_0 = 0.7 \times 0.866 = 0.606A$
- $R_o = V_i/I_w = 200/0.35 = 571.4\Omega$
- $X_o = V_i/I_u = 200/0.606 = 330\Omega$
- These value refers to primary i.e. low-voltage side.
- **From S.C. Test**
- It may be noted that in this test, instrument have been placed in the secondary i.e. high- voltage winding whereas the low-voltage winding i.e. primary has been short-circuited.
- $Z_{o2} = V_{sc}/I_2 = 15/10 = 1.5\Omega$; $K = 400/200 = 2$
- $Z_{o1} = Z_{o2}/K^2 = 1.5/4 = 0.375\Omega$
- Also $I_2^2 R_{o2} = W$; $R_{o2} = 85/100 = 0.85\Omega$; $R_{o1} = R_{o2}/K^2 = 0.85/4 = 0.21\Omega$
- $X_{o1} = \sqrt{(Z_{o2}^2 - R_{o1}^2)} = \sqrt{(0.375^2 - 0.21^2)} = 0.31\Omega$
- Output kVA $= 5/0.8$; output current $I_2 = 5000/0.8 \times 400 = 15.6A$
- This value of I_2 is approximate because V_2(Which is to be calculated as yet) has been taken equal to 400V
- (Which, in fact, is equal to E_2 or $_0V_2$).
- Now, $Z_{o2} = 1.5\Omega$, $R_{o2} = 0.85\Omega$ $\therefore X_{o2} = \sqrt{(1.5^2 - 0.85^2)} = 1.24\Omega$
- Total transformer drop as refered to secondery
- $= I_2(R_{o2}\cos\phi_2 + X_{o2}\sin\phi_2) = 15.6(0.85 \times 0.8 + 1.24 \times 0.6) = 22.2V$
- $\therefore$ $V_2 = 400 - 22.2 =$ **377.8V**

- **Prob5** Starting from the ideal transformer, obtain the approximate equivalent circuit of a commercial transformer in which all the constant are lumped and represented on one side.
- A1-phase transformer has turn ratio of 6. The resistance and reactance of primary winding are 0.9Ω and 5Ω respectively and those of the secondary are 0.03Ω and 0.13Ω respectively. If 330-Vat 50-Hz be applied to high voltage winding with low voltage winding short circuited, find the current in the low voltage winding and its power factor. Neglect magnetizing current.
- **Solution.** Here K =1/6;R01=R1+R2=0.9+(0.03x36)=1.98Ω
- Xo1=X1+X2=5+(0.13x36)=9.68Ω
- Zo1=√(9.682+1.982)=9.9Ω;Vsc=330V
- Full load primary current Ii=Vsc/Zo1=330/0.9=100/3A
- As Io is negligible,hence I1=I’2=100/3A. Now,I’2=KI2
- F.L. secondery current I1=I2/K=(100/3)x6=200A
- Now, power input on short – circuit =Vsc I1cosϕsc ; cosϕsc=**0.2.**

- **Prob6** A 1-phase, 10-kVA,500/250-V,50-Hz transformer has the following constant:
- Reactance: primary 0.2Ω;secondery 0.5Ω
- Ressitance :primary 0.4Ω;secondery 0.1Ω
- Ressitance of equilant exciting circuit referred to primary, Ro= 1500Ω
- Reatance of equilant exciting circuit referred to primary, Xo= 750Ω
- What would be the readings of the instruments when the transformer is connected for the open-circuit and short- circuit tests ?
- **Solution.**
- **<u>O.C.Test</u>**
- Iu=Vi/X=500/750=2/3A;Iw=Vi/Ro=500/1500=1/3A
- ∴ Io=√[(1/3)2+(2/3) 2]=0.745 A
- No load primary input =V1Iw=500x1/3=167W
- Instruments used in primary circuit are: voltmeter, ammeter and wattmeter, their reading being 500V,0.745A and 167W respectively.
- **S.C.Test**
- Suppose S.C. test performed by short-circuiting the l.v. winding i.e. the secondery so that all instruments are in primary.
- R01=R1+R2=R1+R2/K2; here K=1/2 ∴ R01=0.2+(4x0.5)=2.2Ω
- Similarly, X01=X1+X2=X1+X2/K2=0.4+(4x0.1)=0.8Ω
- Z01=√(2.22+0.82)=2.341Ω
- Full load primary current
- I1=10,000/500=20A ∴ Vsc=I1Z01=20x2.341=46.8V
- Power absorbed=I21R01=20x2.2=880W
- Primary instruments will read : **46.8V,20A,880W**.

- **Prob7.** The equivalent circuit for a 200/400-V step-up transformer has the following parameters referred to the low voltage side.
- Equivalent resistance =0.15Ω; equivalent reactance=0.37Ω
- Core-loss component ressitance=600Ω; magnetising reactance=300Ω
- When the transformer is supplying a load of 10 A at a power factor of 0.8lag, calculate (i) the primary current (ii) secondary terminal voltage.
- **Solution.** We are given the following :
- R01=0.15Ω, X01=0.37Ω; R0=600Ω, X0=300Ω
- Using the approximate equivalent circuit of fig., we have,
- Iu=V1/X0=200/300=(2/3)A
- Iw=V1/R0=200/600=(1/3)A
- I0=√(I2u+I2w)=√[(2/3) 2+(1/3) 2]=0.745A
- As seen from fig
- tanθ=Iw/Iu=1/3 / 2/3= ½;θ=26.6
- ∴ϕo=90-26.6=63.4; angle between Io and
- I'2=63.4-36.9=26.5;K=400/200=2
- I2=KI2=2x10=20A
- I1=(0.7452+202+0.745x20xcos26.5) 1/2
- = **20.67 A**
- (ii)R02=K2Ro1=22x0.15=0.6Ω
- X02=22x0.37=1.48 Ω
- Approximate voltage drop=I2(R02 cos ϕ + X0 sin ϕ)
- = 10(0.6x0.8+1.48x0.6)=13.7 V
- ∴secondary terminal voltage = 400-13.7
- =**386.3 V**

- **Prob8 .**The S.C. test on a 1-phase transformer, with the primary winding short-circuited and 30 V applied to the secondary gave a wattmeter reading of 60 W and secondary current of 10 A. if the normal applied primary voltage is 200, the transformation ratio 1:2 and the full load secondary current 10A, calculate the secondary terminal p.d. at full load current for (a) unity power factor (b) power factor 0.8 lagging.
- If any approximation are made, they must be explained. **[394V,377.6V]**
- **Prob9**. A single phase transformer has a turn ratio of 6, the resistances of the primary and secondary windings are 0.9Ω and 0.25 Ω respectively and the leakage reactance of these windings are 5.4Ω and 0.15Ω respectively. Determine the voltage to be applied to the low voltage winding to obtain a current of 100 A in the short- circuited high voltage winding. Ignore the magnetising current **[82V]**
- **Prob10**.draw the equivalent circuit for a 3000/400-V,1-phase transformer on which the following test results were obtained. Input to high voltage winding when l.v. winding is open circuited:3000V,0.5A,500W. input to l.v.winding when h.v.winding is short circuited:11V,100A,500W. insert the appropriate values of ressitance and reactance.
- [**Ro=18,000Ω, Xo=6,360Ω, Ro1=2.81Ω, Xo1=5.51Ω**]
- **Prob11. the iron loss in a transformer core at normal flux density was measured at frequencies of 30 and 50 Hz, results being 30 W and 50 W respectively. Calculate (a) the hysteresis loss and (b) the eddy current loss at 50 Hz.**

  [44W,10 W]

- **TUTOREAL PROBLEM NO. 6**
- The corrected instrument readings obtained from open and short-circuit tests on 10-kVA, 450/120 – V, 50 Hz transformer are :
- **O.C.TEST –**
- $V1$ = 120 V; $I1$ = 4.2 A; $W1$ = 80 W ; $V1$, $W1$ and $I1$ were read on the low-voltage side .
- **S.C.TEST –**
- $V1$ = 9.65 V; $I1$ = 22.2 A; $W1$ = 120 W - with low-voltage winding short- circuited.
- **Compute :**
- the equipment circuit (approximate) constants
- efficiency and voltage regulation for an 80% lagging p.f. load

- **Example 27-21**A 30-kV A,6000/230-V single-phase transformer has the following parameters:-
- Primary winding ressitance=10Ω
- Secondery winding ressitance referred to primary =10.8Ω
- Primary winding leakage reactance=16Ω
- Secondery winding leakage reactance referred to primary =18Ω
- Calculate, neglecting no-load current, the voltage to be applied to the primary to circulate full-load current when the secondery is short-circuited. What is the power factor on short- circuit?
- **Solution.**R01=r1+r2=10+10.8=20.8Ω; X01=X1+X2=16+18=34Ω
- Z01= √R01+ X01=√20.8+34=39.8Ω
- F.L. secondery current,I2=30x10/230=130.4A;K=230/6000=23/600
- F.L. primaery current I1=I2=KI2=(23/600)x130.4=5A
- Vsc=I1Z01=5x39.8=**199V**
- Short circuit p.f.=cos =R01/Z01=20.8/39.8=**0.675**

- **Example 27.22** Obtain the equilant circuit of a 200/400-V,50-Hz,1-phase transformer from the following data:-
- O.C. test :200V,0.7A,70W -on l.v. side
- S.C. test :15V,10A,85W -on h.v.side
- Calculate the secondery voltage when delivering 5kW at 0.8p.f. Langging, the primary voltage being 200V.
- **<u>Solution. From O.C. Test</u>**
- $V_1 I_0 \cos\varnothing_0 = W_0$
- $\therefore 200 \times 0.7 \times \cos\varnothing_0 = 70$
- $\therefore \cos\varnothing_0 = 0.5 \quad \sin\varnothing_0 = 0.866$
- $I_w = I_o \cos\varnothing_0 = 0.7 \times 0.5 = 0.35A$
- $I_u = I_o \sin\varnothing_0 = 0.7 \times 0.866 = 0.606A$
- $R_o = V_i/I_w = 200/0.35 = 571.4\Omega$
- $X_o = V_i/I_u = 200/0.606 = 330\Omega$
- As shown in Fig 27.48 these value refers to primary i.e. low-voltage side.

- **From S.C. Test**
- It may be noted that in this test, instrument have been placed in the secondary i.e. high- voltage winding whereas the low-voltage winding i.e. primary has been short-circuited.
- Now, as shown in Art. 27.22
- $Zo2=Vsc/I2=15/10=1.5\Omega$; $K=400/200=2$
- $Zo1=Zo2/K2=1.5/4=0.375\Omega$
- Also $I2Ro2=W$; $Ro2=85/100=0.85\Omega$;$Ro1=Ro2/K2=0.85/4=0.21\Omega$
- $Xo1=\sqrt{}Zo2-Ro1=\sqrt{}0.375-0.21=0.31\Omega$
- Output kVA =5/0.8;output current $I2=5000/0.8x400=15.6A$
- This value of I2 is approximate because V2(Which is to be calculated as yet) has been taken equal to 400V
- (Which, in fact, is equal to E2 or oV2).
- Now, $Zo2=1.5\Omega$, $Ro2=0.85\Omega$ $\therefore Xo2=\sqrt{}1.5-0.85=1.24\Omega$
- Total transformer drop as refered to secondery
- $=I2(Ro2\cos\varnothing 2+Xo2\sin\varnothing 2)=15.6(0.85x0.8+1.24x0.6)=22.2V$
- $\therefore$ $V2=400-22.2=$**377.8V**

- **Example 27.23** Starting from the ideal transformer, obtain the approximate equilant circuit of a commercial transformer in which all the constant are lumped and represented on one side.
- A1-phase transformer has turn ratio of 6. The ressitance and reactance of primary winding are 0.9Ω and 5Ω respectively and those of the secondery are 0.03Ω and 0.13Ωrespectibvely. If 330-Vat 50-Hz be applied to high voltage winding with low voltage winding short circuited, find the current in the low voltage winding and its power factor. Neglect magnetisiny current.
- **Solution.** Here K =1/6;R01=R1+R2=0.9+(0.03x36)=1.98Ω
- Xo1=X1+X2=5+(0.13x36)=9.68Ω
- Zo1=√(9.68+1.98)=9.9Ω;Vsc=330V
- Full load primary current Ii=Vsc/Zo1=330/0.9=100/3A
- As Io is negligible,hence I1=I2=100/3A. Now,I2=KI2
- F.L. secondery current I1=I2/K=(100/3)x6=200A
- Now, power input on short – circuit =Vsc I1cos∅sc; cos∅sc=**0.2.**

- **Example 27.24** A 1-phase, 10-kVA,500/250-V,50-Hz transformer has the following constant:
- Reactance: primary 0.2Ω;secondery 0.5Ω
- Ressitance :primary 0.4Ω;secondery 0.1Ω
- Ressitance of equilant exciting circuit referred to primary, Ro= 1500Ω
- Reatance of equilant exciting circuit referred to primary, Xo= 750Ω
- What would be the readings of the instruments when the transformer is connected for the open-circuit and short- circuit tests ?