Ch3: Transformer

(1)

Magnetic Materials materials in which a state of magnetisation can be induced.

1. **Paramagnetic materials** which are not strongly attracted by a magnet eg aluminium, tin (μ_r – relative permeability is small but +ive)
2. **Diamagnetic materials** which are repelled by a magnet. eg Zinc, mercury, lead (μ is slightly less than unity)
3. **ferromagnetic materials** The material which are strongly attracted by a magnet eg iron, steel, nickel (μ is very high several hundred to many thousand).

ferromagnetic materials

a) Soft magnetic materials (which are easily magnetized)
eg. iron and its alloy with nickel, cobalt.
Uses Transformer, generators & relay

b) Hard magnetic materials (those retaining their magnetising with great tenacity)
eg. Include cobalt steel & alloys of nickle, Aluminium.
Uses Also known as permanent magnet uses in loudspeaker.

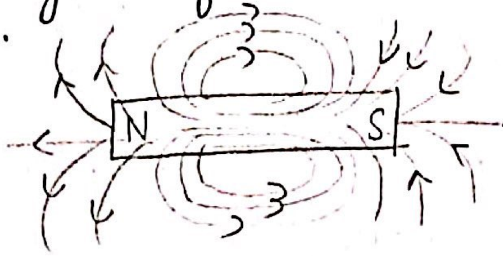
4. **ferrites** A special group of ferromagnetic material that occupy an intermediate position b/w ferromagnetic & non magnetic materials.

Ferrites

a) Hard ~~Soft~~ ferrites
These are ceramic permanent magnetic materials. eg. $BaFeO_3$ (barium Iron oxide)
$SrFeO_3$ (Stronium Iron oxide)
Uses: loudspeaker, telephone

b) Soft ~~Hard~~ ferrites.
Ceramic magnets/ ferromagnetic ceramic are made of Iron oxide (FeO_3) with one or more divalent oxide such as NiO, MnO, ZnO
Uses Tranducer

Magnetic field The space around the pole of a magnetic is called magnetic field and is represented by magnetic lines of force.



field around a bar magnet represented by lines of force :

Magnetic flux is the total no. of line of force comprising the magnetic field. ϕ (symbol) webers (unit)

Magnetic flux Density is defined as magnetic flux passing per unit area through any material (& known as magnetic induction)

$$B = \frac{\phi}{d(\text{area})}$$ (scalar quantity)

Imp

Relationship b/w Induction density & magnetic field intensity

$B = \mu_0 H$ (in free space)

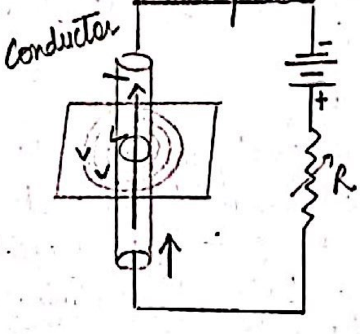
$B = \mu_0 \mu_r H$ — μ_r relative permeability (varies)

$B = \mu H$ — μ_0 = permeability of free space $= 4\pi \times 10^{-7}\ H/m$. (const)

Relative permeability is the ratio of flux density produced in magnetic material to flux density produced in vacuum.

Magnetic field due to electric current flow.

When a conductor carries electric current the magnetic lines of force is set up and the region around the magnet where its poles exert a force is called magnetic field.



* field near the conductor is stronger & become weak as radial distance Ies.
* Strength of magnetic field around the conductor depend upon the current flow through it.
* The direction of M.F ⊥ to direction of flow of current in it reverse then the direction of flow of current reverse

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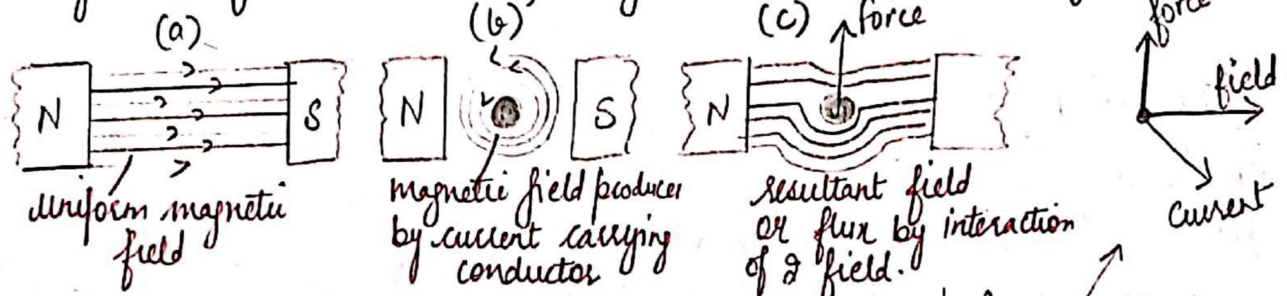
The direction of magnetic lines of force around conductor is determined by: (2)

Right Hand thumb Rule
(thumb point the direction of flow of current
curling fingers: direction of magnetic lines of force)

Right hand cork screw rule
screw rotation (clockwise) direction of magnetic lines of force
current (inward)

force on current carrying conductor place in the M.F

When a current carrying conductor is placed in uniform magnetic field $\perp$ to it, a force is experienced by a conductor



* The direction of force is determine by fleming's left Hand rule.
* If direction of current is reverse in conductor, the force produce on conductor is also reversed.

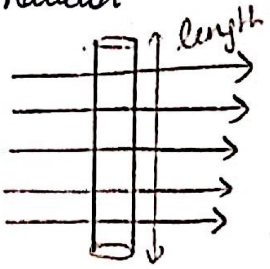
∴ force experienced by current carrying conductor

$f = BIl$ (at right angle)

or

$f = BIl \sin\theta$ (conductor lies at θ with M.f)

B → flux density
I → current
l → effective length of conductor $\perp$ to field.



B-H curve / magnetisation Imp

The curve giving relationship between induction density (B) (magnetic flux density) and magnetising force (H) (magnetic field intensity) is known as B-H curve.

It has 4 distinct region oa, ab, bc and region beyond c.

~~1. oa (In this region the B increases almost linear with H)~~

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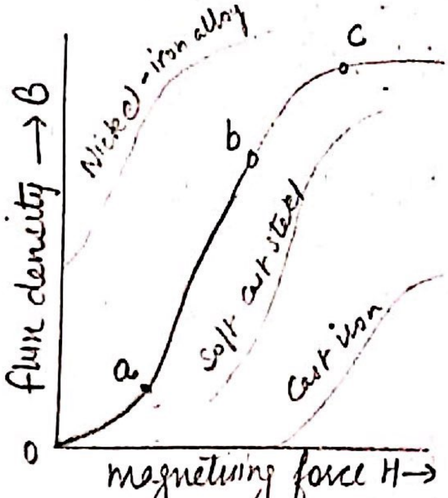
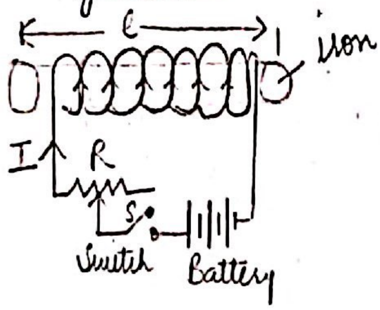
1. Oa: increase in B is very small
2. ab: B increases almost linearly with H
3. bc: Again the increase in B is small
4. Region beyond point C: B is almost const.
(This is due to magnetic saturation of the material)



* BH curve depend on material only. So it is different from cast iron, soft cast steel, nickel iron alloy.

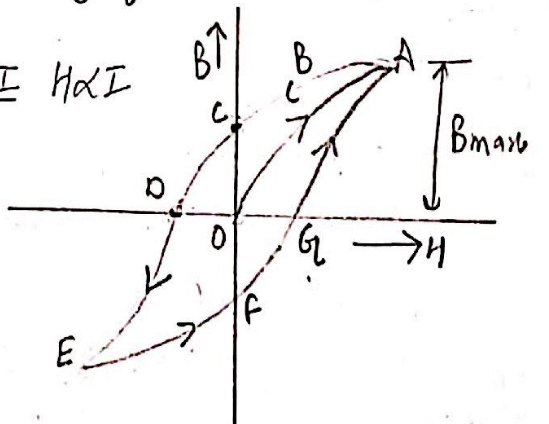
Smaik - V.Imp

Magnetic Hysteresis If magnetic substance is magnetised in strong M.f, it retains magnetism after the magnetic force has been withdrawn. The phenomenon of lagging of magnetisation or (B) behind the magnetising force is known as magnetic hysteresis.



$H = \frac{NI}{l}$ $H \alpha I$

$B = \mu H$



$H = \frac{NI}{l}$

$H \alpha I$

* When current flows the magnetising force produce. Let H is increased from zero to a certain maximum value and then gradually reduce to zero.

* The values of B in the core is determined from various value of magnetising force (H)

* It will observed that B-H curve obtained for decreasing value of H lies above that obtained for increasing values of H.

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* The induction density B is represented by OC and $H=0$ is called as residual magnetism. The power of retaining the RM is called retentivity of the material.

* If direction of current flow is reversed, H is reversed. The current be increased in negative direction until $B=0$ & when $B=0$ $H=OD$ as show in fig. It neutralize the RM, & known as coercive force (demagnetising force)

* If demagnetising force (H) is increased further to the maximum value and again decreased to zero, reversed and further increased in original or true direction of max value, a closed loop ACDEFGA is obtained, which is usually known as hysteresis loop & magnetic cycle

* B lags behind H and these two never attain zero value simultaneously.

Imp

* Faraday's Law of electromagnetic Indution.
* Dynamically & statically induced emf?
* Coefficient of coupling $K = \frac{M}{4L_2}$

Extra

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* Analogy b/w Electric & Magnetic circuit: V.V. Imp

Electric Circuit	Magnetic Circuit
Similarities:	
1. The closed path for electric current	1. The closed path for magnetic flux.
2. current = $\frac{emf}{resistance}$	2. flux = $\frac{mmf}{reluctance}$
3. Current is in ampere	3. flux in weber
4. Emf in volts	4 mmf in AT
5. Resistance $R = \rho \frac{l}{a}$	5 Reluctance $S = \frac{l}{a \mu_0 \mu_r}$
6. conductance = $\frac{1}{Resistance}$	6 Permeance = $\frac{1}{Reluctance}$
7. Conductivity Permitivity (ε)	7 μ Permeability
8. Resistivity	8 Reluctivity
9. $J = \frac{I}{a}$ current density	9 $B = \frac{\phi}{a}$ flux density
10. $\mathcal{E} = \frac{V}{d}$ electric field intensity	10. $H = \frac{NI}{l}$ magnetic field intensity
Dissimilarities	
1. Electric Current flow	1. Magnetic flux doesnot flow it set up.
2. There are large no. of insulators	2. for ϕ, no perfect insulator need. It can be set up in air, rubber, glass.
3. Energy is expanded and dissipated in the form of heat.	3. Once magnetic field is setup no energy is expanded.

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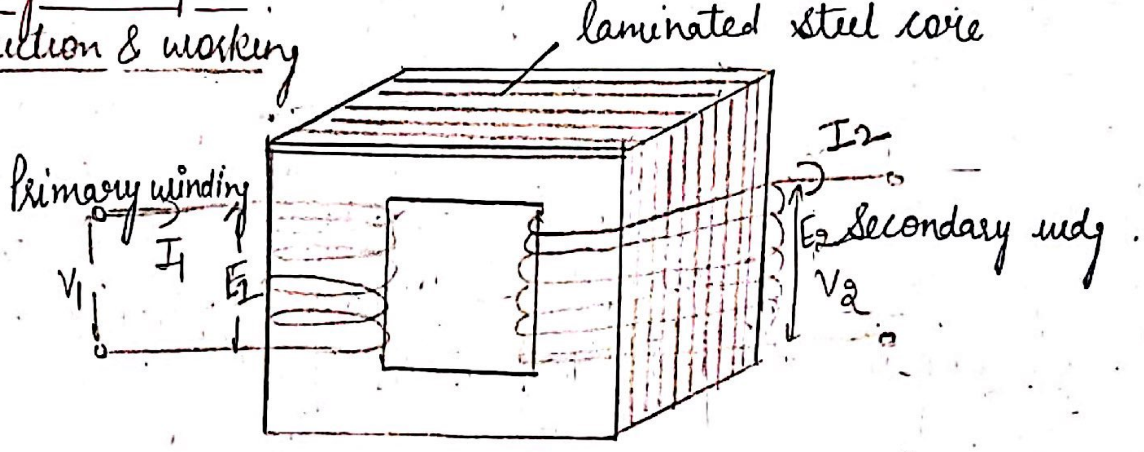
Transformer

A transformer is a static device which transfers ac electric power from one circuit to other at the same freq; but the voltage level is usually changed.

* When the voltage is raised on the output side $V_2 > V_1$ the transformer is called a step up transformer.
* When the voltage is lowered on the output side $V_2 < V_1$ the transformer is said to be step down transformer.

Operating Principle

Construction & working



* The core is built up of thin silicon steel lamination to provide a path of low reluctance to the magnetic flux.
* Primary wdg = connected to supply mains.
  Secondary wdg = connected to the load circuit.
* HV winding: The wdg. connected to higher voltage circuit is called the high voltage winding.
  LV winding: Connected to lower voltage circuit.

Basic principle of transformer is electromagnetic induction.

Working If ac supply is given to primary winding, a current flows through it which produces an alternating flux ϕ in the core. Since this flux is alternating and links it with secondary winding also, induce an emf in secondary winding. The emf in secondary winding enables it to deliver current to an external load connected across it.

* Thus energy is transformed from primary winding to secondary winding by means of electromagnetic induction.

* The flux of core links not only with secondary wdg but also with primary wdg, so produces self induced emf in primary wdg. This induced emf in the primary wdg oppose the voltage applied by the source. ∴ it's known as back emf of the primary.

Transformer on DC

It cannot operate on DC supply and never connected to a dc source.

Reason: If DC voltage is connected to Primary wdg. the flux produced in core will not vary but remain constant in magnitude ∴ no emf will induced in secondary winding except at moment of switching ON. No self induced emf in primary winding. Due to this a heavy current flow through the primary side which may result in damage / burn the primary winding.

* Transformer on load and No load. (refer book) Imp. Phasor diagram

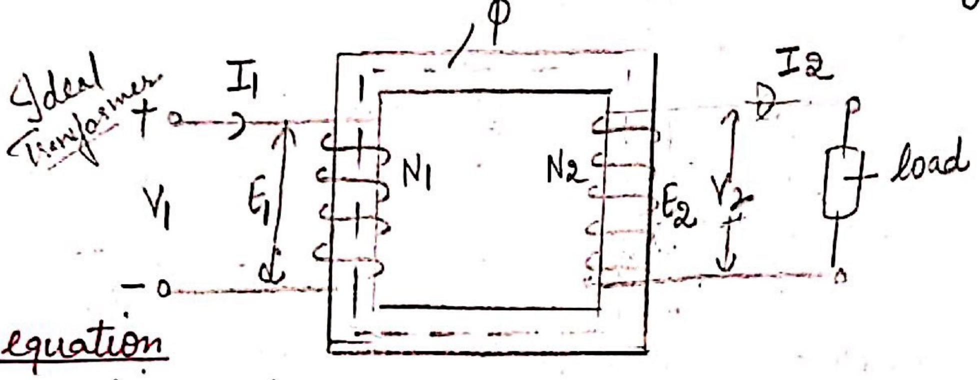
Transformer

Ideal transformer

it is an imaginary transformer that has no winding resistance, no magnetic leakage, no iron loss and zero reluctance

Actual/ Practical transformer

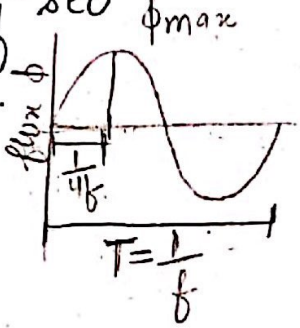
it is an actual transformer which operate at particular frequency and has wdg resistance magnetic leakage, iron losses copper loss & magnetic reluctance



Emf equation

EMF equation ϕ_{max}, f ϕ_{max} at $\frac{1}{4f}$ sec ϕ_{max}

Average Rate of change of flux $\frac{d\phi}{dt} = \frac{\phi_{max}}{\frac{1}{4f}} = 4f\phi_{max}$.



form factor

~~Rms~~ Avg. emf induced per turn $= 4f\phi_{max}$ Volts

$E_{rms} = 1.11$ E_{avg}

Rms value of emf induced $= 1.11 \times 4f\phi_{max}$

On primary side

$$E_1 = 4.44f\,\phi_{max} \times N_1$$

On Secondary side

$$E_2 = 4.44f\,\phi_{max} N_2$$

where $\phi_{max} = B_{max} \times a$ webers)

Transformation Ratio

$$K = \frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{N_2}{N_1}$$ Voltage transformation ratio

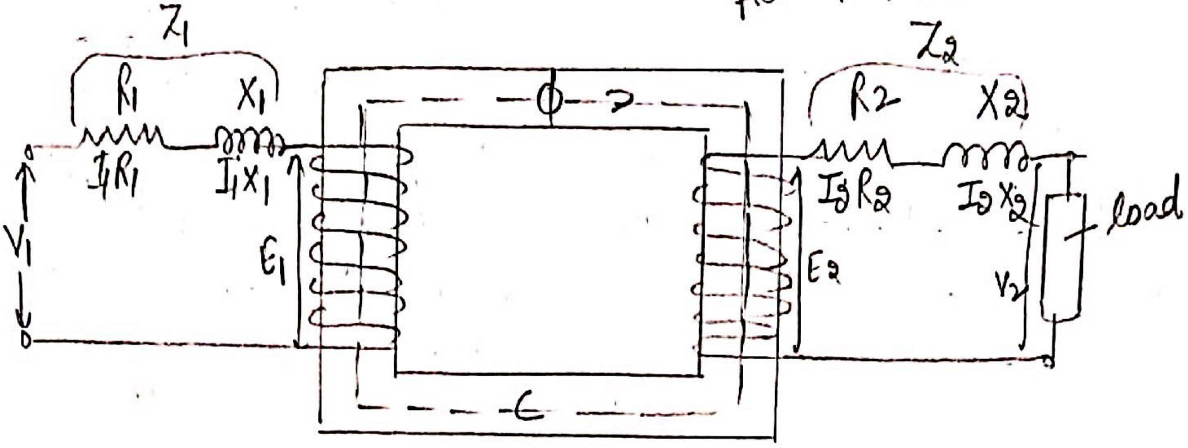
$\because$ Output P = Input P

$V_2 I_2 = V_1 I_1$

$$\frac{I_1}{I_2} = \frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{N_2}{N_1} = K \quad \text{or} \quad \frac{I_2}{I_1} = \frac{1}{K}$$ Current transformation ratio

Equivalent circuit of Transformer Imp

1 Equivalent resistance and reactance — Actual / practical Transformer.



Referred to Sec. side

Total Resistive drop $= KI_1R_1 + I_2R_2$

$I_1 = KI_2$ (primary resistive drop)

(As primary resistive drop referred to sec. will be K times of i.e. KI_1R_1 and KI_1X_1)

Total Res. drop $= K^2 I_2 R_1 + I_2R_2$

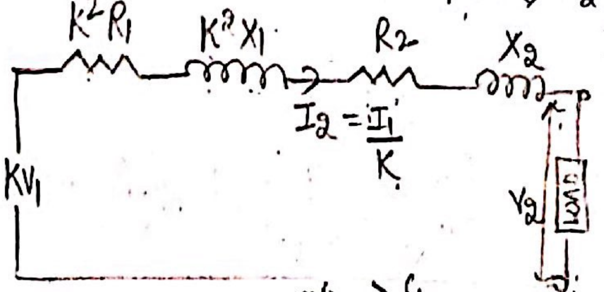
$= I_2(K^2R_1 + R_2) = I_2R_{02}$

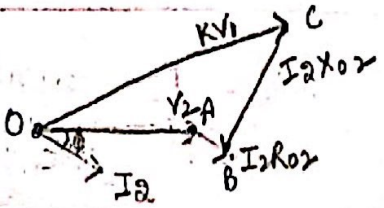
IIly reactive drop

$= KI_1X_1 + I_2X_2$

$= K^2 I_2 X_1 + I_2X_2$

$= I_2(K^2X_1 + X_2) = I_2X_{02}$





Referred to primary side

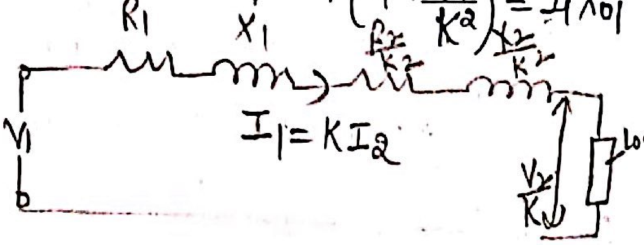
Sec Resistive drop referred to primary

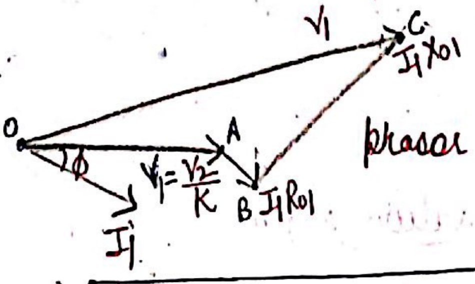
$$\frac{I_2R_2}{K} = \frac{I_1R_2}{K^2}$$

IIly reactive drop $\frac{I_2X_2}{K} = \frac{I_1X_2}{K^2}$

∴ T. Resistive drop $= I_1\left(R_1 + \frac{R_2}{K^2}\right) = I_1R_{01}$

T. Reactive drop $= I_1\left(X_1 + \frac{X_2}{K^2}\right) = I_1X_{01}$





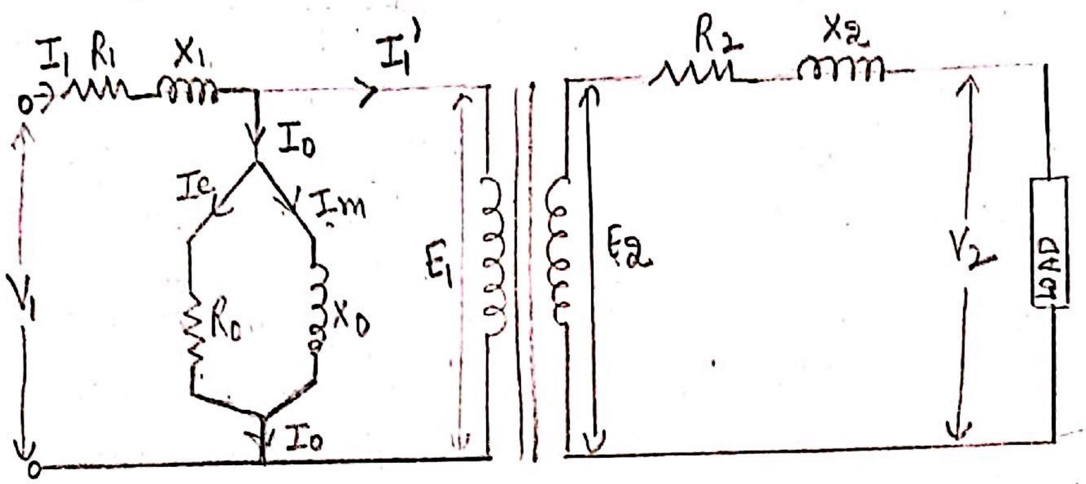
phasor diagram

$$V_1 = \sqrt{\left(\frac{V_2}{K} + I_1R_{01}\cos\phi + I_1X_{01}\sin\phi\right)^2 + \left(I_1X_{01}\cos\phi + I_1R_{01}\sin\phi\right)^2}$$

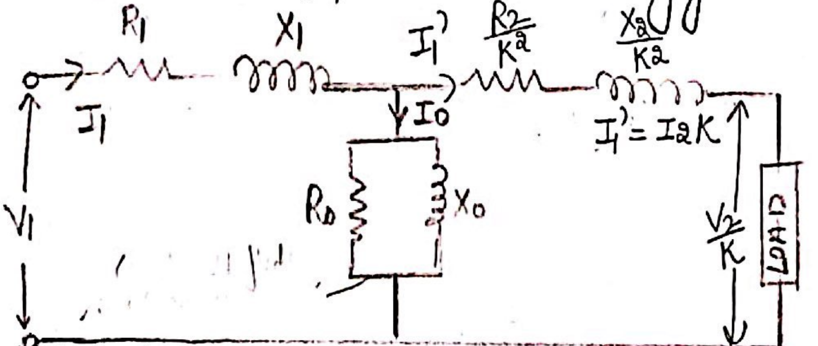
Resistive load $= V_1 = \sqrt{\frac{V_2}{K} + I_1R_{01}\cos\phi}$ small

Capacitive load $V_1 = \sqrt{\frac{V_2}{K} + I_1R_{01}\cos\phi - I_1X_{01}\sin\phi}$

Equivalent circuit of a transformer is very helpful in determination of behaviour of the device under various condition of operation.



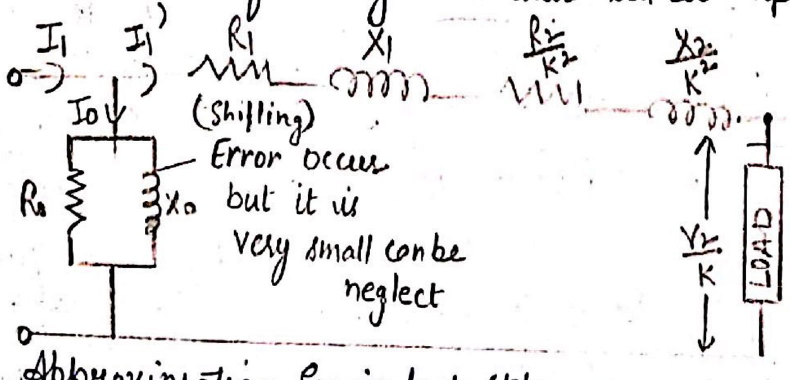
The induced emf in primary wdg. E_1 causes less primary voltage drop. This voltage causes iron loss current (I_c) and magnetising current (I_m) to flow. These 2 component of no load current represented by non inductive resistance R_0 and pure reactance (X_0) as shown in fig.



where $K = \frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{N_2}{N_1}$

No load Condition

Equivalent Circuit of transformer with all Sec. Impedances transferred to Primary side



I_0 is very small as compare to full load rated current.

So under load condition this branch can be omitted.

Approximation Equivalent ckt.

Losses in Tranformer:

The transformer is static device so there are no friction or windage losses.

losses occuring in a transformer

- Iron or Core losses (constant losses)
- Copper or ohmic losses (Variable losses) — full load losses

1. **Iron losses**. Caused by alternating flux in the core.

a) Hysteresis loss: The core is subjected to an alternating magnetizing force and for each cycle of emf a hysteresis loop is traced out.

(When the magnetic material is subjected to reversal of flux, power is required for continous reversal of molecular magnets. This power is dissipated in the form of heat and called hystersis loss. This loss can be minimized by using silicon steel material for construction of core)

$$P_H = K_h (B_{max})^{1.6} f V$$

K_h — hysteresis coefficient; B_{max} — flux Density; f — frequency; V — Volume

2b. Eddy current loss: Since flux in the core of transformer is alternating, it links with the magnetic material of the core itself. This induces an emf in the core & circulates eddy currents. Power is required to maintain these eddy currents. This power is dissipated in the form of heat and is called eddy current loss.

$P_e = K_e V f^2 t^2 B_{max}^2$ (minimised by making core of thin lamination)

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2. Copper or Ohmic losses (7)

These losses occur due to the ohmic resistance of transformer windings.

Copper losses $(P_c) = I^2 R$ or $(I_1^2 R_{01} + I_2^2 R_{02})$ (Primary, Secondary).

These losses are variable loss (as load varies the current varies)

Voltage Regulation

When a T/f is loaded, with a const. supply voltage the terminal voltage changes due to voltage drop in the internal parameter of the transformer i.e. primary and secondary resistance and inductive reactance.

The internal V.D is also depends upon the load and its power factor.

* At const. supply voltage, the change in secondary terminal voltage from no load to full load w.r.t no load voltage is called Voltage regulation of T/f

$$V.R = \frac{E_2 - V_2}{E_2}$$

$$\% V.R = \frac{E_2 - V_2}{E_2} \times 100$$

for inductive load $E_2 = V_2 + I_2 R_{02} \cos\phi + I_2 X_{02} \sin\phi$

for capacitive load $E_2 = V_2 + I_2 R_{02} \cos\phi - I_2 X_{02} \sin\phi$ (leading p.f)

where E_2 = secondary terminal voltage at ~~full~~ no load

V_2 = secondary terminal voltage at full load.

Condition for zero regulation. If numi zero

$I_2 R_{02} \cos\phi + I_2 X_{02} \sin\phi = 0$ $\tan^{-}\phi = \frac{-R_{02}}{X_{02}}$ occur at leading power factor

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V. Imp

Efficiency

$$\eta = \frac{\text{Output power}}{\text{Input power}} = \frac{\text{Output power}}{\text{Output power + losses}}$$

$$\eta = \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + P_i + P_c}$$

P_i (Iron loss) = hysteresis + eddy current losses.

P_c (Copper losses) = $I_2^2 R_{02}$ — equivalent resistance refered to secondary side.

{ If x is the fraction of the full load KVA at which η is maximum

$$\eta = \frac{x \times V_2 I_2 \cos\phi}{x V_2 I_2 \cos\phi + P_i + x^2 I_2^2 R_{02}}$$ }

Condition of η_{max}.

$$\eta = \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + P_i + I_2^2 R_{02}} = \frac{\cancel{I_2}(V_2 \cos\phi)}{\cancel{I_2}\left(V_2\cos\phi + \frac{P_i}{I_2} + I_2 R_{02}\right)}$$

$$\eta = \frac{V_2 \cos\phi}{V_2 \cos\phi + \frac{P_i}{I_2} + I_2 R_{02}}$$

$\frac{d\eta}{dI_2} = 0$ - 2nd

1st: $\boxed{\text{efficiency is max. } \frac{d\eta}{dx} = 0}$

$$\frac{d\eta}{dI_2}\left\{V_2\cos\phi + \frac{P_i}{I_2} + I_2 R_{02}\right\} = 0$$

$$-\frac{P_i}{I_2^2} + R_{02} = 0$$

$$-P_i + I_2^2 R_{02} = I_2^2 \times 0$$

$$I_2^2 R_{02} = P_i$$

$$\boxed{P_c = P_i}$$

Copper losses = iron losses

$$\eta_{max} = \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + P_i + P_i}$$

$$\boxed{\eta_{max} = \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + 2P_i}}$$

$$I_2 = \sqrt{\frac{P_i}{R_{02}}}$$

* All day η or energy efficiency or operational η $= \frac{\text{Output in KWh}}{\text{Input in KWh}}$ } over 24 hours

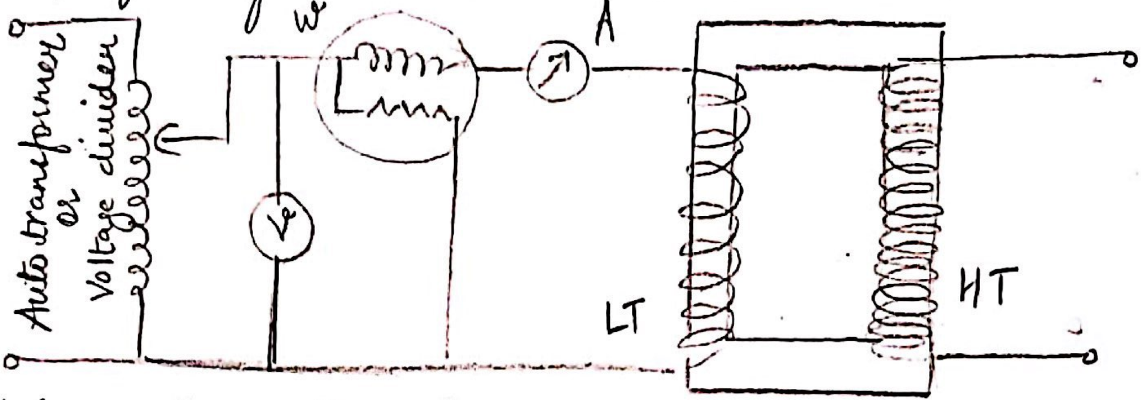
ckt:- circuit

8

Testing of transformer

a) Open ckt test or No load test.

The open circuit test is performed to find out no load current or iron losses of a transformer. This test is performed on low voltage side. The circuit arrangement for performing such test is as shown below.



The low voltage side of transformer is connected to auto transformer or voltage divider for varying the applied voltage. Ammeter, voltmeter and wattmeter are connected to measure I_0, V_{in} and W_{in} (input power). The secondary side is open circuited

Iron loss P_i = Input power at no load = W_0 watt

No load current = I_0 . Applied Voltage = V_{in}

So. $P_i = V_{in} I_0 \cos\phi_0$

$$\phi_0 = \frac{W_0}{V_{in} I_0} \text{ (Angle lag)}$$

No load current energy component $I_e = I_0 \cos\phi_0 = \frac{W_0}{V_{in}}$

No load magnetizing component $I_m = \sqrt{I_0^2 - I_e^2}$ $I_m = I_0 \sin\phi_0$

Equivalent Circuit parameter

$$R_0 = \frac{V_{in}}{I_e} = \frac{V_{in}^2}{W_0} \qquad X_0 = \frac{V_{in}}{I_m} = \frac{V_{in}}{\sqrt{I_0^2 - I_e^2}}$$

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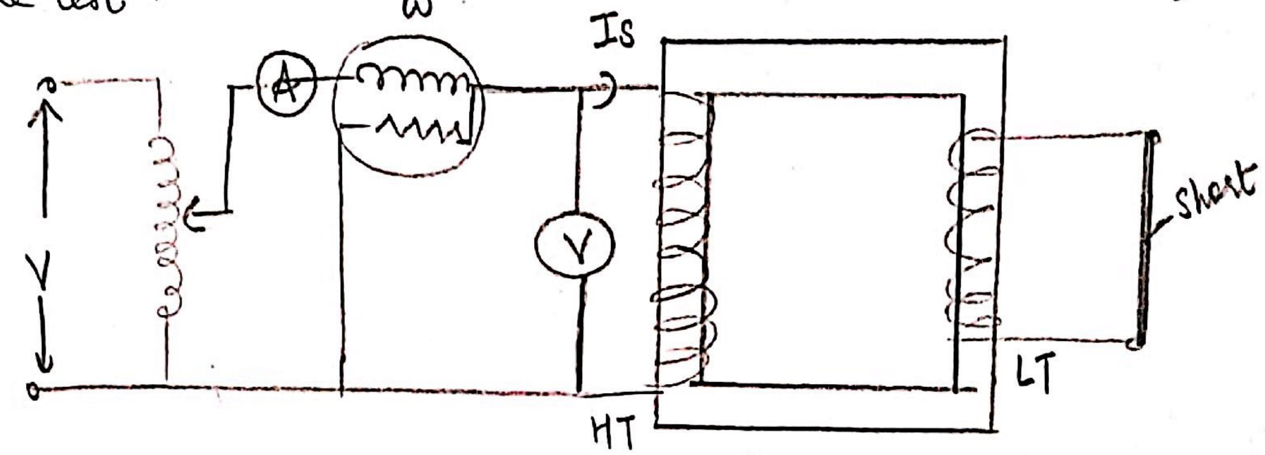
b Short circuit test / impedance test

This test is perform to calculate the full load Cu loss and equivalent Resistance and reactance referred to metering side. The secondary winding (LV wdg) are short circuit by a thick wire while performing the test.



Let the readings of Voltmeter, ammeter and wattmeter be V_s, I_s and W_s respectively.

full load copper loss $= P_c = I_s^2 R_{eq} \doteq W_s$

Equivalent Resistance $R_{eq} = \frac{W_s}{I_s^2}$

Equivalent impedance $Z_{eq} = \frac{V_s}{I_s}$

Equivalent reactance $X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2}$

The above values are referred to the metering side only.

contd.

C. Back to back test / Sumpner's test / Regenerative Test.

This Test is used to calculate temp rise of T/F by operating two X'former back to back for long period & measuring the temp of oil in periodic interval of time ie upto 1 hour.

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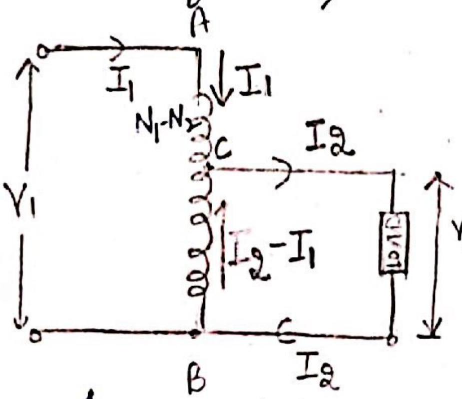
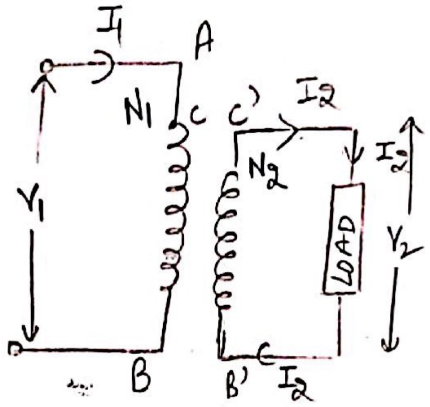
Auto Transformer

The operating principle and general construction of an auto transformer is same as that of conventional two wdg transformer.

(A transformer which has part of winding common to both primary and secondary circuits is called an auto transformer)



Auto Transformer



Conventional 2 winding transformer

Primary wdg. AC I_1 current flow Secondary wdg BC (I_2-I_1) flows.

Power delivered to load $= V_2 I_2$

Power in AC winding $= E_{AC} I_1 = (V_1 - V_2) I_1$.

Power transformed (BC winding) $= V_2 (I_2 - I_1) = V_2 I_2 \left(1 - \frac{I_1}{I_2}\right)$

$= V_2 I_2 (1-K)$

Ratio of $\dfrac{\text{power transformed}}{\text{power delivered}} = \dfrac{\cancel{V_2 I_2}(1-K)}{\cancel{V_2 I_2}} = 1-K$

Power conducted directly = Power delivered − Power transformed

$= V_2 I_2 - V_2 I_2 (1-K) = K \underline{V_2 I_2}$ output power

Conductor material required

In an ordinary transformer wt. of conductor $\propto (N_1 I_1 + N_2 I_2) \propto 2 N_1 I_1$ As $N_1 I_1 = N_2 I_2$

In an auto transformer.

wt. of Cu $\propto$ wt. of copper in section AB + wt. of Cu in BC Section.

Weight of Cu in Section AB $\propto (N_1 - N_2) I_1$

" " " " Section BC $\propto N_2 (I_2 - I_1)$

$\therefore$ weight of conductor in A.T $\propto (N_1 - N_2) I_1 + N_2 (I_2 - I_1)$

Ratio of weights = $\frac{\text{wt. of copper in auto transformer}}{\text{wt of copper in two winding transformer}}$

$$= \frac{(N_1 - N_2) I_1 + N_2 (I_2 - I_1)}{N_1 I_1 + N_1 I_1} = \frac{N_1 I_1 - N_2 I_1 + N_2 I_2 - N_2 I_1}{2 N_1 I_1}$$

$$= \frac{N_1 I_1 + N_2 I_2 - 2 N_2 I_1}{2 N_1 I_1} = \frac{N_1 I_1 + N_1 I_1 - 2 N_2 I_1}{2 N_1 I_1} = \frac{2 N_1 I_1 - 2 N_2 I_1}{2 N_1 I_1}$$

$$= \frac{\cancel{2 I_1} (N_1 - N_2)}{\cancel{2} N_1 \cancel{I_1}} = \left(\frac{N_1}{N_1} - \frac{N_2}{N_1}\right) = (1 - K) \qquad (1-K) = \frac{Wt. auto}{Wt. 2wdg}$$

$\therefore$ $\boxed{\begin{aligned} \text{Saving in copper} &= Wt_{2wdg} - Wt_{o\ auto\ transformer} \\ &= W_{2wdg} - (1-K) W_{2wdg} = K W_{2wdg} \end{aligned}}$

Advantages of Auto transformer

1. Higher efficiency 2. Smaller size 3. lower cost 4. better voltage regulation.

Disadvantages of Autotransformer

1. Due to common connection b/w primary and secondary both side are subject to any stress set up disturbance on either side

2. As voltage ratio of autotransformer increases the common coil is much smaller as compared with entire winding. This means that the economy gained is only a small part of transformer, therefore advantage is minimized

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Uses of autotransformer

1. To give small boost to distribution cable to correct voltage drop.
2. Used as regulating transformer
3. to obtain partial line voltages for starting induction and synchronous motor.
4. As furnances transformer.

Compare Characteristics of autotransformer and a two winding transformer

Autotransformer	Two winding transformer
1. This transformer has only one winding, a part of which is common to both primary and secondary wdg.	1. This transformer has seperate primary and secondary winding.
2. These 2 windings are connected electrically.	2. are not connected electrically.
3. It has lower losses & hence better η.	3. losses are more & hence η is less.
4. It is smaller in size	4. It is larger in size
5. It consume less copper	5. It consume more copper
6. Its cost is less.	6. Its cost is more
7. It has better voltage regulation.	7. It has poor voltage regulation

Three phase Transformer.

A 3ϕ transformer is equivalent to 3 single phase transformer but wound on one core and enclosed with in one common case.

Importance 1. It is cheaper than a bank of 3 single phase transformer due to saving in cost of iron core, tank and oil of the bearings & other auxillary apparatus.

2. More efficient. this is due to the fact that it has shorter magnetic path & volume hence core losses is smaller.

Disadvantages 1. Larger and heavier than one single phase transformer and its difficult to handle, ship & set in place for operation.

2. Difficult & costly to repair. Moreover in case of breakdown in any coil, the entire unit must be removed from service.

So the advantages of three ϕ transformer such as lesser weight, lower initial cost, lesser space requirement overweights its disadvantages.

Different winding arrangment of 3ϕ transformers are

1. Star Star (for high V)
2. Delta Delta (for high I)
3. Delta Star (step up)
4. Star Delta (step down).

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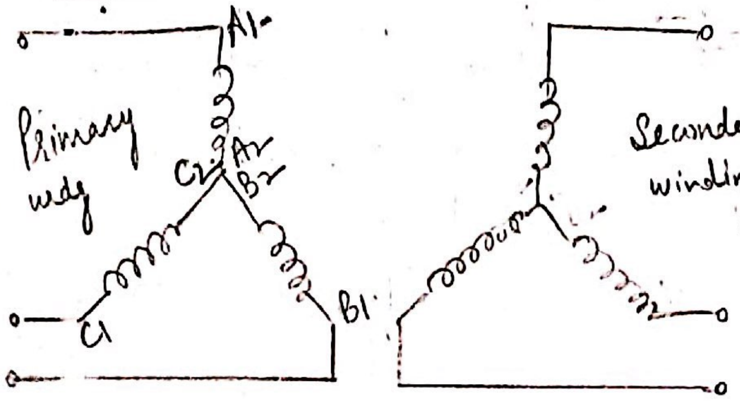
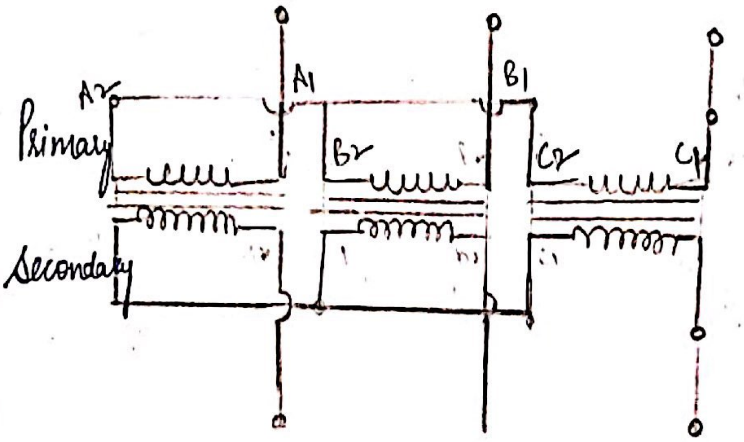
1. Star Star connection (Y-Y)



$V_L = \sqrt{3}\, V_{ph}$

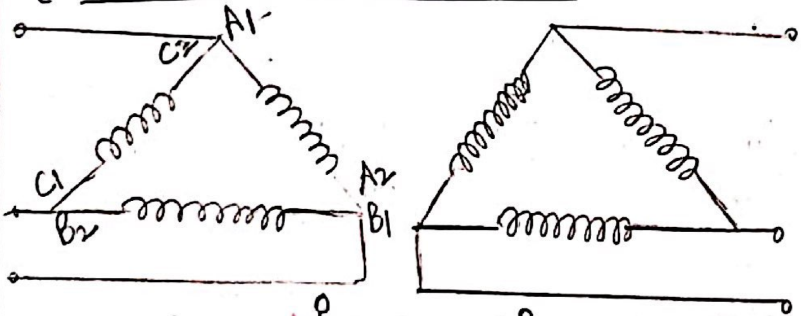
* It is economical for small rating, high voltage transformer as number to turn per phase and amount of installation is less.



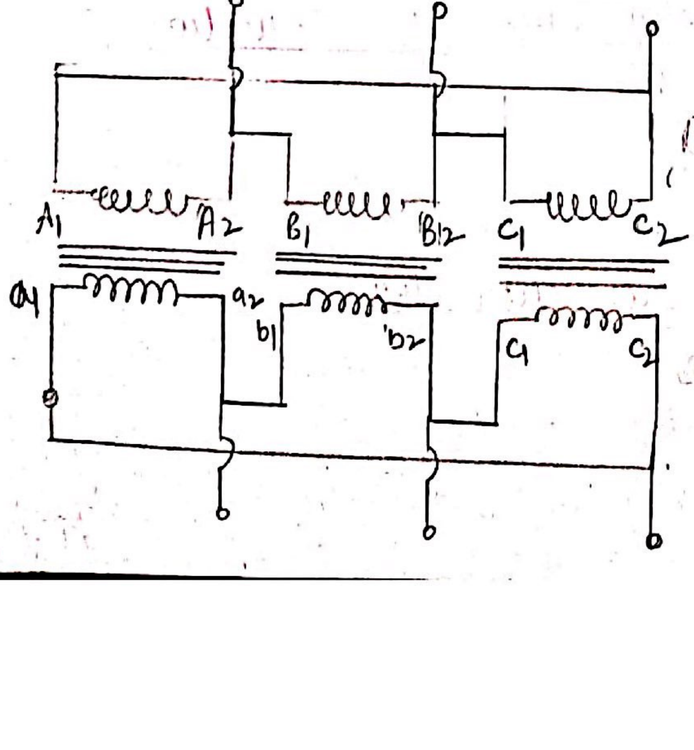
$$V_{ratio} = \frac{V_{L2}}{V_{L1}} = \frac{\sqrt{3}\,V_{ph2}}{\sqrt{3}\,V_{ph1}} = \frac{N_2}{N_1}$$

$$\text{Current ratio} = \frac{I_{L2}}{I_{L1}} = \frac{I_{ph2}}{I_{ph1}} = \frac{N_1}{N_2}$$

2. Delta Delta connection.



* Used in s/s which carry large current on low voltage.
* It maintained continuity of service though fault develop in one of the phase.



$$V_{ratio} = \frac{V_{L2}}{V_{L1}} = \frac{V_{ph}}{V_{ph}} = \frac{N_2}{N_1}$$

$$I_{ratio} = \frac{I_{L2}}{I_{L1}} = \frac{\sqrt{3}\,I_{ph2}}{\sqrt{3}\,I_{ph1}} = \frac{N_1}{N_2}$$

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3: Star Delta

Star || Delta (?)

* These connection are used where the voltage is to be stepped down. (in transmission line). The neutral of primary winding is earthed.

$$V_{ratio} = \frac{V_{L2} \text{ (delta)}}{V_{L1} \text{ (star)}} = \frac{V_{ph2}}{\sqrt{3} V_{ph1}} = \frac{1}{\sqrt{3}} \frac{N_2}{N_1}$$

$$I_{ratio} = \frac{I_{L2}}{I_{L1}} = \frac{\sqrt{3} I_{ph2}}{I_{ph1}} = \sqrt{3} \frac{N_1}{N_2}$$

4. Delta star

* These connection are used to step up the voltage. (Used in high tension transmission line).

Delta Star

$$V_{ratio} = \frac{V_{L2}}{V_{L1}} = \frac{\sqrt{3} V_{ph2}}{V_{ph1}} = \sqrt{3} \frac{N_2}{N_1}$$

$$I_{ratio} = \frac{I_{L2}}{I_{L1}} = \frac{I_{ph2}}{\sqrt{3} I_{ph1}} = \frac{N_1}{\sqrt{3} N_2}.$$

Also used in distribution s/s. The neutral of secondary wdg is earthed to provide 3ϕ 4 wire system.

Advantages of Star connection over delta connection

Each star connected transformer is wound for only $\left(\frac{V_L}{\sqrt{3}}\right)$ 57.7% of line of line voltage. So smaller transformer built for high voltage than possible with delta connection.

Advantages of Delta connection over star.

When three transformer are connected in delta, ~~one may~~ if one transformer is removed the remaining unit will carry 57.7% of original 3ϕ load and maintain the continuity of supply.

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Ideal transformer

It is a transformer which has no ohmic resistance and no magnetic leakage flux i.e flux which produce losses and means all the flux produced in core links with primary as well as secondary hence it has no cu losses, and core losses. so efficiency is 100%. Its end terminal voltage are equal to induced emf and here pure inductor will draw only magnetising current which only produces useful flux.

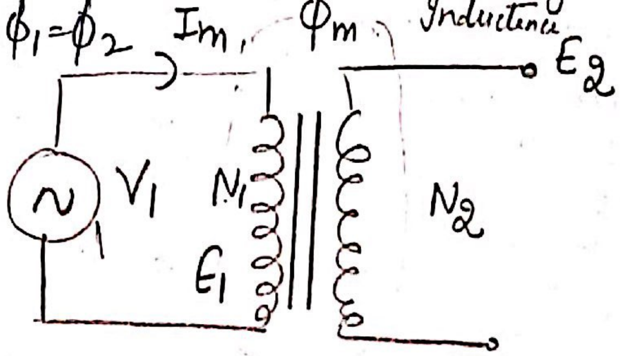
No leakage Inductance

No power losses so i/p = o/p. $\phi_1 = \phi_2$

$$E_2 I_2 \cos\phi_2 = E_1 I_1 \cos\phi_1$$

$$E_2 I_2 = E_1 I_1$$

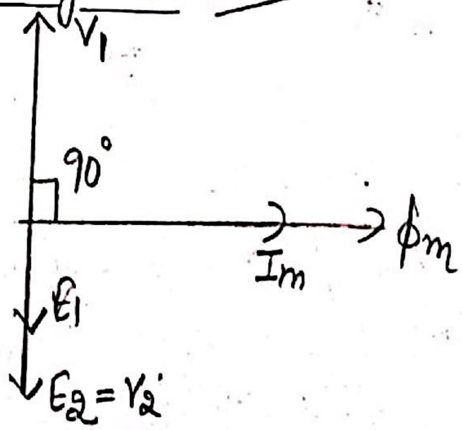
$$\therefore \frac{E_2}{E_1} = \frac{I_1}{I_2}$$



end terminal V = induced emf.

primary and secondary winding behave as pure inductor and draw only useful magnetising current.

Phasor diagram of ideal Transformer



Transformer ON "NO load" condition

1. In actual transformer losses in the wdg cannot be neglected.
2. The current cannot be neglected.

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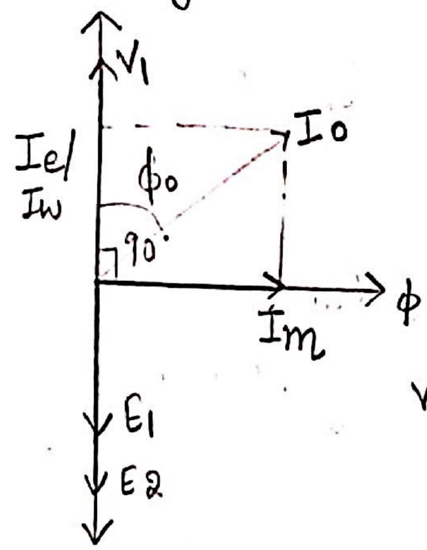
* The current drawn by T/F on ~~on~~ No load condition is called no load or exciting current and is denoted by I_0.

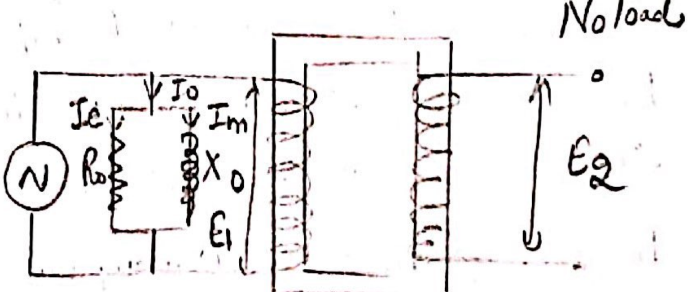
4. This I_0 current lags behind voltage V_1 by angle ϕ_0

5. The component I_w is called active or working component of current which supplies iron and Cu losses in primary. $I_e = I_w$ (energy component)

6. The comp I_m is called the magnetising component which is in quadrature to supply voltage and it produces flux in the core.



R_0 = exciting resistance
X_0 = " reactance



$$I_e = I_0 \cos\phi_0$$
$$I_m = I_0 \sin\phi_0$$
no load current $I_0 = \sqrt{I_e^2 + I_m^2}$

* At no load the primary Cu losses are so small that it can be neglected so power drawn by the circuit is used to produce only iron losses.

$$\cos\phi_0 = \frac{I_w}{I_0}$$

I_0 is very small 2% 5%

$$P_0 = V_1 I_0 \cos\phi_0$$
(Power at ~~not~~ No Load)

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Transformer on ON load V.Imp

(B)

1. This analysis is done by neglecting wdg resistance and leakage flux.
2. when certain load is connected across sec wdg the current I_2 flows in the wdg.
3. The phase angle of I_2 depends upon the nature of load (resistive, capacitive, inductive)
4. T/f is ON No load it draws I_0 current and produce flux in the core.
5. when transformer is loaded the ~~p~~ secondary current I_2 will also produce ϕ_2 in the core which oppose the main flux (ϕ) which is set up by current I_0.
6. As the resultant flux ϕ decreases, the induced emf E_1 also decreases supply Voltage V_1, being the same causes additional flow of current from the supply main. This additional current I_1' is called counter balancing current and it neutralises the effect of flux ϕ_2 by supplying additional flux ϕ_2' in the core which cancel the flux ϕ_2 produced by I_2.

Counter balancing current I_1' will be equal to and opp. to load current I_2.

$$I_1 = I_0 + I_1'$$

Phasor diagram

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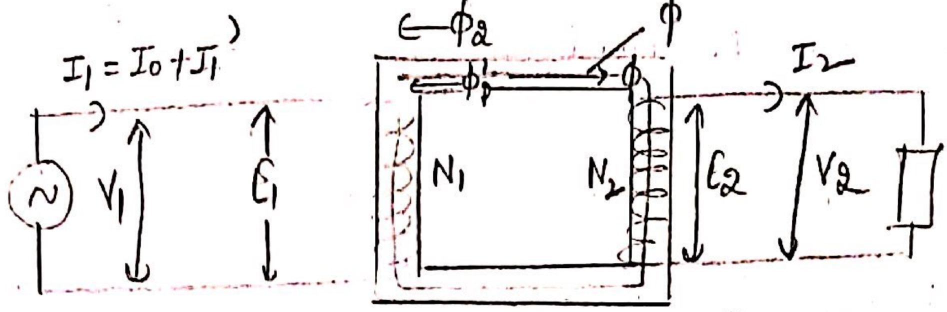
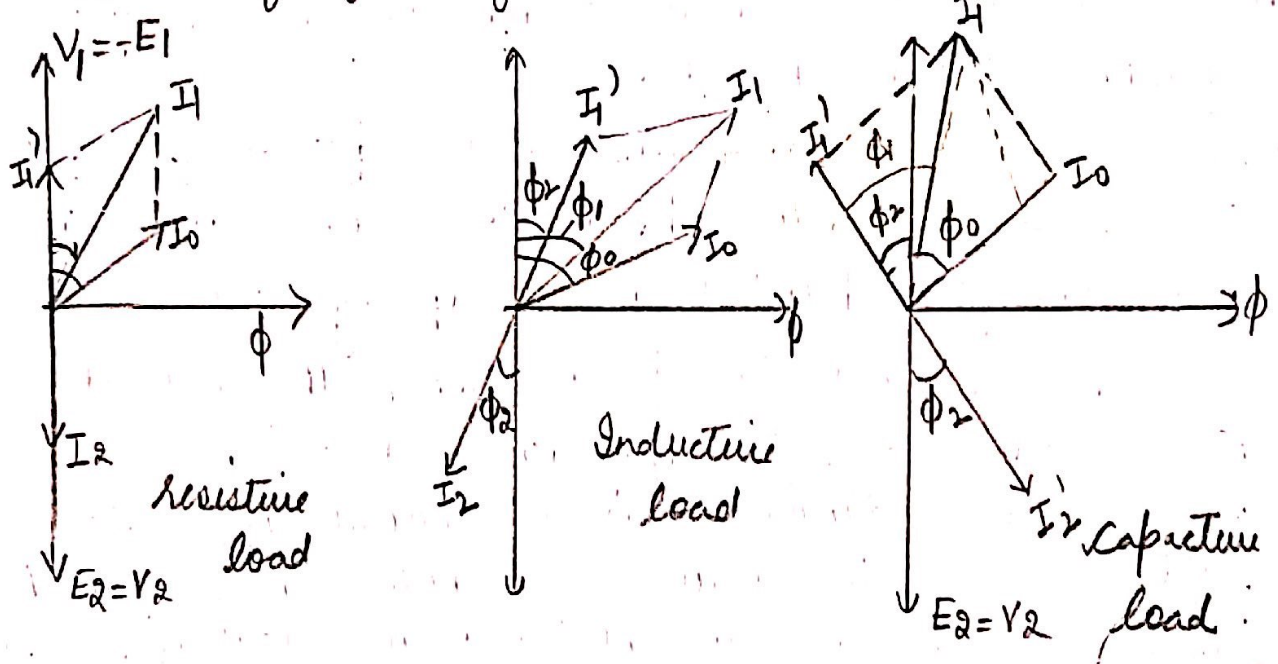


Since no V.D so $V_1 = E_1$ and $E_2 = V_2$.

* I_2 is in phase, lags behind & leads the secondary terminal voltage V_2 by angle ϕ_2 for resistive inductive & capacitive load.



* To primary current

$$I_1 = I_0 + I_1' \; , \quad I_1 = \sqrt{(I_0^2 + I_1'^2 + 2 I_0 I_1' \cos\theta)}$$

θ is angle b/w I_0 and I_1'.

$$\cos\phi_1 = \frac{I_0 \cos\phi_0 + I_1' \cos\phi_2}{I_1}$$

Power factor

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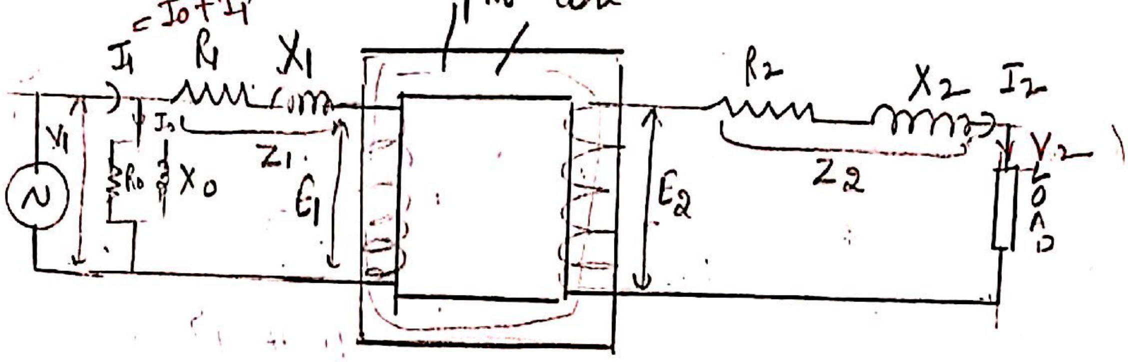
Actual Transformer

(14)

An Actual Transformer has 1. primary and secondery resistance 2. primary and secondary leakage reactance 3. Iron & cu losses.

Equivalent circuit,



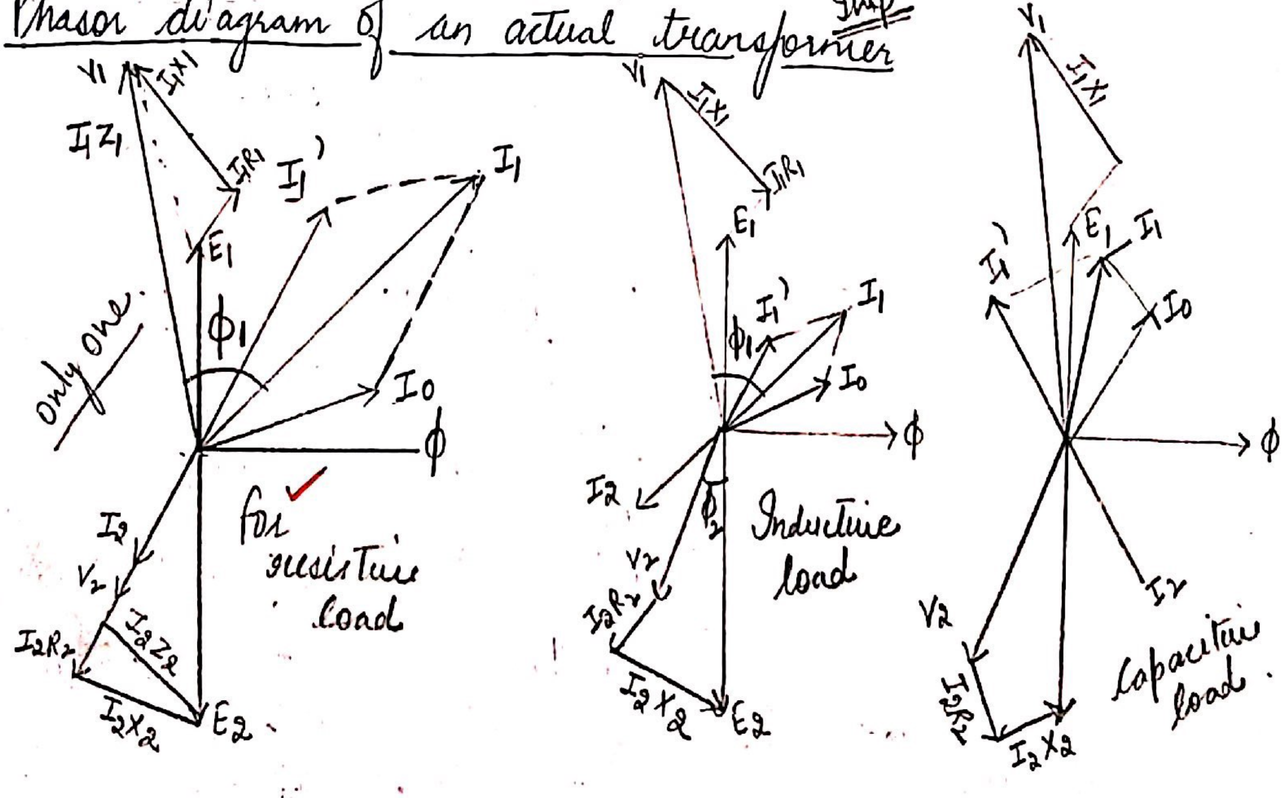
$$E_2 = I_2(R_2 + jX_2) + V_2$$

Voltage drop

$$V_1 = E_1 + I_1(R_1 + jX_1) = E_1 + I_1 Z_1 \quad \text{(primary side)}$$

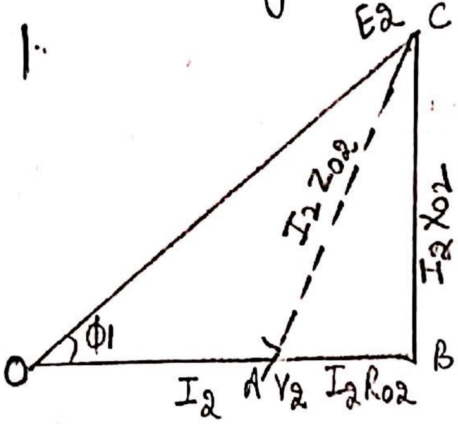
$$V_2 = E_2 - I_2(R_2 + jX_2) = E_2 - I_2 Z_2$$

Phasor diagram of an actual transformer Imp



Expression for NO load Secondary Voltage Extra (imp)

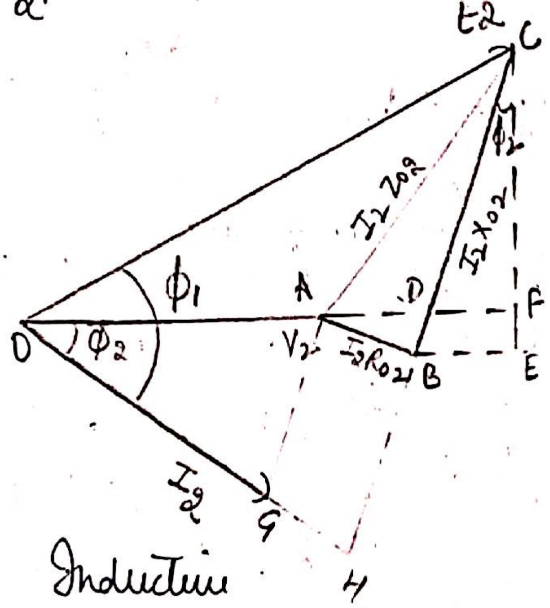
1.



resistive load

$$OC = \sqrt{OB^2 + BC^2}$$
$$= \sqrt{(OA+AB)^2 + BC^2}$$
$$E_2 = \sqrt{(V_2 + I_2 R_{02})^2 + (I_2 X_{02})^2}$$
$$\cos\phi = \frac{OB}{OC} = \frac{OA+AB}{OC} = \frac{V_2 + I_2 R_{02}}{E_2}$$

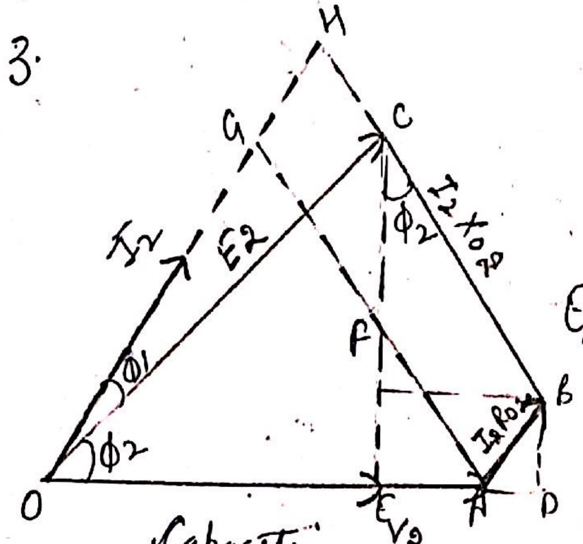
2.



Inductive

$$OC = \sqrt{OH^2 + HC^2}$$
$$= \sqrt{(OG+GH)^2 + (HB+BC)^2}$$
$$= \sqrt{(OG+AB)^2 + (GA+BC)^2}$$
$$E_2 = \sqrt{(V_2 \cos\phi_2 + I_2 R_{02})^2 + (V_2 \sin\phi_2 + I_2 X_{02})^2}$$
$$\cos\phi = \frac{OH}{OC} = \frac{OG+GH}{OC} = \frac{OG+AB}{OC}$$
$$= \frac{V_2 \cos\phi_2 + I_2 R_{02}}{E_2}$$

3.



Capacitive

$$OC = \sqrt{OH^2 + HC^2}$$
$$= \sqrt{(OG+GH)^2 + (HB-BC)^2}$$
$$= \sqrt{(OG+AB)^2 + (GA-BC)^2}$$
$$E_2 = \sqrt{(V_2 \cos\phi_2 + I_2 R_{02})^2 + (V_2 \sin\phi_2 - I_2 X_{02})^2}$$
$$\cos\phi_1 = \frac{HC}{OC} = \frac{OG+GH}{OC} = \frac{OG+AB}{OC}$$
$$= \frac{V_2 \cos\phi_2 + I_2 R_{02}}{E_2}$$

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