Transformer :

1) Single phase transformer construction & working, Emf equation & phasor diagram, Eq ckt, testing of transformers, Efficiency & Regulation, parallel operation.

(common) (common)

2) Transformer II : (3-phase).

Open ckt & Short ckt test (core loss test or Iron loss test) [copper loss or load loss test], Efficiency & Regulation, Autotransformer comparison with two winding transformer on the basis of copper losses & volume of copper

3) Review of 3-phase & single phase ckt, Magnetic ckt & Electromechanical energy conversion principle. Basic of static & rotating Electrical machines, EMF Equations.

$$\boxed{\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1}}$$

$$\boxed{V_1 I_1 = V_2 I_2}$$

→ Transformer is a static which is used to increase or decrease voltage or current without changing its frequency.

$$E = -\frac{d\phi}{dt} \longrightarrow E = 4.44 f \phi_{max} N$$

*) Derive the above formula?

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

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

$$\Rightarrow \boxed{\frac{E_1}{E_2} = \frac{N_1}{N_2}}$$

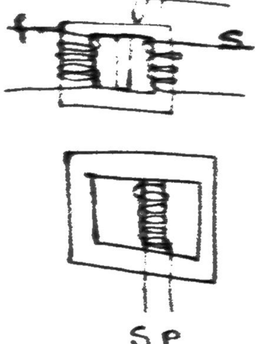
R. S. Bindra
Nagrath Kothari
Jain & Jain
Suresh Hussain

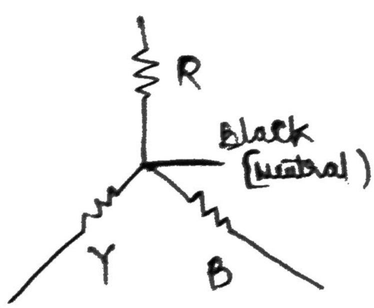
Input power = Output power

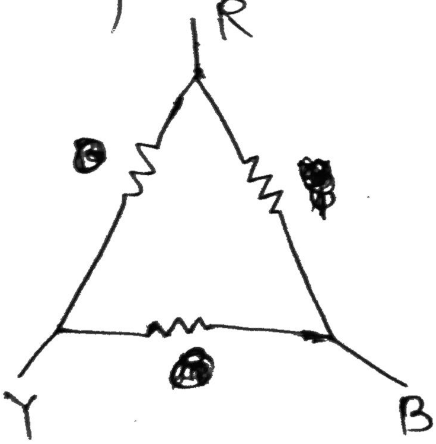
$$V_1 I_1 = V_2 I_2$$

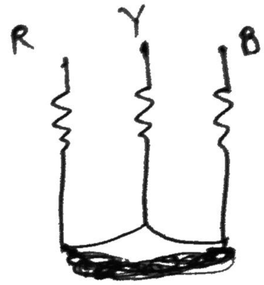
$$\Rightarrow \boxed{\frac{V_1}{V_2} = \frac{I_2}{I_1} = \frac{N_1}{N_2}}$$

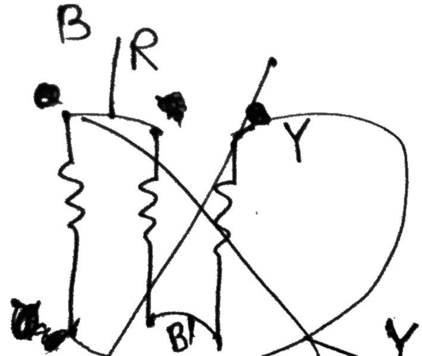
On basis of construction	As per voltage	As per power	As per phase	As per connection
Core type and Shell type	Step up and step down when $E_2 > E_1$ → Step up when $E_1 > E_2$ → Step down	1) Distribution transformer 2) Power transformer. In our country generation voltage is 11 kV * 132 kV, 66 kV, 33 kV used for distribution → Distribution transformer is used for domestic & industrial purpose directly (11 kV/440, 11 kV/220)	Single phase → One line & One neutral 3-phase → Three lines with one neutral (RYB) - With one Black neutral Red, green, Blue	Star-Star Star-delta delta-delta delta-star

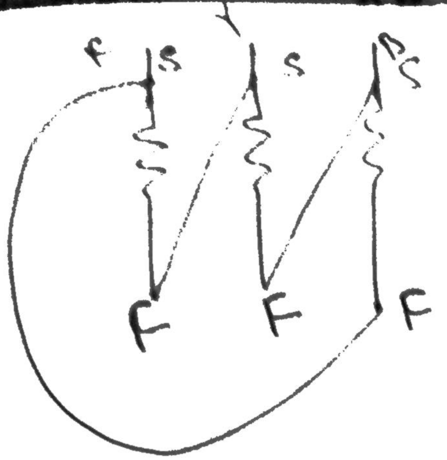












* CORE TYPE Transformer :-

In core type transfomer the magnetic circuit consist of two sections namely two vertical section called limbs and two horizontal sections called yokes. The half of each winding is placed on each limb of the core. So that the flux leakage can be minimized. In the core type low V winding is always placed next to the core and the high voltage winding is placed around the low voltage winding. It is because it reduces the need of insulating material required.

→ Advantage – It is easier to dismantle for repair and maintainance. Also it has efficient ~~co~~ natural cooling.

→ Disadvantage – It needs higher magnetising current.

→ used in high voltage applications.

* Shell Type transformer :-

A shell type transformer consists of one central limb as shown in the figure of shell type transfo... In this both primary and secondary windings are placed on the central limb. The function of two outer limb is to ~~create~~ complete the path of low reluctance for magnetic flux.

In the shell type transformer each winding is divided on to subsections, where the low voltage winding and high voltage winding subctions are alternatively placed on the central limb in form of a sandwich. for this reason the winding is called sandwich or disc winding.

- Advantage- It gives better suppart against the electromagnetic forces between the current carrying conductors. Also the shell type transfarmer provides a shorter magnetic path thus it requires smaller magnetizing current.

Disadvantage- It has poor natural cooling.

* used in low voltage applications such low power ckts and electronic ckts

On the basis of Power :-

Distribution transfarmer :-

An electrical transfarmer which is employed in the power system near the load points for stepping down the high voltage to the safest rated utilisation voltage is known as distribution transformer. Therefore, it is a stepdown transfarmer which reduces the supply voltage to the voltage level demanded by the consumer.

→ They have max^n eff. at 60% to 70% at the load.

Power transformer :-

An electrical transformer having very high MVA rating and is used to transmit high electric power at high voltage level through the power lines to the distribution centres is known as power transformer.

→ A power transformer is rated over 200 MVA with rating of 33 kV, 66 kV, 132 kV, 220 kV, 440 kV and so on. It is mainly used for increasing the low voltage level to a high voltage level for the transmission purpose. The power transformers are designed in such a way that they have maximum efficiency at or near the full load.

On the basis of voltage :

Step-up transformer :

A step-~~down~~ transformer is one which has a primary voltage that is lower than the secondary voltage

So if your building is wired with 208 V but you need 480 V to power a large machine, you will need a step-up transformer to boost the voltage 208 V to 480 V.

→ These examples are small industrial applications

uses → Power companies use massive substation transformers called GSU transformers to step voltages up from power plants at at 7200 V to extra-high voltage like 345,000 V for large-scale power transmission over many miles.

Step-down transformer:

→ A step-down transformer is one which has a primary voltage that is higher than the secondary voltage.

→ ~~To illustrate, let's say~~ Transformer reduces the voltage from 11 kV to 220 V & 440 V for domestic and Industrial use.

*** Proof of Faraday's law:**

$$E_1 = -N_1 \frac{d}{dt}(\phi_m \sin \omega t)$$

$$E_1 = -N_1 \omega \phi_m \cos \omega t = N_1 \omega \phi_m \sin(\omega t - \pi/2)$$

$$E_1(max) = N_1 \omega \phi_m \quad (\because \sin(\omega t - \pi/2) = 1).$$

$$E_1(max) = 2\pi f N_1 \phi_m, \quad E_1(rms) = 4.44 f N_1 \phi_m$$

$$E_1(rms) = \sqrt{2}\pi f N_1 \phi_m.$$

Similarly

$$E_2 = 4.44 f N_2 \phi_m$$

So,

$$\boxed{\frac{E_2}{E_1} = \frac{N_2}{N_1}} = \frac{I_1}{I_2}$$

On the basis of Phase:

Single-Phase Transformer:

A type of transformer which consists of only one pair of the transformer coils or winding. one primary winding and one secondary ~~point~~ winding and is used for transforming the single-phase alternating voltage to the desired value, is known as single-phase transformer.

Three phase transformer:

A transformer which consists of three pairs of transformer windings placed in a three-section iron core, where each section contains a pair of a primary winding and a secondary winding, and is used to step-up or step-down the three-phase alternating voltage is known as three phase-transformer.

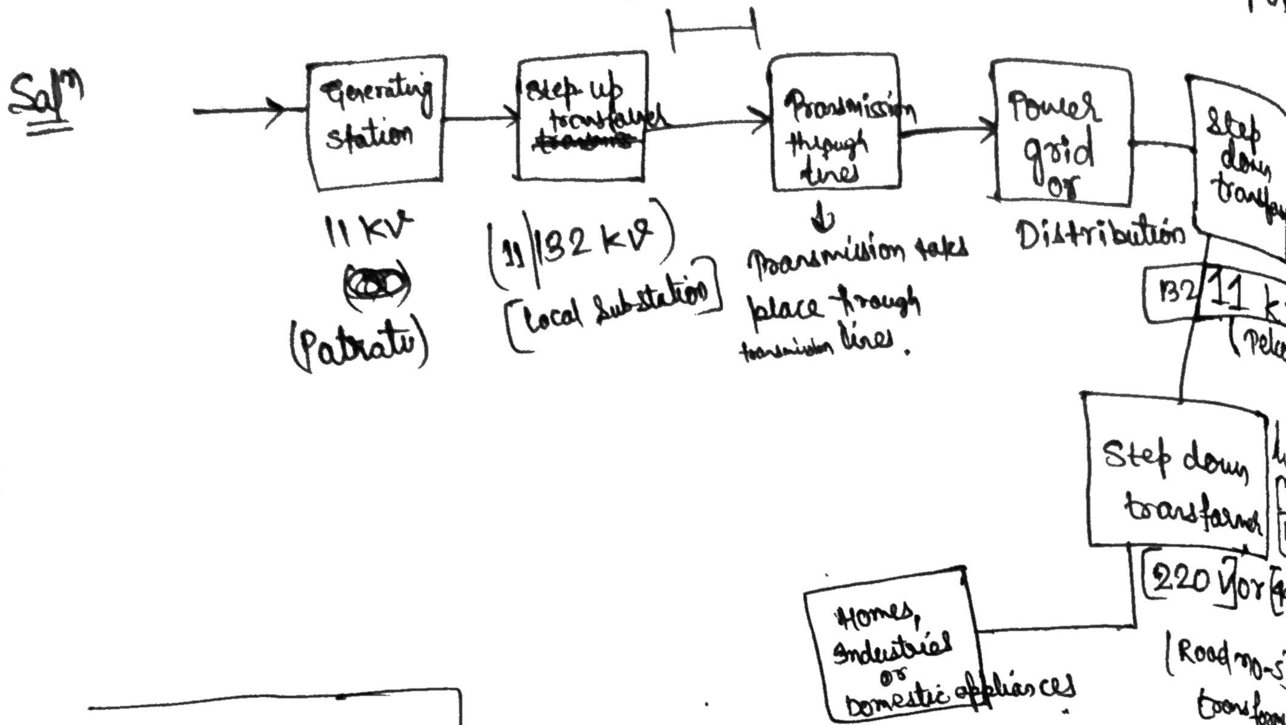
On the basis of connections:

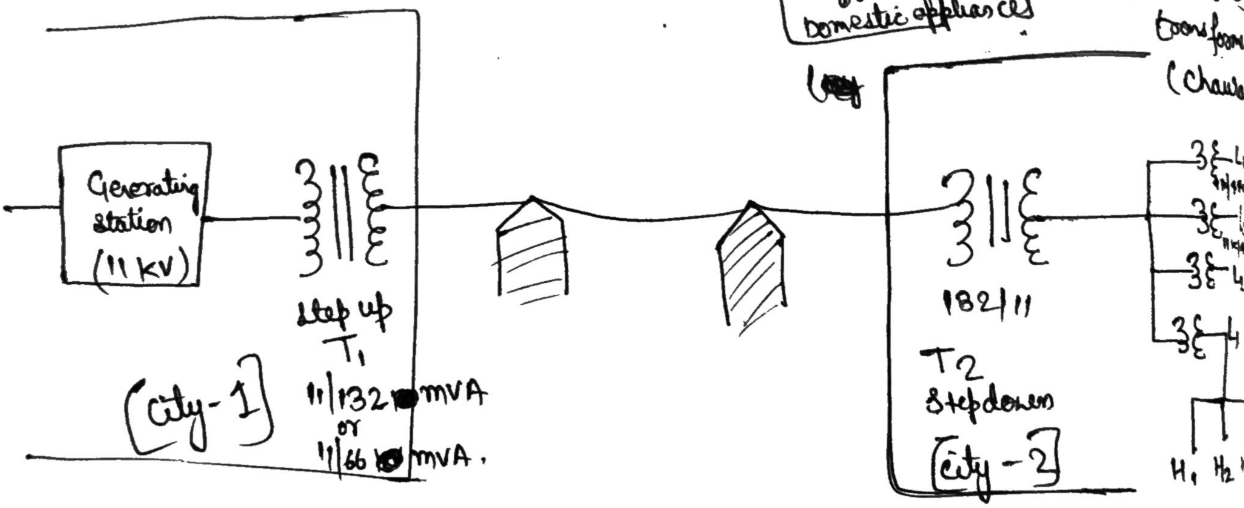
There are four types of transformer connections:

1) Star-star connection
2) Star-delta connection.
3) delta-star connection
4) delta-delta connection.

Q> Draw a single line diagram showing transmission and distribution lines from generating station to end point

Sol^n





Q> Why transformer rating is in KVA? Why not in KW?

Q> Why core is laminated?

Q> Which loss is greater core or copper & why?

8) A 50 KVA single-phase transformer has 600 turns on primary and 40 turns on secondary. The primary winding is connected to 2.2 kV to the supply. Determine i) secondary voltage at no load
ii) Primary & secondary currents at full load.

Sol^n i) $\frac{V_2}{V_1} = \frac{40}{600} = \frac{1}{15} \Rightarrow V_2 = \frac{V_1}{15} = \frac{2200}{15} = 146.666$ Volts.

2) $I_{primary} = \frac{50 \times 1000}{2.2 \times 1000} = \frac{500}{22} = 22.7$ A.

$I_{secondary} = \frac{50 KVA}{146.66} = \frac{50 \times 1000}{146.66} = 341.06$ A.

9) A single phase 4-KVA transformer has 400 primary turns & 1000 secondary turns, the net cross sectional area of the core 60 cm² when the primary winding is connected to 500V, 50Hz supply calculate. i) the maxm value of flux density in the core. ii) the voltage induced in the secondary winding and iii) the secondary full load current.

Sol^n i) $\phi = \frac{500}{\sqrt{2} \times \pi \times 50 \times 400 \times} = \frac{500}{88799.2} = 0.00563$

flux density $= \frac{0.00563}{60 \times 10^{-4}} = \frac{56.3}{60} =$

ii) $V_2 = \frac{N_2}{N_1} \times V_1 = \frac{1000}{400} \times 500 = 50 \times 25 = 1250.$

iii) $I_{\text{primary/secondary}} = \frac{4000}{1250} = 3.2$ Ampere. Ans

Q) why transformer rating is in KVA not in KW?

Soln core losses are dependent on the input voltage copper losses are dependent on the current running through the winding.
Hence total losses depend on voltage & Joining to current but not upon power factor, thus the rating of the transformer is done in KVA not in KW.

Q) why core is laminated?

Soln The iron core of a transformer is laminated to reduce Eddy current losses. Eddy currents are the small currents that result from the changing magnetic field created by the alternating current in the first coil. They need to be minimised so they won't disturb the flow of electricity from the primary coil to the secondary coil.

Q) Which loss is greater core loss or copper loss and why?

Soln A transformer has mainly two types of losses.

1) core losses
2) copper losses.

→ core loss : It is also refered as iron loss, consist of hysteresis loss and eddy current loss.

→ These two losses are constant when the transformer is charged. that means the amount of these losses does not depend upon the condition of secondary load of the transformer. In all loading condition, these are fixed.

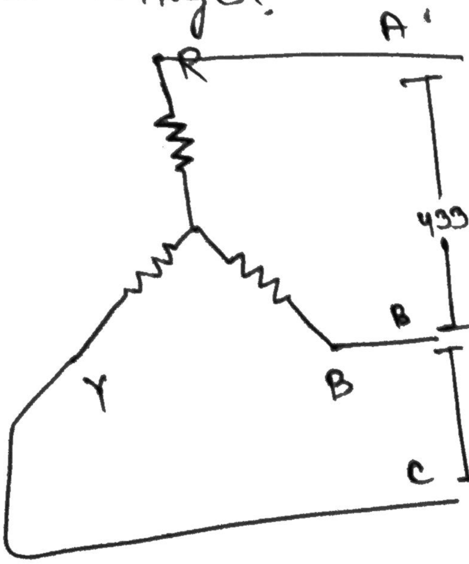
copper loss is also reffered as I^2R loss entirely depends upon load current (I). Hence copper loss are also known as variable loss.

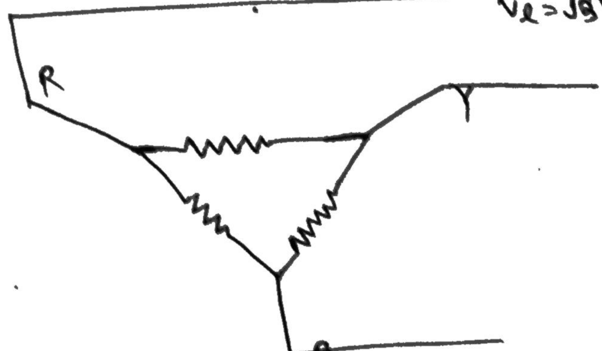
→ ~~copper losses are due to the~~ The iron loss occurs due to variation of flux density in the transformer core and copper loss occurs due to I^2R in the transformer winding.
The transformer is a static piece of equipment and there are no moving parts in it. therefore the mechanical losses in the transformer are almost nil.

8) Draw Y and Δ and Define what is line voltage & phase voltage?

Sol

$V_l = \sqrt{3} V_p$.





$V_l = 433$ volt.

$V_p = V_l/\sqrt{3}$

$V_p = 250$ volt

3KVA { ~~P.V = 250 V~~ HV = 220V ⇒ I = 13.63 A
~~LV~~ LV = 110V ⇒ I = 27.27 A.

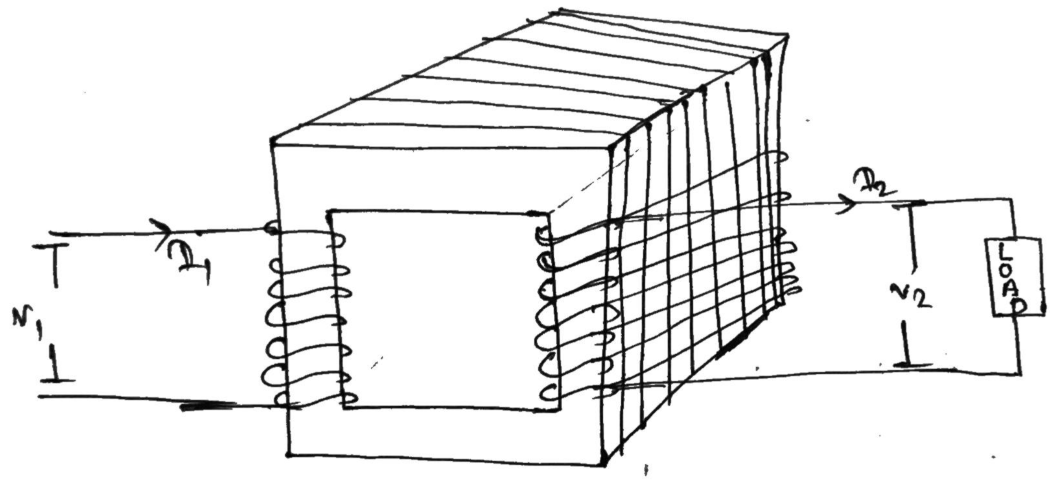
25 KVA { H.V = 11000 I = 2.27 A.
L.V = 433 I = 57.73 A.

Q) Which ~~cross-se~~ winding area is more H.V or L.V side? 7aA.

Sol

Q) Why transformer works on AC? & what will happen transformer works on DC supply?

*



Sol When an Alternating voltage V_1 is applied to the primary an alternating flux ϕ is setup in the core this flux links both the winding and induced emf in them.

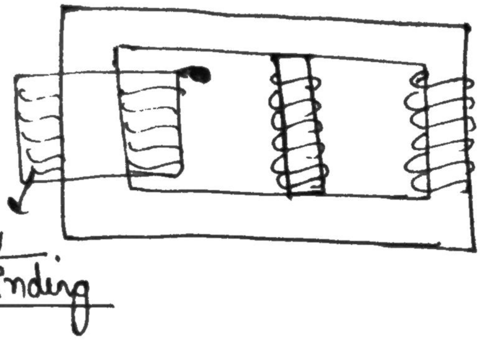
$$E = -N \frac{d\phi}{dt}$$

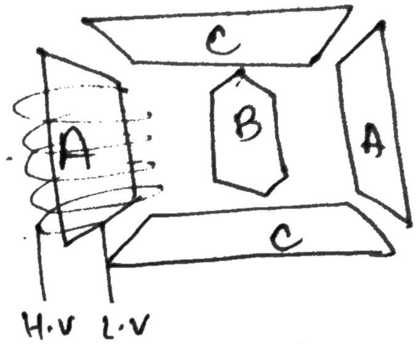
$$E = 4.44 f N \phi_{max}$$

Q) What is an ideal transformer?

Sol
① No flux leakes.
② No copper or core loss
③ No power loss
④ Efficiency 100%.

1





→ core thickness is between 1.8mm to ·40.

Stacking factor

→ It is the ratio of effective cross-sectional area to the physical-cross sectional area is known as the stacking factor. These two are different because of the way cores are constructed.

Topic to read

→ Phasor diagram in case of ideal & no load transformer.

HOMEWORK :-

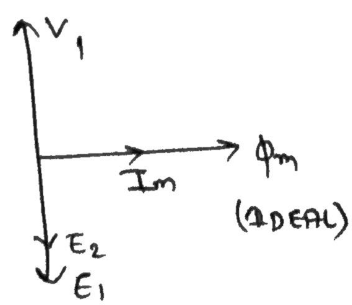
$\phi = \phi_m \sin \omega t$

$E_1 = -N_1 \frac{d\phi}{dt} = E_{1M} \sin(\omega t - \pi/2)$

Similarly :-

$E_2 = E_{2M} \sin(\omega t - \pi/2)$.

$V_1 \rightarrow I_m \rightarrow \phi \rightarrow E_1$

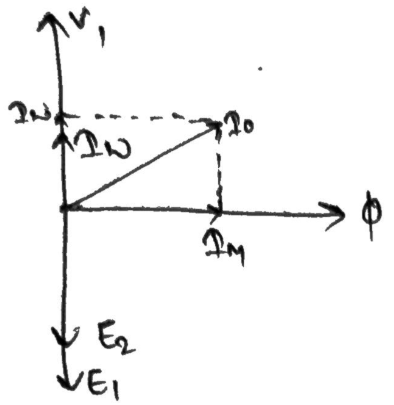


Practically (No load)

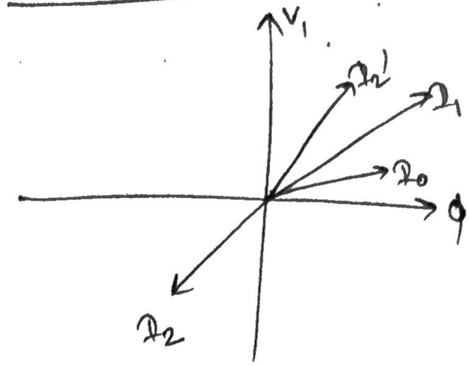
$I_O = I_M + I_W$

I_W – Mag components | Reaction | wattless comp.

I_M – core loss components | Active | wattful comp.



when load is connected :-



$I_1 = I_m + I_w + I_2'$

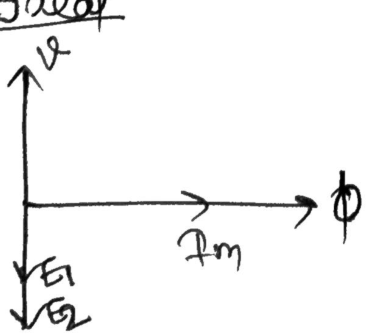
Soln low voltage winding can be primary. High voltage winding carries a lower current, hence the resistance of winding is more.

As the resistance of winding is inversely proportional to the area of cross section, the area of high voltage winding is less compared to low voltage winding.

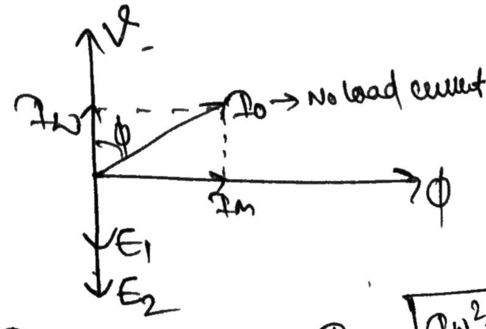
Soln A constant DC source connected to the primary side of transformer will have zero emf. The constant current ~~water~~ creates zero induced emf.

As a result primary side of transformer will behave short-ckt & heavy current will flow through primary which will in turn burn the winding.

Ideal



No load (Practical



$I_W = I_0 \cos\phi$ $\quad I_0 = \sqrt{I_W^2 + I}$

$I_M = I_0 \sin\phi.$

Q) why ϕ is the referrence?

Q) Principle of ideal transformer.

Sol^n

1) Primary & second windig of Ideal transformer have negligible resistance.

2) The core has infinite perimeability so negligible mmf is required to flow the flux.

3) Entire flux is confined in two windings → means there is no leakage.

4) There is no losses & efficiency is 100%

Practical	Ideal
→	→ Primary & secondary windig have some resistance.
→	→ Efficiency is approx 93-98%.
→	→ The core has finite permability.
→	→ Voltage regulation is never zero.
→	→ there is some flux leakage
→ It is impossible to construct ideal transformer	→ All constructed transformer are practical.

Home

Q) A single phase transformer has 1000 turns on the primary & 200 turns on the secondary the no-load current is 3 amp at p.f = 0.2 lag. Calculate the primary current and power factor when secondary current is 280 Amperes at a p.f of 0.8 lagging.

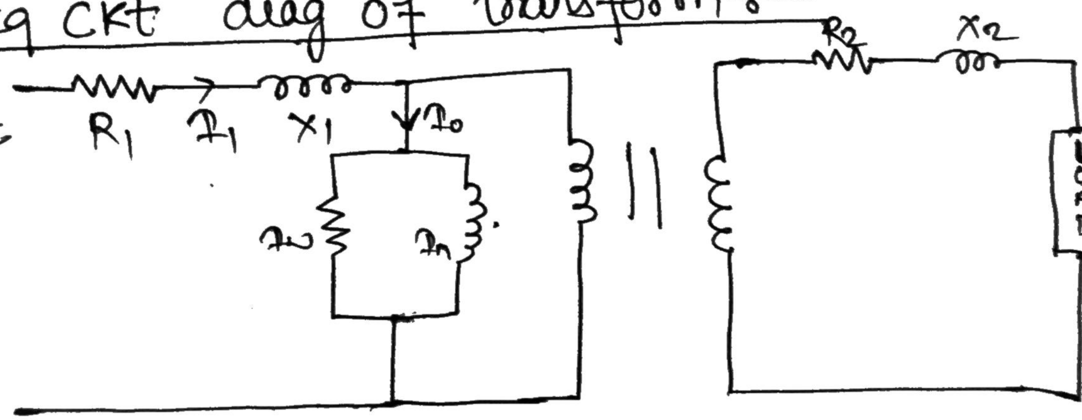
Q) A 1000/200 Volt transformer takes 0.3 Amps at power factor of 0.2 on open ckt. Find the magnetising and iron loss component of no load primary current.

Solⁿ ~~$V_p = 1000$ volt.~~ ~~Power = $1000 \times 0.3 = 300$ watt.~~

$$I_w = I_0 \cos\phi = 0.3 \times 0.2 = 0.06$$
$$I_m = I_0 \sin\phi = 0.3 \times 0.98 = 0.294$$

Eq ckt diag of transform:

Home assignment



Q) What is construction & working principle of trasfarmer?

Q) what is ideal condn of trasfarmer?

Q) What is difference b/w Ideal & pratical trasf.?

Q) What are the parameters of eqn ckt of transformer?

Q) What is Efficiency?

Q) What is allday efficiency?

Q) What is voltage regulation?

Home work Q) Explain phasor diagram? (Ideal case, noload case, load).

→ there are resistive, capacitive inductive.

Q) Why polarity test is required and what will happen when we connect with wrong polarity.

Testing of a transformer :

xi) Ratio test

1) High voltage Winding Resistance test. [with the help of wheatstone] (ohms).

2) low voltage winding " " . [kelvin double bridge] (mohms)

3) Insulation resistance test. [Meger test] (Mohms)

4) Open ckt test. or [No-Load test or Iron loss test]

5) Short ckt test or [Copper loss or load loss test.]

6) Back to Back test

7) Polarity test.

8) DVDf test (Double voltage double freq test). Withstand test for 1 minute.

9) High voltage test for 1 minute.

10) Swin burn test.

xii) Impulse test

xiii) Scott connection test.

sol^n

$\frac{I_P}{I_S} = \frac{N_S}{N_P}$ $\qquad I_P = \frac{N_S}{N_P} \times I_S = \frac{200}{1000} \times 280 = 56\,A$

$\cos\phi_2 = 0.8, \quad \cos\phi_0 = 0.2, \quad \sin\phi_2 = 0.6.$

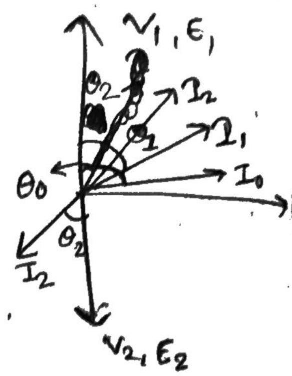
$\sin\phi_0 = 0.98$

$I_1\cos\phi_1 = I_2\cos\phi_2 + I_0\cos\phi_0 = (56\times0.8) + (3\times0.2)$

$= 45.4\,A.$

$I_1\sin\phi_1 = I_2\sin\phi_2 + I_0\sin\phi_0 = (56\times0.6) + 3\times0.98$

$= 36.54\,A.$



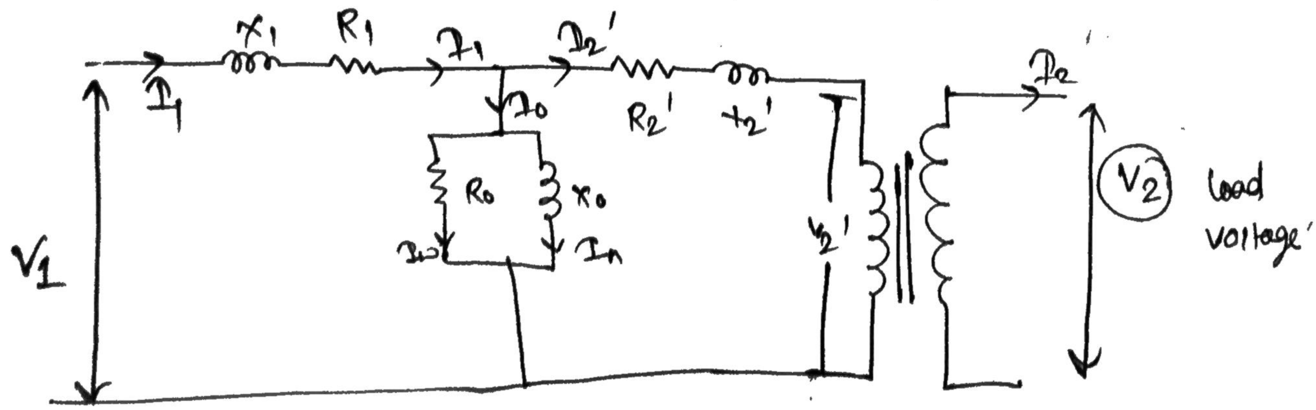
$I_1 = \sqrt{(45.4)^2 + (36.54)^2} = 58.3\,A.$

$I_M = I_0\sin\phi_0 = 3\times0.6 = 1.8\,A.$

$\tan\phi_1 = \frac{36.54}{45.4} = 0.805. \Rightarrow \phi_1 = 38^\circ.$

P.f ; $\cos\phi_1 = \cos 38^\circ = 0.78$ lagging.

Eq ckt diagram of transformer :-

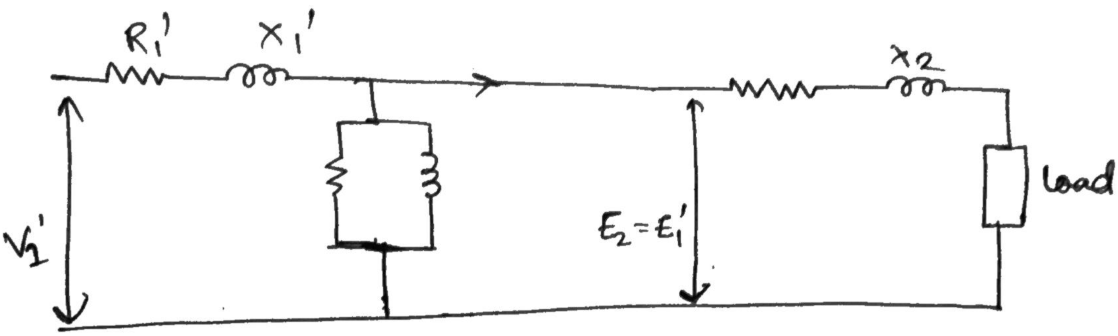


Equivalent ckt reffered to primary. (T-circuit)

$$\boxed{R_2' = R_2\left(\frac{N_1}{N_2}\right)^2} \qquad \boxed{X_2' = X_2\left(\frac{N_1}{N_2}\right)^2}$$

$$\boxed{V_2' = V_2 \cdot \frac{N_1}{N_2}}$$

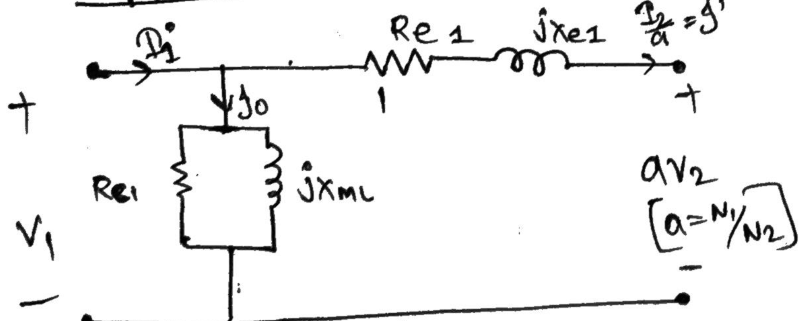
Eq ckt reffered to secondary :

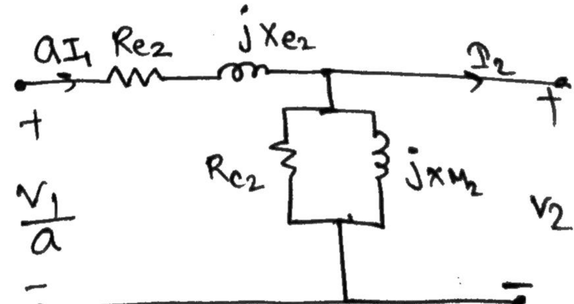


$V_1' = V_1\left(\frac{N_2}{N_1}\right)$ $\quad R_1' = R_1\left(\frac{N_2}{N_1}\right)^2$ $\quad X_1' = X_1\left(\frac{N_2}{N_1}\right)^2$ $\quad R_0' = R_0\left(\frac{N_2}{N_1}\right)^2$

$X_m' = X_m\left(\frac{N_2}{N_1}\right)^2$ $\quad I_2' = I_1\left(\frac{N_1}{N_2}\right)$ $\quad I_0' = I_0\left(\frac{N_1}{N_2}\right)$.

→ these ckts are ~~calcul~~ complex/complicated so we need to approximate them :





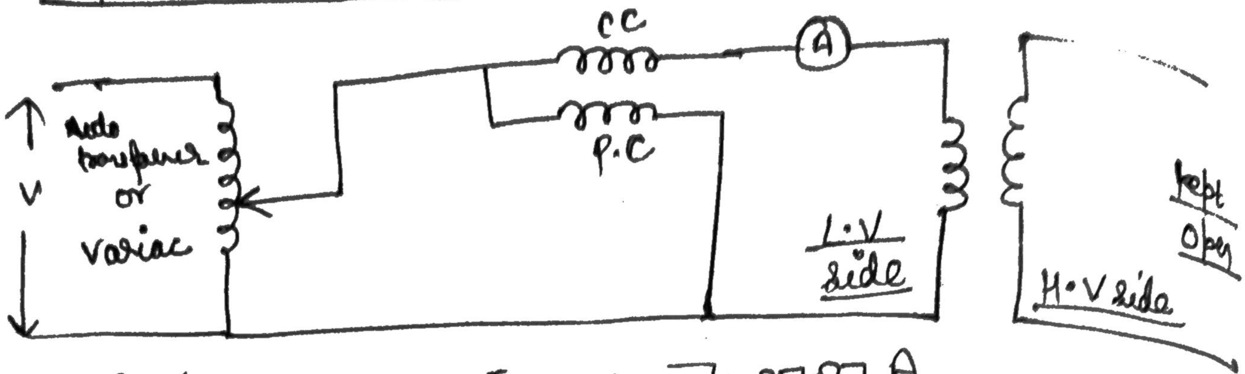
(moved towards primary) $\qquad$ (move towards load) (rarely used)

$$Re_1 = R_1 + R_2' = R_1 + R_2\left(\frac{N_1}{N_2}\right)^2$$

- No load V_D is ignored
- No load Cu loss is ignored
- Core loss is over-estimated.

$$Xe_1 = X_1 + X_2' = X_1 + X_2\left(\frac{N_1}{N_2}\right)^2$$

Open ckt test [no load test or core iron loss test).



3KVA [L.V → 110 → 27.27 A. ; H.V − 220 → 13.63 A]

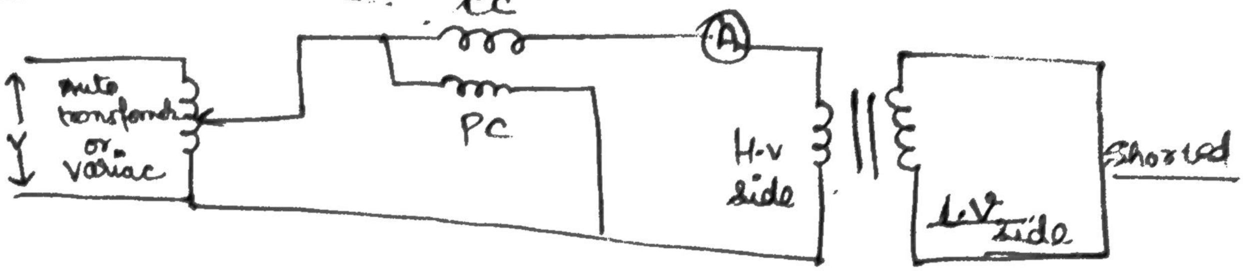
5 KVA [220/110] → 45.44 A ; → 22.72 A

100 KVA [11000/440] $I_{H.V} = 9.09$ A ; $I_{L.V} = 227$ A.

5MVA [11000/440] $I_{H.V} = 454.54$ A ; $I_{L.V} = 11363.63$ Ampere

→ the aim of this test is to determine the iron losses of the transformer this test is performed at normal supply voltage & frequency. the primary winding (L.V) preferable is supplied with a normal voltage at normal frequency ~~at no~~ i.e 50Hz. & the other winding (H.V) is kept open.} Iron loss & no load current will be very small so small ammeter & voltmeter of low range are connected in the primary. No load current will be approximately 3−4% of rated current.

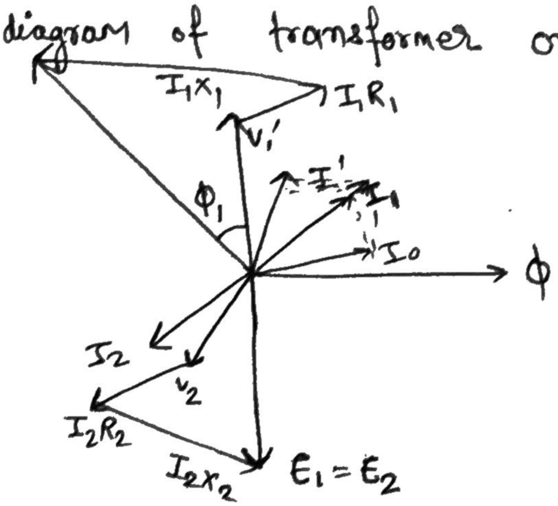
Short ckt test :-



→ In this test primary winding (H.V) is supplied the rated current or full load current with reduced voltage at normal frequency. This reduced is called impedance voltage. ~~this~~ This impedance voltage is 3–8 % of the rated voltage.

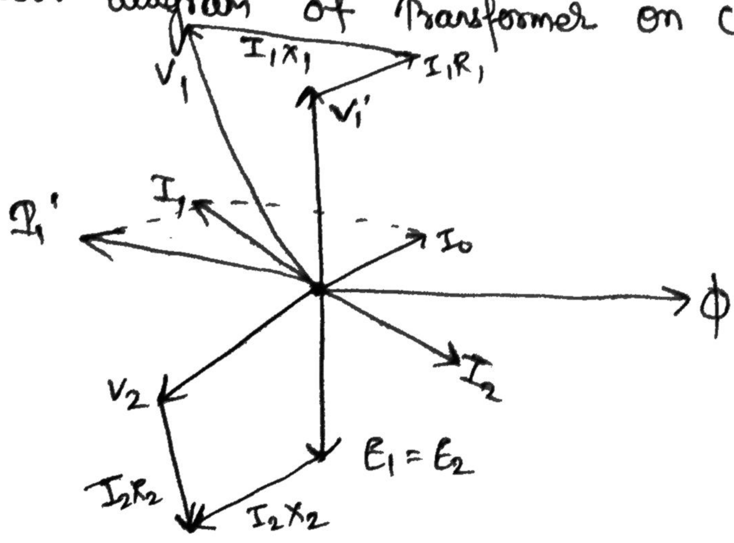
Homework solution :-

(i) Phasor diagram of transformer on inductive load.



{lagging power factor}.

(ii) Phasor diagram of transformer on capacitive load.

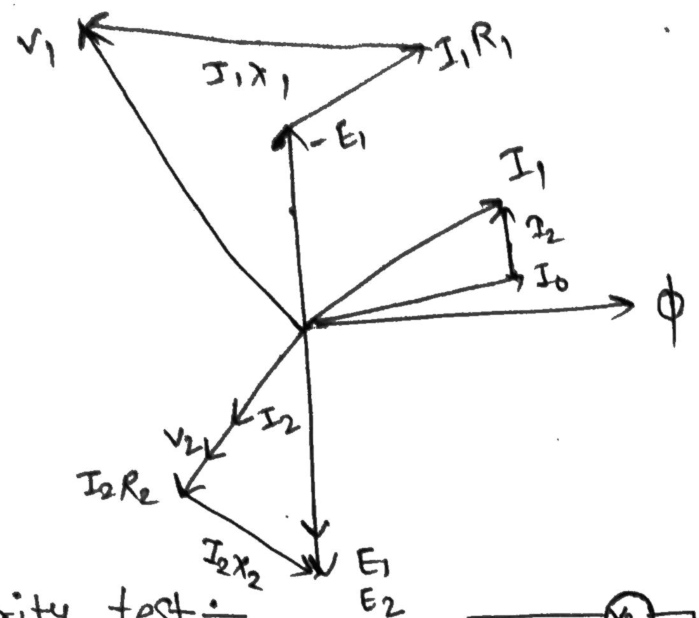


ϕ → flux

E_1, E_2 → induced emfs

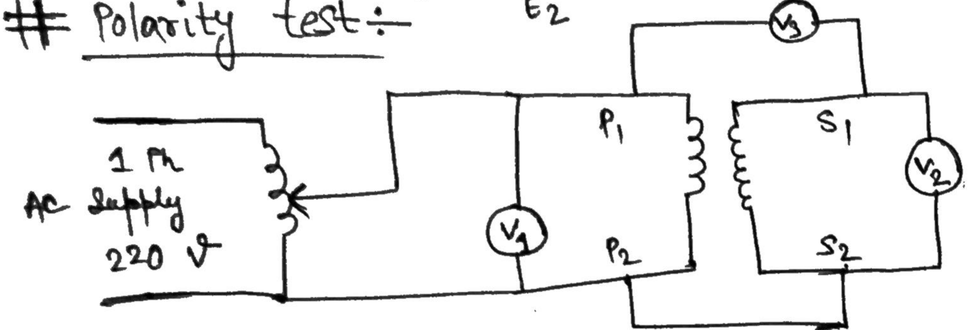
{ leading power factor }.

(iii) Phasor diagram of transformer on Resistive load.



{unity power factor}

Polarity test :-



→ we should know when we connect a transformer to AC supply then a particular instant one terminal of the primary. w.r.t to other terminal is positive or at higher potential

→ The purpose of polarity test to ensure that all single phase device (switch, fuse, circuit breaker, MCB) etc certainly connected in the lines.

→ For parallel operation of two or more than two transformer so that to increase the power or load capacity delivered by transformer

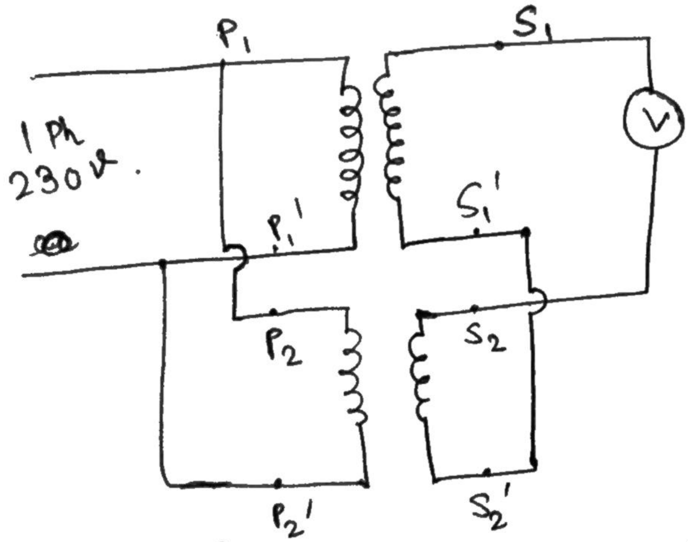
→ P_1 + S_1 are of the same palarity.

for similar palarity ⇒ $V_1 = 100$ $V_2 = 50$ $V_3 = (100 - 50) = 50V$.

→ for opposite polarity ÷

$V_1 = 100V$, $V_2 = 50V$. $V_3 = 100 + 50 = 150V$.

→ we conclude that if V_3 is less than the appleid voltage the terminal S_1 should be marked +ve whereas the voltmeter reads more than applied voltage it should be marked negative.



The two transformers to be connected in parallel should be connected that there primary + secondary have the same palarity This can be done by conducting a palarity test.

1> Switch on the supply.

2> Note the reading in the voltmeter connected on the secondary side It may be either 0 or twice the secondary terminal voltage

3> If the voltmeter reads 0 the correct palarity has been connected.

4> If the voltmeter reads double then its secondary opposite palarity has been connected, then terminal S_1 should be connected to S_2'.