**Important suggestions to examiners**:

1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more importance. (Not applicable for subject English and communication skills)
4) While assessing figures, examiner may give credit for principle components indicated in a figure. The figures drawn by candidate and model answer may vary. The examiner may give credit for any equivalent figure drawn.
5) Credits may be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer.
6) In case some questions credit may be given by judgment on part of examiner of relevant answer based on candidate understands.
7) For programming language papers, credit may be given to any other program based on equivalent concept.

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**Q.1 Attempt any Ten of the following: -------------------------------------------------20 Marks**

**a) Give the classification of DC generator based on their winding connections.**

**Classification of DC generator based on their winding connections:**

**(Any two expected: 1 Mark)**

1) D.C Shunt Generator
2) D.C Series Generator
3) D.C Compound Generator:
   i) Cumulative compound generator
   ii) Differential compound Generator

**b) State the function of armature winding and name the material used for its construction.**

**The function of armature winding:** **(1 Mark)**

The armature conductors are connected in systematic manner to from armature winding. It is used to circulate armature current (load current) when DC machine gets loaded.

**Name the material used for its construction:** **(1 Mark)**

The armature winding is made up of super insulated copper or aluminum wire.

**c) State Fleming's Left Hand Rule.** **(2 Mark)**

**Fleming's Left Hand Rule:**

When we hold the first three fingers of our left hand namely thumb, fore finger and middle finger, mutually perpendicular to each other and if fore finger indicates the direction of magnetic field, middle finger indicates the direction of applied current through armature conductors, then thumb indicates the direction of exerted force/torque on the armature conductor.

**d) List the various losses on a DC Motor.** **(Each losses: 1/2 mark)**

**The various losses on a DC Motor:**

1) Winding losses (Copper losses):

   i) Armature winding losses

   ii) Shunt field losses

   iii) Series field losses

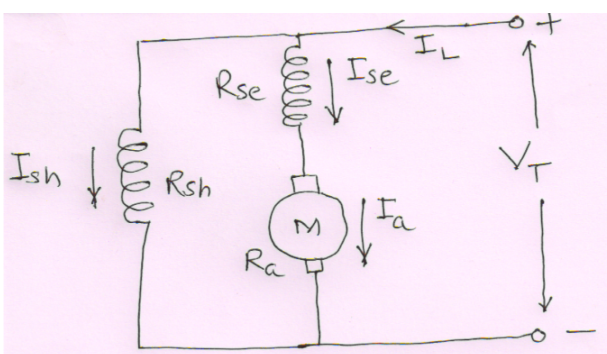
2) Core losses (iron losses):

3) Brush contact losses:

4) Windage and frictional (Mechanical losses):

**e) Draw labeled schematic circuit diagram of long shunt compound motor, showing clearly the direction of all the currents.**

**Schematic circuit diagram of long shunt compound motor:** **(2 Mark)**



**f) State the need of Starter in a DC Motor.**

**Necessity of the starter for DC. Motor:** **(2 Mark)**

The current drawn by motor $I_a = \frac{V - E_b}{R_a}$, at start speed $N = 0$, $\therefore$ $E_b = 0$ and $I_a = \frac{V}{R_a}$.

As $R_a$ is very small $I_a$ will be dangerously high at the time of starting. This high starting current may damage the motor armature (& series field winding in the case of dc series motors). Hence to limit the starting current suitable resistance is inserted in series with armature which is called as starter. This starting resistance is cut-off in steps with increase in speed.

The protective devices like overload release and no volt release are also provided in starter.

**g) State any two characteristics of a shell type transformer.**

**Two characteristics of a shell type transformer:** **(Any Two points expected: 1 Mark each)**

1. The core surrounds a considerable portion of the windings.
2. Natural cooling is poor since the windings are placed on the central limb only.
3. More economical for low voltage transformer.
4. It provides a double magnetic circuit.
5. When the coils are to be withdrawn for repairs, a large number of laminations are to be dismantled.
6. As the windings are placed on the central limb, it provides better mechanical protection to the windings.

**h) Define the following related to single phase transformer: i) Transformation ratio ii) Turns ratio.**

**i) Transformation ratio:** **(1 Mark)**

It is defined as the ratio of secondary voltage to primary voltage. i.e $V_2$ / $V_1$ and it is denoted by 'k'

**ii) Turns ratio:** **(1 Mark)**

It is defined as the ratio of secondary no. of turns to primary no. of turns. i.e $N_2$ / $N_1$ and it is denoted by 'k'

**i) State reason why the rating of the transformer is in KVA and not in KW. (2 Mark)**

Output power of transformer is given by P= VICosØ, for different types of load i.e (resistive, capacitive, inductive) cosØ changes so, for same voltage and current output power will different, so transformer is designed to operate at particular voltage and current levels and it not designed to deliver particular output power that is why rating of transformer is in KVA.

**OR**

As copper loss of a transformer depends on current and iron loss on voltage, Hence total transformer loss depends on volt-ampere and not on phase angle between voltage and current ie. It is independent of load power factor. That is why rating of transformer is in KVA.

**j) State any two necessary conditions required to be satisfied in order to ensure successful parallel operation of single phase transformers.**

**Necessary conditions required to be satisfied in order to ensure successful parallel operation of single phase transformers: (Any Two points expected: 1 Mark each)**

1. Only transformers having the same phase displacement between primary and secondary voltage can operate in parallel. The clock-hour which indicate the phase displacement is stamped on the transformer rating plate, e.g. Dyn11, Yd11,
2. Terminals with the same polarity on HV- and LV side shall be connected in parallel,
3. Transformers should have approximately the same voltage ratio, within +-0.05%
4. The short-circuit impedance voltage should be the same, within +-10%,
5. The power rating of the transformers should not deviate more than 1:3,
6. Tap changers should have tap position giving voltage ratios as close as possible.
7. The phase sequence must be followed strictly on HV and LV side connection.

**k) Give any two advantages of open delta connection of 3-phase transformer.**

**Advantages of open delta connection of 3-phase transformer: (2 Mark)**

1. When one of the phase in case of delta-delta bank is out of order by any reason, the service will be continued till the faulty phase is repaired or a new transformer is installed.

2. In case of future, increase in the load demand can be anticipated by using open delta connection. The present load can be supplied by using open delta connection and the additional demand in future (about 33%) will be supplied by converting open delta connection to delta-delta connection.

**l) Compare a bank of three single phase transformers with three phase transformer based on the following parameters: i) Number of cores ii) Space occupied iii) Weight iv) If one phase is inoperative** **(Each point 1/2 Mark)**

| S.No | Parameters | Three single phase transformers | Three phase transformer |
|---|---|---|---|
| 1 | Number of cores | Three | One |
| 2 | Space occupied | More | Less |
| 3 | Weight | More | Less |
| 4 | If one phase is inoperative | Service will be continued by making open delta connection | The old transformer is required to repair |

**Q.2 Attempt any Four of the following: --------------------------------------------------16 Marks**

**a) Compare lap winding and wave winding on the basis of : i) Number of parallel paths in the winding. ii) voltage generating capability iii) Current sourcing capability iv) Number of brush sets.** **(Each point 1/2 Mark)**

| S.No | Parameters | Lap winding | Wave winding |
|---|---|---|---|
| 1 | Number of parallel paths in the winding. | A =P (A= No. of parallel path & P= No. of poles) | A=2 always (A= No. of parallel path) |
| 2 | voltage generating capability | Low | High |
| 3 | Current sourcing capability | High | Low |
| 4 | Number of brush sets. | Equal to number of pole | Equal to 2 always |

**b) An 8 pole armature has 96 slots with 8 conductors per slot. It is driven at 600 rpm. The useful flux per pole is 10 m Wb. Calculate the induced emf in armature winding when it is: i) Lap connected ii) Wave connected.**

**Given Data:**

P= 8, Slots=96, conductors/slot =8

N= 600 r.p.m. $\phi = 10$ m Wb= $10 \times 10^{-3}$ Wb

**We have,**

Z = Total no. of armature conductors

= (conductors/Slot) X No. of Slots

Z = 8 X 96

Z = 768------------------------------------------------------------------------------- **(1 Mark)**

We have,

$$E = \frac{P \times \phi \times N}{60} \times \frac{Z}{A}$$ ----------------------------------------------------------------- **(1 Mark)**

**i) When the armature winding is Lap connected**, $\therefore A = P = 8$

$$E = \frac{8 \times 10 \times 10^{-3} \times 600}{60} \times \frac{768}{8}$$

$E = 76.8\,Volt$ ------------------------------------------------------------- **(1 Mark)**

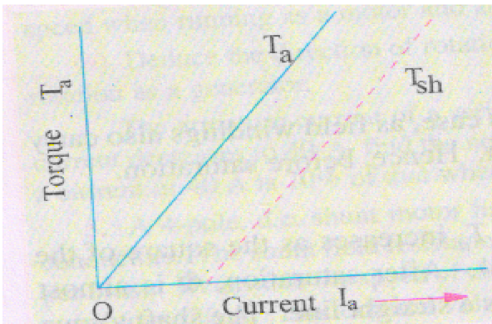
**ii) When the armature winding is wave connected**, $\therefore A = 2$

$$E = \frac{8 \times 10 \times 10^{-3} \times 600}{60} \times \frac{768}{2}$$

$E = 307.2\ Volt$ ----------------------------------------------------------- **(1 Mark)**

**c) Draw and explain the following characteristics of DC motor: i) Torque Vs Armature current characteristics ii) Speed Vs Torque characteristics**

**Characteristics of DC motor: i) Torque Vs Armature current characteristics:** **(1 Mark)**

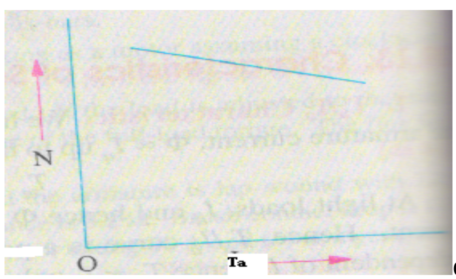



$T_a$ = Armature torque, $T_{sh}$ = Shaft torque

**Explanation:** **(1 Mark)**

- At no load $I_a$ is very small, therefore $T_a$ is approximately equal to zero and characteristics start from origin.
- The starting torque of dc shunt motor is poor. Therefore it can never be started on heavy load.
- As load increases, $I_a$ increases and nature of the characteristics will be linear because Ta proportional to $I_a$

**Characteristics of DC motor: ii) Speed Vs Torque characteristics:** **(1 Mark)**



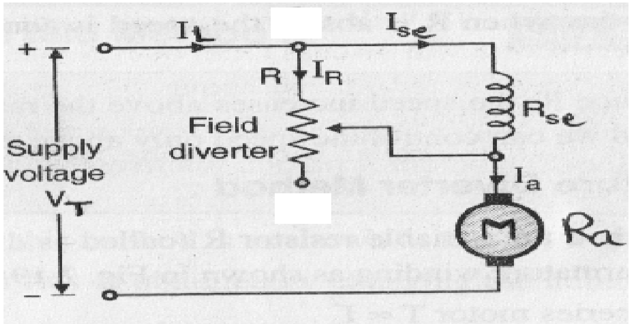

**or equivalent figure**

**Explanation:** **(1 Mark)**

- $N \ \alpha \ \frac{E_b}{\phi}$ for constant input voltage $V_T$, $E_b$ and $\phi$ are almost constant therefore from no load to full load conditions Dc shunt motor is having almost constant speed.
- But for higher values of load i.e for higher values of torque (Ta), Speed drops somehow due to internal voltage drops in armature i.e $I_aR_a$ drop.
- DC shunt motor is almost constant speed motor.

**d) Describe the flux control method using field diverter method for speed control of DC series motor with the help of neat diagram.**

**Flux control method using field diverter method for speed control of DC series Motor:** **(2 Mark)**

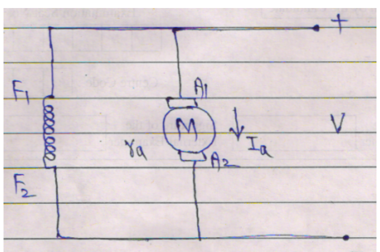



**or equivalent figure**

**Explanation:** **(2 Mark)**

- Variable resistance 'R' called field diverter is connected in parallel with series field resistance $R_{se}$
- By varing filed diverter 'R, the effective value of field current through the filed winding can be varied.
- When R= 0, all the current will be diverted from the field winding therfore flux ($\phi$) will be minimum and speed will be maximum because $N \,\alpha\, \frac{E_b}{\phi}$
- If 'R' incrases speed decreases.
- By using this method we can control those speeds which are below rated value.

**e) A DC shunt motor takes an armature current of 120A from 400V supply and runs at 800 rpm. Calculate armature current and motor speed when magnetic field is reduced to 80% of its initial value. Armature resistance is 0.25 ohm and given that torque developed remains the same.**



$I_{a1} = 120\ A,\ V = 400\ V,\ N_1 = 800\ rpm\ \ and\ \ r_a = 0.25\ \ ,\ \ \phi = \phi_1$

$\therefore\ E_{b1} = V - I_{a1} \times r_a$

$\therefore\ E_{b1} = 400 - (120 \times 0.25)$

$\therefore\ E_{b1} = 370\ \ Volt$ ------------------------------------------------------------- **(1 Mark)**

$\therefore\ Given,\ \phi_2 = 0.8\,\phi_1$

$\therefore\ Given: Torque\ developed\ \ remains\ \ the\ same,\ \phi_2 = 0.8\,\phi_1$

$\therefore\ \ \phi_1 \times I_{a1} = \ \phi_2 \times I_{a2}$

$\therefore\ \ 120 \times \phi_1\ \ =\ \ 0.8\,\phi_1 \times I_{a2}$

$\therefore\ \ \ I_{a2} = 150\ A$ ------------------------------------------------------------- **(1 Mark)**

$\therefore\ E_{b2} = V - I_{a2} \times r_a$

$\therefore\ E_{b2} = 400 - (150 - 0.25)$

$\therefore\ E_{b2} = 362.5\ \ Volt$ ------------------------------------------------------------- **(1 Mark)**

**We have,**

$\therefore\ E_b\ \alpha\ \phi.N$

$$\therefore\ \frac{E_{b1}}{E_{b2}} = \frac{\phi_1}{0.8\,\phi_1} \times \frac{N_1}{N_2}$$

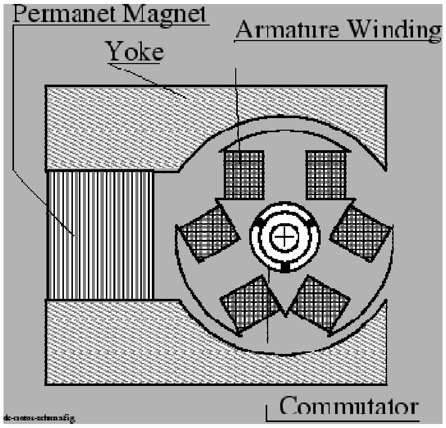
$$\therefore\ \frac{370}{362.5} = \frac{\phi_1}{0.8\,\phi_1} \times \frac{800}{N_2}$$

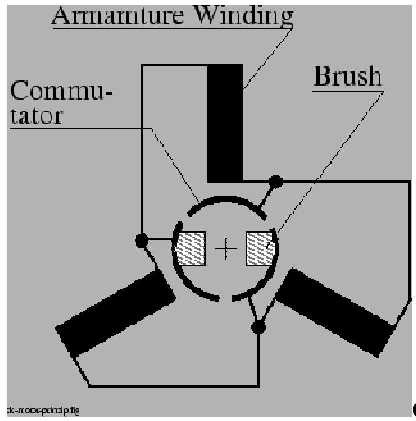
$$\therefore\ 1.02 = \times \frac{800}{0.8\ N_2}$$

$\therefore N_2 = 980.4\ \ rpm$ ------------------------------------------------------------- **(1 Mark)**

**f) With the help of necessary sketch, explain in brief the working of brushless DC motor.**

**Constructional Diagram of Brushless DC Motor: (Figure:2 Mark & Explanation:2 Mark)**




**or equivalent figure**

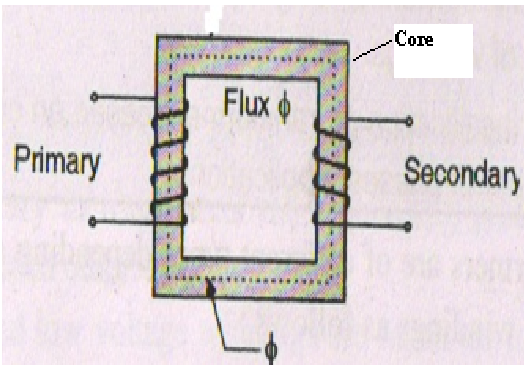
**Working of brushless DC motor:**

- The brushless DC motor is the combination of a permanent excited synchronous motor and a frequency inverter.
- The inverter has to replace the commutator of a conventional DC motor. Fig. 2 and Fig. 3 show how a brushless DC motor can be derived from a mechanically commutated DC motor with three armature slots. Its armature winding corresponds to a three phase winding in delta connection.
- The commutator acts like a three phase frequency converter. Stator (excitation) and rotor (armature) change places. The construction of brushless DC motor is similar to that of permanent magnet synchronous motor.
- The commutation of a brushless DC motor depends on the position of the rotor. The angle between the magneto-motive forces of stator and rotor is fixed to $90^{\circ}$ (el.), so the motor produces maximum torque and needs low reactive current - it might be useful to advance commutation by few degrees to compensate the effects of the stray inductance and minimize reactive current.
- Speed can only be controlled by the the motor voltage.
- The motor behaves like a DC motor. Unlike the synchronous motor there are no problems with instability at any speed.
- Because of the PWM frequency inverter, variation of the motor voltage can be achieved easily by changing the duty cycle of the pulse width modulation. Suitable PWM techniques allow regenerative breaking, which increases dynamic and efficiency of the drive.

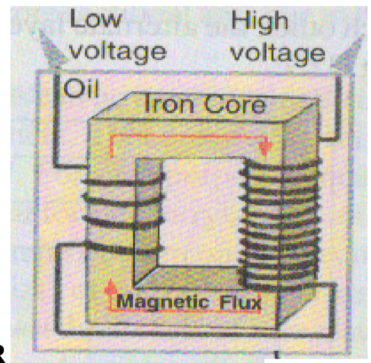
**Q.3 Attempt any Four of the following: --------------------------------------------------16 Marks**

**a) Draw diagram of a core type single phase transformer showing its constructional details. Also state any two characteristics of this transformer. (2 Mark)**

**Diagram of a core type single phase transformer:** **(2 Mark)**




OR




**Characteristics of Core type transformer:** **(Any Two point expected: 1 Mark each)**

1. In this type of transformer the core has only one window.
2. Winding enclose the core.
3. The transformer is easy for repair.
4. Better cooling.
5. Less mechanical protection

**b) The no load current of a transformer is 15 Amp at 0.2 pf. When connected to a 460V, 50Hz supply. If the primary winding has 550 turns, Calculate: i) Magnetizing component ii) Core loss component of no load current iii) Maximum flux**

**Given Data:**

$I_o = 15$ A, $\cos\phi_0 = 0.2 \quad \therefore \phi_0 = \cos^{-1}(0.2) = 78.46$

$V = 460V \quad , \quad f = 50\ Hz \quad and \quad N_1 = 550\ turns$

**i) Magnetizing component:**

$I_m = I_0 \sin\phi_0 = 15 \sin 78.46$ ---------------------------------------------------- **(1/2 Mark)**

$I_m = 16.69\ A$ ------------------------------------------------------------------------ **(1 Mark)**

**ii) Core loss component of no load current:**

$$I_{core} = I_0 \cos\phi_0 = 15 \cos 78.46$$

$$I_{core} = 3\ Amp$$ ---------------------------------------------------------------------- **(1 Mark)**

**iii) Maximum flux:**

$$E_1 = 4.44\,\phi_m\ f\ N_1$$ ------------------------------------------------------------- **(1/2 Mark)**

$$\phi_m = \frac{E_1}{4.44 \times f \times N_1}$$

$$\phi_m = \frac{460}{4.44 \times 50 \times 550}$$

$$\phi_m = 3.76\ mWb$$ --------------------------------------------------------------------- **(1 Mark)**

**c) Describe any two methods for transformer cooling.**

**Methods of Cooling of Transformer: -** **(Any Two types are expected: 2 Mark each)**

**i) Oil Natural Air natural (O.N.A.N.):-**

- This type of cooling is used for transformer upto rating of 30 MVA.
- The basic structure of transformer is immersed completely in the oil kept in transformer tank.
- When transformer gets loaded, the windings and core gets heated, the generated heat is absorbed by the oil as per the principle of convection.
- The heated oil is being cooled by the natural air. For effective cooling of oils is made by providing cooling tubes to the transformer tank

**ii) Oil Natural Air forced cooling (O.N.A.F):-**

- In this method the transfer of heat from the various parts of transformer takes place naturally like O.N.A.N. type cooling.
- However the cooling fans are used which are mounted below or near the transformer, the forced airs from these fans are directed to the cooling tubes of transformer tanks. These improve the rate of cooling.

**iii) Air Natural cooling (A.N):-**

- This type of cooling is used for small dry type transformers.
- The air in the surrounding vicinity of the transformer is used for cooling.
- This type is suitable for transformers upto a rating of 25 KVA.

**iv) Air forced cooling (A.F):-**

- This type of cooling is suitable for dry type transformers of slightly higher ratings.
- The air is forced upon the bank surface to increase the rate of heat dissipation.

**v) Oil forced Air forced cooling (O.F.A.F):-**

- This type of cooling is used for the transformers of ratings above 60MVA.
- A separate cooler is mounted away from the transformer tank and this cooler is connected to the transformer with pipes at the bottom and top.
- The oil is circulated from transformer to the cooler with the help of an oil pump. This oil is then subjected to forced air cooling with the help of fans installed inside the cooler.
- The O.F.A.F type of cooling is used for the high rating transformer at the substation and power station.

**vi) Oil forced Water forced cooling (O.F.W.F):-**

- This type of cooling is used for the large transformers, and cooling needs a heat exchanger.
- Inside heat exchanger the heat from the oil is transferred to the cooling water.
- The cooling water is taken away and cooled in separate coolers. The oil is forced to circulate through the heat exchanger by using a pump.
- This type of cooling is used for transformers having rating of few MVA (generating transformer)

**d) Derive the emf equation of a transformer.**

**Emf equation of transformer:**

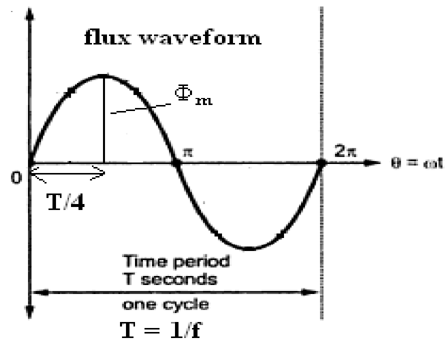
$N_1$ = No. of turns on primary winding

$N_2$ = No. of turns on secondary winding

$\Phi_m$ = maximum value of flux linking both the winding in Wb

f = Frequency of supply in Hz

**First method:**




Maximum value of flux is reached in time $t = 1/4f$
Avg. rate of change of flux = $\Phi_m/t = \Phi_m/(1/4f) = 4\Phi_m f$ Wb/sec
From faraday's laws of electromagnetic induction
Avg. emf induced in each turn = Avg. rate of change of flux = $4\Phi_m f$
Form factor = ( RMS value)/( Avg. value) = 1.11
R.M.S. emf induced in each turn = 1.11 x Avg. value = 1.11 x $4\Phi_m f$
= 4.44 $\Phi_m f$ volts
R.M.S. emf induced in primary winding = ( RMS emf / turn) x $N_1$
$E_1 = 4.44\ \Phi_m f N_1$ volts
Similarly, $E_2 = 4.44\ \Phi_m f N_2$ volts

**OR**

**Second method:**

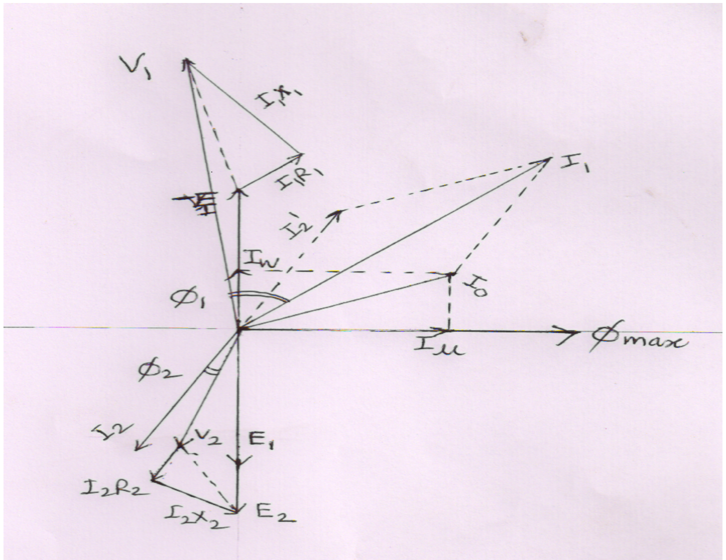
$\Phi = \Phi_m \sin \omega t$
According to Faraday's laws of electromagnetic induction
Instantaneous value of emf/ turn = $-d\Phi/dt = -d/dt(\Phi_m \sin \omega t)$
$= -\omega\Phi_m \cos \omega t$
$= \omega\Phi_m \sin(\omega t - \pi/2)$ volts

Maximum value of emf/turn= $\omega\Phi_m$ But $\omega = 2\pi f$
Max. value of emf /turn = $2\pi f\ \Phi_m$
RMS value of emf /turn = 0.707 x $2\pi f\ \Phi_m$
= $4.44\Phi_m f$ volts

RMS value of emf in primary winding:

$E_1 = 4.44\Phi m\ f \times N_1$ volts and
$E_2 = 4.44\ \Phi m f N_2$ volts

**e) Draw the complete phasor diagram of a transformer at a load of 0.8 P.f lagging.**




**or equivalent phasor diagram**

**f) A single phase 100 KVA, 3.3 KV/230V, 50Hz transformer has 89.5 % efficiency at 0.85 lagging P.f both at full load and also at half load. Calculate the iron loss and full load copper loss.**

$$\eta_{(FL)} = \frac{100\times1000\times0.85}{(100\times1000\times0.85)+Pi+Pcu}$$ ---------------------------------------- **(1/2 Mark)**

$$0.895 = \frac{85000}{85000+Pi+Pcu}$$

$$76075 + 0.895 \quad (Pi + Pcu) = 85000$$

$$0.895 \quad (Pi + Pcu) = 8925. \qquad (Pi + Pcu) = \frac{8925}{0.895}$$

$$(Pi + Pcu) = 9972.06 \qquad eq^n \rightarrow I$$ ---------------------------------------- **(1/2 Mark)**

$$\eta_{(NL)} = \frac{0.5\times100\times1000\times0.85}{(0.5\times100\times1000\times0.85)+Pi+0.25\,Pcu}$$ ------------------------------- **(1/2 Mark)**

$$0.895 = \frac{42500}{42500+Pi+0.25\,Pcu}$$

$$38037.5 + 0.895 \quad (Pi + 0.25\ Pcu) = 42500$$

$$0.895 \quad (Pi + 0.25\ Pcu) = 4462.5$$

$$(Pi + 0.25\ Pcu) = 4986.03 \ \ eq^{n} \ \rightarrow II$$ ------------------------------------- **(1/2 Mark)**

**From equation No. I & II**

$$(Pi + Pcu) - (Pi + 0.25\ Pcu) = 9972.06 - 4986.03$$

$$Pcu - 0.25\ Pcu = 4986.03 \qquad 0.75\ Pcu = 4986.03$$

$$Copper\ losses\ (Pcu) = 6648.04\ \ Watt$$ ------------------------------------------ **(1 Mark)**

**From equation No. I**

$$(Pi + Pcu) = 9972.06 \qquad Pi + 6648.04 = 9972.06$$

$$Iron\ Losses\ (Pi)\ = 3324.02\ \ Watt$$ ------------------------------------------ **(1 Mark)**

**Q.4 Attempt any Four of the following: -------------------------------------------------16 Marks**

**a) A 20 KVA, 100/250V, 50Hz,1-phase transformer gave the following test results.**

**OC Test (with LV open) : 1000V, 2A, 250W, SC Test (with HV shorted) : 5V, 50A, 200W,**

**Calculate the efficiency of this transformer at half full load 0.8 p.f. lagging.**

Iron Losses ($P_i$) =250 watt Copper Losses ($P_{cu}$) =200 watt , 1-ph Transformer

$$\eta_{(HL)} = \frac{0.5 \times KVA \times \cos\phi \times 1000}{(0.5 \times KVA \times \cos\phi \times 1000) + Pi + 0.25\ Pcu}$$ -------------------------------- **(1 Mark)**

$$\eta_{(HL)} = \frac{0.5 \times 20 \times 1000 \times 0.8}{(0.5 \times 20 \times 1000 \times 0.8) + 250 + (0.25 \times 200)}$$ ------------------------------ **(1 Mark)**

$$0.895 = \frac{8000}{8000 + 250 + 50}$$ ------------------------------------------------------------ **(1 Mark)**

$$= 0.9638$$

$$half \quad full\ load\ \ Efficiency\ (\eta) = 96.38\ \%$$ ---------------------------------------- **(1 Mark)**

**b) A 30 KVA, 2400/120V, 50Hz transformer has HV winding resistance of 0.1 ohm and leakage reactance of 0.22 ohm. The LV winding resistance is 0.035 ohm and the leakage reactance is 0.012 ohm. Find the equivalent impedance referred to i) HV side ii) LV side**

**Given data:**

HV Winding Side: Resistance = 0.1 ohm & leakage reactance = 0.22 ohm

LV Winding Side: Resistance = 0.035 ohm & leakage reactance = 0.012 ohm

$$k = \frac{V_2}{V_1} = \frac{120}{240} = 0.05$$ ---------- **(1 Mark)**

**i) LV Winding Side:**

$$Z_{1T} = \sqrt{(R_{1T})^2 + (X_{1T})^2}$$

$$R_{1T} = R_1 + \frac{R_2}{K^2} = 0.1 + \frac{0.035}{(0.05)^2} = 14.1\,\Omega$$ ---------- **(1/2 Mark)**

$$X_{1T} = X_1 + \frac{X_2}{K^2} = 0.22 + \frac{0.012}{(0.05)^2} = 5.02\,\Omega$$

$$Z_{1T} = \sqrt{(14.1)^2 + (5.02)^2}$$

$$equivalent\ \ impedance Z_{1T} = 14.96\,\Omega$$ ---------- **(1 Mark)**

**i) HV Winding Side:**

$$Z_{2T} = \sqrt{(R_{2T})^2 + (X_{2T})^2}$$

$$R_{2T} = R_1 \times K^2 + R_2 = 0.1\,(0.05)^2 + 0.035$$

$$R_{2T} = 0.03525\,\Omega$$

$$X_{2T} = X_1 \times K^2 + X_2 = 0.22\,(0.05)^2 + 0.012$$

$$X_{2T} = 0.01255\,\Omega$$ ---------- **(1/2 Mark)**

$$Z_{2T} = \sqrt{(0.03525)^2 + (0.01255)^2}$$

$$equivalent\ \ impedance Z_{2T} = 0.03741\,\Omega$$ ---------- **(1 Mark)**

**c) State the different types of losses occurring in a single phase transformer and suggest remedies to minimize these losses.**

**Types of losses occurring in a single phase transformer:** **(2 Mark)**

1) **Core or Iron losses:**
   i) These losses are called as constant losses.
   ii) These losses take place in transformer core:
      a) **Hysteresis loss:** Takes place due to rapid reversal of magnetization by alternating flux
      b) **Eddy current loss:** Caused due to flow of eddy current in the core.

2) **Copper losses:**
   i) These losses are called as variable losses.
   ii) These losses takes place in the winding of transformer
   iii) These losses take place due to resistance of primary and secondary winding.
   Total copper losses $=I_1^2R_1+I_2^2R_2$

**Remedies to minimize these losses:** **(2 Mark)**

1. The hysteresis losses can be minimized by selecting proper material for core which is having low hysteresis losses e.g. Silicon steel
2. The eddy current can be minimized by making the core of laminated nature.
3. The copper losses can be minimized by selecting high quality super insulated copper wire for making primary & secondary windings.
4.

**d) A single phase transformer with a ratio of 500/200V takes a no load current of 3 Amp at 0.4 p.f. lag. If the secondary supplies a current of 50 Amp at a pf of 0.85 lag, estimate the current taken by the primary.**

**We know that:**

$I_o = 3A$ at $Cos\phi_0 = 0.4 \Rightarrow \phi_0 = 66.42$ $I_2 = 50A$ ------------------------------------ **(1/2 Mark)**

$Cos\phi_2 = 0.85 \Rightarrow \phi_2 = \phi_2' = 31.78$ ------------------------------------------ **(1/2 Mark)**

$$I_2' = \frac{N_2}{N_1} \times I_2$$ ------------------------------------------------------------ **(1/2 Mark)**

$$I_2' = \frac{200}{500} \times 50 \ = 20A$$ ------------------------------------------------- **(1 Mark)**

**Current taken by the primary:**

$$I_1 = \sqrt{(I_0)^2 + (I_2')^2 + I_0 I_2' \cos(\phi_0 - \phi_2')}$$ ------------------------------------ **(1/2 Mark)**

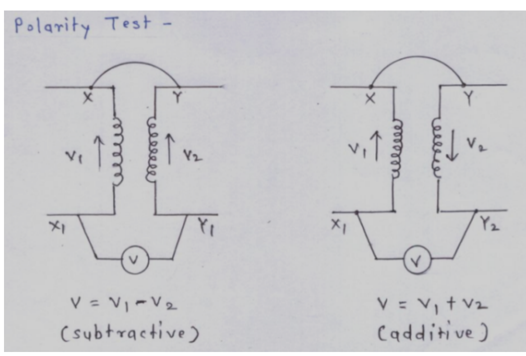
$$I_1 = \sqrt{(3)^2 + (20)^2 + 2 \times 3 \times 20 \times \cos(66.42 - 31.78)}$$

$$I_1 = \sqrt{9 + 400 + 98.72}$$

$$Current\ taken\ by\ primary\ \ (I_1) = 22.53\ A$$ -------------------------------------------- **(1 Mark)**

**e) Draw and explain the circuit diagram to carry out polarity test on single phase transformer.**

**Circuit Diagram to carry out polarity test on 1-ph transformer:** **(2 Mark)**




**or equivalent diagram**

**Explanation:** **(2 Mark)**

The primary & secondary are supposed to have the same polarity when the turns in both winding go round the core in the same direction & the start & end leads are marked in the same ways. The direction of current in the two winding will then be the same.

**Subtractive Polarity:**

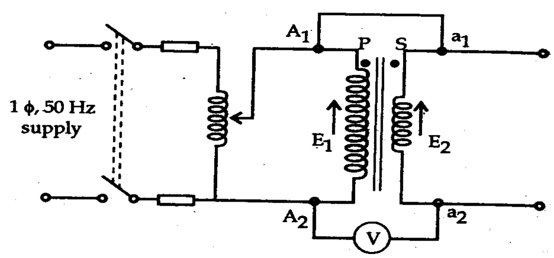
If 'X' & 'Y' connected together the voltage across $X_1$ & $Y_1$ will be found to be V= $V_1$-$V_2$ & the polarity is said to be same is called subtractive polarity.

**Additive Polarity: -**

If 'X' & 'Y' connected together the voltage across $X_1$ & $Y_1$ will be found to be $V = V_1 + V_2$ & the polarity is said to be opposite is called additive polarity.

**OR**

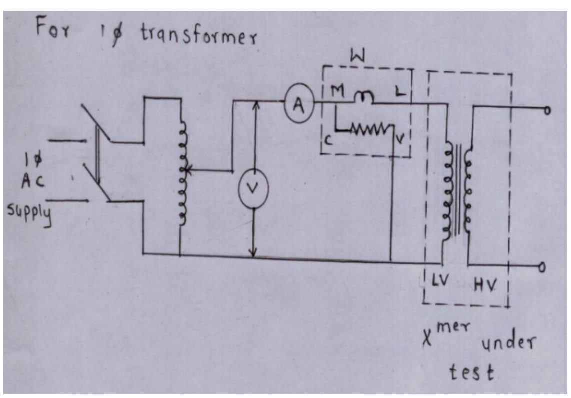
Polarity test is conducted to determine the relative polarity of the mutually inductive windings of a transformer (primary, secondary and tertiary).

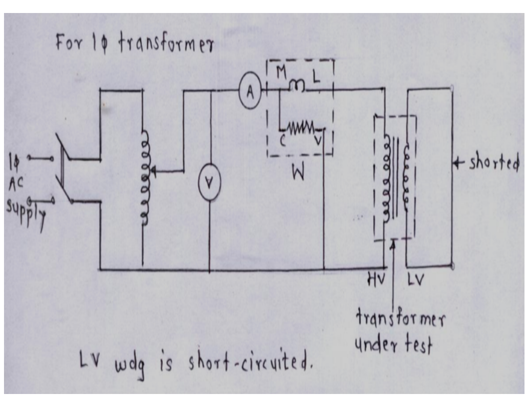



- Transformer is connected to a single phase supply.
- The primary terminals are say $A_1$ and $A_2$ while secondary terminals are $a_1$ and $a_2$.
- Let $A_1$ and $a_1$ are shorted and a voltmeter is connected between $A_2$ and $a_2$.
- If voltmeter reading is $V = E_1 - E_2$ ( subtractive ), then marked polarities are correct.
- If voltmeter reading is $V = E_1 + E_2$ ( additive ) , then marked polarities are not correct. One of them should be reversed.
- Polarity marking is important while connecting two transformers in parallel ( other method can be considered )

**f) Draw the experimental set up to perform OC & SC Test on a 1KVA, 1-ph, 50Hz, 230/115V transformer. Select the range of instruments.**

**Experimental Setup to Open Circuit: (1 Mark) Experimental Setup to Short Circuit :(1Mark)**



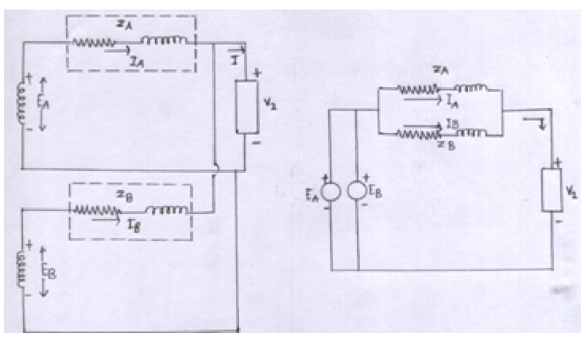



- **Range of instruments in Open circuit Test on 1-ph transformer:** **(1 Mark)**
  1. Ammeter $A_1$ = 0-1/2 A
  2. Voltmeter $V_1$ = 0-150 V
  3. Wattmeter $W_1$ = 0- 2A, 0-150V low p.f wattmeter
- **Range of instruments in Short circuit Test on 1-ph transformer:** **(1 Mark)**
  4. Ammeter $A_1$ = 0-5 A
  5. Voltmeter $V_1$ = 0-10/20 V
  6. Wattmeter $W_1$ = 0-5A, 0-150V

**Q.5 Attempt any Four of the following: ---------------------------------------------------16 Marks**

**a) With necessary diagrams, show the derivation for division of load between two transformer with equal voltage ratios connected in parallel.**

**Load Sharing of Two transformer operating in parallel with equal voltage ratio:** **(1 Mark)**



**or equivalent figure**

$E_A$ & $E_B$ are the no load e.m.f's of the two secondaries. $\therefore E_A = E_B$

$Z_A$ & $Z_B$ are the transformer impedance referred to their respective secondary $Z_A \neq Z_B$

$V_2$ is the common terminal voltage across the secondaries.

$I_A$ = Current shared by transformer A and $I_B$ = Current shared by transformer B

We have, $V_2 = E_A - I_A Z_A$ Also $V_2 = E_B - I_B Z_B$

But we have, $E_A = E_B$

$\therefore I_A Z_A = I_B Z_B$------------------------------------I

This arrangement is similar to a large transformer supplying the same load current I at the same terminal Voltage $V_2$ but its internal impedance is given by

$$Z_{AB} = \frac{Z_A Z_B}{Z_A + Z_B}$$

$\therefore I_A Z_A = I_B Z_B$ = ----------------------------------------II

**From equation No. II we have:**

$$I_A = I \frac{Z_B}{Z_A + Z_B}$$

Similarly, $I_B = I \frac{Z_A}{Z_A + Z_B}$ ---------------------------------------------------- **(1 Mark)**

**Note:-** 1) $\frac{I_A}{I_B} = \frac{Z_B}{Z_A}$ (The currents shared are inversely proportional to their internal impedance)

2) $Z_A$ & $Z_B$ is ohmic magnitudes

1) Multiply the two equation by $I_A$ & $I_B$ by $V_2$ x$10^{-3}$ on both sides use get $S_A$

$$S_A = V_2 I_A \times 10^{-3}\ KVA$$

$$S_A = V_2 I \frac{Z_B}{Z^A + Z_B} \times 10^{-3}\ KVA$$

$$= S \frac{Z_B}{Z_A + Z_B} \text{ -------- } where\ (S = V_2 I \times 10^{-3})$$ **(1 Mark)**

And Similarly: $S_B = V_2 I \frac{Z_A}{Z_A + Z_B} \times 10^{-3}\ KVA$

$$= S \frac{Z_A}{Z_A + Z_B} \text{ -------- } where\ (S = V_2 I \times 10^{-3})$$ **(1 Mark)**

**b) For a 1000 KVA transformer, the full load copper and iron losses are 9 KW and 7 KW respectively. During a day of 24 hours; it is loaded ad follows:**

| S.No. | Number of hours | Loading | Power factor |
|---|---|---|---|
| 1 | 6 | 800 KW | 0.8 |
| 2 | 10 | 600 KW | 0.75 |
| 3 | 4 | 200 KW | 0.8 |
| 4 | 4 | 0 | - |

**Calculate the all day efficiency.**

**<u>(IMPORTANT NOTE): EXPECTED ANY ONE ANSWER</u>**

**The data given in the load cycle 3, particularly the data of P.f is 2.8. According the basic concept of P.f, it must be always less than ONE, but the calculation are made according to given data.**

**Step-I :** Convert the loading from kW to KVA ------------------------------------------------- **(1 Mark)**

i) The loading of 800 kW at p.f of 0.8 is equivalent to (800/0.8) = 1000 KVA

ii) The loading of 600 kW at p.f of 0.75 is equivalent to (600/0.75) = 800 KVA

iii) The loading of 200 kW at p.f of 2.8 is equivalent to (200/2.8) = 71.42 KVA

**Step-II :** Calculate copper losses at different KVA values

i) The 1000 KVA = 9 kW is given

ii) The 800 KVA = $(\frac{800}{1000})^2 \times 9\ kW = 5.76\ kW$

ii) The 71.42 KVA = $(\frac{71.42}{1000})^2 \times 9\ kW = 0.046 kW$

**Total copper losses** Pcu= (9 x 6) + (10 x 5.76) + (4x 0.046) = 111.78 KWHr ---- **(1 Mark)**

**Step-III:**

Total iron losses in 24 hours Pi= 7 x 24 = 168 KWHr ---------------------------------- **(1 Mark)**

**Step IV:**

Output Power ($P_{out}$) = (800 x 6) + (600 x 10) + (200 x 4) = 11600 KWhr

$$All\ day\ efficiency\ \eta = \frac{output\ \ power}{o/p\ \ power + P_i + P_{cu}}$$

$$All\ day\ efficiency\ \eta = \frac{11600}{11600 + 168 + 111.78} \times 100$$

$All\ day\ efficiency\ \eta = 97.64\ \%$ ----------------------------------------------------- **(1 Mark)**

**OR Student may write the answer by taking the P.F. of 3rd cycle = 0.8**

**Step-I :** Convert the loading from kW to KVA ------------------------------------------------- **(1 Mark)**

i) The loading of 800 kW at p.f of 0.8 is equivalent to (800/0.8) = 1000 KVA

ii) The loading of 600 kW at p.f of 0.75 is equivalent to (600/0.75) = 800 KVA

iii) The loading of 200 kW at p.f of 0.8 is equivalent to (200/0.8) = 250 KVA

**Step-II :** Calculate copper losses at different KVA values

i) The 1000 KVA = 9 kW is given

ii) The 800 KVA = $(\frac{800}{1000})^2 \times 9\ kW = 5.76\ kW$

ii) The 250 KVA = $(\frac{250}{1000})^2 \times 9\ kW = 0.56\ kW$

**Total copper losses** Pcu= (9 x 6) + (10 x 5.76) + (4x0.56) = 113.84 KWHr ---- **(1 Mark)**

**Step-III:**

Total iron losses in 24 hours Pi= 7 x 24 = 168 KWHr **-----------------------------------** **(1 Mark)**

**Step IV:**

Output Power ($P_{out}$) = (800 x 6) + (600 x 10) + (200 x 4) = 11600 KWhr

$$All\ day\ efficiency\ \eta = \frac{output\ \ power}{o/p\ \ power + P_i + P_{cu}}$$

$$All\ day\ efficiency\ \eta = \frac{11600}{11600 + 168 + 113.84} \times 100$$

$All\ day\ efficiency\ \eta = 97.62\ \%$ ------------------------------------------------------- **(1 Mark)**

**c) Two 1-phase transformers with equal turns have impedances of (0.5+j3) ohm and (0.6+j10) ohm with respect to secondary. If they operate in parallel, determine how they will share a load of total 100 KW at P.f of 0.8 Lagging.**

**Given Data:**

$$Z_1 = 0.5 + j\,3 = 3.04\angle 80.53$$

$$Z_2 = 0.6 + j\,10 = 10\angle 86.56$$

$$Q = 100\,kW \quad , \quad P.f = 0.8\,lag \quad \therefore Q = 125\angle -36.86$$

**i) Load shared by the I^st^ Transformer:**

$$Q_1 = \frac{Z_2}{Z_1 + Z_2} \times Q$$ ---------------------------------------------------------- **(1 Mark)**

$$Q_1 = \frac{10 \angle 86.56}{(0.5 + j\,3) + (0.6 + j\,10)} \times 125 \angle -36.86$$

$$Q_1 = \frac{10 \angle 86.56}{(1.1 + j\,13)} \times 125 \angle -36.86$$

$$Q_1 = \frac{10 \angle 86.56}{13.04 \angle 85.16} \times 125 \angle -36.86$$

$$Q_1 = (0.76 \angle 1.4)\,(125 \angle -36.86)$$

$$Q_1 = 95 \angle -35.46\ KVA \quad or \quad 76.95\ kW$$ ------------------------- **(1 Mark)**

**ii) Load shared by the II[nd] Transformer:**

$$Q_2 = \frac{Z_1}{Z_1 + Z_2} \times Q$$ ---------------------------------------------------------- **(1 Mark)**

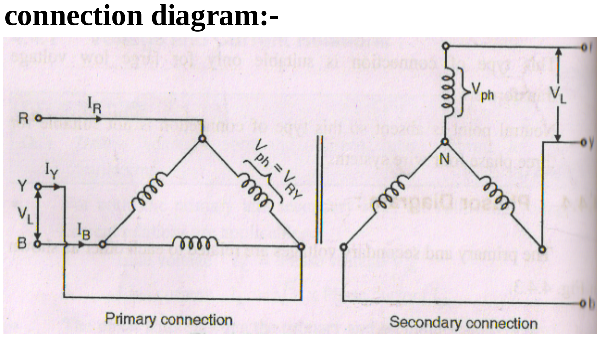
$$Q_1 = \frac{3.04 \angle 80.53}{13.04 \angle 85.16} \times 125 \angle -36.86$$

$$Q_2 = (0.23 \angle -4.63\,(125 \angle -36.86)$$

$$Q_2 = 28.75 \angle -41.49\ KVA \quad or \quad 21.27\ kW$$ ---------------------------- **(1 Mark)**

**d) for Delta-Star connection of 3-phase transformer: i) Draw the connection diagram ii) List any two advantages of this connection iii) State its area of application.**

**i) Draw the connection diagram:-** **(2 Mark)**




or equivalent diagram

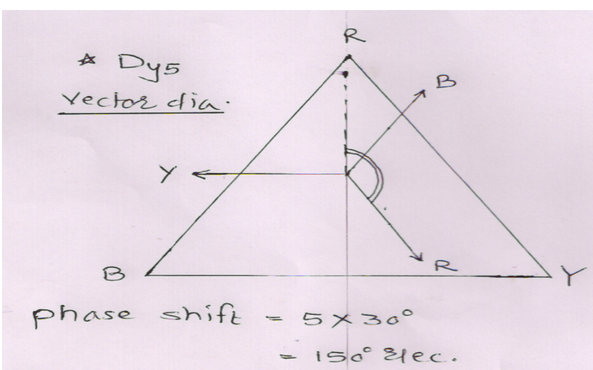
**ii) List any two advantages of Delta-Star connection: (Any Two expected)** **(1 Mark)**

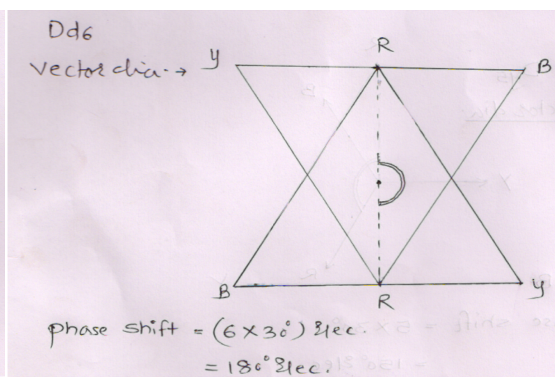
1. As primary is connected in delta, distortion due to third harmonic is absent
2. Phase shift of 30 degree elec. is present between the primary and secondary line voltages and line currents
3. Small cross section wire can be used on primary side due to delta connection.
4. Due to availability of neutral on the secondary side, it is possible to use it for three phase four wire system.

**iii) State its area of application (any two expected)** **(1 Mark)**

1. It is used for step up the voltages at the sending end of high tension transmission lines.
2. Used as distribution transformer
3. Due to star type secondary used for small as well as large loads.
4. As the neutral is available on secondary side it is used for three phase four wire system that is applicable for both single phase as well as three phase load.

**e) Draw the vector diagram and calculate its phase shift for the following vector group: i) $Dy_5$ ii) $Dd_6$**




**or equivalent diagram**

**f) Compare Power transformer and distribution transformer based on the following parameters: i) Typical voltages ii) Power rating iii) Maximum efficiency iv) type of efficiency** **(Each point 1/2 Mark)**

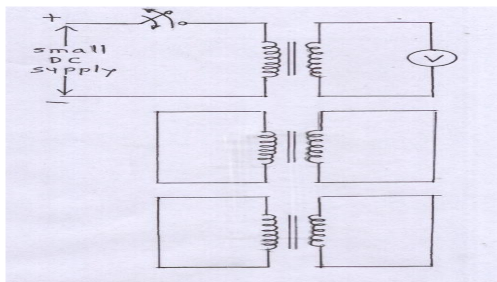
| S.No | Parameters | Power Transformer | Distribution Transformer |
|---|---|---|---|
| 1 | **Typical voltages** | 33 KV,66KV,110KV,220KV and 400 KV | 3.3 KV, 6.6 KV, 11KV, 220V and 440 V |
| 2 | **Power rating** | Greater than 200 MVA | Less than 200 MVA |
| 3 | **Maximum efficiency** | Obtained near 100 % full load | Obtained near 70 % full load |
| 4 | **type of efficiency** | Only power efficiency is sufficient | All day efficiency needs to be defined |

**Q.6 Attempt any Four of the following: --------------------------------------------------16 Marks**

**a) State what is the significance of conducting phasing out test on a 3-phase transformer? Explain its procedure with a suitable connection diagram.**

**Objective: -** This test is carried out to identify primary & secondary windings belonging to same phase.

**Figure:** **(2 Mark)**




**or equivalent figure**

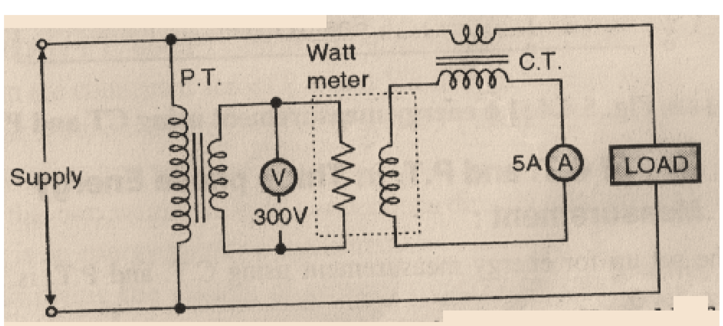
**Procedure:-** **(2 Mark)**

- Short primary & secondary winding of other phases expect the one under test.
- Connect voltmeter to secondary winding.
- A small DC current is circulated through the primary winding through switch.
- Now with the help of switch interrupt the DC supply instantly & repeatedly.
- If voltmeter indicator deflects than it indicates the two windings concerned belong to the same phase.
- If not deflect then two windings are not belong to same phase.
- Repeat the procedure by connecting voltmeter to secondary side to next secondary winding till voltmeter gives deflection.

In this way we can search the phasing out test.

**b) Describe with neat circuit diagram the method of measurement of power in a High voltage, high current a.c circuit.**

**Circuit diagram:** **(2 Mark)**




**or equivalent figure**

**Explanation:** **(2 Mark)**

- The primary winding of P.T is connected across high voltage side and secondary winding is connected to pressure coil of low range wattmeter. The high voltage is proportionally converted to low volt within the range of pressure coil of wattmeter.
- The primary winding of C.T is connected in series with load which carries high load current. And the secondary winding of C.T is connected to current coil of low range wattmeter. The high load current is proportionally converted to low current which within the range of current coil of wattmeter
- The real power consumed in the load can be calculated the following formula is used
- Real power consumed = reading of wattmeter x ratio of C.T x ratio of P.T

**c) Explain why a C.T should never be operated with an open secondary?**

**Reason:-** **(4 Mark)**

CT secondary should never be kept open because it will cause saturation of the core to a high level and very high voltage will appear across the secondary which can breakdown the insulation.

One terminal of PT secondary is always grounded to avoid capacitive induction and for human safety

**d) Describe any two functions of Isolation transformer.**

**Function of isolation transformer**: **(Any two points expected: 2 Mark each)**

1. Primary purpose of isolation transformer is to isolate the two circuits and not to step-up or step-down the voltage.
2. The ground connection which may produce noise in sensitive and expensive instruments, the removal of ground connection is achieved by isolation transformer.
3. These transformers block the transmission of direct current (DC) signals, but allow AC signals to pass from one circuit to another.
4. These are built with special insulation between primary and secondary.
5. The isolation transformer reduces the transients of high amplitudes and short time interval

**e) Give any three features and any two applications of welding transformer.**

**Features of welding transformer: (Any three points expected)** **(1 Mark each point)**

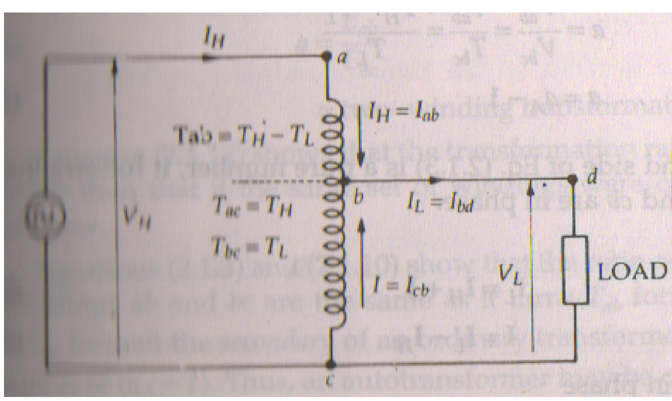
1. It is a step down transformer with large number of primary turns but very small secondary turns, therefore welding transformer is having low primary current and large high secondary or welding current
2. The primary winding is made up of thin wire and secondary winding is made up of thick wire.
3. The welding transformer supplies the welding current almost at short circuit condition.
4. The primary winding of the transformer is connected to supply available in practice and secondary is connected to work piece & electrode.
5. The welding current can be controlled by using following type of reactor: i) Tapped reactor ii) magnetic shunt reactor
6. When welding is under process the supply system will be considerably affected due to voltage variations.

**Applications of welding transformer:** **(1/2 Mark each point)**

1. For spot welding applications
2. For arc welding applications
3. For the portable welding machines which operate directly on the single phase AC supply.

**f) With proper derivation, show how copper saving is obtained in auto transformer.**

**Diagram:** **(1 Mark)**




**or equivalent figure**

**Derivation:** **(3 Mark)**

- The cross section of a conductor is proportional to the current through it and the length of the conductor in a winding is proportional to the number of turns.
- Hence the weight of conductor material in a winding is proportional to the product of current and number of turns.
- For two winding transformer, weight of conductor material in primary $\alpha\ I_H \times T_H$ , weight of conductor material in secondary $\alpha\ I_L \times T_L$ and total weight of conductor material $\alpha\ (I_H \times T_H) + (I_L \times T_L)$
- For the auto transformer, the portion ab has $(T_H - T_L)$ turns and the current through it is $I_H$. Therefore the weight of conductor material in section ab, $\alpha\ I_H\ (T_H - T_L)$
- The portion hc has $T_L$ turns and the current through it is, $I\ = (I_L - I_H)$. Therefore the weight of conductor material in section bc $\alpha\ \ (I_L - I_H) \times T_L$
- Total weight of conductor material

$$\alpha\ [\ I_H\ (T_H - T_L) + (I_L - I_H) \times T_L]$$

$$\frac{W_{auto}}{W_{2W}} = \frac{Weight\ of\ \ conductor\ material\ in\ auto\ transformer}{Weight\ of\ \ conductor\ material\ in\ two\ winding\ transformer}$$

$$\therefore \frac{W_{auto}}{W_{2W}} = 1 - \frac{1}{a_A}$$

$$Where,\ a_A = \frac{V_H}{V_L} = \frac{T_H}{T_L} = \ Transformation\ \ ratio$$

**Therefore saving of conductor material (Copper) in using auto transformer**

$$= W_{2W} - W_{auto}$$

$$= \frac{1}{a_A} \times W_{2W}$$

Hence, the use of auto transformer is more economical