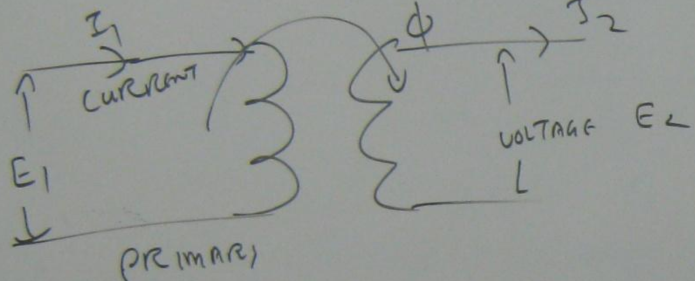
TRANSFORMER



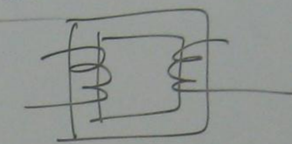
$$\frac{E_1}{E_2} = \frac{I_2}{I_1} = \frac{N_1}{N_2} = a$$

IRON CORE — LAMINATED CORE

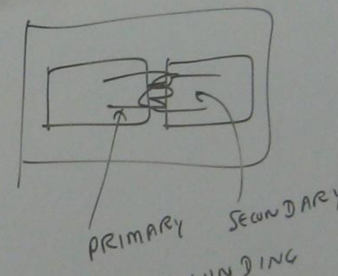
TO REDUCE EDDY CURRENT LOSS.

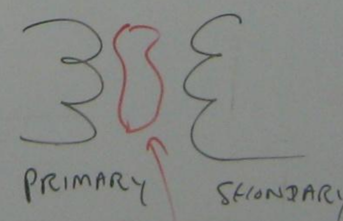
CORE CONSTRUCTION

SHELL

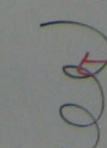


CORE





MAJOR INSULATION – INSULATION BETWEEN WINDINGS.



INSULATION BETWEEN TURNS → MINOR INSULATION

TRANSFORMER VOLTAGE EQUATION

$$E = 4.44 \, f N \phi$$

f = FREQUENCY (HZ)

N = NO. OF TURNS

ϕ = FLUX (Wb)

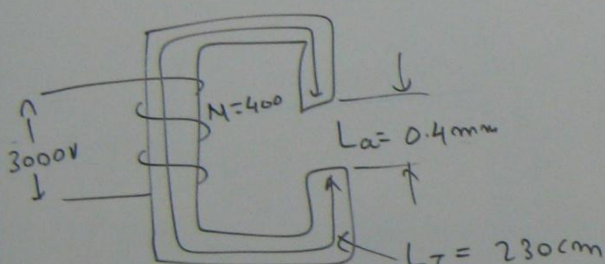
ϕ = FLUX DENSITY × CORE C.S.A

$\phi = B \times A$

pb/ CALCULATE IRON CORE FLUX DENSITY AND RMS MAGNETIZING CURRENT FOR THE FOLLOWING 1ϕ TRANSFORMER

$N_p = 400$ $\quad E_p = 3000$ V (RMS), CORE CSA = 200 Sq cm $\quad \mu_r = 1900$

CORE LENGTH = 230 cm, AIR GAP = 0.4 mm



$$H \times L = N \times I$$

MAGNETIZING FORCE = $\dfrac{\text{FLUX DENSITY}}{\text{PERMEABILITY}}$

$$= \frac{B}{\mu}$$

$$H_a \times l_a + H_I \times l_I = N I$$

$$\frac{B}{\mu} \times l_a + \frac{B}{\mu} l_I = N \times I$$

$$\frac{\phi/A}{\mu_0} \times \frac{0.4}{1000} + \frac{\phi/A}{\mu_r \mu_0} \times \frac{230}{100} = 400 \times I$$

$$E = 4.44 f \phi N$$

$$3000 = 4.44 \times 50 \times \phi \times 400$$

$$\phi = 0.028 \text{ wb}$$

$$\frac{0.028/200\times10^{-4}}{4\pi\times10^{-7}} \times \frac{0.4}{100} + \frac{0.028/200\times10^{-4}}{1900\times4\pi\times10^{-7}} \times \frac{230}{100} = 400 \times I$$

$I = 4.5$ A (MAX)

$$I_{rms} = \frac{I_{max}}{\sqrt{2}}$$

$$= \frac{4.5}{\sqrt{2}}$$

$$= 3.17 \text{ Amp}$$

TRANSFORMER COOLING — AIR | OIL

FREE FROM MOISTURE → AIR

SILICA GEL

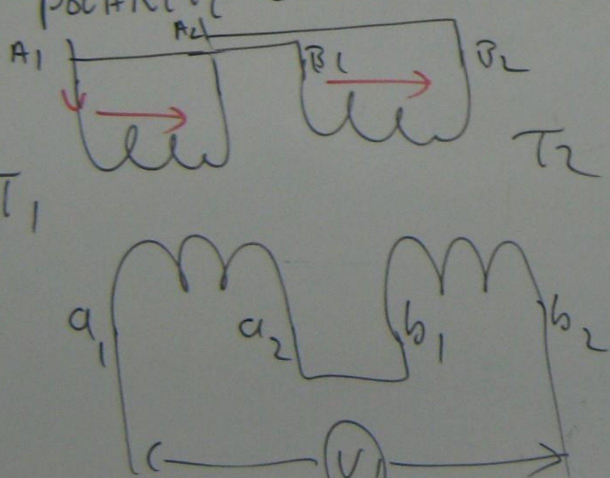
OIL:

- LOW VISCOSITY
- HIGH FLASA POINT
- LOW ACIDITY
- LOW SLUDGE
- HIGH INSULATION PROPERTIES

AS 1767 , AS 1883 → TRANSFORMER OIL

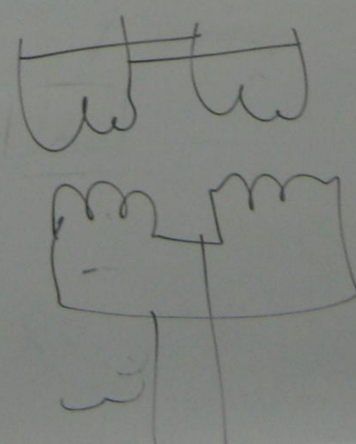
PARALLEL CONNECTION

POLARITY CHECK



$V_1 \simeq 0$

THEN CONNECT



$V \simeq$ LINE VOLTAGE

CHANGE THE CONNECTION & TEST AGAIN

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pb

TRANSFORMER (A) RATED 15 MVA

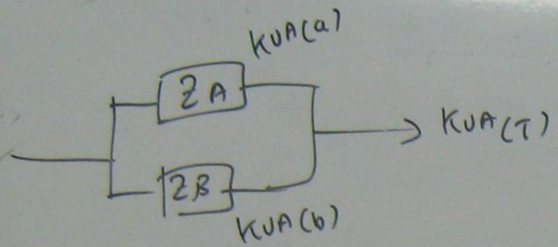
$\% Z_a = 3 + j6\%$

TRANSFORMER (B) RATED 30 MVA

$\% Z_b = 4 + j8\%$

CALCULATE (a) %Z of 30 MVA TRANSFORMER BASED ON 15 MVA

(b) MVA SUPPLIED BY EACH TRANSFORMER WHEN THE COMBINATION OF THEM ARE SUPPLYING 12 MVA UNITY p.f



$$KVA(a) = \frac{Z_B}{Z_A + Z_B} \times KVA(T)$$

$$KVA(b) = \frac{Z_A}{Z_A + Z_B} \times KVA(T)$$

$$\% X_2 = \frac{MVA(BASE)}{MVA_1} \times \% X_1$$

(a) $$Z_2 = \frac{MVA(BASE)}{MVA_1} \times Z_1$$

$$= \frac{15}{30}(4+j8)$$

$Z_B = 2+j4$ BASE ON 15 MVA

$Z_A = 3+j6$ BASE ON 15 MVA

$$KVA(a) = \frac{Z_B}{Z_A+Z_B} \times KVA\,T$$

$$= \frac{2+j4}{3+j6+2+j4} \times 12$$

$$= \frac{\sqrt{2^2+4^2}}{\sqrt{5^2+10^2}} \times 12$$

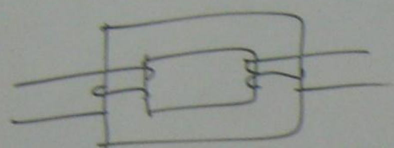
$= 4.79$ MVA

$$KVA(B) = \frac{Z_A}{Z_A+Z_B} \times 12$$

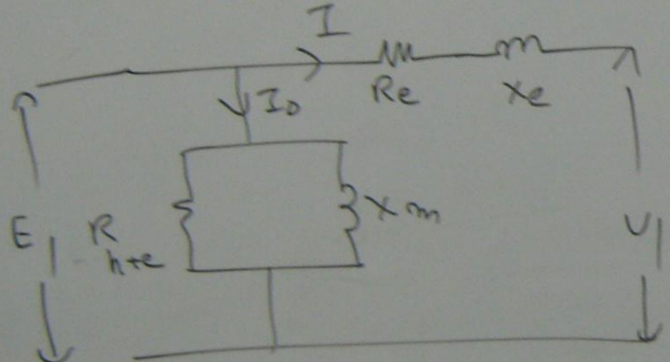
$$= \frac{3+j6}{3+j6+2+j4} \times 12$$

$$= \frac{\sqrt{3^2+6^2}}{\sqrt{5^2+10^2}} \times 12 = 7.19$$

TRANSFORMER EQUIVALENT CIRCUIT



PRIMARY SECONDARY



$$R_e' = R_1 + a^2 R_2$$

R_1 = PRIMARY WINDING RESISTANCE

R_2 = SECONDARY WINDING RESISTANCE

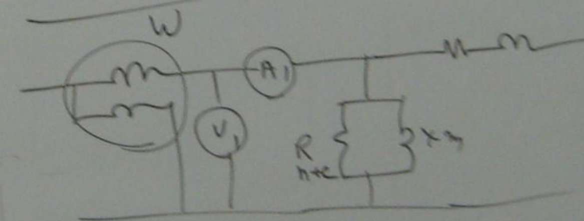
$a = \frac{N1}{N2}$ = TURN RATIO

$$X_e' = X_1 + a^2 X_2$$

R_{h+e} = CORE RESISTANCE

X_m = CORE INDUCTIVE REACTANCE

OPEN CIRCUIT TEST



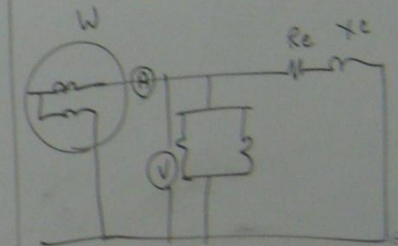
$$R_{h+e} = \frac{V^2}{W}$$

$$VAR = \sqrt{(VI)^2 - (W)^2}$$

$$X_m = \frac{V^2}{VAR}$$

SHORT CIRCUIT TEST

L.V WINDING SIDE IS SHORT CIRCUITED



$$I^2 R_e = W$$

$$R_e = \frac{W}{I^2}$$

$$Z_e = \frac{V}{I}$$

$$X_e = \sqrt{Z_e^2 - R_e^2}$$

INPUT POWER → OUTPUT POWER

CORE LOSS — WINDING LOSS

R_{h+e} loss — R_e loss

CONSTANT — DEPENDING ON LOAD

WINDING LOSS AT ANY LOAD (COPPER LOSS) = $(\text{LOAD RATIO})^2 \times$ Full LOAD COPPER LOSS

$\frac{1}{2}$ LOAD COPPER LOSS = $\left(\frac{1}{2}\right)^2 \times$ Full LOAD COPPER LOSS

TRANSFORMER MAXIMUM EFFICIENCY

CONSTANT LOSS (CORE LOSS) = VARIABLE LOSS (COPPER LOSS)

19

pb

THE followings ARE TEST RESULTS of 3ϕ 66/11kV 30 MVA

Y/Y TRANSFORMER

No LOAD TEST

L.V SIDE VOLTAGE = 11kV, L.V SIDE CURRENT = 50 Amp

POWER = 25 kW

SHORT CIRCUIT TEST

LINE VOLTAGE = 1650V, LINE TO LINE CURRENT = RATED CURRENT

POWER = 20 kW.

$$R_{h+e}'' = \frac{V_{ph}^2}{1\phi \text{ No load power}} = \frac{(11000/\sqrt{3})^2}{\frac{25000}{3}} = 4840\,\Omega$$

$$I_m = \sqrt{I^2 - I_{h+e}^2} = \sqrt{50^2 - \left(\frac{V_{ph}}{R_{h+e}}\right)^2} = \sqrt{50^2 - \left(\frac{11000/\sqrt{3}}{4840}\right)^2}$$

$$= 49.98\,\text{Amp}$$

$$X_m'' = \frac{V_{ph}}{I_m} = \frac{11000/\sqrt{3}}{49.98} = 127.06\,\Omega$$

SHORT CIRCUIT TEST

$I^2 \times R_{eq}' = 1\phi$ SHORT CIRCUIT POWER

$$\left(\frac{30\times10^6}{\sqrt{3}\times66\times10^3}\right)^2 \times R_{eq}' = \frac{20\times10^3}{3}$$

$$R_{eq}' = 0.097\,\Omega$$

$$Z_{eq}' = \frac{V_{ph}}{I} = \frac{1650/\sqrt{3}}{\frac{30\times10^6}{\sqrt{3}\times66\times10^3}}$$

$$= 3.63\,\Omega$$

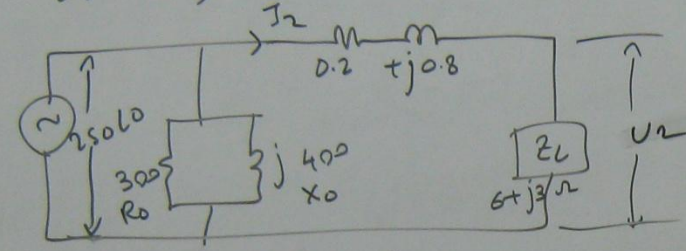
$$X_{eq}' = \sqrt{(Z_{eq}')^2 - (R_{eq}')^2}$$

$$= \sqrt{3.63^2 - 0.097^2}$$

$$= 3.62\,\Omega$$

$$R_{h+e}' = a^2(R_{h+e}'') = \left(\frac{66}{11}\right)^2 \times 4840 =$$

ph IN THE FOLLOWING PROBLEM, FIND (a) IRON LOSS, (b) SECONDARY LOAD CURRENT, (c) COPPER LOSS (d) LOAD POWER (e) EFFICIENCY



(a) IRON LOSS $= \frac{V^2}{R_0} = \frac{250^2}{300} = 208.1$ WATT

(b) $I_2 = \frac{V}{Z_e + Z_L}$

$= \frac{250}{0.2 + j0.8 + 6 + j3}$

$= \frac{250}{6.2 + j3.8}$

$= \frac{250}{\sqrt{6.2^2 + 3.8^2}} = 34.38$ Amp

(c) COPPER LOSS $= I^2 R_e$

$= (34.38)^2 \times 0.2$

$= 236.39$ WATT

(d) LOAD POWER $= I_L^2 \times R_L = 34.38^2 \times 6$

$= 7075$ WATT

INPUT = LOAD POWER + COPPER LOSS + IRON LOSS

$= 7075 + 236.39 + 208.1$

$= 7536$ WATT

% EFFICIENCY $= \frac{\text{OUTPUT}}{\text{INPUT}} \times 100$

$= \frac{7075}{7536} \times 100 = 94.1\%$

TRANSFORMER AT LOAD — % REGULATION (VOLTAGE DROP)

EFFICIENCY ⟷ ALL DAY EFFICIENCY

% VOLTAGE REGULATION = $\%R\cos\theta \pm \%X\sin\theta$ + LAGGING, − LEADING

pb A 1500 KVA 6600/415V 3ϕ Δ/λ TRANSFORMER

$\%R = 1.8$, $\%X = 5$

MAXIMUM EFFICIENCY OCCURS AT 1/4 LOAD

CALCULATE (a) IRON LOSS (b). MAX. EFFICIENCY AT 0.9 PF LAGGING

(c) FULL LOAD % REGULATION AT 0.8 PF LEADING.

$$I_{LINE} = \frac{KVA \times 10^3}{\sqrt{3}\,V} = \frac{1500\times10^3}{1.7321 \times 6600} = 131.2 \text{ Amp}$$

$$\Delta \quad I_{ph} = \frac{I_{LINE}}{\sqrt{3}} = \frac{131.2}{1.7321} = 75.76 \text{ Amp}$$

$$\%R = \frac{IR}{V_{ph}} \times 100$$

$$1.8 = \frac{75.76 \times R}{66\times10^3} \times 100$$

$$R = 1.57\Omega$$

$$\%X = \frac{IX}{V_{ph}} \times 100$$

$$5 = \frac{75.76 \times X}{66\times10^3} \times 100$$

$$X = 4.36\Omega$$

FULL LOAD COPPER LOSS $= 3 I_{FL}^2 \times R$

$$= 3\times(75.76)^2 \times 1.57$$

1/4 LOAD → MAXIMUM EFFICIENCY

IRON LOSS = 1/4 LOAD COPPER LOSS

$$\text{IRON LOSS} = (1/4)^2 \times 3\,(75.76)^2 \times 1.57$$

$$= 1689\ W$$

O/P

MAX E

EFFIC

O|P AT 0.9 P.F LAGGING = 1500 KVA × P.F

$= 1500 \times 0.9$

=

MAX EFFICIENCY = 1/4 LOAD = $\frac{1}{4} \times 1500 \times 0.9$

MAX EFFICIENCY COPPER LOSS = $\left(\frac{1}{4}\right)^2 \times 3\,(75.76)^2 \times 1.57 = 1689$

MAX EFFICIENCY IRON LOSS = 1689

$$\text{EFFICIENCY} = \frac{\text{OUT PUT}}{\text{OUT PUT} + \text{IRON LOSS} + \text{COPPER LOSS}} \times 100$$

$$= \frac{\frac{1}{4} \times 1500 \times 10^3 \times 0.9}{\frac{1}{4} \times 1500 \times 10^3 \times 0.9 + 1689 + 1689} \times 100$$

$= 99\%$

% REGULATION = $\%R\cos\theta \pm \%X\sin\theta$

FOR LEADING PF

% REG = $\%R\cos\theta - \%X\sin\theta$

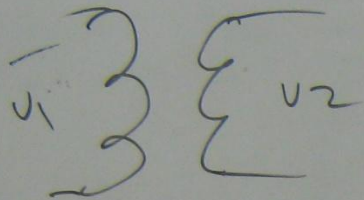
$\cos\theta = 0.8$

$\theta = \cos^{-1} 0.8 = 36.8$

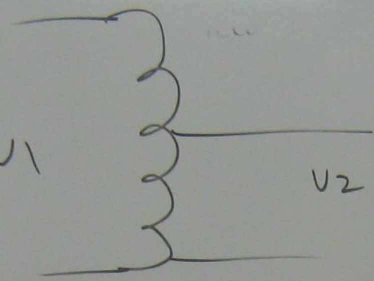
$\sin\theta = \sin 36.8 = 0.6$

% REG = $1.8 \times 0.8 - 5 \times 0.6$

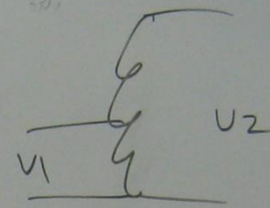
=



2 WINDING TRANSFORMER

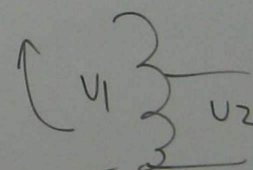


STEP DOWN AUTO TRANSFORMER



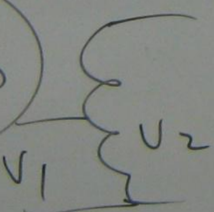
STEP UP AUTO TRANSFORMER

AUTO TRANSFORMER POWER RATING (V.A) $= \left(1 - \frac{1}{k}\right) \times$ 2 WINDING TRANSFORMER V.A



STEP DOWN

STEPUP



AUTO V.A $= (1-k) \times$ 2 WINDING TR. V.A

$$k = \frac{V1}{V_2}$$

ph

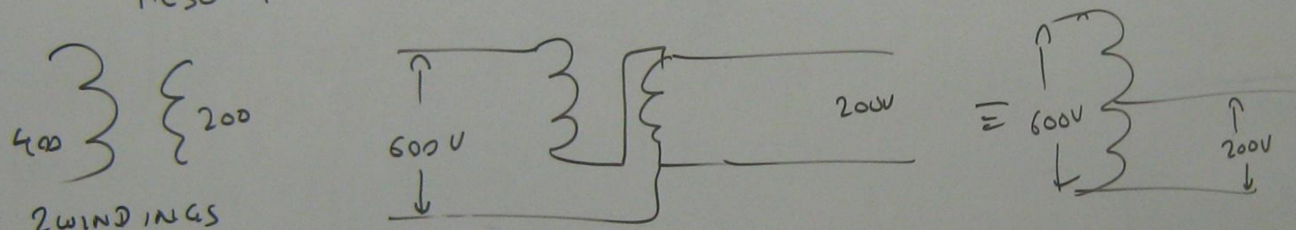
400/200 V 2 WINDING TRANSFORMER

1ϕ RATED 5 KVA. THE TRANSFORMER IS TO SUPPLY 600/200 V

DRAW THE CIRCUIT DIAGRAM HOW TO SUPPLY THE LOAD.

ALSO FIND IT'S RATING WHILE SUPPLYING 600/200 V.

x sinα



nα

$$\text{Auto T.R VA} = \left(1 - \frac{1}{k}\right) \times \text{2 WINDING T.R V.A}$$

$$k = \frac{V_1}{V_2} = \frac{600}{200} = 3$$

$$\text{Auto VA} = \left(1 - \frac{1}{3}\right) \times 5$$

$$= \tfrac{2}{3} \times 5 = 3.33 \text{ KVA}$$