CLASS TEST

S.No.: 01SK_ABCDEFG_08072024

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Transformer

ELECTRICAL ENGINEERING

Date of Test : 08/07/2024

ANSWER KEY

1.	(a)	7.	(b)	13.	(b)	19.	(a)	25.	(d)
2.	(b)	8.	(b)	14.	(b)	20.	(b)	26.	(a)
3.	(a)	9.	(a)	15.	(c)	21.	(c)	27.	(d)
4.	(c)	10.	(d)	16.	(c)	22.	(c)	28.	(c)
5.	(c)	11.	(b)	17.	(c)	23.	(a)	29.	(c)
6.	(b)	12.	(b)	18.	(a)	24.	(b)	30.	(b)

DETAILED EXPLANATIONS

1. **(a)**

We know for per unit loading,

$$\left(\overrightarrow{S_{f\,\text{p.u.}}}^{*}\right) \propto \frac{1}{(Z_{f\Omega})(S_{f\,\text{rated}})}$$

for first transformer produced $(Z_{j\,\Omega}) \times (S_{j\,\text{rated}})$ is lowest

i.e. $(Z_{j\,\Omega}) \times (S_{j\,\text{rated}}) = 1000 \times 2 = 2000$

So, it will reach full load first.

2. **(b)**

When *h.v.* side is exicted,

$$\text{core loss} = VI\cos\phi$$
$$= 1000 \times 3 \times 0.75 = 2250 \text{ W}$$

When *l.v.* side is excited,

$$\text{core loss} = VI\cos\phi = 2250 \text{ W}$$

$$I = \frac{2250}{V \times \cos\phi} = \frac{2250}{400 \times 0.75} = 7.5 \text{ A}$$

Power factor is same for a transformer.

3. **(a)**

Primary is star connected and secondary is delta connected.

$$(V_L)_{\text{primary}} = 11000 \text{ V}$$

$$(V_{\text{ph}})_{\text{primary}} = \frac{11000}{\sqrt{3}}$$

$$\frac{(V_{\text{ph}})_{\text{sec}}}{(V_{\text{ph}})_{\text{prim}}} = \frac{1}{5}$$

$\therefore$ $$\text{Turns ratio} = \left(\frac{\text{High voltage}}{\text{Low voltage}}\right)_{\text{phase}}$$

$\therefore$ $$(V_{\text{ph}})_{\text{sec}} = \frac{11000}{5\sqrt{3}} \text{ V}$$

$$(V_{\text{ph}})_{\Delta} = (V_L)_{\Delta}$$

$$\text{Output kVA} = \sqrt{3}V_L I_L$$

$$= \sqrt{3} \times \frac{11000}{5\sqrt{3}} \times 423 = 930.6 \text{ kVA}$$

4. **(c)**

$$\text{kVA shared} \propto \frac{1}{\text{leakage impedance}}$$

5. **(c)**

Transformer-1,

$$750 \text{ kVA}, Z_1 = 0.018 + j0.09 \text{ p.u. (on 750 kVA base)}$$

Transformer-2,

$$250 \text{ kVA}, Z_2 = 0.022 + j0.10 \text{ p.u. (on 250 kVA base)}$$

$$Z_{2\,new} = (0.022 + j0.10) \times \frac{750}{250}$$

$$= (0.066 + j0.30) \text{ p.u (on 750 kVA base)}$$

Load shared by transformer 2 is,

$$\vec{S}_2^* = \left(\frac{\vec{Z}_1}{\vec{Z}_1 + \vec{Z}_2}\right)\vec{S}_L^* = \frac{0.018 + j0.09}{0.084 + j0.39} \times (1000\angle - \cos^{-1}(0.8))$$

$$= 230.06\angle{-36.02°}$$

Load shared by second transformer,

$$\vec{S}_2 = 230.06\angle 36.02 \text{ kVA}$$

6. (b)

At maximum efficiency,

$$P_{cu} = P_i$$

$$\text{Efficiency, } \eta = \frac{\text{Output}}{\text{Output} + P_{cu} + P_i}$$

$$0.97 = \frac{1}{1 + 2P_i}$$

$$P_i = 0.01546 \text{ p.u.}$$

$$(P_{cu})_{fl} = 0.01546 \text{ p.u.}$$

$$(P_{cu})_{fl} = R_{pu} = 0.01546 \text{ p.u.}$$

$$\text{Voltage regulation} = R_{pu}\cos\phi + X_{pu}\sin\phi$$

$$= 0.01546 \times 0.8 + 0.1 \times 0.6 = 0.07237$$

$$\%V_R \approx 7.24\%$$

7. (b)

Point R is corresponding to maximum voltage regulation.

For maximum voltage regulation load power factor is equal to

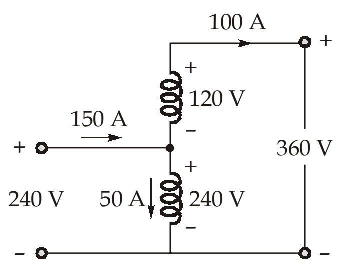
$$\cos\phi = \frac{R}{Z}$$

$$Z = \sqrt{R^2 + X^2} = \sqrt{0.05^2 + 0.5^2}$$

Power factor, $\cos\phi = 0.0995$ lagging

8. (b)

240 V/120 V, 12 kVA has rated current of 50 A/100 A.



$$\text{Auto-transformer rating} = 360 \times 100 \times 10^{-3}$$

$$= 36 \text{ kVA}$$

For 2 winding transformer,

$$\text{Output, } P_0 = 12 \times 1 = 12 \text{ kW}$$

$$\eta = \frac{P_0}{P_0 + P_L} = \frac{1}{1 + \frac{P_L}{P_{L0}}} = 0.962$$

$$1 = 0.962 + 0.962\left(\frac{P_L}{P_0}\right)$$

(or) $$\frac{P_L}{P_0} = \frac{0.038}{0.962};$$

Power loss, $$P_L = \frac{12 \times 0.038}{0.962} = 0.474 \text{ kW}$$

In autotransformer connection, full-load loss remains the same

At 0.85 p.f. $$P_0 = 36 \times 0.85 = 30.6 \text{ kW}$$

Efficiency, $$\eta = \frac{1}{1 + \frac{0.474}{30.6}} = 0.985 \text{ (or) } 98.5\%$$

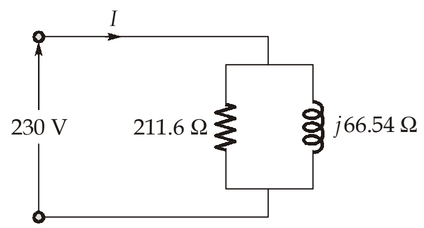
9. (a)

When test is conducted on high voltage side,

$$R_c = \frac{V^2}{P} = \frac{2300^2}{250} = 21160\ \Omega$$

and $$X = \frac{R}{\tan\phi} = \frac{21160}{\tan(\cos^{-1}(0.3))} = j6654.5\ \Omega$$

Referred to low voltage side,



$$\text{Impedance, } Z = \frac{211.6 \times j66.54}{211.6 + j66.54} = 63.475\angle 72.54°\ \Omega$$

Low voltage winding current,

$$I = \frac{230}{Z} = 3.623\angle{-72.54} \text{ A}$$

10. (d)

$$\text{Full load current, } I_{fl} = \frac{12 \times 10^3}{2200} = 5.45 \text{ A}$$

Short circuit test is conducted at $I = 4.09$ A

Full load short circuit losses,

$$P_{cu} = 150 \times \left(\frac{5.45}{4.09}\right)^2 = 266.34 \text{ W}$$

$$\text{Efficiency, } \eta = \frac{12000 \times 0.8}{12000 \times 0.8 + 80 + 266.34} = 96.51\%$$

11. (b)

For first case; $\frac{V_1}{f_1} = \frac{400}{50} = 8$

For second case; $\frac{V_2}{f_2} = \frac{200}{25} = 8$

Since, $\frac{V_1}{f_1} = \frac{V_2}{f_2} = 8$; the flux density B_m remains constant

Now, Hysteresis loss, $P_h = K_1 f$

and Eddy current loss, $P_e = K_2 f^2$

Then, Iron loss, $P_i = K_1 f + K_2 f^2$

or, $\frac{P_i}{f} = K_1 + K_2 f$ ...(i)

Now, from I[st] case:

$$\frac{3200}{50} = K_1 + K_2 \times 50 \quad \text{...(ii)}$$

From II[nd] case:

$$\frac{1000}{25} = K_1 + 25\,K_2 \quad \text{...(iii)}$$

From (ii) and (iii), we get

$$K_1 = 16$$

and $K_2 = \frac{24}{25}$

Hysteresis loss, $P_h = 16 \times 50 = 800$ W

and, eddy current loss, $P_e = \frac{24}{25} \times 2500 = 2400$ W

12. (b)

kVA supplied by *Vee* connection transformer,

$$S_{Vee} = \frac{1}{\sqrt{3}} \times S_{3-\phi} = \frac{3000}{\sqrt{3}} = 1732 \text{ kVA}$$

p.f. angle of transformer-1 = $\phi + 30° = \cos^{-1}(0.95) + 30° = 48.19°$

$\cos\phi_1 = \cos 48.19° = 0.67$ lagging

p.f. angle of transformer-2 = $\phi - 30° = \cos^{-1}(0.95) - 30° = -11.8°$

$\cos\phi_2 = \cos 11.8° = 0.98$ leading

$$\vec{S}_1 = 1732\angle 48.19° \text{ kVA}$$

$$\vec{S}_2 = 1732\angle -11.8° \text{ kVA}$$

13. **(b)**

We know approximate voltage regulation formula,

$$V.R. = Z_{p.u.} \cos(\theta_{eq} - \phi)$$

For maximum voltage regulation,

$$\theta_{eq} - \phi = 0°$$

$$V.R. = Z_{p.u.} \cos 0° = Z_{p.u.}$$

For minimum voltage regulation,

$$\phi = -90°$$

$$V.R. = Z_{p.u.} \cos(90° + \theta_{eq}) = -Z_{p.u.} \sin(\theta_{eq}) = -X_{p.u.}$$

14. **(b)**

Given that,

$$V_{OC} = 230 \text{ V},$$
$$I_{OC} = 1.3 \text{ A},$$
$$P_{OC} = 100 \text{ W}$$

$$R_C = \frac{V_{0C}^2}{P_{0C}} = \frac{230^2}{100} = 529\ \Omega$$

Power factor angle,

$$\phi_{OC} = \cos^{-1}\left(\frac{P_{OC}}{V_{OC}I_{OC}}\right) = \cos^{-1}\left(\frac{100}{230 \times 1.3}\right) = 70.46°$$

$$X_\phi = \frac{R_C}{\tan\phi_{OC}} = \frac{529}{\tan 70.46°} = 187.73\ \Omega$$

Referred to high voltage side,

$$R_C = 529 \times \left(\frac{400}{230}\right)^2 = 1600\ \Omega$$

$$X_\phi = 187.73 \times \left(\frac{400}{230}\right)^2 = 567.8\ \Omega$$

15. **(c)**

Base current in secondary side,

$$I_{2\,(base)} = \frac{100 \times 10^6}{\sqrt{3} \times 110 \times 10^3} = 524.86 \text{ A}$$

Since the transformer supplies a load of 80 MVA at 0.8 pf lagging, so secondary line current of the transformer is

$$I_S = \frac{80 \times 10^6}{\sqrt{3} \times 110 \times 10^3} \approx 420 \text{ A}$$

$$(I_S)_{pu} = \frac{420}{525}\angle\cos^{-1}(0.8) = 0.8\angle -36.87° \text{ p.u.}$$

Per unit no load voltage of this transformer is

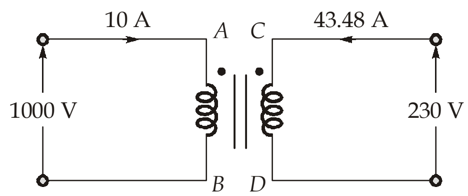
$$E_{NL} = V_S + Iz$$
$$= 1\angle 0° + (0.8\angle -36.87°)\ (0.02 + j0.05)$$
$$= 1.037\angle 1.24°\ \text{p.u.}$$

According to definition of V.R. $= \dfrac{\text{No load voltage} - \text{Full load voltage}}{\text{Full load voltage}} \times 100$

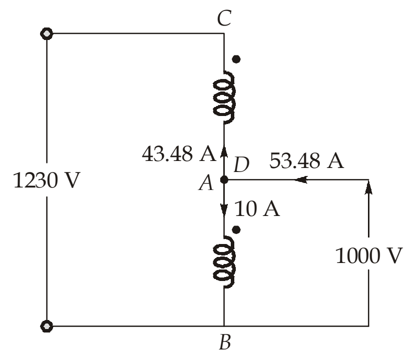
$$\text{V.R.} = \frac{1.037 - 1}{1} \times 100\% = 3.7\ \%$$

16. (c)

Two winding transformer:



Best connection for autotransformer is additive polarity



kVA rating = series winding current × voltage
= 43.48 × 1230 = 53.48 kVA

Conductive transfer = Total kVA – Inductive transfer
= 53.48 – 10 = 43.48 kVA

$$\frac{\text{Conductive transfer}}{\text{Total transfer}} = \frac{43.48}{53.48} = 0.813$$

17. (c)

Hysteresis loss, $p_h \propto f B^x \propto f\left(\dfrac{V}{f}\right)^x$

$$\frac{p_{h_1}}{p_{h_2}} = \frac{f_1}{f_2}\left(\frac{V_1}{V_2} \times \frac{f_2}{f_1}\right)^x$$

$$\frac{700}{p_{h_2}} = \frac{50}{100}\left(\frac{1000}{2000} \times \frac{100}{50}\right)^x$$

or $$p_{h2} = \frac{700 \times 100}{50} = 1400\ \text{W}$$

Eddy current loss, $p_e \propto B^2 f^2 \propto f^2\left(\frac{V}{f}\right)^2$

$$\frac{p_{e_1}}{p_{e_2}} = \left(\frac{f_1}{f_2}\right)^2\left(\frac{V_1}{V_2}\times\frac{f_2}{f_1}\right)^2$$

$$\frac{300}{p_{e_2}} = \left(\frac{50}{100}\right)^2\left(\frac{1000}{2000}\times\frac{100}{50}\right)^2$$

$$p_{e2} = 300 \times 4 = 1200 \text{ W}$$

Total core loss, $p_c = p_{h2} + p_{e2} = 1400 + 1200 = 2600$ W

18. (a)

Note that core loss remains fixed at 40 W, whereas ohmic losses vary as the square of the kVA load.

7 A.M. to 1 P.M. kVA load $= \frac{3}{0.6} = 5$ kVA

$\therefore$ ohmic losses for 6 hours $= 100\left(\frac{5}{5}\right)^2 \times 6 = 600$ W

1 P.M. to 6 P.M.; kVA load $= \frac{2}{0.8} = 2.5$ kVA

$\therefore$ ohmic losses for 5 hours $= 100\left(\frac{2.5}{5.0}\right)^2 \times 5 = 125$ W

6 P.M. to 1 A.M.; kVA load $= \frac{6}{0.9} = \frac{20}{3}$ kVA

$\therefore$ ohmic losses for 7 hours $= 100\left(\frac{20}{3\times 5}\right)^2 \times 7 = 1244.44$ W

1 A.M. to 7 A.M.; ohmic losses = 0

$\therefore$ Daily energy lost as ohmic losses

$$= \frac{1}{1000}[600 + 125 + 1244.44]$$

$$= \frac{1969.6}{1000} = 1.97 \text{ kWh}$$

Daily energy lost as core loss $= \frac{40 \times 24}{1000} = 0.960$ kWh

$\therefore$ Total kWh lost $= 1.970 + 0.960 = 2.93$ kWh

Daily kWh output $= [3 \times 6 + 2 \times 5 + 6 \times 7 + 0]$

= 70 kWh

$\therefore$ All day $\eta = 1 - \frac{\text{Daily losses in kWh}}{(\text{Dailyoutput + Daily losses}) \text{ in kWh}}$

$$= 1 - \frac{2.93}{72.93} = 0.9598 \text{ (or) } 95.98\%$$

19. (a)

The inrush current of the transformer at no load is maximum when the supply voltage is switched on at the instant of zero crossing and going to positive peak.

20. (b)

$$P_{\text{core loss}} = 100 \text{ W}$$

$$\text{Copper loss at half load} = 60 \text{ W}$$

$$\therefore \text{Copper loss at full load} = \frac{60}{(0.5)^2} = 240 \text{ W}$$

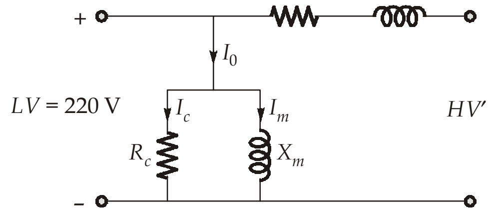
$$\therefore \quad \% \, \eta_{fl} = \frac{(10 \times 10^3 \times 0.8)}{(10 \times 10^3 \times 0.8) + P_{\text{core}} + P_{\text{copper}}} \times 100$$

$$= \frac{(10 \times 10^3 \times 0.8)}{(10 \times 10^3 \times 0.8) + 100 + 240} \times 100$$

$$\eta_{fl} = 95.92\%$$

21. (c)

Lets take circuit referred to low voltage side,



$$\text{Watt meter reading} = VI \cos \phi$$

$$\cos \phi = \frac{100}{220 \times 2.5} = 0.1818$$

$$\sin \phi = \sin (\cos^{-1} (0.1818)) = 0.9833$$

$$I_c = I_0 \cos \phi = 2.5 \times 0.1818 = 0.4545 \text{ A}$$

$$I_m = I_0 \sin \phi = 2.5 \times 0.9833 = 2.46 \text{ A}$$

$$\therefore \quad R_c = \frac{V}{I_c} = \frac{220}{0.4545} = 484 \; \Omega$$

$$X_m = \frac{V}{I_m} = \frac{220}{2.46} = 89.43 \; \Omega$$

$\therefore$ Option (c) is the only equivalent circuit matching.

22. (c)

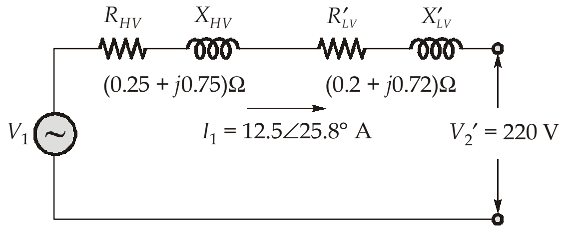
$$I_{1 \text{ rated}} = \frac{3000}{240} = 12.5 \text{ A}$$

I_2 rated is obtained by,

$$\frac{I_1}{I_2} = \frac{N_2}{N_1}$$

$$I_2 = I_1 \times \frac{N_1}{N_2} = 12.5 \times \frac{240}{120} = 25 \text{ A (rated current)}$$

Since given load voltage, V_2 = 110 V so, V_2' = 220 V



$$Z'_{LV} = Z_{LV} \times \left(\frac{N_1}{N_2}\right)^2$$

$$= (0.05 + j0.18) \times \left(\frac{240}{120}\right)^2$$

$$Z'_{LV} = (0.2 + j0.72)\ \Omega$$

$$I_1 = 12.5\angle\cos^{-1}(0.9) = 12.5\angle 25.8°\ \text{A}$$

$$V_1 = \left[(12.5\angle 25.8°)(0.45 + j1.47)\right] + (220\angle 0°)$$

$$V_1 = 217.9\angle 5°\ \text{V}$$

Percentage voltage regulation $= \dfrac{217.9 - 220}{220} \times 100 = -0.95\%$

23. **(a)**

$$\text{Flux, } \phi = BA \times 0.95$$

$$= 1.2 \times 25 \times (10^{-2})^2 \times 0.95 \times \sin 377t$$

$$\phi = 2.85 \times 10^{-3} \sin 377t$$

$$\text{emf} = N_1 \frac{d\phi}{dt} = 200 \times \frac{d}{dt}(2.85 \times 10^{-3} \sin 377t)$$

$$= 200 \times 2.85 \times 10^{-3} \times 377 \times \cos 377t\ \text{V}$$

$$e = 214.89 \cos 377t$$

Rms value of applied voltage $= \dfrac{214.89}{\sqrt{2}} = 151.95$ V

24. **(b)**

The maximum secondary line current without over loading the transformers is,

$$I_L = \frac{\text{KVA}}{\text{V}} = \frac{250 \times 10^3}{460} = 543.48\ \text{A}$$

In open delta connection,

$$P_1 = VI\cos(30° + \phi)$$

$$P_2 = VI\cos(30° - \phi)$$

$$P_{\text{delivered}} = P_1 + P_2 = VI[\cos(30° + \phi) + \cos(30° - \phi)]$$

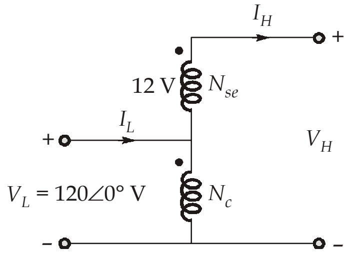
$$= 2\,VI\cos 30° \cos\phi$$

$$= \sqrt{3} V_L I_L \cos\phi$$

$$= \sqrt{3} \times 460 \times 543.48 \times 0.8$$

$$P = 346.41\ \text{kW}$$

25. (d)



$$V_H = 132 \text{ V}$$

The maximum volt-ampere rating in either winding of this transformer is 100 VA.

The voltage on series winding is 12 V

$$I_{\text{series, max}} = \frac{S_{\max}}{V_{\text{series}}} = \frac{100}{12} = 8.33 \text{ A}$$

Since I_{series} is equal to I_H, so secondary apparent power is

$$S_{\text{out}} = V_S I_S = V_H I_H = 132 \times 8.33 = 1100 \text{ VA}$$

26. (a)

Maximum efficiency occurs at unity power factor and when copper loss is equal to the iron loss

kVA rating at maximum efficiency

$$S_m = S_{fl}\sqrt{\frac{P_i}{P_{cu}}} = 300 \times \sqrt{\frac{1.5}{4.5}} = 173.205 \text{ kVA}$$

$$\therefore \quad \text{Maximum efficiency} = \frac{\text{Power output}}{\text{Power output} + \text{losses}}$$

$$\%\ \eta_{\max} = \frac{173.205}{173.205 + 1.5 + 1.5} \times 100 = 98.29\%$$

27. (d)

Turn ratio for the two winding,

$$= \frac{6.6}{\frac{1.1}{\sqrt{3}}} = \frac{6\sqrt{3}}{1}$$

$$\text{Phase voltage} = 300 \text{ V}$$

$$\text{Phase current} = \frac{131.2}{\sqrt{3}} = 75.75 \text{ A}$$

Power dissipated per phase,

$$= \frac{30}{3} = 10 \text{ kW}$$

$$(75.75)^2 R_{e1} = 10 \times 10^3$$

$$R_{e1} = 1.743\ \Omega$$

$$\frac{300}{\sqrt{R_{e1}^2 + X_{e1}^2}} = 75.75$$

$$\sqrt{R_{e1}^2 + X_{e1}^2} = 3.96$$

$$X_{e1} = 3.556\ \Omega$$

28. (c)

$$R_0 = \frac{V^2}{P} = \frac{120 \times 120}{400} = 36\ \Omega$$

$$I = \sqrt{\left(\frac{V}{R}\right)^2 + \left(\frac{V}{X}\right)^2}$$

$$\left(\frac{I}{V}\right)^2 = \frac{1}{R^2} + \frac{1}{X^2}$$

$$\frac{1}{X^2} = \left(\frac{16}{120}\right)^2 - \left(\frac{1}{36}\right)^2$$

$$X = 7.668\ \Omega$$

The magnetizing component of no load current

$$I_m = \frac{V}{X} = \frac{120}{7.668} = 15.65\ \text{A}$$

Alternative Solution:

Given, $V_{NL} = 120$ V

$I_{NL} = 16$ A

$P_{NL} = 400$ W (Open circuit test data)

$\because$ $P_{NL} = V_{NL} I_{NL} \cos\phi$

$400 = 120 \times 16 \times \cos\phi$

$\cos\phi = 0.2083$

$\sin\delta = 0.978$

$I_m = I_{NL} \sin\phi$

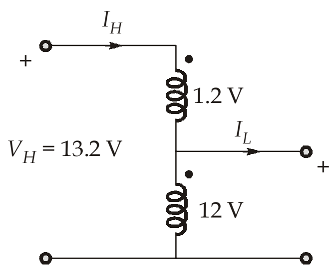
$= 16 \times 0.978 = 15.65$ A

29. (c)

The apparent power rating will be

$$S_{auto} = \frac{N_{series} + N_{common}}{N_{series}} S_{TW}$$

$$= \frac{1.2 + 12}{1.2} \times 1000 = 11000\ \text{KVA}$$



The transformer impedance in p.u. system when connected in two winding manner is,

$$Z_{eq} = (0.01 + j0.08)\ \text{p.u.}$$

The apparent power advantage of this auto transformer is 11, so the per unit impedance of the auto transformer is,

$$Z_{eq} = \frac{0.01 + j0.08}{11} = (0.00091 + j0.00727)\ \text{p.u.}$$

30. (b)

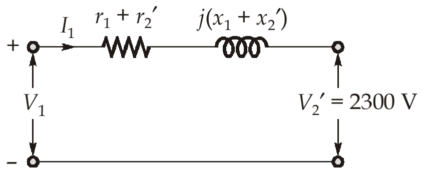
$$\text{Turns ratio} = \frac{2300}{230} = 10$$

$$r_2' = r_2 \times a^2 = 100 \times 0.0396$$

$$= 3.96\ \Omega$$

$$x_2' = x_2 \times a^2 = 100 \times 0.158$$

$$= 15.8\ \Omega$$



Rated current on HV side at 0.8 p.f. lagging

$$2300 \times I_1 = 10 \text{ kVA}$$

$$I_1 = 4.35\angle{-36.87°}\ \text{A}$$

Taking V_2' as reference,

$$V_1 = V_2' + I_1(r_1 + r_2') + jI_1(x_1 + x_2')$$

$$= 2300\angle 0° + (4.35\angle{-36.87°} \times (7.92 + j31.6))$$

$$= 2411.69\angle 2.12°\ \text{V}$$

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