<u>EE6303: ELECTRIC MACHINES II</u>

ASSIGNMENT 01

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SEMESTER: 06

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1. An ideal 3-phase step-down transformer connected delta/star delivers power to a balanced 3-phase load of 120 kVA at 0.8 power factor. The input line voltage is 11 kV and the turn ratio of the transformer, phase-to-phase is 10. Determine the line voltages, line currents, phase voltages and phase currents on both the primary and the secondary sides.

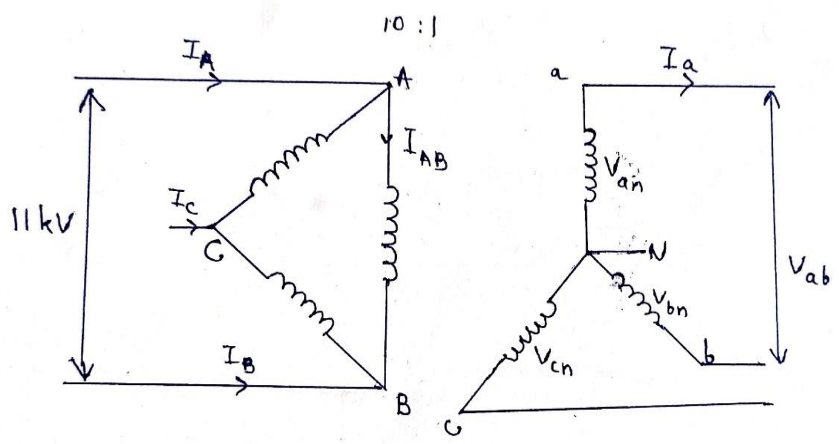


Figure 1: Ideal 3-phase step down transformer connected in delta/star

Output power to the load	= 120 KVA
Input Line voltage	= Phase Voltage
	= 11 kV
Power factor	= 0.8
Phase to phase turn ration	= 10

Considering phase voltages of primary and secondary side,

$$\frac{V_{AB}}{V_{an}} = \frac{V_{BC}}{V_{bn}} = \frac{V_{CA}}{V_{cn}} = 10$$

Since primary side is delta connected,

$$Primary\ side\ line\ voltage\ =\ Primary\ side\ phase\ voltage$$

$$v_{AB} = 11\angle 0°\ kV$$

$$v_{BC} = 11\angle -120°\ kV$$

$$v_{CA} = 11\angle -240°\ kV$$

Secondary side phase voltages,

$$|v_{an}| = \frac{V_{AB}}{10}$$

$$|v_{an}| = \frac{11 \times 10^3}{10}$$

$$|v_{an}| = 1.1 \times 10^3$$

$$\underline{\underline{|v_{an}| = 1.1\ kV}}$$

$$v_{an} = 1.1\angle 0°\ kV$$

$$v_{bn} = 1.1\angle -120°\ kV$$

$$v_{cn} = 1.1\angle -240°\ kV$$

Secondary side line to line voltage,

$$|v_{ab|} = \sqrt{3} \times 1.1 \times 10^3$$

$$\underline{\underline{|v_{ab}| = 1.905\ kV}}$$

$$v_{ab} = 1.905\angle 30°\ kV$$

$$v_{bc} = 1.905\angle -90°\ kV$$

$$v_{ca} = 1.905\angle -210°\ kV$$

Considering primary side,

$$S = \sqrt{3}\, v_{AB} I_A$$

$$120 \times 10^3 = \sqrt{3} \times 11 \times 10^3 \times |I_A|$$

$$\underline{\underline{|I_A| = 6.298\ A}}$$

Therefore,

Primary side line currents,

$$I_A = 6.298\ \angle -66.87°\ A$$

$$I_B = 6.298\angle -186.87\ \mathrm{A}$$

$$I_C = 6.298\angle -306.87°\ \mathrm{A}$$

Primary side phase current, I_{AB}

$$|I_{AB}| = \frac{6.298}{\sqrt{3}} A$$

$$\underline{\underline{|I_{AB}| = 3.636\ A}}$$

$$I_{AB} = 3.636\ \angle -36.87°\ A$$

$$I_{BC} = 3.636 \angle -156.87\ \text{A}$$

$$I_{CA} = 3.636 \angle -276.87°\ \text{A}$$

Now,

$$\frac{I_{AB}}{I_a} = \frac{I_{BC}}{I_b} = \frac{V_{CA}}{I_c} = \frac{1}{10}$$

Therefore,

$$\begin{aligned} \text{Secondary side phase current} &= 10\ \times |\ I_{AB}| \\ &= 10\ \times\ 3.636\ A \\ &= \underline{\underline{36.36\ A}} \end{aligned}$$

$$Secondary\ side\ Line\ current\ =\ Secondary\ side\ phase\ current$$

$$\underline{\underline{|I_a| = 36.36A}}$$

$$I_a = 36.36\ \angle -36.87°\ A$$

$$I_b = 36.36 \angle -156.87\ \text{A}$$

$$I_c = 36.36 \angle -276.87°\ \text{A}$$

2. Two single-phase transformers operate in parallel to supply a load of 44 + j 18.6 Ω. The transformer A has a secondary emf of 600 V on open circuit with an internal impedance of 1.8 + j 5.6 Ω referred to the secondary. The corresponding figures for transformer B are 610 V and 1.8 + j 7.4 Ω. Calculate the terminal voltage, current and power factor of each transformer.

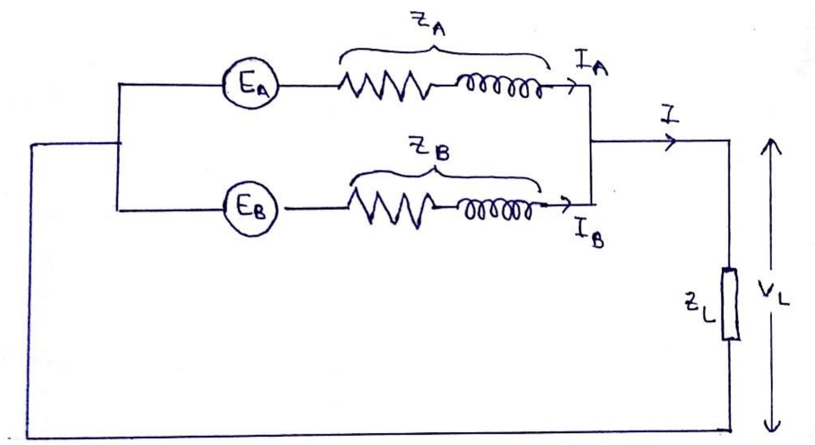


Figure 2: Single phase transformers operate in parallel to supply a load

Load		= (44 + j18.6) Ω
		$= 47.770\angle 22.92° \ \Omega$

Transformers data referred to secondary side,

A:	Secondary emf (E_A)	= 600V
	Internal Impedance (Z_A)	= 1.8 + j5.6
		$= 5.882\angle 72.18° \ \Omega$
B:	Secondary emf (E_B)	= 610V
	Internal Impedance (Z_B)	= 1.8 + j7.4
		$= 7.616\angle 76.33° \ \Omega$

According to the Figure 2,

$$I_A + I_B = I \qquad \text{———— (01)}$$

$$I_A = \frac{E_A - V_L}{Z_A}$$

$$I_A = \frac{E_A - IZ_L}{Z_A} \text{ ——————} (02)$$

Similarly,

$$I_B = \frac{E_B - IZ_L}{Z_B} \text{ ——————} (03)$$

From Equation (01), (02) and (03),

$$I_A = \frac{E_A Z_B \; + \; (E_A - E_B) Z_L}{Z_A Z_B \; + \; Z_L (Z_A + Z_{B)}} \text{ ——————} (04)$$

$$I_A = \frac{E_B Z_A \; + \; (E_B - E_A) Z_L}{Z_A Z_B \; + \; Z_L (Z_A + Z_{B)}} \text{ ——————} (05)$$

By using equation (04),

$$I_A = \frac{600(7.616\angle 76.33°) + (600 - 610)(47.770\angle 22.92°)}{(5.882\angle 72.18°)(7.616\angle 76.33°) + (47.770\angle 22.92°)[(5.882\angle 72.18°) + (7.616\angle 76.33°℃)]}$$

$$\underline{\underline{I_A \; = \; 6.388\angle - 18.96° \, A}}$$

By using equation (05),

$$I_B = \frac{610(5.882\angle 72.18°) + (610 - 600)(47.770\angle 22.92°)}{(5.882\angle 72.18°)(7.616\angle 76.33°) + (47.770\angle 22.92°)[(5.882\angle 72.18°) + (7.616\angle 76.33°℃)]}$$

$$\underline{\underline{I_B \; = \; 5.815\angle - 33.53° \, A}}$$

From Equation (01)

$$I = I_A + I_B$$

$$\mathrm{I} = (6.388\angle -18.96°) + (5.815\angle -33.53°)$$

$$\underline{\underline{I = 12.105\angle -25.90°}}$$

Now terminal voltage, V_L

$$V_L = IZ_L$$
$$= (12.105\angle -25.90°)(47.770\angle 22.92°)$$
$$\underline{\underline{V_L = 578.256\angle -2.19°\, V}}$$

Consider transformer A,

$$cos\emptyset_A = cos(\emptyset_V - \emptyset_{I_A})$$
$$= cos(-2.19 + 18.96)$$
$$\underline{\underline{cos\emptyset_A = 0.9574 \text{ lagging}}}$$

Hence power factor of transformer A = 0.9574 lagging

Consider transformer B,

$$cos\emptyset_A = cos(\emptyset_V - \emptyset_{I_A})$$
$$= cos(-2.19 + 33.53)$$
$$\underline{\underline{cos\emptyset_A = 0.8541 \text{ lagging}}}$$

Hence power factor of transformer B = 0.8541 lagging

3. A 400/100 V, 10 kVA, 2-winding transformer is to be employed as an autotransformer to supply a 400 V circuit from a 500 V source. When tested as a 2-winding transformer at rated load, 0.85 pf lagging, its efficiency is 97%.

   a) Determine its kVA rating as an autotransformer.

   b) Find its efficiency as an autotransformer.

(a)

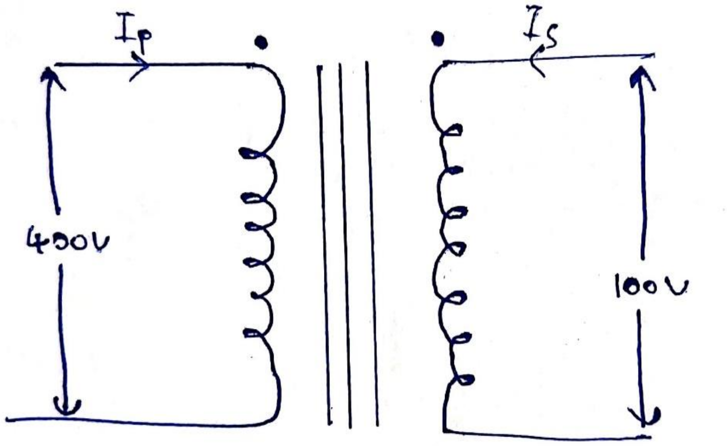


Figure 3: Two winding transformer

Considering rated conditions,

$$P = VI$$

$$I_{p,rated} = \frac{P}{V_{p,rated}}$$

$$I_{p,rated} = \frac{10 \times 10^3}{400}$$

$$I_{p,rated} = 25\ A$$

$$I_{s,rated} = \frac{P}{V_{s,rated}}$$

$$I_{s,rated} = \frac{10 \times 10^3}{100}$$

$$I_{s,rated} = 100\ A$$

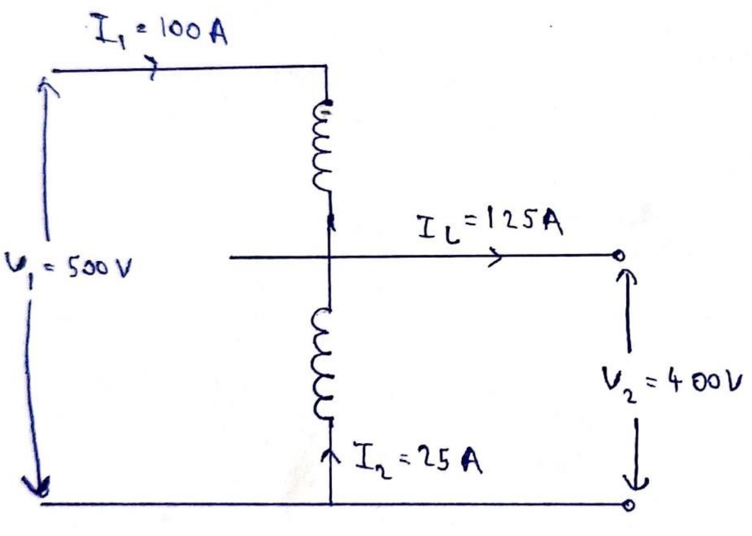


Figure 4: 2 winding transformer connected as a autotransformer

Voltage ratings of the autotransformer is,

$$S = S_{ind} + S_{cond} \text{ ——————— } (01)$$

$$S_{ind} = I_2 V_2$$
$$= 25\,A \times 400V$$
$$S_{ind} = 10\,kVA$$

$$S_{cond} = I_1 V_2$$
$$= 100\,A \times 400V$$
$$S_{ind} = 40\,kVA$$

Therefore, rated kVA from equation 1,

$$S = (10 + 40)kVA$$
$$S = 50kVA$$

(b)

Consider two winding transformers,

$$P_{out} = S \times PF$$
$$= 10 \times 10^3 \times 0.85$$
$$P_{out} = 8.5\ kW$$

$$P_{in} = P_{out} + P_{loss}$$
$$= 8.5\ kW + P_{loss}$$

$$\text{Efficiency}, \eta = \frac{P_{out}}{P_{in}}$$
$$0.97 = \frac{8.5}{8.5 + P_{loss}}$$
$$P_{loss} = 0.263\ kW$$

Considering Autotransformer,

$$P_{out} = 50 \times 10^3 \times 0.85$$
$$= 42.5\ kW$$

$$\eta = \frac{42.5}{42.5 + 0.263} \times 100\%$$
$$\underline{\underline{\eta = 99.385\%}}$$

Therefore, Auto transformer efficiency is 99.385%

4. A 6000 V/150 V, 50 Hz potential transformer has the following parameters with reference to Figure Q4 as seen from HV side.

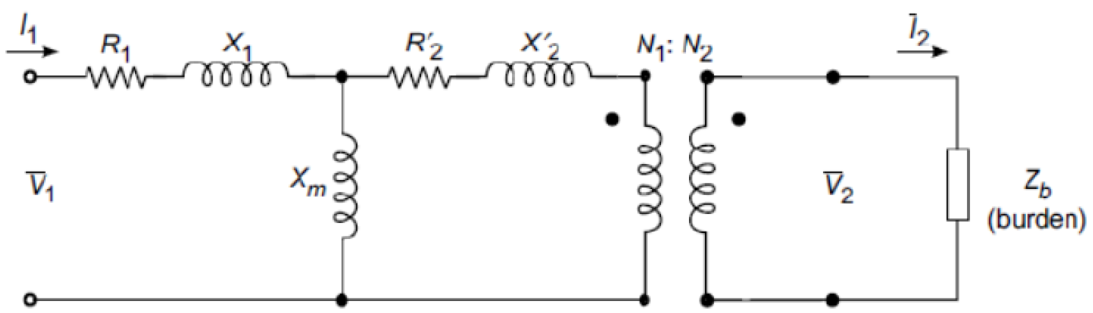
$X_1 = 876\ \Omega$ $X'_2 = 996\ \Omega$ $X_m = 398\ k\Omega$

$R_1 = 684\ \Omega$ $R'_2 = 887\ \Omega$

(a) The primary is excited at 6400 V and the secondary is left open. Calculate the secondary voltage magnitude and phase.

b) The secondary is loaded with 10 kΩ resistance, repeat part a).

c) Calculate the percentage error in the measurement for the two cases in part a) and b)



a)

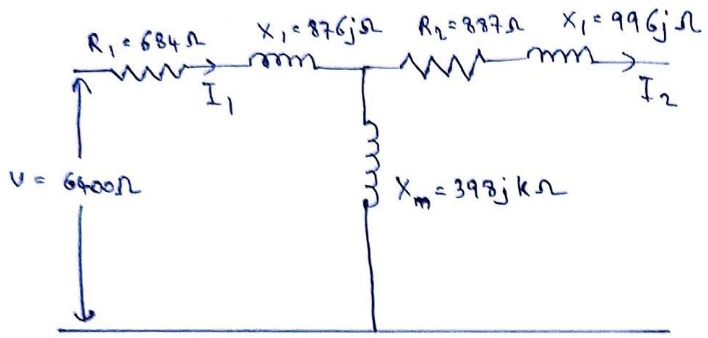


Figure 6: Equivalent circuit of a potential transformer when left open

Secondary side is open. Therefore, $I_2 = 0$.

Hence,

$$I_1 = \frac{6400}{684 + 876j + 398000j}$$
$$= 2.751 \times 10^{-5} - 0.016j$$
$$I_1 = 0.016\angle -89.902°\ A$$

Secondary voltage referred to primary,

$$V_2{}' = I_1 X_m$$
$$= (0.016\angle -89.902°) \times 398000j$$
$$V_2{}' = 6385.935\angle 0.098°\ V$$

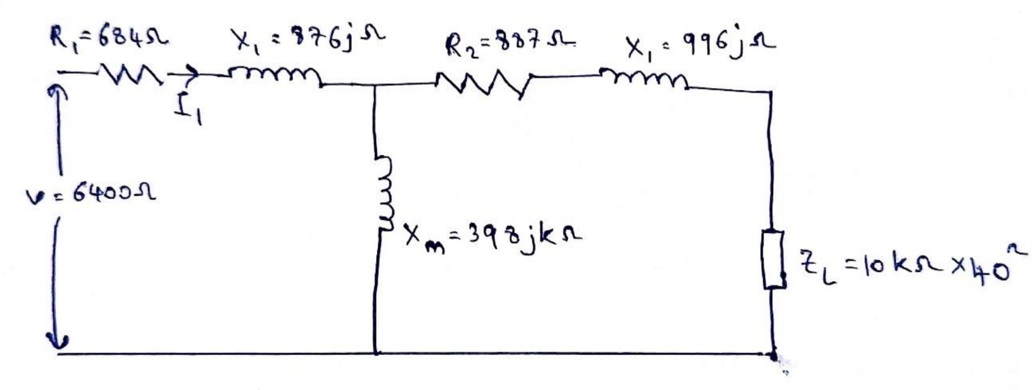
Turn ratio,

$$\frac{N_1}{N_2} = \frac{V_p}{V_s} = a$$
$$a = \frac{6000}{150}$$
$$a = 40$$

Secondary voltage, V_2

$$V_2 = \frac{V_2{}'}{40}$$
$$= \frac{6385.935\angle 0.098°}{40}$$
$$\underline{\underline{V_2 = 159.648\angle 0.098°\ \text{V}}}$$

b)



$$Z_L{}' = 10 \times 10^3 \times 40^2$$
$$= 16 \times 10^6 \Omega$$

$$Z_{eq} = 684 + 876j + (398000j)//(887 + 996j + 16 \times 10^6)$$
$$= 398.770\angle 88.48°\ k\Omega$$

Therefore,

$$I_1 = \frac{6400}{(398.770 \times 10^3 \angle 88.48°)}$$
$$= 0.016\angle -88.48° \, A$$

Now,

$$I_2 = \frac{398000j}{398000j + 887 + 996j + 16 \times 10^6} \times 0.016\angle -88.48° \, A$$
$$= 3.979 \times 10^{-4} \angle 0.092° \, A$$

Therefore, secondary voltage referred to primary, $V_2^{`}$

$$V_2{}' = I_2 Z_L{}'$$
$$= (3.979 \times 10^{-4} \angle 0.092°) \times 16 \times 10^6$$
$$V_2{}' = 6366.4\angle 0.092° \, V$$

Secondary voltage, V_2

$$V_2 = \frac{6366.4\angle 0.092°}{40^2}$$
$$\underline{\underline{V_2 = 159.16\angle 0.092° \, V}}$$

c) The actual value should be $= \frac{6400}{6000} \times 150$

= 160 V

For part a),

$$Percentage\ error = \frac{|159.648 - 160|}{160} \times 100\%$$
$$\underline{\underline{Percentage\ error = 0.22\%}}$$

For part b),

$$Percentage\ error = \frac{|159.160 - 160|}{160} \times 100\%$$
$$\underline{\underline{Percentage\ error = 0.525\%}}$$