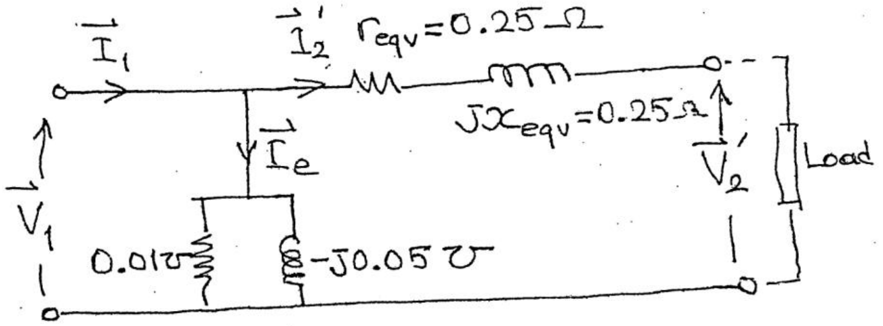
Example A 10-kVA, 220/110V, 50-Hz single-phase transformer delivers rated power (operates at full-load) to its load at rated secondary voltage and 0.8 pf lagging. Compute

a. Primary voltage (use approximate equivalent circuit),

b. Efficiency,

c. Voltage regulation.



← Given

Soln

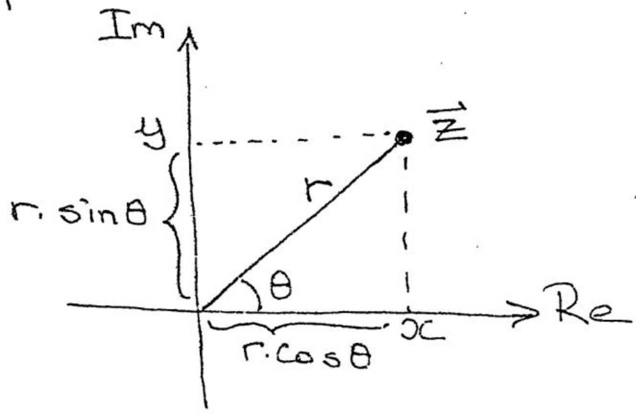
Voltage and current phasors should be expressed as complex numbers on complex plane.

Rectangular Form : $\vec{Z} = x + jy$

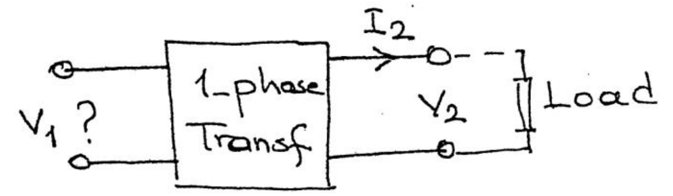
Polar or Steinmetz Form : $\vec{Z} = r\angle\theta$

Trigonometric Form : $\vec{Z} = r(\cos\theta + j\sin\theta)$

Exponential Form : $\vec{Z} = re^{j\theta}$



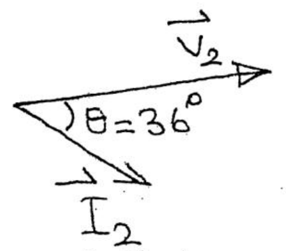
a)



Rated power delivered to load, $S_{rated} = S_{out} = S_{load} = 10\,000$ VA

At rated secondary voltage, $V_2 = V_{2rated} = V_{load} = 110$ V

At 0.8 pf lagging,



$pf = \cos\theta = 0.8$
$\Rightarrow \theta = 36°$

Secondary current, $I_2 = I_{load} = S_{out}/V_2 = 10\,000/110 = 90.\overline{90}$ A

Since equivalent crct is given on the primary side, secondary voltage and current should be referred to primary side.

$V_2' = n \cdot V_2 = 2 \cdot 110 = 220$ V where, $n = (220/110) = 2$

$I_2' = I_2/n = 90.\overline{90}/2 = 45.\overline{45}$ A

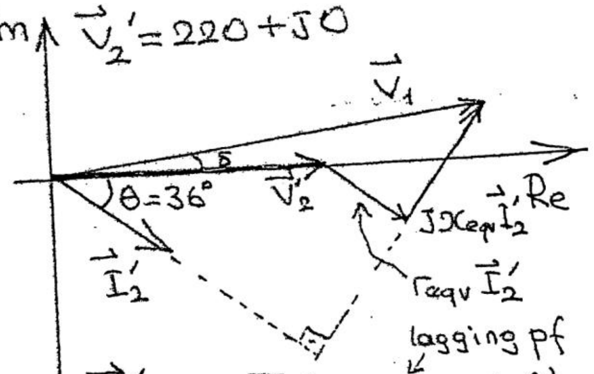
$\vec{V_2}'$ can be chosen as the reference phasor!

Kirchhoff's Voltage Law:

$$\vec{V_1} = \vec{V_2}' + (r_{equ} + jX_{equ})\vec{I_2}'$$

$$\vec{V_1} = 220 + (0.25 + j0.25)\,45.\overline{45}\,(0.8 - j0.6)$$
$$= 220 + 45.\overline{45}\,(0.35 + j0.05)$$
$$= 235.\overline{90} + j\,2.\overline{27}$$

$$\vec{V_1} = 236\angle{+0.6°} \text{ Volts rms}$$



$\vec{I_2}' = 45.\overline{45}(\cos\theta - j\sin\theta)$
$= 45.\overline{45}(0.8 - j0.6)$

$\vec{V_1} = V_1\angle\delta$?

b) $\text{Efficiency} = \dfrac{\text{Output Power}}{\text{Output Power} + \text{Losses}}$

Output Power, $P_{out} = P_{load} = S_{out} \cdot \cos\theta = 10\,kVA \cdot 0.8$
$= 8\,kW$

Copper Loss, $I_2'^2 \cdot r_{eqv} = (45.\overline{45})^2 \cdot 0.25 = 516.5\,W$

Core loss, $E_1^2 g_c \simeq V_1^2 g_c = (236)^2\, 0.01 = 557\,W$

$\therefore$ Efficiency, $\eta = \dfrac{8000}{8000 + 557 + 516.5} = 0.88$

$\eta = 88\,\%$ //

c) In this problem, voltage regulation is the change in secondary terminal voltage from no-load to full-load:

No-load voltage, $V_2' = V_1 = 236$ Volts rms (Since $I_2' = 0$ at no-load)

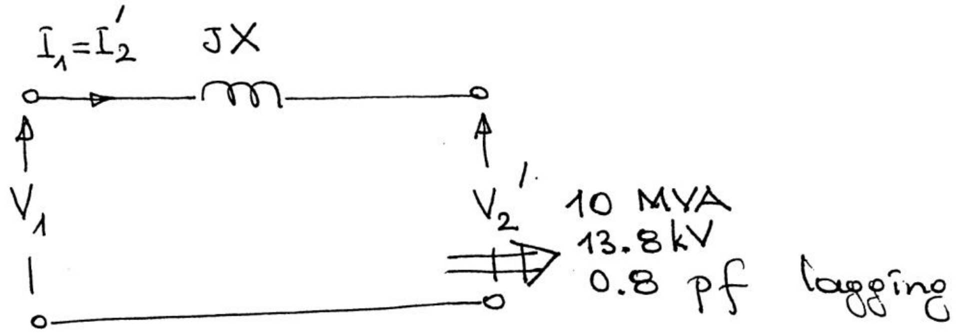
Full-load voltage, $V_2' = V_{2\,rated} = 220$ V rms

It is usually expressed as a percentage of no-load value:

$\text{Voltage Regulation} = \dfrac{236 - 220}{236} \times 100 = +6.8\,\%$ //

Drooping terminal voltage characteristic because of the inductive character of the load.

Ex A 10 MVA 13.8/79.7 kV step-up transformer has a total leakage reactance of $X = 1.9\ \Omega$ referred to primary. Neglecting all transformer losses and magnetizing current, find the primary voltage when transformer is supplying the rated MVA at rated voltage and 0.8 pf lagging.



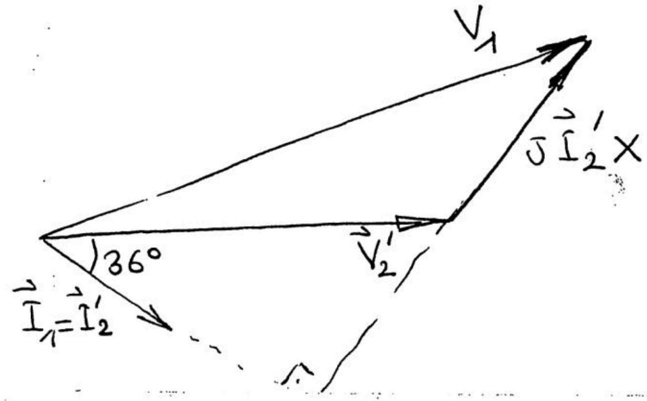
$P_{out} = V_2' I_2' \cos\theta$

$S_2 = V_2 I_2 = V_2' I_2' = 10$ MVA (Rated power of the transformer given on the nameplate is an output quantity)

$P_{out} = 10 \times 0.8 = 8$ MW

$I_2' = 10 \times 10^6 / 13.8 \times 10^3 = 725$ A

$I_2 = 725 \times (13.8/79.7) = 125$ A ($I_2 < I_2'$ because it is a step-up transformer)



phasor diagram

$$\vec{V}_1 = \vec{V}_2' + j\vec{I}_2' X$$

$$\vec{V}_1 = \underset{\text{reference phasor}}{(13.8 + j0.0)} \times 10^3 + j\,1.9 \times \underset{|I_2'|}{725}\,\underset{\substack{\text{0.8 pf lagging} \\ (\cos 36^\circ - j\sin 36^\circ)}}{(0.8 - j0.6)}$$

$$\vec{V}_1 = 13800 \quad + j\,1102 + 826.5$$

$$\vec{V}_1 = 14626.5 + j\,1102$$

$$\vec{V}_1 = 14668 \angle 4.3^\circ$$

$$|\vec{V}_1| = 14.7 \text{ kV}$$

$$Reg = \frac{V_1 - V_2'}{V_2'} \times 100$$

$$= \frac{14.7 - 13.8}{13.8} \times 100$$

$$= +6.5\ \%$$

Now solve the same problem for the leading load

$$\vec{V}_1 = 13.8 \times 10^3 + j1.9 \times 725\,\underset{\text{leading pf}}{(0.8 + j0.6)}$$

$$|\vec{V}_1| = \underset{\text{less than 13.8 kV because of the capacitive load}}{13} \text{ kV}$$

$$Reg = \frac{13 - 13.8}{13.8} \times 100 = \underset{\text{because of the capacitive load.}}{-}\,5.7\ \%$$