$8 + 15 + 6 + 3 = $ **32 points**

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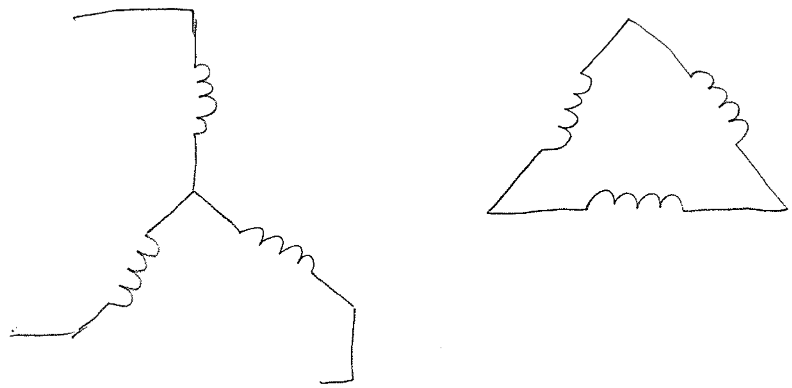
HW 6
ECE 476

Problem 1

8 points

Draw out the Y-Δ circuits for better visualization.



Each winding on Y-side must handle line-neutral voltage while on Δ-side, line-line voltage. Power rating will be same on both sides.

a) Each Transformer ratings:

Power: $\frac{2.1\ MVA}{3} = \boxed{0.7\ MVA}$ both sides

2 points

Voltage: $\frac{13.8}{\sqrt{3}} : 2.3 = \boxed{7.96\ kV\ (Wye) : 2.3\ kV\ (Delta)}$

Current: $\frac{0.7}{7.96} = \boxed{87.94A\ (Wye)}$

$\frac{0.7}{2.3} = \boxed{304.3A\ (Delta)}$

Problem 1

b) Power: 0.7 MVA

Voltage: $13.8 : \frac{2.3}{\sqrt{3}} =$ 13.8 KV (Delta) : 1.33 KV (Wye)

2 points Current: $\frac{0.7}{13.8} =$ 50.7 A (Delta)

526.3 A (Wye)

c) Power: 0.7 MVA

Voltage: 7.96 KV : 1.33 KV

2 points

Current: 87.94 A on High Side

526.3 A on Low Side

d) Power: 0.7 MVA

Voltage: 13.8 KV : 2.3 KV

2 points

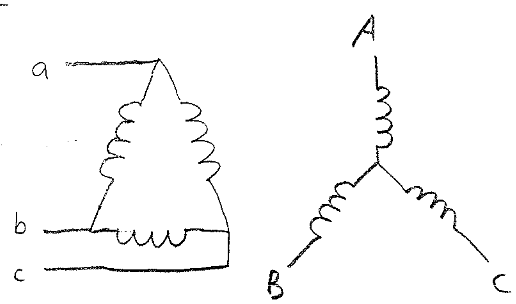
Current: 50.7 A High Side

304.3 A Low Side

Problem 2

15 points

↳ 5+4+4+2



$X_\ell = 0.11$ p.u.

Problem 2

a) Some clarification first... (this was not added in original problem because all power engineers speak like this in industry ⇒ students should get used to it).

i) 230 kV ⇒ line-line voltage (standard voltage), positive seq. assumed

ii) $S_{Base} = 100$ MVA for <u>entire system</u>

Each transformer has its own power base equal to its rating. In this case, it's 330 MVA, which is independent of $S_{Base} = 100$ MVA. This way, X_ℓ can be stated in p.u. independent of the system.

iii) $X_\ell = 0.11$ p.u. if for 1ϕ.

Now, supply system load of 240 MVA at 0.9 pf lag

$$\Rightarrow |\bar{I}_A| = |\bar{I}_B| = |\bar{I}_C| = \frac{S_{1\phi}}{\bar{V}_{line-neutral}} = \frac{240/3 \text{ MVA}}{230/\sqrt{3} \text{ kV}} = 602.45 \text{ A}$$

↑ think per phase equivalent (3ϕ Y to 1ϕ) ∴ line-neutral

$\bar{V}_A = 1.0\angle 0°$ p.u., $\theta = \cos^{-1}(0.9) = 25.8° \Rightarrow \theta_i = -25.8°$ (lag)

∴ $\bar{I}_A = 602.45\angle -25.8°$ A

$\bar{I}_B = 602.45\angle -145.8°$ A

$\bar{I}_C = 602.45\angle 94.2°$ A

To find p.u., we need $I_{Base, 1\phi} = \frac{S_{Base,1\phi}}{V_{Base,\ell-n}} = \frac{\frac{100}{3} \text{ MVA}}{\frac{230}{\sqrt{3}} \text{ kV}} = 251.02$ A

∴ In per unit,

$$\frac{\bar{I}_A}{I_{Base,1\phi}} = \bar{I}_{A,p.u.} = \frac{602.45}{251.02}\angle -25.8° = \boxed{2.4\angle -25.8°}$$

$\bar{I}_{B,p.u.} = \boxed{2.4\angle -145.8°}$

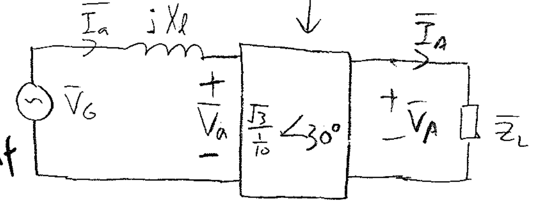
5 points $\quad \bar{I}_{C,p.u.} = \boxed{2.4\angle 94.2°}$

↳ 2 for work, 3 for answers

Problem 2

b)

← Complex turns ratio, see notes from class



1 point

1 point, any figure that is close is ok. No need to plug in values.

$$\bar{I}_a = \frac{\bar{I}_A}{\frac{\sqrt{3}}{\frac{1}{10}}\angle 30°}$$ but in p.u., magnitudes of current do not change, only I_{Base} changes

∴ just account for the phase shift.

$$\bar{I}_{a,p.u.} = \bar{I}_{A,p.u.} \cdot e^{-j(\frac{\pi}{6})} = \boxed{2.4\angle -55.8°}$$

3 points

$$\bar{I}_{b,p.u.} = \boxed{2.4\angle -175.8°}$$

$$\bar{I}_{c,p.u.} = \boxed{2.4\angle 64.2°}$$

c) First, we need X_ℓ. Although it is given p.u., it's not the <u>system</u> p.u. To see this, find X_ℓ in Ω's first.

4 points

2 points for work, 2 points for answer, each answer gets 1 point

$$X_{\ell,1\phi} = 0.11 \times Z_{\text{Base of Transformer}} = 0.11 \times 1.603 = 0.176\ \Omega$$

For Δ side (Low side), $Z_{\text{Base Transformer}} = \frac{V_{Base}^2}{S_{Base}} = \frac{\left(\frac{23kV}{\sqrt{3}}\right)^2}{\frac{330}{3}MVA} = 1.603\ \Omega$

To find $X_{\ell,p.u}$ in system, use $Z_{\text{Base System}} = \frac{\left(\frac{23kV}{\sqrt{3}}\right)^2}{\frac{100}{3}MVA} = 5.29\ \Omega$

$$\therefore X_{\ell,p.u.} = \frac{0.176}{5.29} = 0.0333\ p.u$$

Alternatively, $X_{\ell,p.u.} = 0.11\left(100/330\right) = \frac{1}{30}$, which matches above.

KVL: $\bar{V}_G = \bar{I}_a \cdot jX_{\ell,p.u.} + \bar{V}_a$

$= 2.4\angle -55.8° (j0.0333) + 1\angle -30°$

↳ see notes, $\bar{V}_a = \bar{V}_A\angle -30°$

$= 0.932 - j0.455$ p.u

$= 1.037\angle -26.02°$ p.u.

Problem 2

c) $\bar{V}_G = 23\,kV \cdot 1.037 \angle -26.02°$

$= 23.85 \angle -26.02°\ kV$ for phase A

$\Rightarrow$ Magnitude = **23.85 kV**

$\bar{S}_G = \bar{V}_G \bar{I}_a^* = (1.037 \angle -26.02°)(2.4 \angle 55.8°)$

$= 2.48 \angle 29.78°$ p.u.

$\Rightarrow P_{G,p.u.} = 2.15$

$P_{G,3\phi} = 2.15 \times 100 =$ **215 MW 3ϕ**

Short-cut: No loss ($R=0$) $\Rightarrow$ all power supplied goes to load

$\therefore P_{G,3\phi} = 240\ MVA \cdot 0.9 = 216\ MW$ //
(0.9 ↳ PF)

2 points d) Check. $|\bar{V}_G|$ should stay same, $P_{G,3\phi}$ stay same (duh, no loss in system)

1 point for showing effort (right or wrong), ie, show work

1 point for correct conclusion

Problem 3

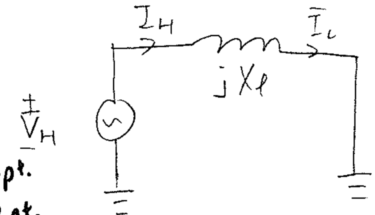
6 points a) High voltage windings are Wye

Low voltage Wye ⇒ No phase shift.

Let $S_{Base} = 10\,MVA$, $V_{Base_{High}} = \frac{115\,kV}{\sqrt{3}} = 66.4\,kV$ ↳ l-n, $V_{Base_{Low}} = 12.5\,kV$

Equivalent Circuit:

4 points
↳ answer 2pt.
work 2pt.



Everything is Line-Neutral

$$I_{Base_{High}} = \frac{S_{Base}}{V_{Base_{High}}} = \frac{10\,MVA}{66.4\,kV} = 150.6\,A$$

$$I_{Base_{Low}} = \frac{S_{Base}}{V_{Base_{Low}}} = \frac{10\,MVA}{12.5\,kV} = 800\,A$$

$$\bar{I}_H = \bar{I}_L = \frac{\bar{V}_H}{jX_\ell} = \frac{1\angle 0^\circ}{j0.1} = 10\angle -90^\circ \text{ p.u.}$$

$\therefore |\bar{I}_H| = 10 \cdot 150.6 = \boxed{1506\,A}$

$|\bar{I}_L| = 10 \cdot 800 = \boxed{8000\,A}$

b) $I_{Base_{High}}$ stays same. $I_{Base_{Low}}$ changes since $V_{Base_{Low}}$ is changed

2 points

← each of these can handle 12.5 kV ⇒ Δ to per phase equivalent, we need line-N

$$I_{Base_{Low}} = \frac{S_{Base}}{V_{Base_{Low}}} = \frac{10\,MVA}{\frac{12.5\,kV}{\sqrt{3}}} = 1385\,A$$

$|\bar{I}_H| = \boxed{1506\,A}$

$|\bar{I}_L| = 10 \cdot 1385 = \boxed{13.85\,kA}$

Problem 4

3 points

Phase Shift Angle	Real Power Loss (MW)
-10°	24.91
-9°	23.37
-8°	21.99
-7°	20.77
-6°	19.70
-5°	18.79
-4°	18.04
-3°	17.44
-2°	17.01
-1°	16.73
0°	16.60
1°	16.64
2°	16.83
3°	17.19
4°	17.69
5°	18.36
6°	19.18
7°	20.16
8°	21.30
9°	22.59
10°	24.04

0° minimizes real power loss

2 points
1 point for table OR if sketch is labeled with correct axis values
1 point for answer 0°

Sketch

1 point for sketch. If sketch is labelled with correct values on axes, table above is not needed