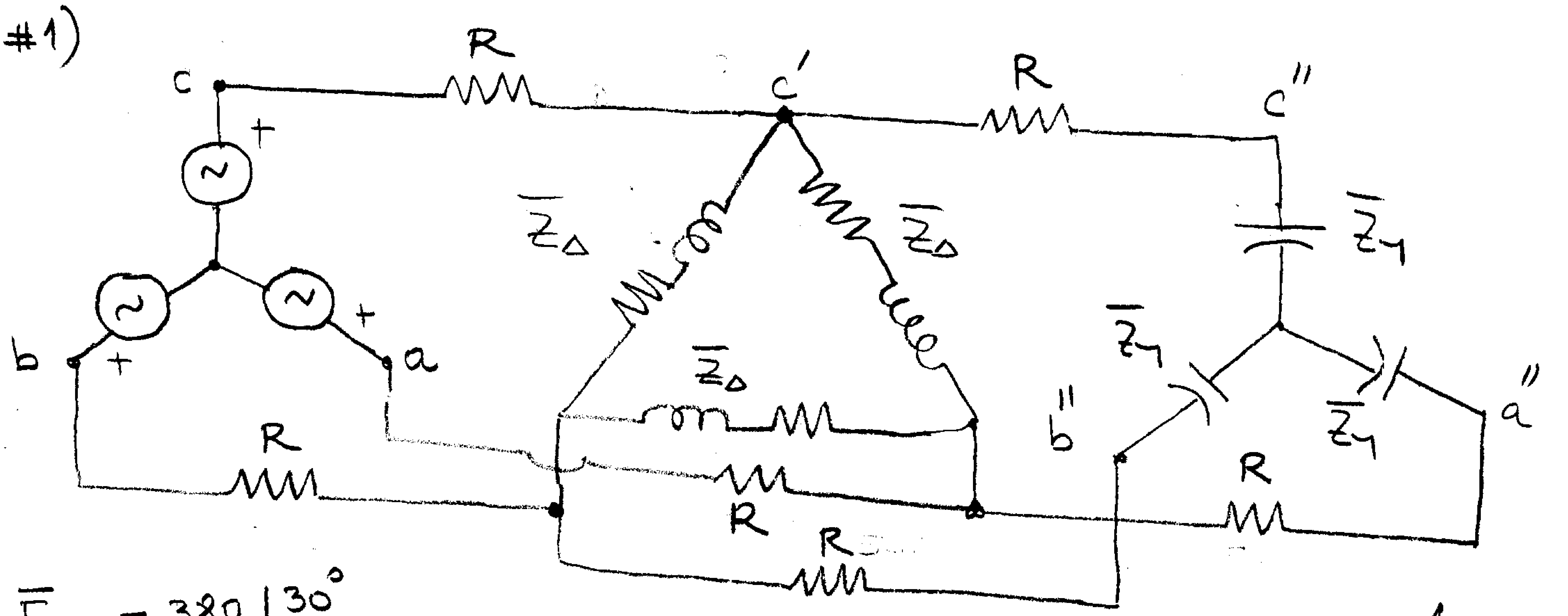
PRINCIPLES OF ENERGY CONVERSION FINAL EXAM

Dr. Salih FADIL   June 12, 2009

#1)



$\overline{E}_{ab} = 380\angle 30^\circ$, $R = 5\,\Omega$, $\overline{Z}_\Delta = 15\angle 30^\circ\ \Omega$ $\overline{Z}_Y = -j\frac{1}{5}\ \Omega$

Three phase system given in the figure is balanced and its phase sequence is abc.

a) Calculate three phase active and reactive power delivered by the source.

b) Calculate

i) three phase active power absorbed by the series resistances

ii) three phase active and reactive powers, absorbed by Δ-connected load and Y-connected loads.

iii) Is conservation of active and reactive power satisfied in this circuit.

#2) A three phase load draws 30 kW active power from 3 kV_{LL} system at 0.75 lagging power factor. A capacitor bank, which is connected as Δ, is connected accross the load to make its new power factor unity.

→ see back!

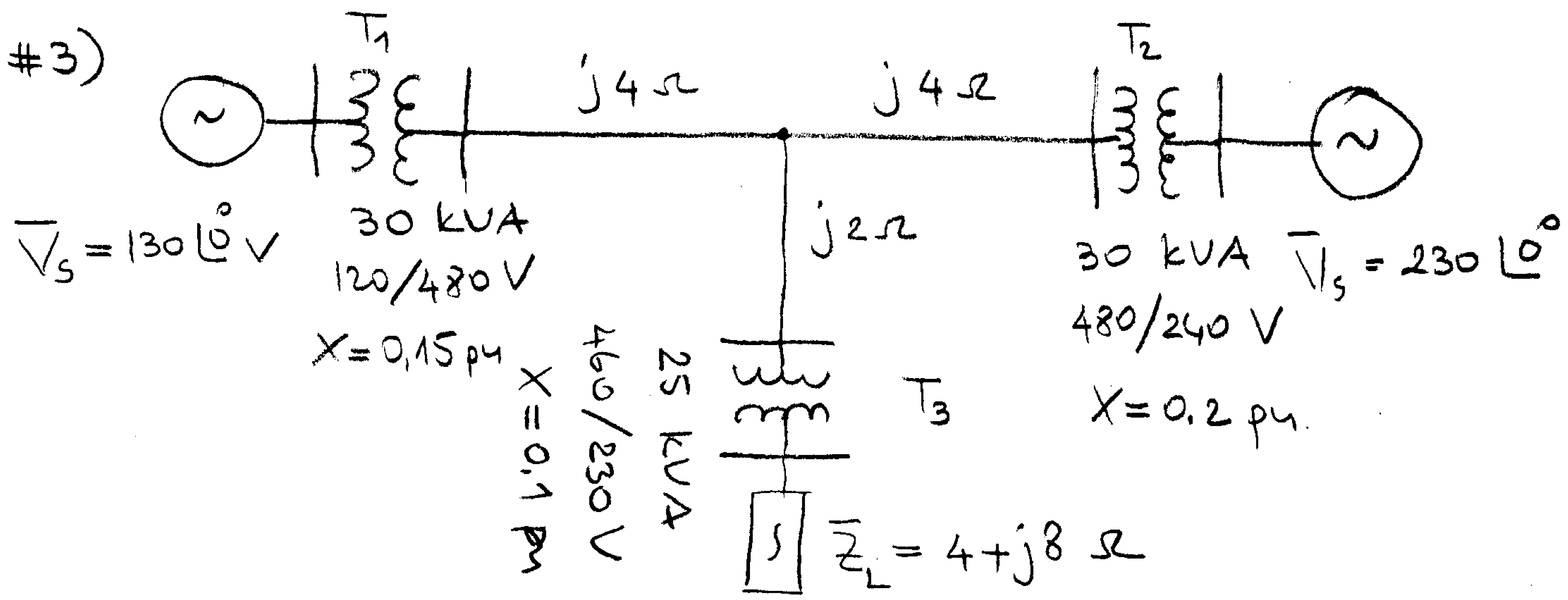
a) Calculate the capacity value of the capacitors in each branch of the capacitor bank.

b) If the capacitors are connected as Y, what is the new power factor seen across the capacitor bank

c) The load is fed through a three-phase line whose series impedance is $5+j10\ \Omega$. If phase a to neutral voltage across the load is $\frac{3000}{\sqrt{3}}\angle 0^\circ$ V and kept constant. Calculate the total active power loss on the line before and after the capacitor bank (Δ-connected) connection

Assume that voltage across the load is kept constant at 3 kV_{LL} in part a and b. Frequency of the applied voltage is 50 Hz.

#3)



Consider the single phase power system given in the above figure. Take $S_{base} = 30$ kVA, and voltage base in the load region 240 V.

a) Draw the pu equivalent circuit of the system

b) Find the complex power delivered by the source located on the left hand side.

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SOLUTION MANUAL

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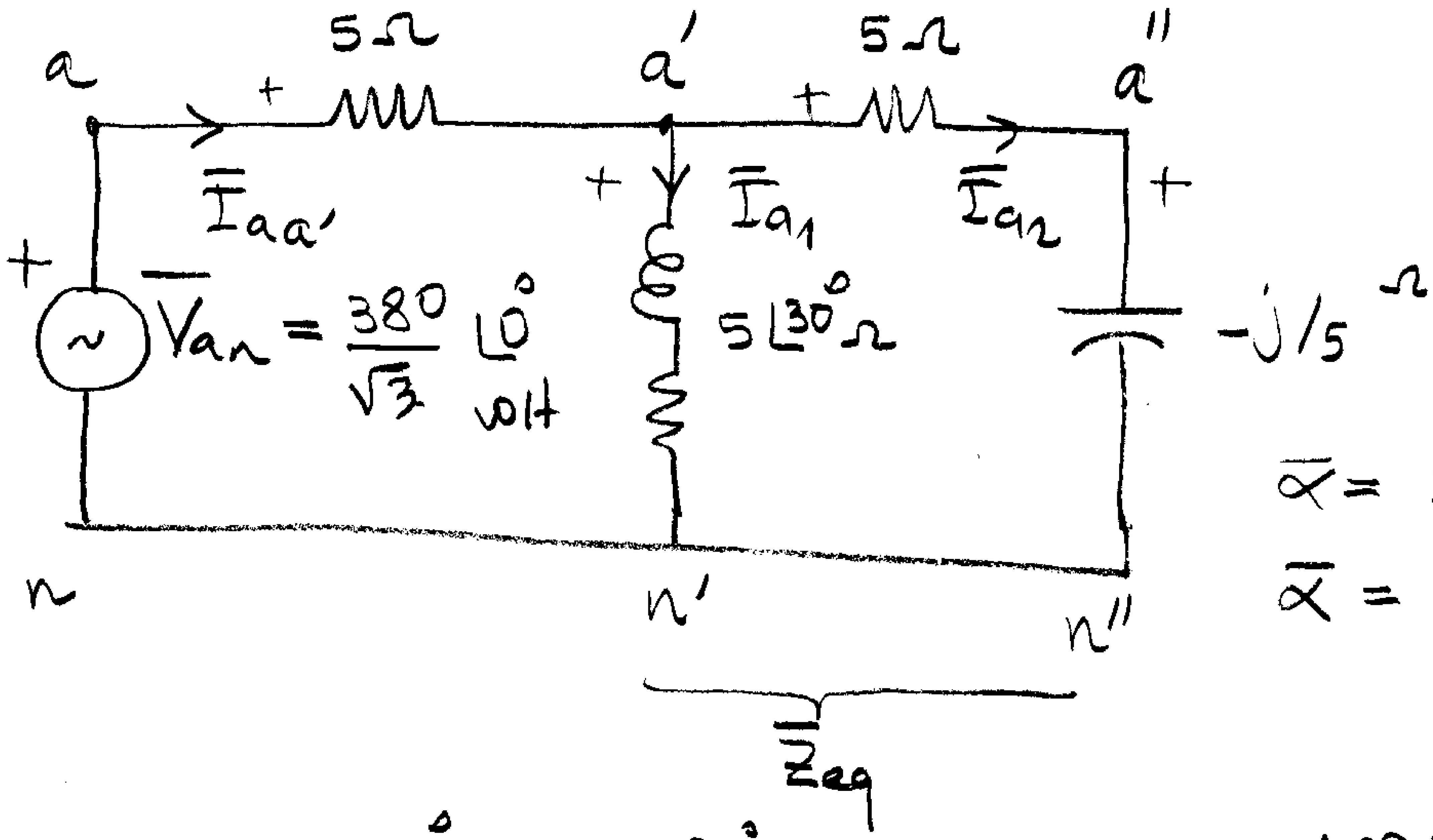
#1)

a)



$\bar{\alpha} = 5 - j0.2$ Ω

$\bar{\alpha} = 5.004 \angle -2.3^\circ$

$$\bar{Z}_{eq} = \frac{5.004\angle -2.3^\circ \times 5\angle 30^\circ}{\underbrace{5 - j0.2 + 4.33 + j2.5}_{9.33 + j2.3}} = \frac{25.02\angle 27.7}{9.609\angle 13.8} = 2.6038\angle 13.9$$

$$= 2.527 + j0.625$$

$$\bar{I}_{aa'} = \frac{(380/\sqrt{3})\angle 0^\circ}{7.527 + j0.625} = \frac{\left(\frac{380}{\sqrt{3}}\right)\angle 0^\circ}{7.553\angle 4.746^\circ} = 29.04\angle -4.746 \text{ A.}$$

$$\bar{S}_{s,3\phi} = 3 \cdot \frac{380}{\sqrt{3}} \cdot 29.04\angle +4.746 = 19113.5\angle 4.746^\circ$$

$$= 19047.99 + j1581.4 \text{ VA}$$

$P_{s,3\phi} = 19048$ W delivered

$Q_{s,3\phi} = 1581$ VAr. delivered.

b) $$\bar{I}_{a1} = 29.04\angle -4.746^\circ \cdot \frac{5.004\angle -2.3^\circ}{9.609\angle 13.8} = 15.123\angle -20.846^\circ \text{ A.}$$

$$\bar{I}_{a2} = 29.04\angle -4.746^\circ \cdot \frac{5\angle 30^\circ}{9.609\angle 13.8} = 15.11\angle 11.454^\circ \text{ A}$$

i) $P_{R,3\phi} = 3\{(29.04)^2 5 + (15.11)^2 5\} = 16074.50$ W. absorbed

ii) $P_\Delta = 3\{(15.123)^2 (5 \cos 30^\circ)\} = 2971$ W absorbed

$Q_\Delta = 3((15.123)^2 (5 \sin 30^\circ)\} = 1715.29$ VAr. absorbed

$P_\lambda = 0$ W

$Q_\lambda = -3((15.11)^2 (0.2)) = -136.987$ VAr absorbed

$= +136.987$ VAr delivered

iii)

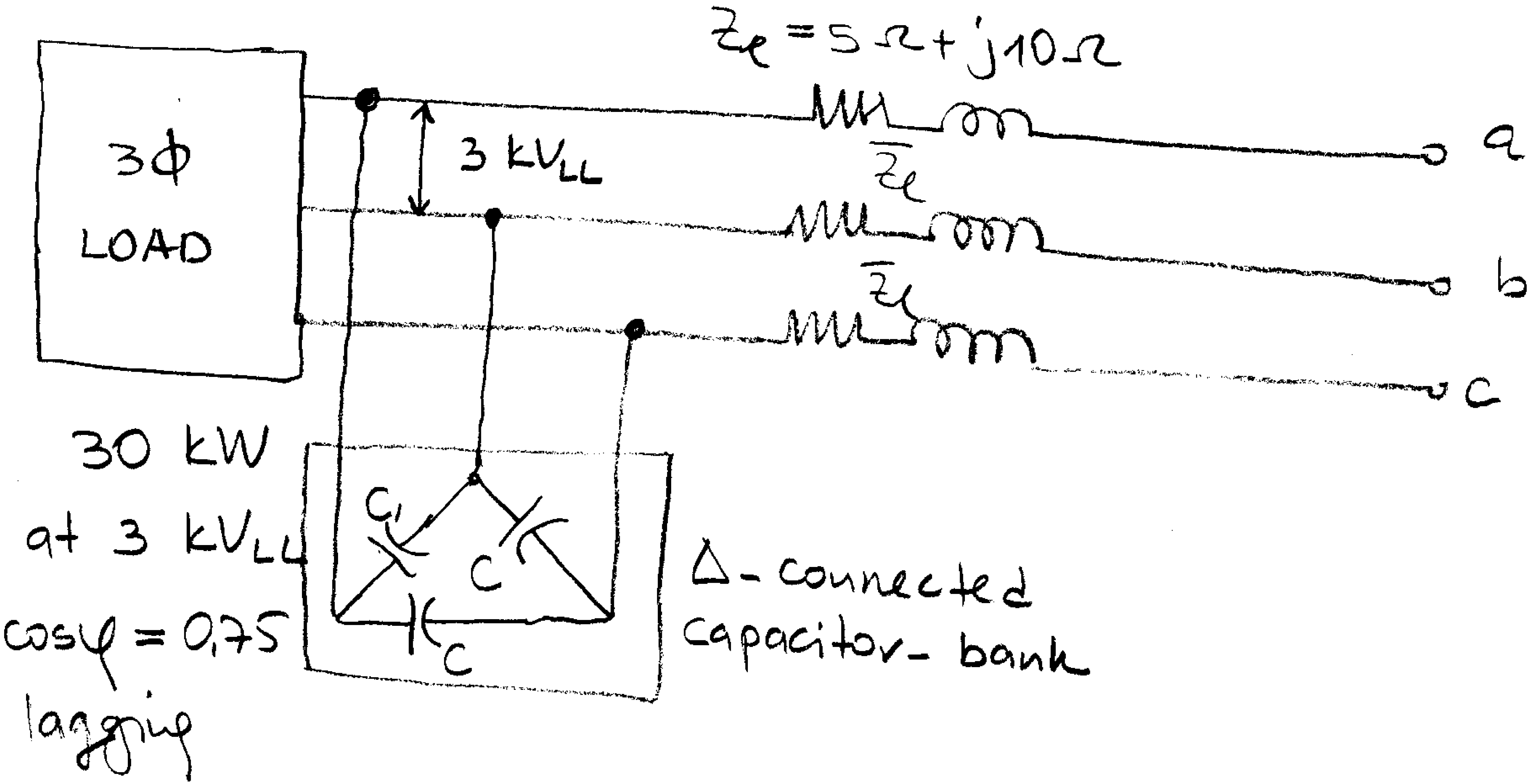
$P^{total}_{absorb} = 16074.50 + 2971 = 19045$ W

$Q^{total}_{absorb} = 1715.29 - 136.987 = 1578.303$ VAr

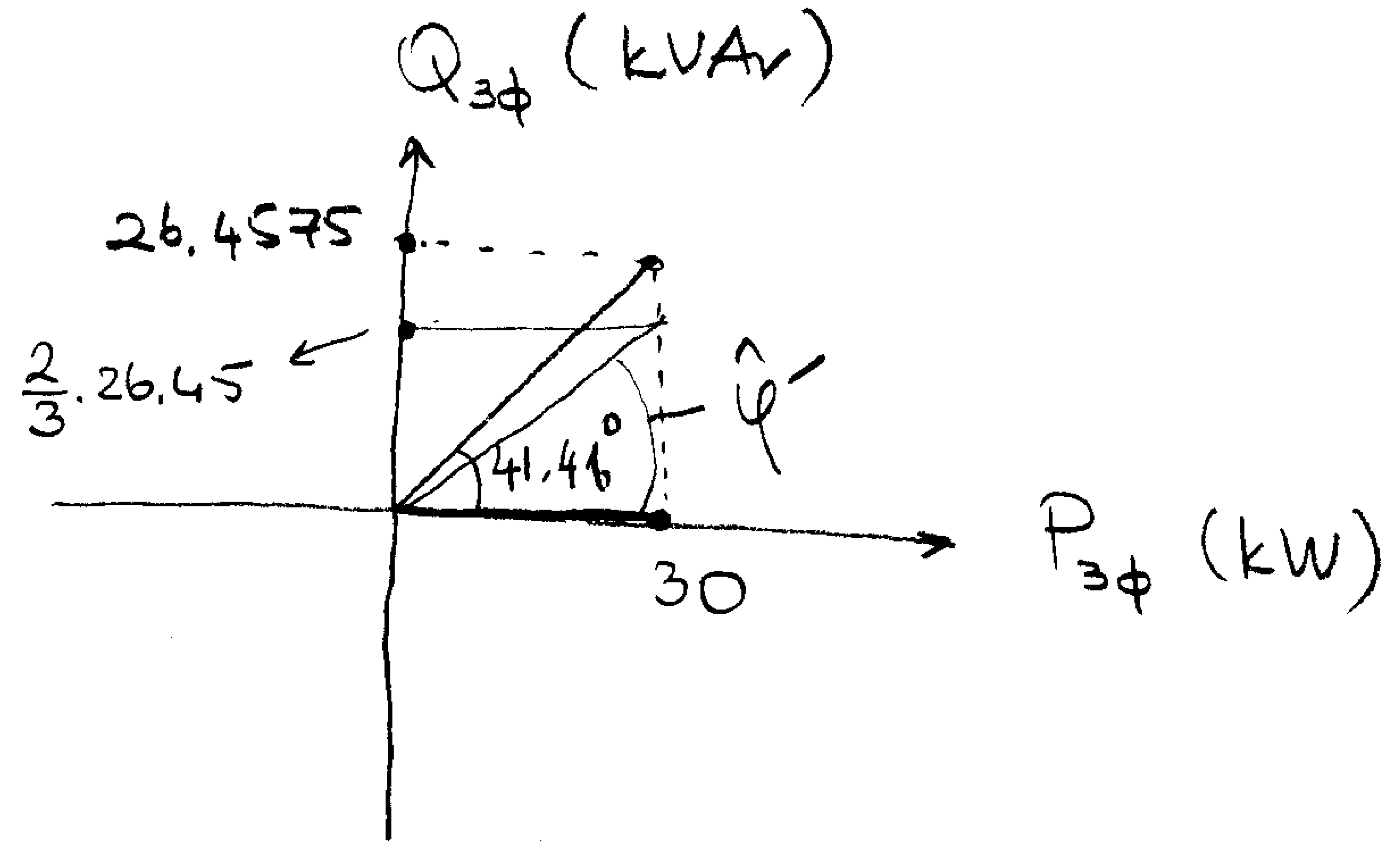
$P^{total}_{delivered} = 19048$ W , $Q^{total}_{delivered} = 1581$ VAr

Conservation of active and reactive power (delivered power = absorbed power) is satisfied. The small discripencies between the figures come from the rounding error in used arithmetic.

#2)



a)



$P_{3\phi} = 30$ kW

$\varphi = \cos^{-1}(0{,}75) = 41.41°$

$Q_{3\phi} = P_{3\phi} \tan\varphi$

$Q_{3\phi} = 30 \tan(41.41°) = 26.4575$ kVAr

After connection of the capacitor bank (Δ-connected), the new power factor will be unity (one), (i.e, the new power angle will be zero). Therefore;

$$\hat{\varphi} = 0 \rightarrow Q^{\Delta}_{C,3\phi} = 26.4575 \text{ kVAr} = 3\,\omega C V_{LL}^2$$

$$26.4575\ 10^3 = 3(2\pi 50)\, C\, (3\ 10^3)^2$$

$$C = \frac{26457{,}5}{3\,(100\pi)\ 9\ 10^6} = \boxed{3{,}1191\ \mu F}$$

b) If the capacitors are connected as Y;

$$Q^{\lambda}_{C,3\phi} = 3\,(100\pi)\ 3.11914\ 10^{-6} \left(\frac{3\ 10^3}{\sqrt{3}}\right)^2 \text{ or}$$

$$= \frac{26457{,}5}{3} = 8819.16 \text{ VAr.}$$

$$\tan\hat{\varphi}' = \frac{\frac{2}{3}\ 26.4575}{30} = \frac{2 \times 26.4575}{90} = 0{,}58794 \quad \hat{\varphi}' = 30{,}45° \text{ lagging}$$

$$\boxed{\cos\hat{\varphi}' = 0.862 \text{ lagging}}$$

c) Before capacitor bank connection

$$I_L = \frac{30\ 10^3}{\sqrt{3} \times 3000 \times 0.75} = 7.698\ A.$$

$$P_{loss,3\phi} = 3\left(7.698\right)^2 5 = 888.88\ W$$

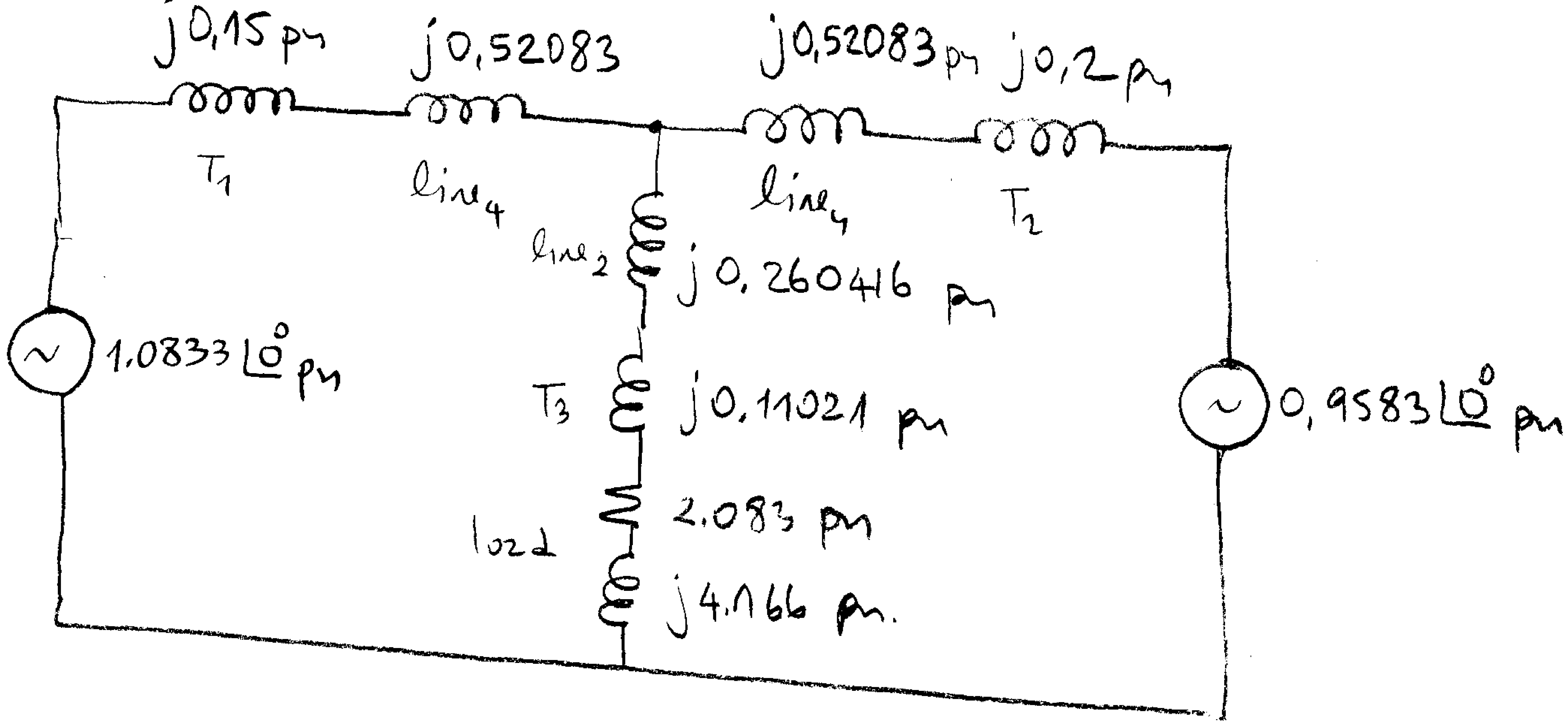
After capacitor bank (Δ-connected)

$$\hat{I}_L = \frac{30\ 10^3}{\sqrt{3} \times 3000 \times 1} = 5.7735 A.$$

$$\hat{P}_{loss,3\phi} = 3\left(5.7735\right)^2 5 = 500\ W < 889\ W$$

3)

a)



$V_{base} = 240$ load region

$V_{base} = 480$ line region

$V_{base} = 120$ source_left region

$V_{base} = 240$ source-right region

$S_{base} = 30\ kVA.$

$$\overline{V}_{s\text{-}left} = \frac{130\angle 0^\circ}{120} = 1.0833\angle 0^\circ\ pu.$$

$X_{T_1} = 0{,}15\ pu$

$$X_{4\Omega} = \frac{4}{\left(\frac{(480)^2}{30\ 10^3}\right)} = \frac{120\ 10^3}{(480)^2} = 0.52083 \text{ pu.}$$

$$X_{2\Omega} = \frac{1}{2} X_{4\Omega} = 0.260416$$

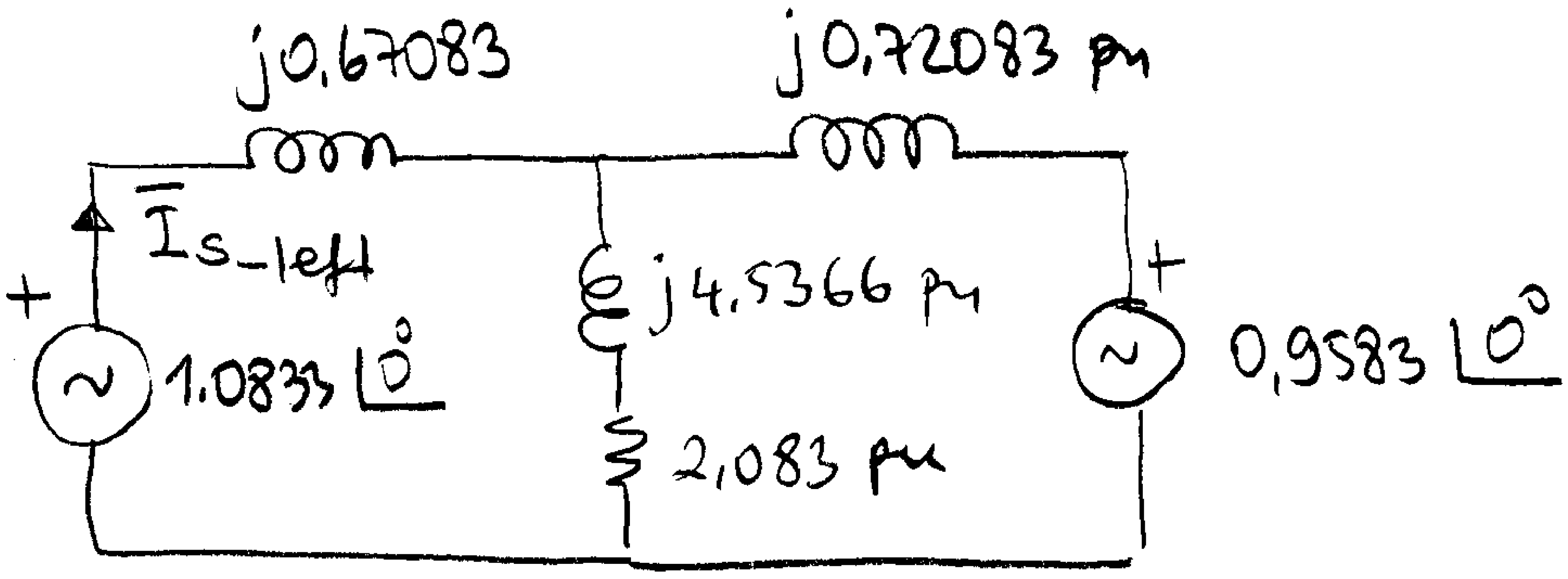
$$X_{T_2} = 0{,}2 \text{ pu}$$

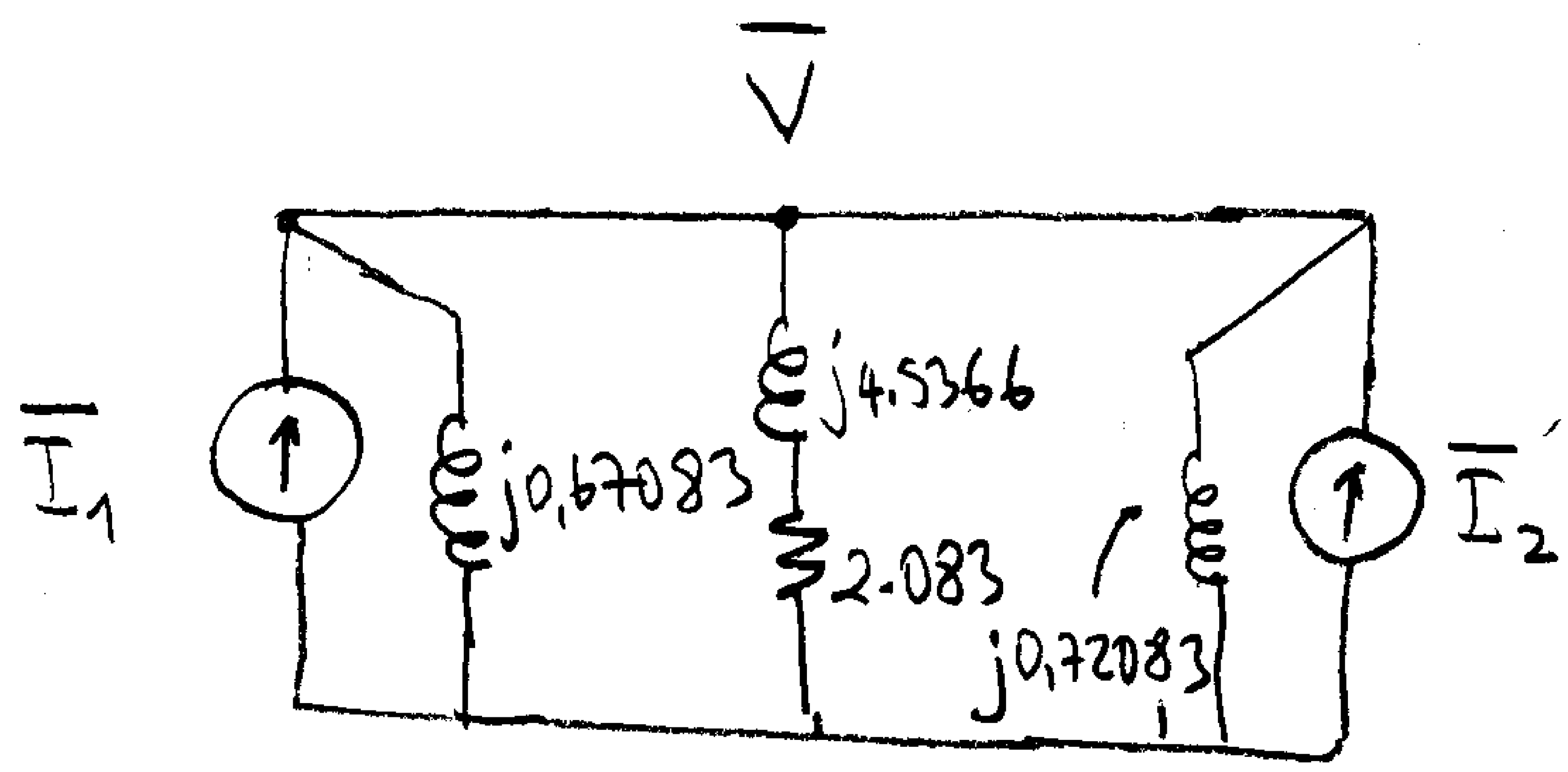
$$V_{s-right} = \frac{230 \angle 0^\circ}{240} = 0{,}9583 \angle 0^\circ \text{ pu.}$$

$$X_{T_3} = 0{,}1 \left(\frac{460}{480}\right)^2 \left(\frac{30}{25}\right) = 0{,}11021 \text{ pu}$$

$$\bar{Z}_{load} = \frac{4 + j8}{\frac{(240)^2}{30\ 10^3}} = \frac{120\ 10^3}{(240)^2} + j\frac{240\ 10^3}{(240)^2} = 2.083 + j\,4.166 \text{ pu}$$

b)





$$\bar{I}_1 = \frac{1{,}0833}{0{,}67083} \angle -90^\circ = 1.6148 \angle -90^\circ \text{ pu}$$

$$\bar{I}_2 = \frac{0{,}9583}{0{,}72083} \angle -90^\circ = 1{,}3294 \angle -90^\circ \text{ pu}$$

$$\left(-j\frac{1}{0{,}67083} + \frac{1}{\underbrace{2.083 + j\,4.5366}_{4.992 \angle 65.3^\circ}} + \frac{-j}{0{,}72083}\right)\bar{V} = (1.6148 + 1{,}3294) \angle -90^\circ$$

$$\bar{V}\left[(1.490 + 1.387) \angle -90^\circ + 0.2 \angle -65^\circ\right] = 2{,}9442 \angle -90^\circ$$

$$\bar{V}\left[-j\,2.887 + 0.0845 - j\,0.1812\right] = -j\,2.9442$$

$$\overline{V}\left[0{,}0845 - j\,3.068\right] = 2.9442\,\angle{-90^\circ}\,, \quad \overline{V}\;3.069\,\angle{-88.4^\circ} = 2.9442\,\angle{-90^\circ}$$

3.069

$$\overline{V} = \frac{2.9442\,\angle{-90^\circ}}{3.069\,\angle{-88.4^\circ}} = \underline{\underline{0{,}9593\,\angle{-1.6^\circ}}} \text{ pu}$$

$$\overline{I}_{s-left} = \frac{1.0833 - 0{,}9593\,\angle{-1.6^\circ}}{0{,}67083\,\angle{90^\circ}} = \frac{1.0833 - 0{,}9589 + j\,0{,}0267}{0{,}67083\,\angle{90^\circ}}$$

$$\overline{I}_{s-left} = \frac{0{,}1244 + j\,0{,}0267}{0{,}67083\,\angle{90^\circ}} = \frac{0{,}1272\,\angle{12{,}11^\circ}}{0{,}67083\,\angle{90^\circ}} = 0{,}18966\,\angle{-77.89^\circ} \text{ pu}$$

$$\overline{S}_{s-left} = (1{,}0833 \times 0{,}18966)\,\angle{0 + 77{,}89} \times 30\,10^3 \text{ VA.}$$

$$\overline{S}_{s-left} = (0{,}043103 + j\,0{,}20088)\,30\,10^3$$

$$\overline{S}_{s-left} = 1293.09 + j\,6026.4$$

$P_{s-left} = 1293{,}09$ W delivered.

$Q_{s-left} = 6026.4$ VAr delivered.