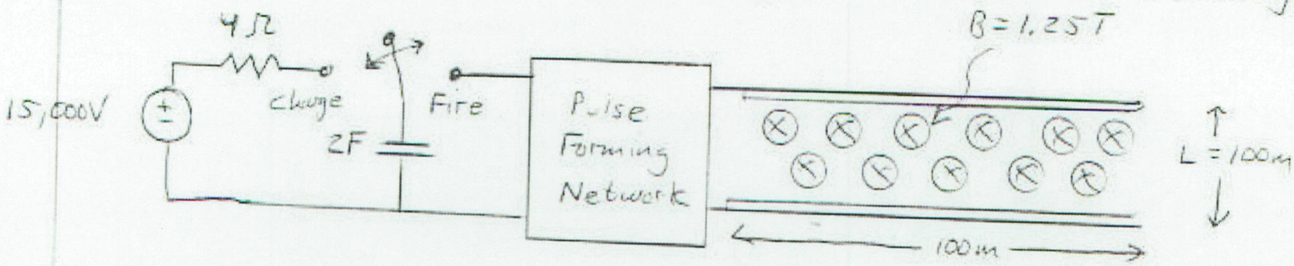
EE 331 Solution Review R2-1

Exam #2

Problem 1 Given the linear motor aircraft launcher from lecture but this time assume that we have the capacitive energy storage system "up front" and that the pulse-forming network and rails are 50% efficient. The plane mass is 50,000 kg.



(a) How long does it take for the capacitor bank to "fully" charge? How much energy is stored?

STEADY-STATE = 5 × τ $\tau = RC = (4\Omega)(2F) = 8s$

$5(8s) = \underline{\underline{40s}}$

(b) How much energy is available for launching and what is the terminal velocity?

$W_{STORED} = \frac{1}{2}CV^2 = \frac{1}{2}(2F)(15000V)^2 = 225\,MJ$

$W_{LAUNCH} = 0.5\,W_{STORED} = 0.5(225\,MJ) = \underline{\underline{112.5\,MJ}}$

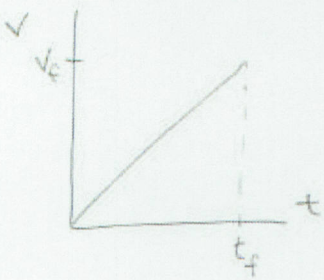
$\frac{1}{2}mv^2 = 112.5\,MJ$

$\frac{1}{2}(50{,}000kg)v^2 = 112.5\,MJ$

$\boxed{v = 67.1\,m/s}$

(c) How much time does it take to launch?

ASSUME CONSTANT ACCELERATION SO THAT



$$x = \frac{1}{2} v_f t_f$$

$$100\,m = \frac{1}{2}\left(67.1\,m/s\right) t_f$$

$$\boxed{t_f = 2.98\,s}$$

(d) What is the rail current?

$$F = BLI$$

$$F = ma$$

$$a = \frac{\Delta v}{\Delta t} = \frac{67.1\,m/s}{2.98\,s} = 22.52\,m/s^2$$

$$F = (50{,}000\,kg)(22.52\,m/s^2) = 1.13\,MN$$

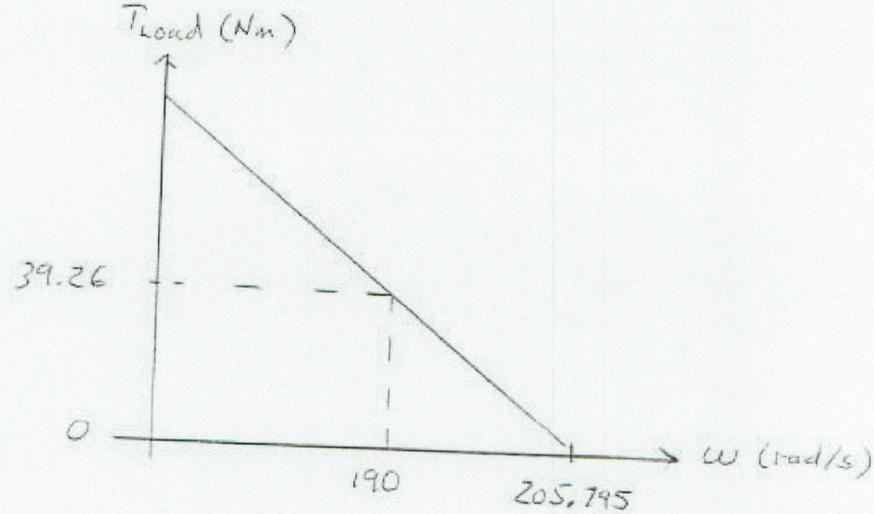
$$1.13\,MN = BLI = (1.25\,T)(100\,m)\,I$$

$$\boxed{I = 9000\,A}$$

T F The back EMF is 15,000V upon takeoff

$$E = BLu = (1.25\,T)(100\,m)(67.1\,m/s) = 8.4\,kV$$

Problem 2 The load torque on a permanent magnet DC motor is measured at different speeds so we assemble the following curve. The data is taken with $V_a = 120V$. The vendor reports that the nominal armature resistance is $0.1353\,\Omega$



(a) Assuming T_{LOSS} is constant, Find K_v and T_{LOSS}

$$V_a = I_a R_a + K_v \omega \rightarrow I_a = \frac{V_a - K_v \omega}{R_a}$$

$$T_e = K_v I_a = \frac{K_v V_a}{R_a} - \frac{K_v^2 \omega}{R_a}$$

$$T_e = T_{LOSS} + T_{LOAD}$$

$$T_{LOSS} + T_{LOAD} = \frac{K_v V_a}{R_a} - \frac{K_v^2 \omega}{R_a}$$

$$T_{LOSS} + 39.26\,N\cdot m = \frac{K_v(120V)}{0.1353\,\Omega} - \frac{K_v^2(190\,rad/s)}{0.1353\,\Omega}$$

$$T_{LOSS} + 0\,N\cdot m = \frac{K_v(120V)}{0.1353\,\Omega} - \frac{K_v^2(205.795\,rad/s)}{0.1353\,\Omega}$$

$$\boxed{T_{LOSS} = 2.81\,N\cdot m} \qquad \boxed{K_v = 0.58\,V\cdot s}$$

OR

Case 1

$$\underset{120V}{V_A} - I_{a_{NL}} \cdot \underset{0.1353\Omega}{R_a} - K_V \underset{205.795\ rad/s}{\omega_{nL}} = 0$$

Case 2

$$\underset{120V}{V_a} - I_{a_L} \underset{0.1353\Omega}{R_a} - K_V \underset{190\ rad/s}{\omega_L} = 0$$

3 Equations, 3 unknowns

$\boxed{K_V = 0.5799}$

$I_{anL} = 4.85A \Rightarrow \boxed{\tau_{Loss} = K_V I_{anL} = 2.81\ N.m}$

$I_{aL} = 72.55A$

$$\tau_{Load} = K_V I_{a_L} - K_V I_{anL} = K_V (I_{a_L} - I_{anL}) = 39.26\ N.m$$

and $\tau_{Loss} = K_V \underbrace{I_{anL}}_{NoLoad}$ ← Constant

(b) Find the motor efficiency when it operates at $\omega = 190$ rad/s

$$\eta = \frac{P_{LOAD}}{P_{IN}} = \frac{T_{LOAD}\,\omega}{P_{IN}} =$$

$$P_{IN} = V_a I_a$$

$$T_e = T_{LOAD} + T_{LOSS} = 39.26\,N\cdot m + 2.81\,N\cdot m = 42.07\,N\cdot m$$

$$T_e = K_V I_a \rightarrow I_a = \frac{42.07\,N\cdot m}{0.58\,N\cdot m/A} = \underline{72.53A}$$

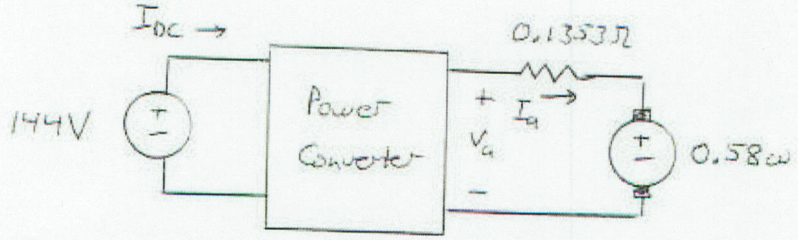
$$\eta = \frac{T_{LOAD}\,\omega}{V_a I_a} = \frac{(39.26\,N\cdot m)(190\,rad/s)}{(120V)(72.53A)} = \boxed{85.7\%}$$

T F The armature of a rotating PM DC machine is stationary

The brushes of a PM DC machine connect to

(a) The armature (b) The commutator

Problem 3. Given the same motor from prob. 2 is controlled with a power converter where the duty cycle is set for 0.6. The converter is 96% efficient and is supplied from a 144V battery bank. The load torque applied to the motor is governed by $T_{Load} = 0.001\omega^2$



(a) Find the average armature voltage

$\overline{V}_a = D V_{DC} = 0.6(144V) = \underline{\underline{86.4V}}$

(b) Find the average armature current and rotor speed

$$\begin{cases} V_a = I_a R_a + K_v \omega \\ K_v I_a = T_{LOAD} + T_{LOSS} \\ K_v I_a = 0.001\omega^2 + 2.81\,N\cdot m \end{cases}$$

$$\begin{cases} 86.4V = I_a(0.1353\,\Omega) + (0.58\,V\cdot s)\,\omega \\ (0.58\,N\cdot m/A)\,I_a = 0.001\omega^2 + 2.81\,N\cdot m \end{cases}$$

$\boxed{I_a = 38.62\,A}$ $\boxed{\omega = 140\,rad/s}$

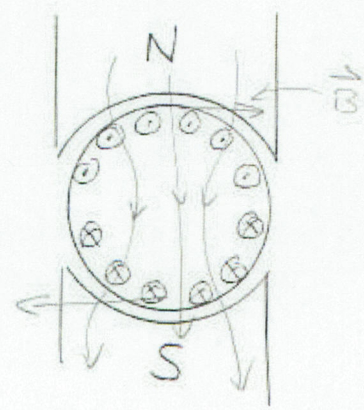
(c) Find the average current supplied by the battery

$$\eta_{conv} = \frac{P_{conv,out}}{P_{conv,in}} = \frac{V_a I_a}{V_{DC} I_{DC}} = \frac{(86.4V)(38.62A)}{(144V)\, I_{DC}} = 0.96$$

$$\boxed{I_{DC} = 24.14A}$$

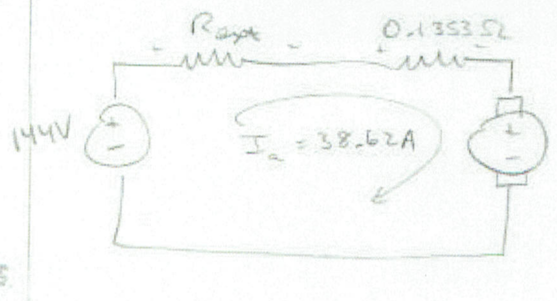
Q. What direction will the armature turn if the current distribution is for motor operation?

$I\vec{L} \times \vec{B}$



$\underline{\underline{CW}}$

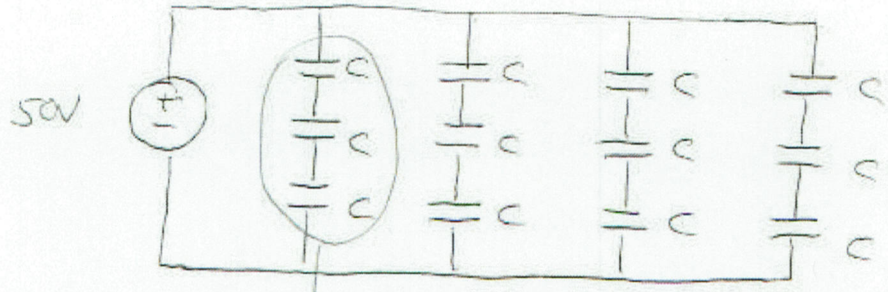
(d) If we attach external resistance (no converter) to control speed, what value is required to achieve $\omega = 140 rad/s$?



KVL: $-144V + (38.62A)R_{ext} + (38.62A)(0.1353\Omega) + (0.58 V\text{-}s)(140\ rad/s) = 0$

$$\boxed{R_{ext} = 1.5\,\Omega}$$

Problem 4. What value of capacitance C is required to store 1000J of energy?



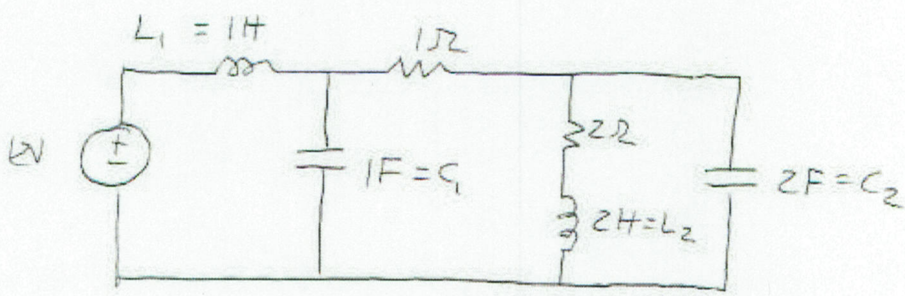
$$\frac{C}{3} + \frac{C}{3} + \frac{C}{3} + \frac{C}{3}$$

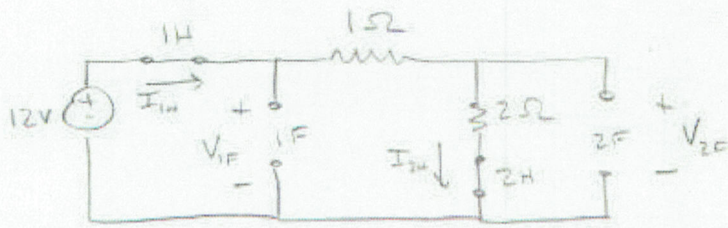
$$C_{eq} = \frac{4C}{3}$$

$$1000J = \frac{1}{2} C V^2 \longrightarrow 1000J = \frac{1}{2}\,\frac{4C}{3}\,(50V)^2$$

$$\boxed{C = 600\,mF}$$

Problem 5 Determine the steady-state energy stored in each component





$$V_{1F} = 12V \qquad V_{2F} = \left(\frac{2\Omega}{3\Omega}\right) 12V = 8V$$

$$I_{1H} = \frac{12V}{3\Omega} = 4A \qquad I_{2H} = I_{1H} = 4A$$

$$W_{1F} = \frac{1}{2}(1F)(12V)^2 = 72J$$

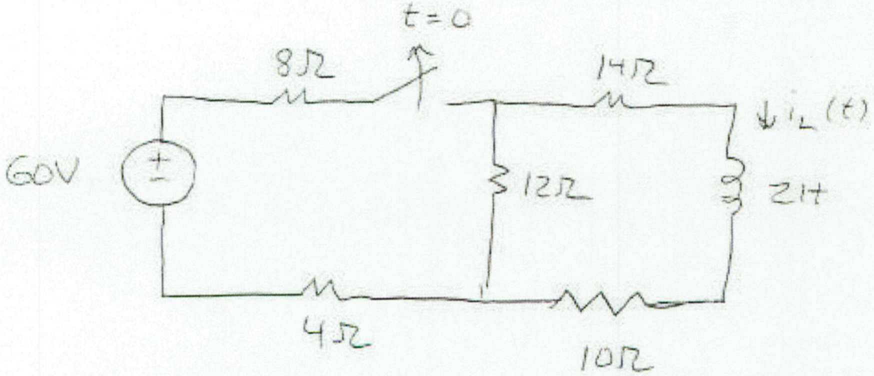
$$W_{2F} = \frac{1}{2}(2F)(8V)^2 = 64J$$

$$W_{1H} = \frac{1}{2}(1H)(4A)^2 = 8J$$

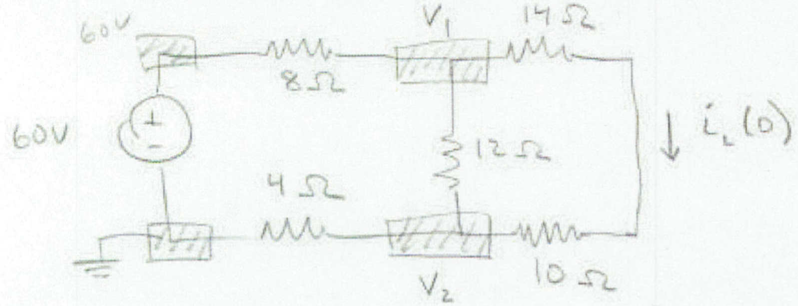
$$W_{2H} = \frac{1}{2}(2H)(4A)^2 = 16J$$

The instantaneous change of inductor (voltage, current, power) will cause a problem.

Problem 6. Given the following circuit, Find $i_L(t)$ for $t \geq 0$



STEADY-STATE WITH SWITCH SHUT:



$$\begin{cases} \dfrac{V_1 - 60V}{8\Omega} + \dfrac{V_1 - V_2}{12\Omega} + \dfrac{V_1 - V_2}{24\Omega} = 0 \\[2ex] \dfrac{V_2 - V_1}{24\Omega} + \dfrac{V_2 - V_1}{12\Omega} + \dfrac{V_2}{4\Omega} = 0 \end{cases}$$

$V_1 = 36V \qquad V_2 = 12V$

$$i_L(0) = \frac{V_1 - V_2}{24\Omega} = \frac{36V - 12V}{24\Omega} = \underline{1A}$$

$i_L(\infty) = 0A$

$\tau = \dfrac{L}{R_{Th}} \qquad R_{Th} = 14\Omega + 12\Omega + 10\Omega = 36\Omega$

$\tau = \dfrac{2H}{36\Omega} = 55.6\ ms$

$$i_L(t) = i_L(\infty) + [i_L(0) - i_L(\infty)]e^{-t/\tau}$$

$$\boxed{i_L(t) = (1A)\, e^{-t/55.6ms}}$$

(b) At what time does the energy drop to 6.25% of its original value?

$$W_0 = \frac{1}{2}(2H)(1A)^2 = 1J$$

$$W_t = 0.0625J = \frac{1}{2}(2H)i^2 \rightarrow i = 250mA$$

$$250mA = (1A)e^{-t/55.6ms}$$

$$-\frac{t}{55.6ms} = -1.386 \rightarrow \boxed{t = 77.1ms}$$

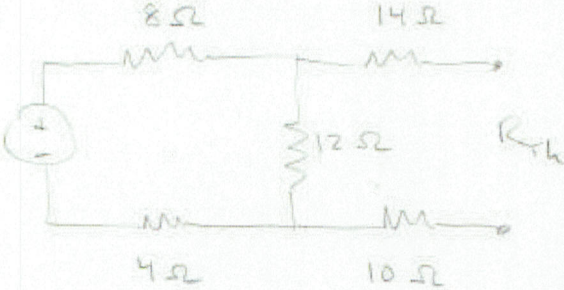
(c) When is the energy "fully" depleted?

$$t = 5 \times \tau = 5(55.6ms) = \underline{\underline{278ms}}$$

(d) If we reclosed the switch, how long for the current to charge up to $\frac{1}{2}$ A?

$i_L(0) = 0\,A \qquad i_L(\infty) = 1\,A$

$\tau = \frac{L}{R_{Th}}$



$$\underbrace{\underbrace{(8\Omega + 4\Omega)}_{12\Omega} \| 12\Omega}_{} + 14\Omega + 10\Omega = R_{Th}$$

$$6\Omega + 14\Omega + 10\Omega = \underline{30\Omega}$$

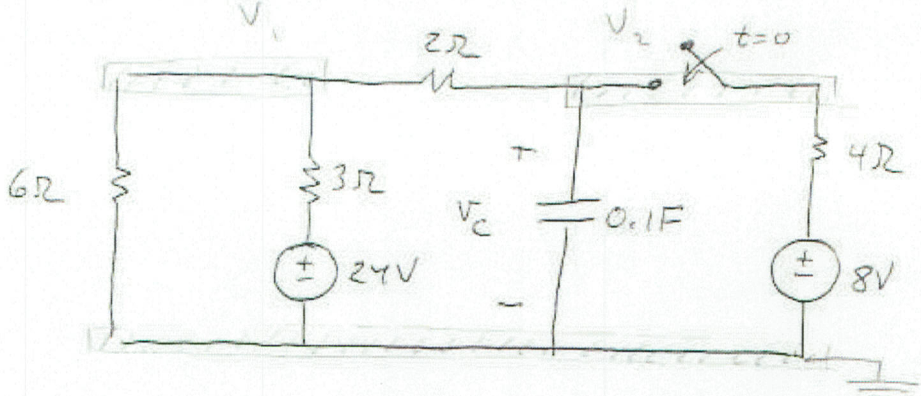
$$\tau = \frac{2H}{30\Omega} = 66.7\,ms$$

$$i_L(t) = 1A\left(1 - e^{-t/66.7ms}\right) = 0.5A$$

$$e^{-t/66.7ms} = 0.5$$

$$-\frac{t}{66.7ms} = -.693 \quad \rightarrow \quad \underline{\underline{t = 46.2ms}}$$

Problem 7 Given the following circuit

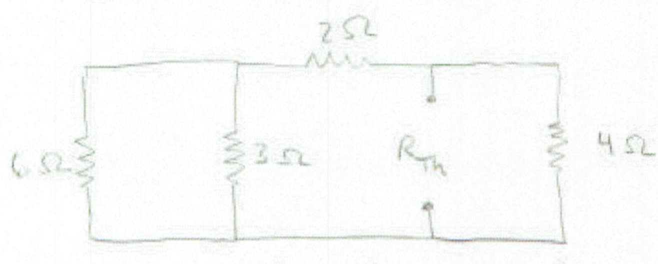


Find the expression for $v_C(t)$ for $t \geq 0$

$$v_c(0) = \left(\frac{6\Omega}{9\Omega}\right) 24V = 16V$$

$$\left.\begin{aligned} \frac{V_1}{6\Omega} + \frac{V_1 - 24V}{3\Omega} + \frac{V_1 - V_2}{2\Omega} &= 0 \\ \frac{V_2 - V_1}{2\Omega} + \frac{V_2 - 8V}{4\Omega} &= 0 \end{aligned}\right\} \quad \begin{aligned} V_1 &= 14V \\ V_2 &= 12V \end{aligned}$$

$$v_c(\infty) = V_2 = 12V$$

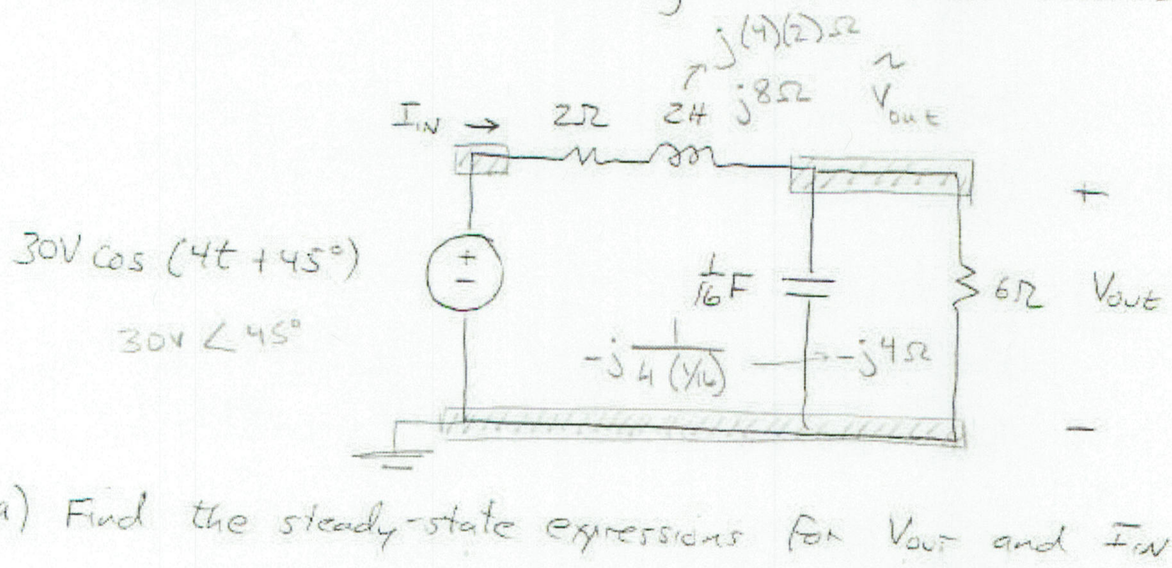


$$R_{Th} = 4\Omega \parallel (2\Omega + 3\Omega \parallel 6\Omega)$$
$$= \underbrace{4\Omega \parallel \underbrace{(2\Omega + 2\Omega)}_{4\Omega}}$$
$$R_{Th} = 2\Omega \quad \longrightarrow \quad \tau = R_{Th}C = (2\Omega)(0.1F)$$
$$\tau = 0.2s$$

$$v_c(t) = 12V + (16V - 12V)\, e^{-t/0.2s}$$

$$\boxed{v_c(t) = 12V + (4V)\, e^{-t/0.2s}}$$

Problem 8 Given the following time-domain circuit



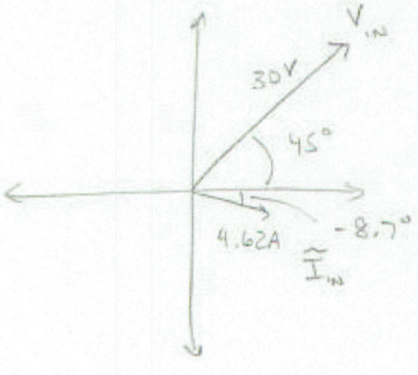
(a) Find the steady-state expressions for V_{OUT} and I_{IN}

$$\frac{\hat{V}_{out} - 30V\angle 45°}{2\Omega + j8\Omega} + \frac{\tilde{V}_{out}}{-j4\Omega} + \frac{\tilde{V}_{out}}{6\Omega} = 0$$

$$\boxed{\tilde{V}_{out} = 15.38\,V\angle -65°}$$

$$\tilde{I}_{IN} = \frac{30V\angle 45° - 15.38V\angle -65°}{2\Omega + j8\Omega} = \boxed{4.62A\angle -8.7°}$$

(b) Sketch the phasors $\tilde{V}_{IN}$ and $\tilde{I}_{IN}$ and state who leads whom and by what angle

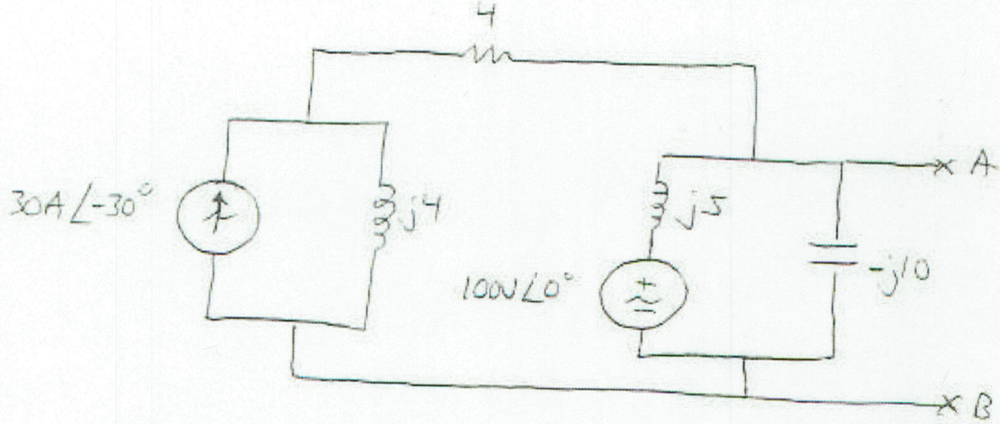


$\tilde{V}_{IN}$ leads $\tilde{I}_{IN}$ by 53.7°

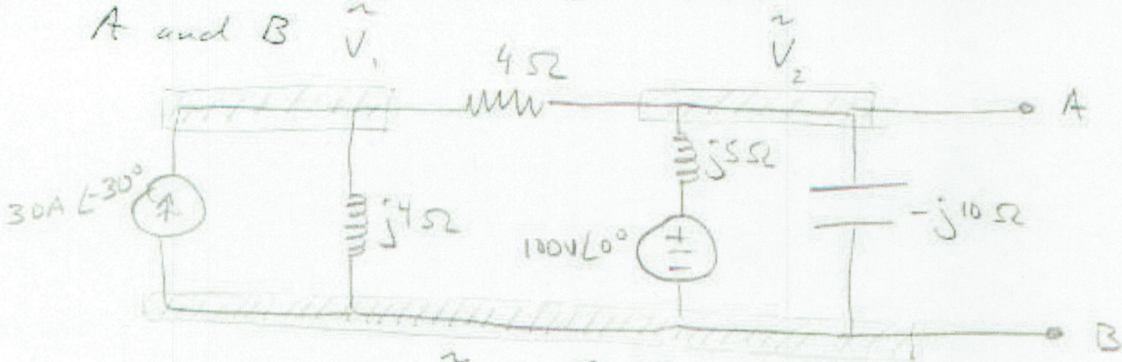
(c) Find the circuit input impedance from your values

$$Z = \frac{\hat{V}_{IN}}{\tilde{I}_{IN}} = \frac{30\,V \angle 45^\circ}{4.62\,A \angle -8.7^\circ} = \underline{\underline{6.49\,\Omega \angle 53.7^\circ}}$$

Problem 9 Given the following frequency-domain circuit



Find the Thevenin Equivalent "seen" from terminals A and B



$$-(30A\angle -30^\circ) + \frac{\tilde{V}_1}{j4\,\Omega} + \frac{\tilde{V}_1 - \tilde{V}_2}{4\,\Omega} = 0$$

$$\frac{\tilde{V}_2 - \tilde{V}_1}{4\,\Omega} + \frac{\tilde{V}_2 - 100V\angle 0^\circ}{j5\,\Omega} + \frac{\tilde{V}_2}{-j10\,\Omega} = 0$$

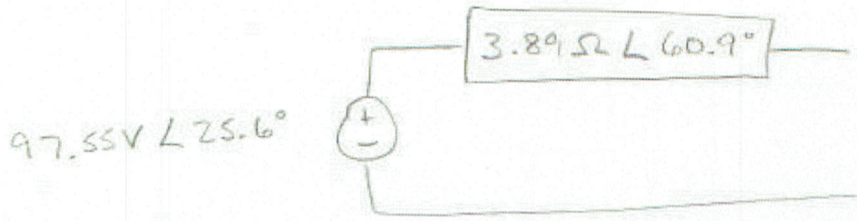
$\tilde{V}_1 = 136.25V\angle 39.7^\circ$

$\tilde{V}_2 = 97.55V\angle 25.6^\circ = \tilde{V}_{Th}$

$$Z_{Th} = (-j10\,\Omega) \,||\, (j5\,\Omega) \,||\, (4\,\Omega + j4\,\Omega)$$

$$Z_{Th} = 3.89\,\Omega\angle 60.9^\circ$$

$$= 1.89\,\Omega + j3.4\,\Omega$$

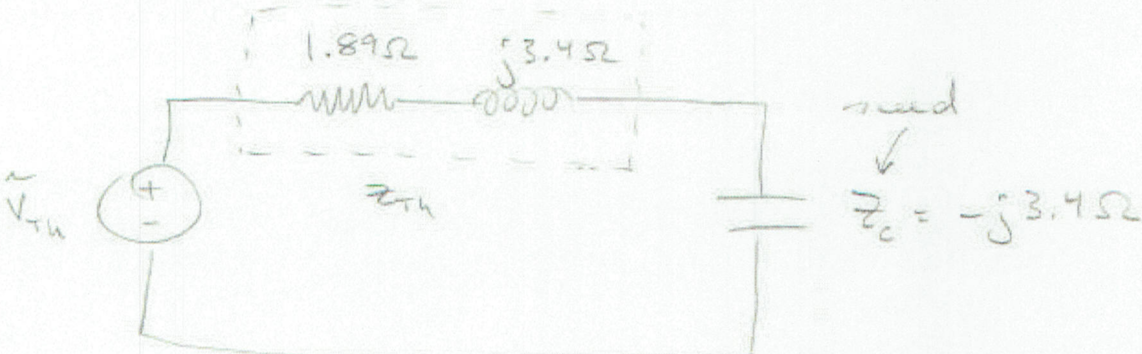

3.89 Ω ∠ 60.9°
97.55V ∠ 25.6°

If the source frequencies are 20rad/s, what capacitor do we need to attach to the Thevenin so that the voltage source and its current are in phase?

$\tilde{V}$ in phase with $\tilde{I}$ means

impedance angle $\theta = 0°$ or $X = 0$

$\rightarrow \; -X_c = X_{Th}$



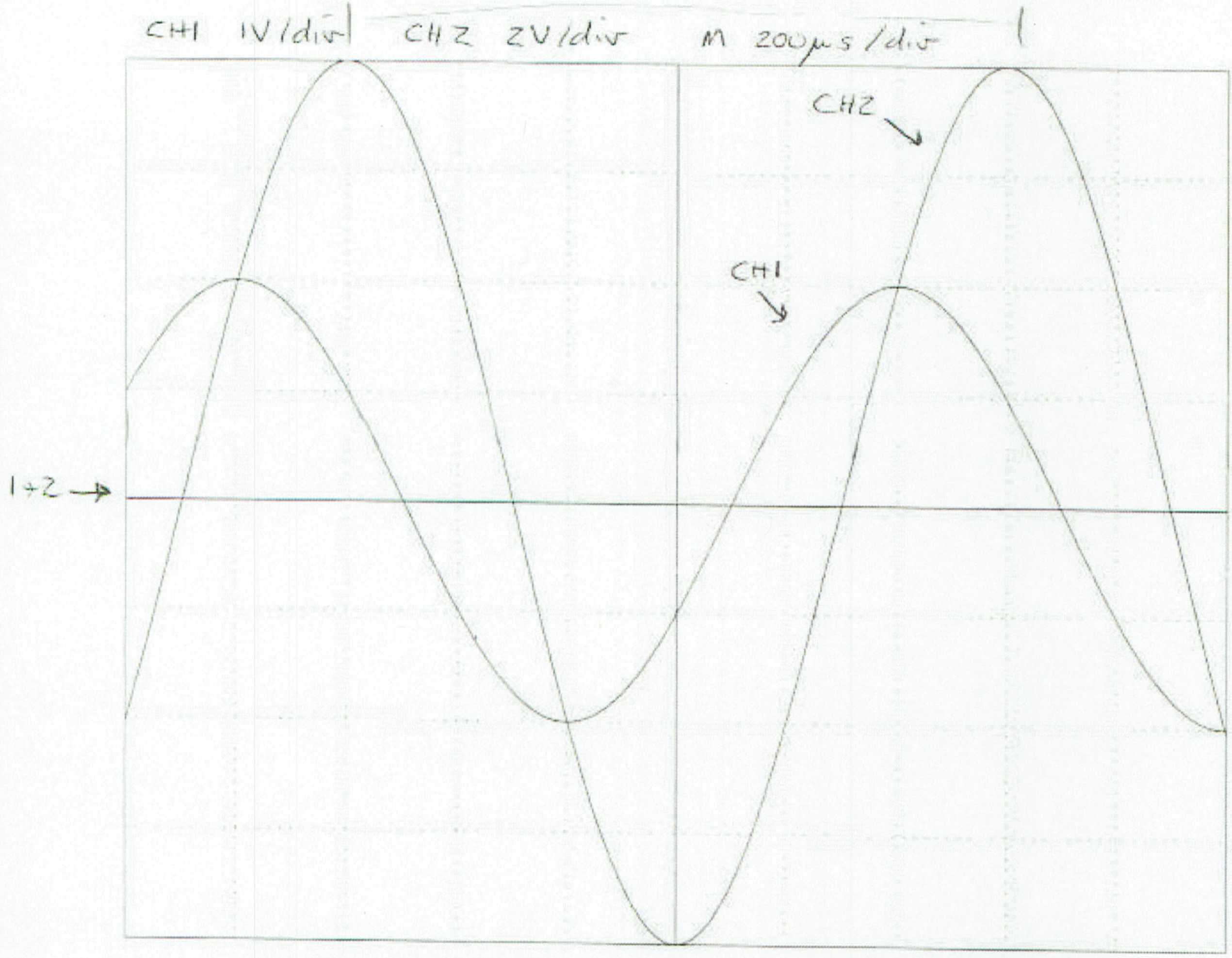
$$Z_c = -j\frac{1}{\omega C} \rightarrow \frac{1}{(20\,\text{rad/s})\,C} = 3.4\Omega$$

$$\boxed{C = 14.7\text{ mF}}$$

Problem 10 Given the following scope image

a. Find the frequency (in Hz)

$$f = \frac{1}{T} = \frac{1}{6(200\,\mu s/div)} = \underline{833\,Hz}$$



b. Who leads whom and by how much

CH1 leads CH2 by 1 div

$$\Delta\phi = \frac{\Delta t}{T}(360°) = \frac{1\,div}{6\,div}(360°) = \underline{60°}$$

c. RMS value of CH2 signal

$$V_p = 4(2V/div) = 8V$$

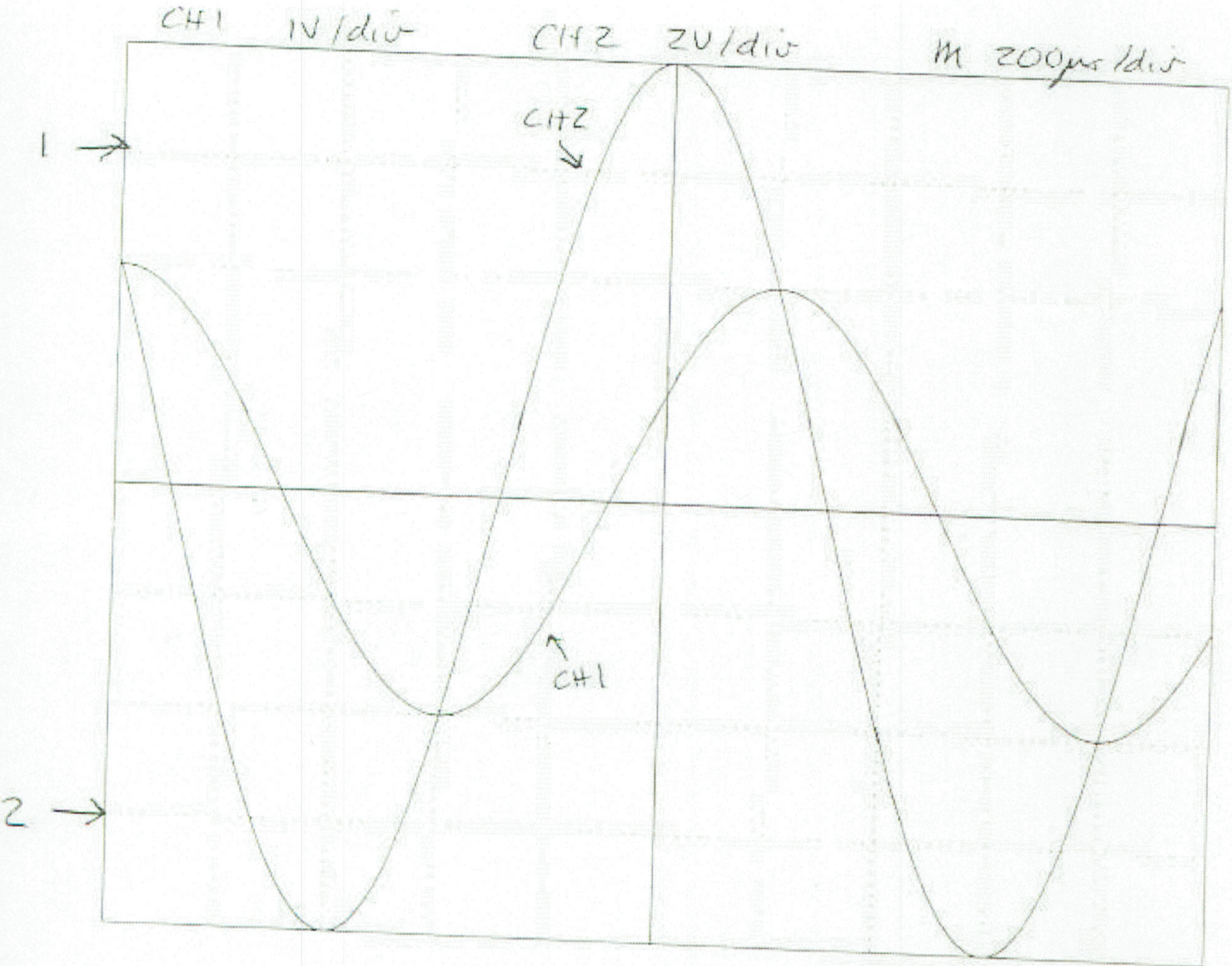
$$V_{rms} = \frac{8V}{\sqrt{2}} = \boxed{5.66V}$$

Problem 11, Given the following scope image

a. Determine the DC offset

CH1 $\rightarrow$ $-3\text{div}\left(\frac{1V}{\text{div}}\right) = \underline{\underline{-3V}}$

CH2 $\rightarrow$ $+3\text{div}\left(\frac{2V}{\text{div}}\right) = \underline{\underline{6V}}$



b. If we use the DMM VAC measure on CH1, what does it read?

CH1 amplitude $= 2\text{div}\left(\frac{1V}{\text{div}}\right) = 2V$

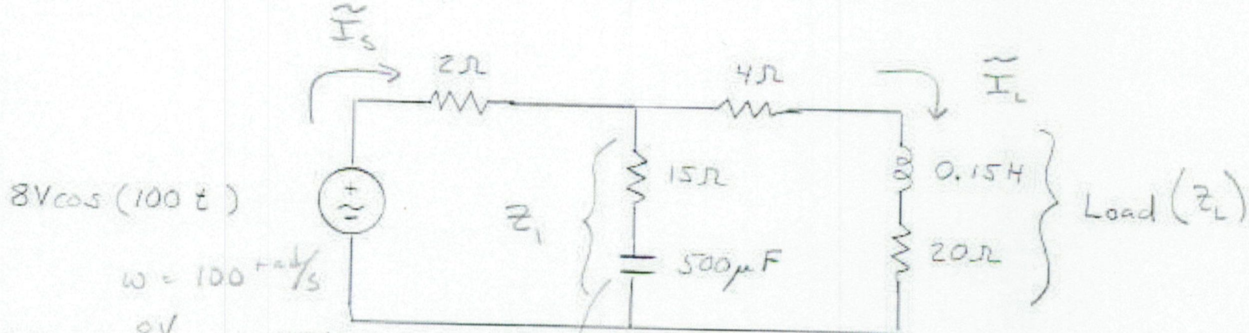
$V_{rms} = \frac{2V}{\sqrt{2}} = \boxed{1.41V}$

EE 331 | Exam Review

Topics

- Single-Phase AC Power
- Power Factor Correction
- Ideal Transformers
- Three-Phase Circuit Analysis
- Three-Phase Power

ex. 1 Given the following circuit, Find the real and reactive power consumed by the load



$\omega = 100 \text{ rad/s}$

$V_{rms} = \frac{8V}{\sqrt{2}} = 5.66V$

$Z_c = \frac{1}{(100 \text{ rad/s})(500\mu F)} \angle -90^\circ = 20\Omega \angle -90^\circ$

$Z_{0.15H} = (100 \text{ rad/s})(0.15H) \angle 90^\circ = 15\Omega \angle 90^\circ$

$Z_1 = 15\Omega + 20\Omega \angle -90^\circ = 25\Omega \angle -53.13^\circ$

$Z_L = 20\Omega + 15\Omega \angle 90^\circ = 25\Omega \angle 36.87^\circ$

alternate method: nodal analysis... see page 3

$Z_{eq_T} = 2\Omega + Z_1 \,||\, (4\Omega + Z_L)$

$= 2\Omega + (25\Omega \angle -53.13^\circ) \,||\, \underbrace{(4\Omega + 25\Omega \angle 36.87^\circ)}$

$= 2\Omega + (25\Omega \angle -53.13^\circ) \,||\, (28.3\Omega \angle 32^\circ)$

$= 2\Omega + 18\Omega \angle -13.82^\circ = \underline{19.94\Omega \angle -12.45^\circ}$

$$\tilde{I}_s = \frac{\tilde{V}_s}{Z_{eq}} = \frac{5.66\,V\angle 0^\circ}{19.94\,\Omega\angle -12.45^\circ} = 0.284\,A\angle 12.45^\circ$$

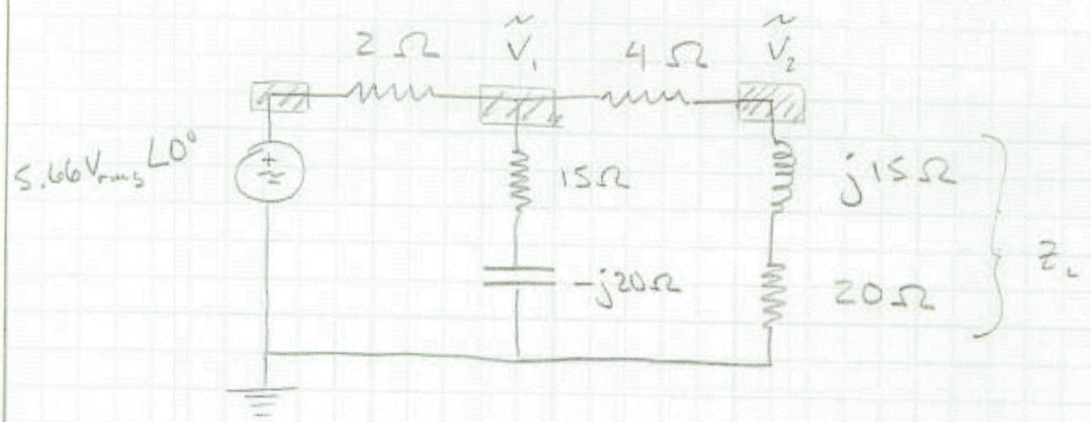
Current divider to find $\tilde{I}_L$:

$$\tilde{I}_L = \left(\frac{Z_1}{Z_1 + 4\,\Omega + Z_L}\right)\tilde{I}_s = \frac{25\,\Omega\angle -53.13^\circ}{25\,\Omega\angle -53.13^\circ + 4\,\Omega + 25\,\Omega\angle 36.87^\circ}\tilde{I}_s$$

$$\tilde{I}_L = 180.6\,mA\angle -33.37^\circ$$

$$P_L = I_L^2 R_L = (180.6\,mA)^2(20\,\Omega) = 652.3\ mW$$

$$Q_L = I_L^2 X_L = (180.6\,mA)^2(15\,\Omega) = 489.2\ mVAR$$



$$\begin{cases} \dfrac{\tilde{V}_1 - 5.66V\angle 0^\circ}{2\,\Omega} + \dfrac{\tilde{V}_1}{15\,\Omega - j20\,\Omega} + \dfrac{\tilde{V}_1 - \tilde{V}_2}{4\,\Omega} = 0 \\ \dfrac{\tilde{V}_2 - \tilde{V}_1}{4\,\Omega} + \dfrac{\tilde{V}_2}{20\,\Omega + j15\,\Omega} = 0 \end{cases}$$

$\tilde{V}_1 = 5.11V \angle -1.37^\circ$ $\qquad$ $\tilde{V}_2 = 4.51V \angle 3.5^\circ$

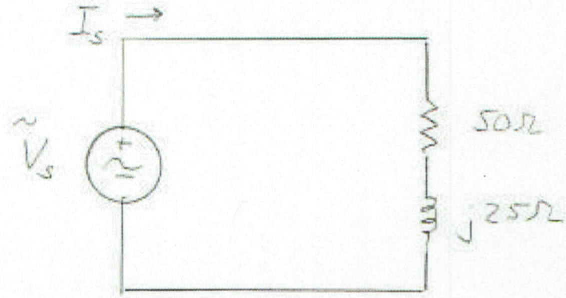
$\tilde{V}_{LOAD} = \tilde{V}_2 \qquad \tilde{I}_{LOAD} = \dfrac{\tilde{V}_2}{Z_L} = \dfrac{4.51V \angle 3.5^\circ}{20\,\Omega + j15\,\Omega}$

$\tilde{I}_{LOAD} = 180.4\,mA \angle -33.4^\circ$

$P_L = I_L^2 R_{LOAD} = (180.4\,mA)^2 (20\,\Omega) = \underline{650.9\,mW}$

$Q_L = I_L^2 X_{LOAD} = (180.4\,mA)^2 (15\,\Omega) = \underline{488.2\,mVAR}$

ex. 2 The Follow R-L load consumes 800W



Determine $\tilde{V}_s$ and $\tilde{I}_s$ and the source apparent power

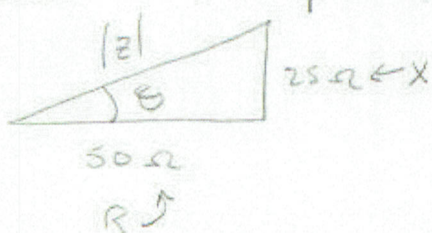
$$P = I^2 R \quad \longrightarrow \quad 800W = I_s^{\,2}(50\Omega)$$

$$I_s = 4\,A_{rms}$$

Traditionally choose $\tilde{V}_s$ to be reference phasor;

$$\tilde{V}_s = V_s \angle 0^\circ \quad \longrightarrow \quad \tilde{I}_s = I_s \angle -\theta$$

where θ is impedance angle given by:



$$\theta = \tan^{-1}\left(\frac{25}{50}\right) = 26.57^\circ$$

so that $\boxed{\tilde{I}_s = 4A \angle -26.57^\circ}$ (rms)

and $\tilde{V}_s = \tilde{I}_s Z = (4A \angle -26.57^\circ)(50\Omega + j25\Omega)$

$$\boxed{\tilde{V}_s = 223.6V \angle 0^\circ}$$

rms

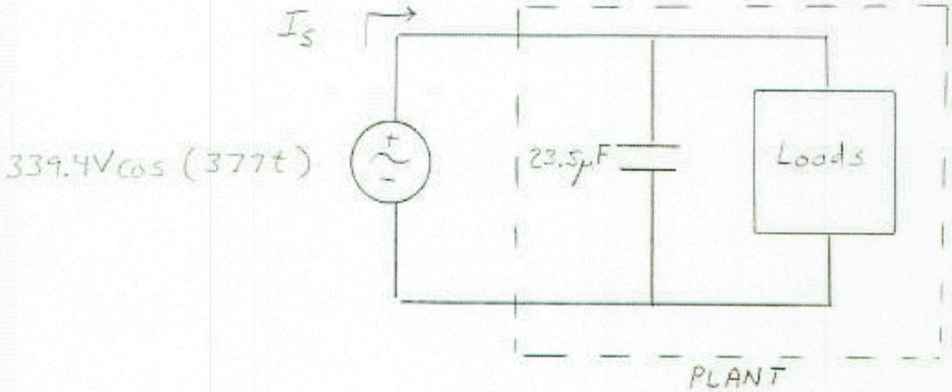
ex. 3 For the previous circuit, if the source frequency is 60Hz, Find the capacitor required to power factor correct to unity.

Find Q : $Q = I^2 X = (4A)^2 (25\Omega) = 400\,VAR$

$$C = \frac{Q}{\omega V^2} = \frac{400\,VAR}{(377\,rad/s)(223.6V)^2}$$

$$\boxed{C = 21.22\,\mu F}$$

ex. 4 Given the Following system, if $I_s = 3.929A\cos(377t - 25.84°)$,



Find the power Factor and real & reactive power of the load

make $\tilde{V}_s$ and $\tilde{I}_s$ rms phasors :

$$V_s = \frac{339.4V}{\sqrt{2}} = 240\,V_{rms} \qquad I_s = \frac{3.929A}{\sqrt{2}} = 2.78\,A_{rms}$$

$$\tilde{V}_s = 240V_{rms}\angle 0° \qquad \tilde{I}_s = 2.78A_{rms}\angle -25.84°$$

* → change sign

$$S = \tilde{V}_s \tilde{I}_s^{\,*} = (240V\angle 0°)(2.78A\angle 25.84°)$$

$$S = 667.2VA\angle 25.84°$$

alternate method: Ps and Qs... see next page

$$S = S_{CAP} + S_{LOADS}$$

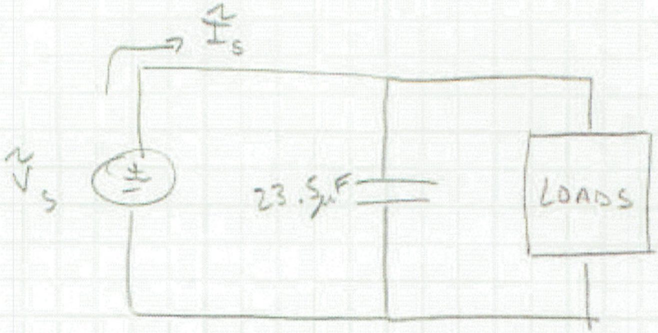
$$S_{CAP} = \frac{V_s^2}{Z_{CAP}^{\,*}} \qquad Z_{CAP} = \frac{1}{\omega C}\angle -90° = \frac{1}{(377\,rad/s)(23.5\mu F)}\angle -90°$$

$$Z_{CAP} = 112.87\Omega\angle -90°$$

$$S_{CAP} = \frac{(240V)^2}{112.87\Omega\angle 90°} = 510.3VA\angle -90°$$

$$667.2VA\angle 25.84° = 510.3VA\angle -90° + S_{LOADS}$$

$$\boxed{\begin{array}{l} S_{LOADS} = 1000VA\angle 53.15° = 600W + j800VAR \\ \qquad\qquad\qquad\qquad\qquad\quad P \qquad\quad Q \\ pf = \cos 53.15° = 0.6 \text{ lagging} \end{array}}$$



$\tilde{V}_s = 240\,V_{rms} \angle 0°$ $\qquad$ $\tilde{I}_s = 2.78\,A_{rms} \angle -25.84°$

$$Z_C = -\frac{j}{\omega C} = -\frac{j}{(377)(23.5\mu F)} = -j112.87\,\Omega$$

$P_{TOTAL} = V_s I_s \cos\Theta_{TOT}$ where $\Theta_{TOT} = \phi_V - \phi_I$

$\Theta_{TOT} = 0° - (-25.84°)$

$\Theta_{TOT} = 25.84°$

$P_{TOTAL} = (240V)(2.78A)\cos 25.84° = 600.5W$

$Q_{TOTAL} = V_s I_s \sin\Theta_{TOT}$

$= (240V)(2.78A)\sin 25.84° = 290.8VAR$

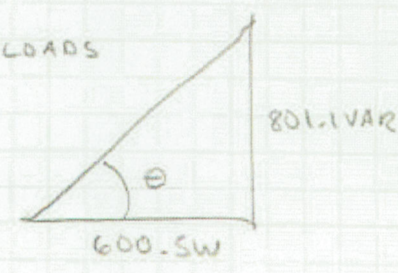
$P_{TOTAL} = \cancel{P_{CAP}}^{0} + P_{LOADS} \longrightarrow \boxed{P_{LOADS} = 600.5W}$

$Q_{TOTAL} = Q_{CAP} + Q_{LOADS}$

$$Q_{CAP} = \frac{V^2}{X_C} = \frac{(240V)^2}{-112.87\Omega} = -510.3\ VAR$$

$290.8\ VAR = -510.3\ VAR + Q_{LOADS}$

$\boxed{Q_{LOADS} = 801.1\ VAR}$



$$\Theta_{LOADS} = \tan^{-1}\left(\frac{801.1}{600.5}\right) = 53.1°$$

$pf = \cos\Theta_{LOADS} = \cos(53.1°) = \boxed{0.6\ \text{lagging}}$