Worked Example

Figure below shows a reactor being disconnected from its 7.2 kV supply. During the process of opening, the circuit breaker chops a current of 1.0 A.

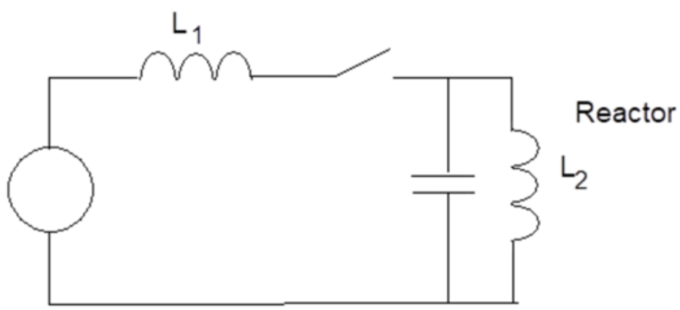
Determine

(a) The peak voltage which will appear across the reactor

(b) Sketch the reactor voltage, the reactor current and the source voltage as a function of time.

(c) Rework with a 10,000 Ohms equivalent resistance in parallel with reactor.

L1 = 35 mH, L2= 350 mH, C = 3200 pF



ECE 587
FALL 2019

CURRENT CHOPPING EXAMPLE

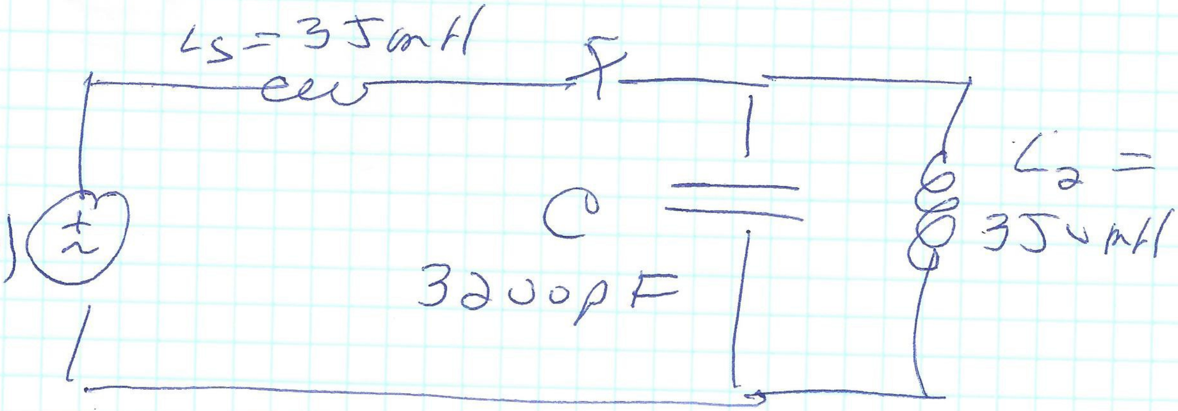
12.47 KV 3ϕ CIRCUIT, INDUCTIVE LOAD.

LOOK AT CURRENT CHOP OF 1A FOR A CB OPENING

$v_s(t) =$

$= \sqrt{2}\, 7200 \sin(377t + \theta)$

θ POINT ON WAVE



FIND PEAK VOLTAGE

$$\omega L_2 = 377(350\,mH) = 131.95\,\Omega$$

$$\frac{1}{\omega C} = \frac{1}{377(3200\times10^{-12})} = 828{,}912\,\Omega$$

$\omega L_2 << \frac{1}{\omega C}$ FOR INITIAL CONDITIONS, NEGLECT CAPACITOR CURRENT

BEFORE SWITCHING
$$\hat{I} = \frac{\hat{V}}{Z} = \frac{7200\angle\theta}{j377(0.035+0.35)} = 49.6\angle\theta-90^\circ$$

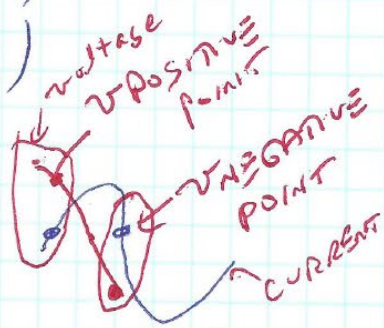
$$i(t) = \underbrace{\sqrt{2}\,49.6}_{70.15} \sin(377t + \theta - 90^\circ)$$

$$i(t=0) = 1.0 = 70.15 \sin(\theta - 90^\circ)$$

$$\theta_1 = \sin^{-1}\left(\frac{1}{70.15}\right) + 90^\circ$$

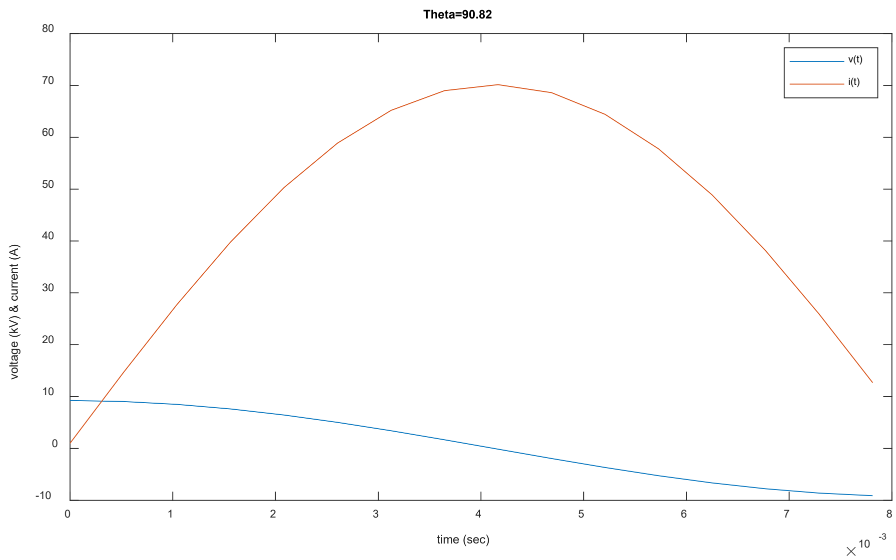
$$\theta_2 = \cancel{180}\ 360^\circ - \theta_1 \qquad \theta_1 = \cancel{89.18^\circ} \qquad \theta_1 = 90.82^\circ$$

$$(\theta_2 - 90^\circ) = 180 - (\theta_1 - 90^\circ) \qquad \theta_2 = 269.18^\circ\ (-90.82)$$

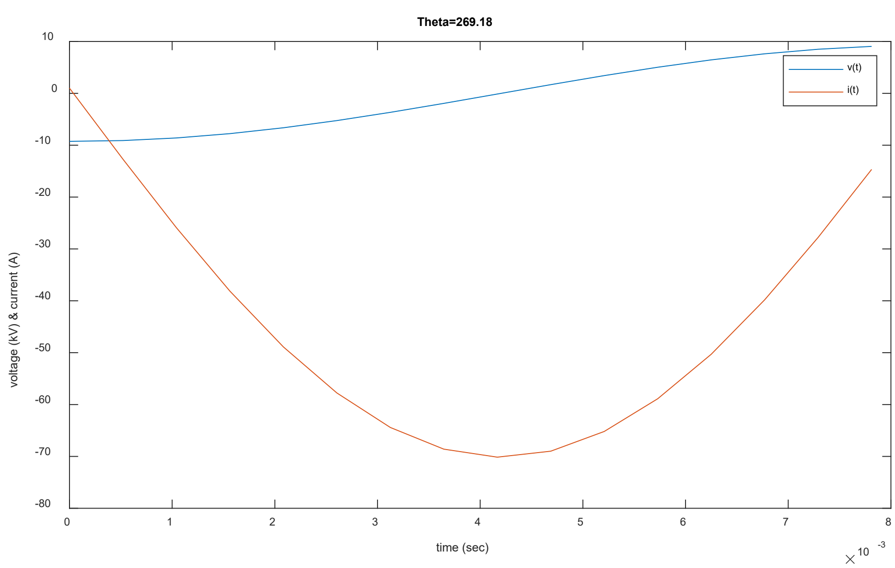


$$\hat{v} = \frac{j\omega L_2}{j\omega L_S + j\omega L_2}\sqrt{2}\,7200\angle\theta$$

$$v(t) = \frac{350}{385}\sqrt{2}\,7200 \sin(\omega t + \theta)$$



For Theta = 90.82 deg, note that at t=0, current is 1 A, but increasing. So can't have a current chop condition here, since current is not approaching a natural current zero.
Note since current lags voltage by 90 degrees, this corresponds to positive voltage.



For Theta = 269.18 deg, note at t=0 that current is 1 A, but decreasing. So have the condition where we can have a current chop before the natural current zero. This corresponds to a negative voltage.

CURRENT CHOPPING EXAMPLE

$$v_c(0) = \frac{350}{385}\sqrt{2}\,7200\sin(-\cancel{89.18°}\;-90.82)$$

CHOOSE ANGLE SO VOLTAGE IS NEGATIVE

$$= \boxed{-9256\ V}$$

$v_c(0) = -9256$; $i_L(0) = 1.0A$; $i_c(0) = -1.0A$

$$\frac{1}{C}\frac{d}{dt}\left(C\frac{dv_c}{dt} + \frac{1}{L}\int v_c\,dt + i_L(0) = 0\right)$$

$$\frac{d^2 v_c}{dt^2} + \frac{1}{LC}v_c = 0$$

$$s_1, s_2 = \pm j\frac{1}{\sqrt{LC}} \Rightarrow \omega_0 = \frac{1}{\sqrt{0.350 \times 3200 \times 10^{-12}}}$$

$= 29{,}881$ RAD/SEC

$\sim$ 5 KHZ

$$v_c(t) = A_1\cos\omega_0 t + A_2\sin\omega_0 t$$

$$v_c(0) = A_1 \Rightarrow A_1 = -9256$$

$$\frac{dv_c(0)}{dt} = \frac{1}{C}i_c(0) = \frac{1}{C}(-I_0) = \omega_0 A_2$$

$$A_2 = \frac{1}{C}(-I_0)/\omega_0 = -10{,}458$$

$$v_c(t) = -9256\cos(29{,}881t) - 10{,}458\sin(29{,}881t)\ V$$

$$= 13{,}986\cos(29{,}881t + 131.40) \qquad t \geq 0$$

CURRENT CHOPPING EXAMPLE (9/1/20)

ADD 10,000 Ω RESISTANCE IN PARALLEL TO REPRESENT DAMPING

$\omega L_2 = 131.95$, DO WE NEED TO INCLUDE FOR INITIAL CONDITIONS

NO $R \rightarrow Z_{LOAD} = j131.95 = 131.95\angle 90°$

WITH $R \rightarrow Z_{LOAD} = \dfrac{R(j\omega L)}{R + j\omega L} = 131.94 \angle 89.20°$

NOT MUCH DIFFERENCE

AS FAR AS ANGULAR DIF. $\sin(90°) = 1$, $\sin(89.2) \simeq 1$ } NOT MUCH DIF.

SO CAN NEGLECT SINCE COMPONENT TOLERANCE > 1%

SO NEGLECTING R IN INITIAL CONDITIONS GIVES US $v_1(0) = -9256\,V = v_c(0)$; $i_C(0) = -1A$

AFTER SWITCHING, APPLY KCL

$$\frac{1}{C}\frac{d}{dt}\left(C\frac{dv_c}{dt} + \frac{1}{L}\int_0^t v_c\,dt + i_L(0) + \frac{v_c}{R}\right) = 0$$

$$\frac{d^2v_c}{dt^2} + \frac{1}{RC}\frac{dv_c}{dt} + \frac{1}{LC}v_c = 0$$

$$s_1, s_2 = \frac{-1/RC}{2} \pm \frac{\sqrt{\left(\frac{1}{RC}\right)^2 - \frac{4}{LC}}}{2} = -15{,}625 \pm j25{,}470$$

(4 kHz)

$$v_c(t) = e^{-15{,}625t}\left(A_1\cos(25{,}470t) + A_2\sin(25{,}470t)\right)$$

$$v_c(0) = -9256 = e^{(0)}\left(A_1(1) + A_2(0)\right);\ A_1 = -9256$$

$$\frac{dv_c(0)}{dt} = \frac{1}{C}\left(\underbrace{-i_L(0) - i_R(0)}_{-1}\right) = \frac{1}{C}\left(-1.9256 - \frac{-9256}{10{,}000}\right)$$

$$= -3.125 \times 10^8$$

CURRENT CHOPPING EXAMPLE 9/1/2020

$$\frac{dv_C(0)}{dt} = -15{,}625e^0(A_1(1) + A_2(0)) + e^{(0)}(A_1 25470(0) + A_2 25470\cos(0))$$

$$\Rightarrow A_2 = \frac{-3.125\times10^8 + 15625(A_1)}{25{,}470}$$

$$= -17{,}948$$

$$v_C(t) = e^{-15{,}625t}(-9256\cos(25{,}470t) - 17{,}948\sin(25{,}470t))$$

$$= e^{-15{,}625t}\left[20{,}194\cos(25{,}470t + 117.3^\circ)\right]$$

WHEN $25{,}470t + 117.3^\circ = \pi \Rightarrow t_m = 4.296\times10^{-5}$

$$e^{-15625t_m}(-20{,}194) = \underline{-10{,}320\ V}$$

NEED TO PLOT

BUT $-12.3k$ IN PSCAD SIMULATION

FROM PLOT $-12.3KV$