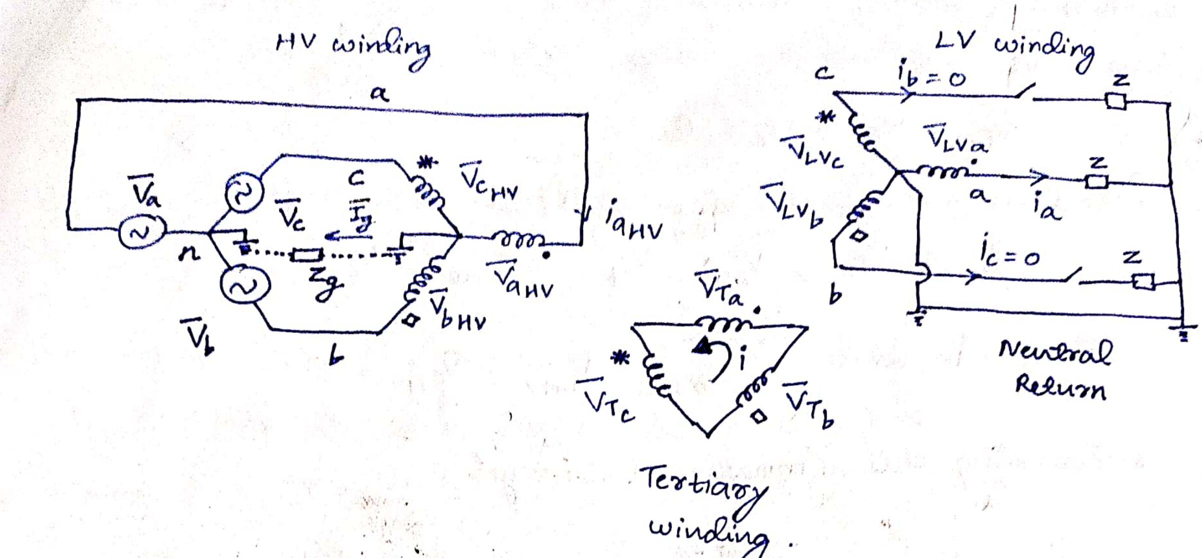
Problem ①:

TUTORIAL 5: A Review of Power Conditioning Circuits



Applying KVL equations to the HV side winding, we get,

$$\bar{V}_a - \bar{V}_{a_{HV}} - \bar{I}_g Z_g = 0$$

$$\bar{V}_b - \bar{V}_{b_{HV}} - \bar{I}_g Z_g = 0$$

$$\bar{V}_c - \bar{V}_{c_{HV}} - \bar{I}_g Z_g = 0.$$

Adding the above 3 equations, we get,

$$(\bar{V}_a + \bar{V}_b + \bar{V}_c) - (\bar{V}_{a_{HV}} + \bar{V}_{b_{HV}} + \bar{V}_{c_{HV}}) = 3\bar{I}_g Z_g$$

$$0 - (\bar{V}_{a_{HV}} + \bar{V}_{b_{HV}} + \bar{V}_{c_{HV}}) = 3\bar{I}_g Z_g$$

(since source is balanced, $\bar{V}_a + \bar{V}_b + \bar{V}_c = 0$

$$\therefore \bar{V}_{a_{HV}} + \bar{V}_{b_{HV}} + \bar{V}_{c_{HV}} = -3\bar{I}_g Z_g \quad \text{———} \quad ①$$

Let us assume 'i_a' flows through 'a-winding of LV side.

Due to this current, some current 'i' flows through ...

Applying KVL to the tertiary winding, we get,

$$\bar{V}_{Ta} + \bar{V}_{Tb} + \bar{V}_{Tc} = 0$$

Since the turns ratio for 3 windings are same, we can say

$$\bar{V}_{aHV} = \bar{V}_{Ta}, \quad \bar{V}_{bHV} = \bar{V}_{Tb}, \quad \bar{V}_{cHV} = \bar{V}_{Tc}$$

$\therefore$ we can also write, $\bar{V}_{aHV} + \bar{V}_{bHV} + \bar{V}_{cHV} = 0$

substituting this in equation ①, we get,

$$0 = -3\bar{I}_g Z_g$$

$$\therefore \bar{I}_g = 0.$$

Using per-phase MMF balance, we can write,

$$\bar{I}_{aHV} + \bar{I} = \bar{I}_a \quad \text{—②} \quad \text{(for phase 'a')}$$

$$\bar{I}_{bHV} + \bar{I} = 0 \Rightarrow \bar{I}_{bHV} = -\bar{I} \quad \text{—③}$$

$$\bar{I}_{cHV} + \bar{I} = 0 \Rightarrow \bar{I}_{cHV} = -\bar{I} \quad \text{—④}$$

we know, $\bar{I}_{aHV} + \bar{I}_{bHV} + \bar{I}_{cHV} = \bar{I}_g = 0$

Adding equations ②, ③ and ④,

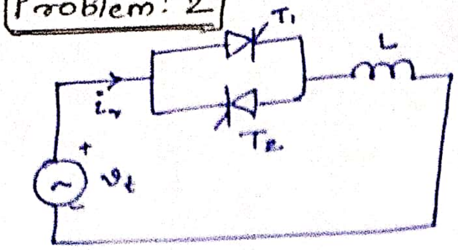
$$\bar{I}_{aHV} + \bar{I}_{bHV} + \bar{I}_{cHV} + 3\bar{I} = \bar{I}_a$$

$$0 + 3\bar{I} = \bar{I}_a$$

$$\therefore \bar{I} = \frac{\bar{I}_a}{3}$$

$$\therefore \bar{I}_{bHV} = -\bar{I} = \frac{-\bar{I}_a}{3}; \quad \bar{I}_{cHV} = -\bar{I} = \frac{-\bar{I}_a}{3}; \quad \bar{I}_{aHV} = \bar{I}_a - \frac{\bar{I}_a}{3} = \frac{2\bar{I}_a}{3}$$

Problem: 2

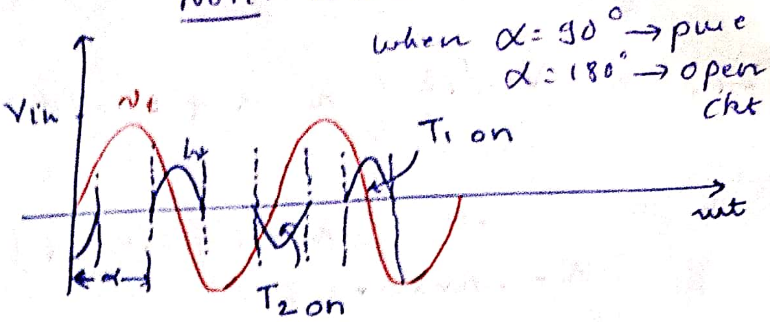


L = 500 mH

Note: here $90° \le \alpha \le 180°$

when $\alpha = 90° \rightarrow$ pure L

$\alpha = 180° \rightarrow$ open Ckt.



In order to find expression for fundamendal component of current, let us do Fourier analysis. Let $v_t = V_m \sin\omega t$

Current i_r for 1/2 cycle is given by,

$$i_r = \begin{cases} \dfrac{v_t}{\omega L} & \text{for } 0 < \omega t < 180 - \alpha \\ & \& \quad \alpha < \omega t < 180° \\ 0 & \text{otherwise.} \end{cases}$$

So the fundamental component will be:

$$I_{1r} = \frac{1}{\pi}\left[\int_0^{180-\alpha} \frac{v_t}{\omega L} \sin\omega t \, dt + \int_\alpha^{180} \frac{v_t}{\omega L} \sin\omega t \, dt\right]$$

$$= \frac{1}{\pi}\left[\int_0^{180-\alpha} \frac{V_m \sin\omega t \cdot \sin\omega t}{\omega L} \, d\omega t + \int_\alpha^{180} \frac{V_m \sin\omega t \sin\omega t}{\omega L} \, d\omega t\right]$$

$$= \frac{V_m}{\pi\omega L}\left[\int_0^{180-\alpha} \sin^2\omega t \, d\omega t + \int_\alpha^{180} \sin^2\omega t \, d\omega t\right]$$

$$= \frac{V_m}{2\pi\omega L}\left[\int_0^{180-\alpha} (1-\cos 2\omega t)\, d\omega t + \int_\alpha^{180} (1-\cos 2\omega t)\, d\omega t\right]$$

$$= \frac{V_m}{2\pi\omega L}\left[\pi - \alpha + \frac{\sin 2\alpha}{2} + \pi - \alpha + \frac{\sin 2\alpha}{2}\right]$$

$$= \frac{V_m}{\pi\omega L}\left[\pi - \alpha + \frac{\sin 2\alpha}{2}\right]$$

It is given that $I_{1r} = 1\ A$ rms.

$$I_{1r} = \frac{V_m/\sqrt{2}}{\pi \omega L}\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)$$

$$1 = \frac{230}{\pi * 2\pi * 50 * 0.5}\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)$$

Solving for α we get, (using N-R Method)

$\alpha = 2.84^c$ or $162.7°$ From response: $\alpha = 162.7°$ is the solution.

—x—

Problem ③

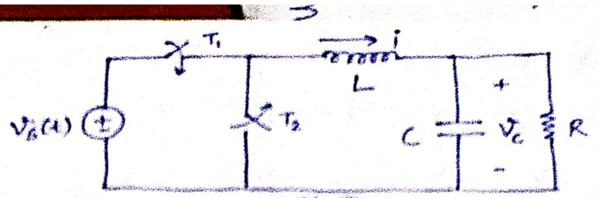


Fig ①

When switch T_1 is ON,

$$L\frac{di}{dt} = V_S(t) - V_C$$

$$i = C\frac{dV_C}{dt} + \frac{V_C}{R}$$

When switch T_2 is ON

$$L\frac{di}{dt} = -V_C$$

$$i = C\frac{dV_C}{dt} + \frac{V_C}{R}$$

Since we know that dual of circuit has same equations with voltages replaced by current and vice-versa, inductors replaced by capacitors, resistances replaced by conductances, loops replaced by nodes and vice-versa, we can write equations for dual of circuit of fig ① as :

When switch T_1 is ON,

$$C\frac{dV_C}{dt} = i_S(t) - i$$

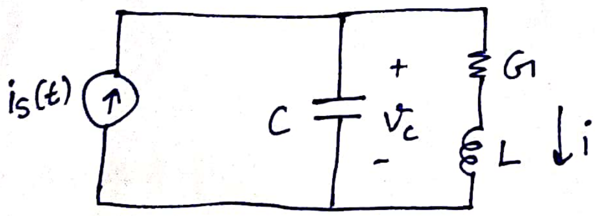
$$V_C = L\frac{di}{dt} + \frac{i}{G}$$

When switch T_2 is ON,

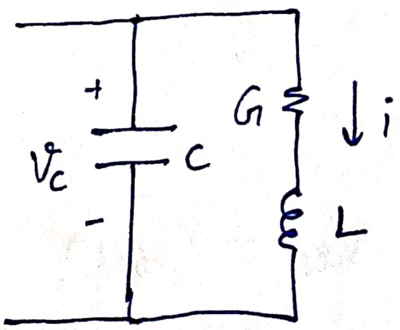
$$C\frac{dV_C}{dt} = -i$$

$$V_C = L\frac{di}{dt} + \frac{i}{G}$$

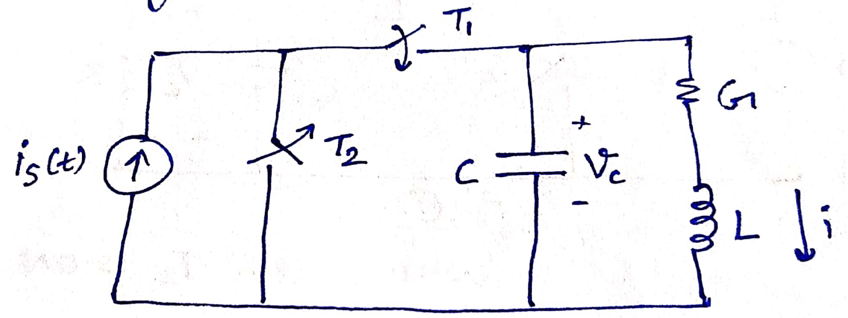
∴ From above equations (when T_1 is ON), the equivalent circuit will be :



From equations (when T_2 is ON and T_1 is OFF), equivalent circuit will

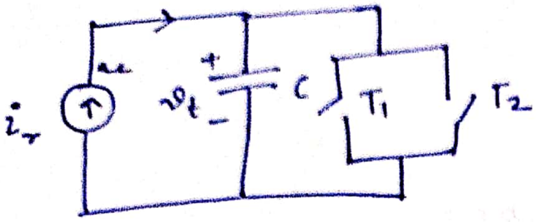


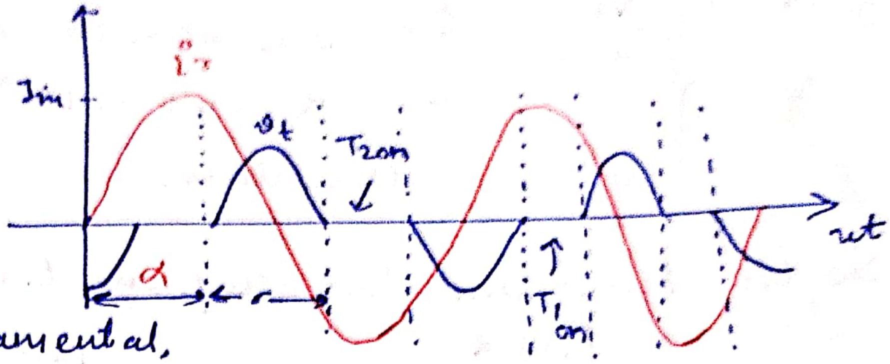
Combining above two using T_1 and T_2 switches, circuit will be :



This is the dual of Circuit in fig. ①.

Problem : 4





In order to find fundamental, we have,

$$v_t = \frac{i_r}{\omega C} \quad \text{for} \quad 0 < \omega t < 180 - \alpha$$
$$\text{and} \quad \alpha < \omega t < 180^\circ$$
$$0 \quad \text{otherwise.}$$

Fundamental component will then be,

$$V_{1t} = \frac{1}{\pi}\left[\int_0^{180-\alpha} \frac{i_r}{\omega C}\sin\omega t\, d\omega t + \int_\alpha^{180^\circ} \frac{i_r}{\omega C}\sin\omega t\, d\omega t\right]$$

$$= \frac{I_m}{\pi\omega C}\left[\int_0^{180-\alpha} \sin^2\omega t\, d\omega t + \int_\alpha^{180^\circ} \sin^2\omega t\, d\omega t\right]$$

$$= \frac{I_m}{\pi\omega C}\left[\pi - \alpha + \frac{\sin 2\alpha}{2}\right]$$

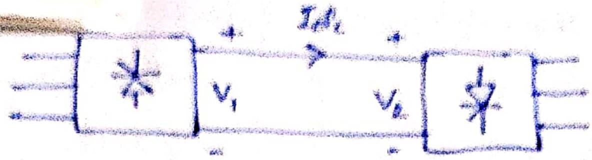
, put $\alpha = \pi - \sigma/2$ + get expression in terms of σ.

Scanned with CamScanner

As can be seen from waveform when T_1 or T_2 turns ON, current is not zero, which means switches T_1 and T_2 should have controlled turn off. Thus we should have switches with turn off capability.

3

Problem 5



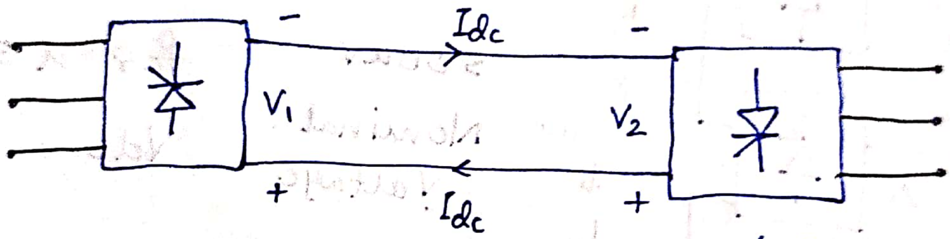
$(\alpha_1 < 90°)$ $(\alpha_2 > 90°)$

$P_1 \longrightarrow$ $\longrightarrow P_2$

$Q_1 \longrightarrow$ $\longleftarrow Q_2$

To reverse the direction of power flow, we cannot reverse the direction of curr because of presence of thyristors which will not allow reverse current.

$\therefore$ We will have to reverse the voltage polarity.



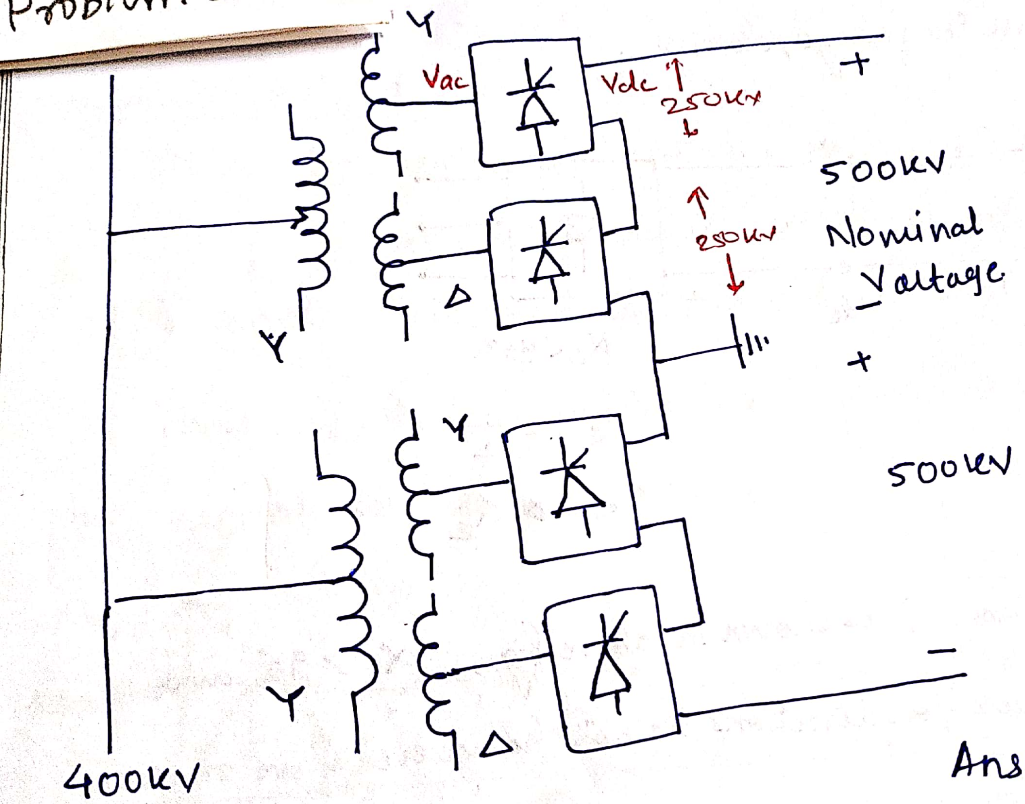
$\alpha_1 > 90°$ $\alpha_2 < 90°$

$\longleftarrow P_1$ $\longleftarrow P_2$

$\longrightarrow Q_1$ $\longleftarrow Q_2$

For voltage polarities of V_1 and V_2 as shown in above fig., $\alpha_1 > 90°$ and $\alpha_2 < 90°$. Reactive power flow directions do not change even if we reve the active power flow direction.

Problem 5



for a thyristor bridge

for $\alpha = 0°$,

$$V_{dc} = \frac{3\sqrt{2}\,V_{ac}}{\pi}$$

$$V_{ac} = \frac{\pi \cdot 250}{3\sqrt{2}}$$

$$= 185.12\,kV$$

The nearest AC value is 212 kV ($\alpha \approx 30°$)

Ans: (a) 400 : 212

the nearest AC value is 212 kV ($\alpha \approx 30^\circ$)

Ans: (a) 400 : 212

Problem 7

$R = 0.75\,\Omega$, $L = 15.2\,mH$, $C = 4.2\,\mu F$

at fundamental frequency (50 Hz)

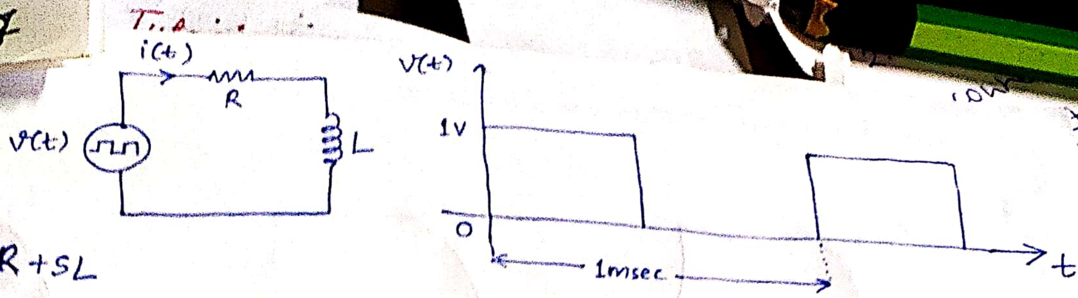
$$j(X_L - X_C) = j\left(2\pi \times 50 \times 15.2 \times 10^{-3} - \frac{1}{2\pi \times 50 \times 4.2 \times 10^{-6}}\right)$$

$$= -j753.10\,\Omega$$

As $j(X_L - X_C)$ is negative, so this filter will generate reactive power at the fundamental frequency.

Ans: (a) generate reactive power at the fundamental frequency.

Problem # 8



$$\frac{V(s)}{I(s)} = R + sL$$

$$\therefore I(s) = \frac{1}{(R+sL)} \cdot V(s) \Rightarrow I(s) = \left(\frac{1}{R}\right) \cdot \frac{1}{(1+s\tau)} \cdot V(s)$$

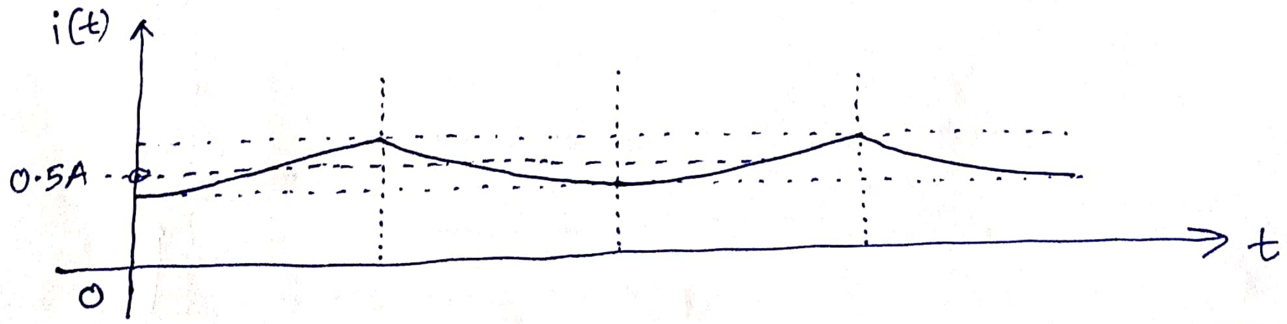
(a) $I(s) = \left(\frac{1}{R}\right)\left(\frac{1}{1+s\tau}\right) \cdot V(s)$

If $\tau = 1\text{sec}$, then $s\tau >> 1$ (fundamental freq. is 1KHz)

$$\therefore I(s) \cong \left(\frac{1}{R}\right) \cdot \frac{1}{s\tau} V(s) = \frac{1}{s\tau} V(s) = \frac{V(s)}{s}$$

$$\therefore i(t) \cong \int v(t)\, dt$$

$\therefore$ Current waveform will approximately be as shown below :

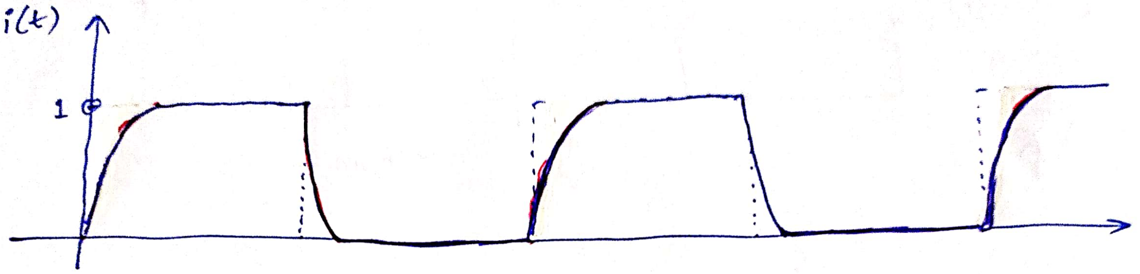


(b) $I(s) = \left(\frac{1}{R}\right)\left(\frac{1}{1+s\tau}\right) \cdot V(s)$

If $\tau = 1\mu\text{sec}$, then $s\tau << 1$.

$$\therefore I(s) \cong \left(\frac{1}{R}\right) \cdot V(s) \cong V(s)$$

∴ Current waveform in this case will be :



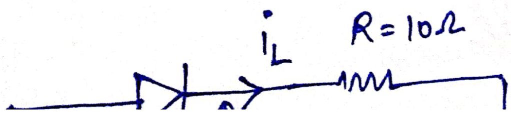
Problem 9

RMS value of fundamental component of voltage,

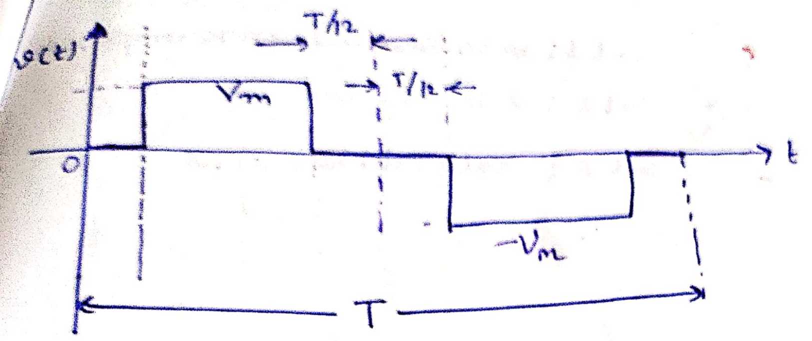
$$V_{1rms} = \frac{4 \times 240}{\pi \times \sqrt{2}} = 216.11 \text{ volt}.$$

$$Z_{(\text{at fundamental freq.})} = R + j\omega L = 10 + j(2\pi \times 50 \times 0.06) = 10 + j18.85\ \Omega$$

$$\therefore I_{1rms} = \frac{V_{1rms}}{|Z|} = \frac{216.11}{\sqrt{(10)^2 + (18.85)^2}} = 10.13 \text{ A}$$



Problem: 16



The expression for voltage $v(t)$ after doing fourier analysis is given by,

$$v(n) = \frac{4 V_m}{n \pi \sqrt{2}} \cos(n \pi / 6)$$

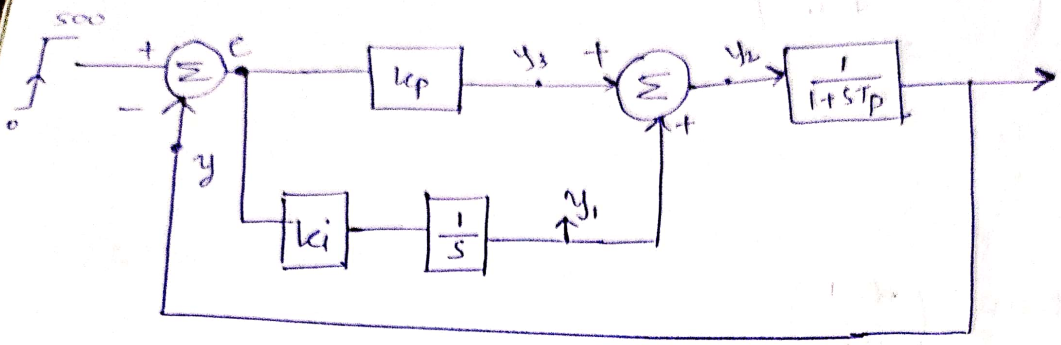
where $v(n)$ is n^{th} component of voltage.

for $n = 3$,

$$v(3) = 0$$

Thus magnitude of the 3^{rd} harmonic component will be zero.

Problem : 11



We know that steady state error = 0 for PI controller, thus,

$e = 0$, which means $y = 500$ at steady state.

At steady state gain of $\frac{1}{1+sT_p} = 1$ thus, $y_2 = 500$

$$y_2 = y_3 + y_1$$

$y_3 = e \times k_p = 0$, thus $y_2 = y_1 = 500$.

Thus at steady state $y_1 = 500$.

Problem : 5

Problem : 12

$$G(s) = \frac{5(1+0.136s)}{(1+0.01s)(1+0.1s)}$$

The poles are $s = -10, -100$

Clearly the systems are well separated with one fast mode (-100) and one slow mode (-10). So initial response will be only due to $s=100$ and steady state will be due to both poles.

Using partial fractions,

$$G(s) = \frac{7}{1+0.01s} - \frac{2}{1+0.1s}$$

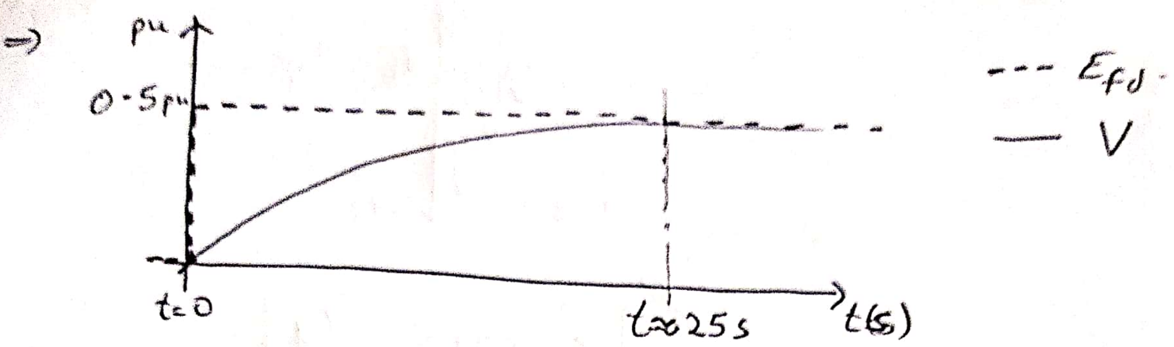
So response will go towards 7 in $5\tau_1$ (0.05s). Then finally it will reach steady state (5) in $5T_2$ (0.5s).

(b) option 2 is correct.

Problem - ~~16~~ 13

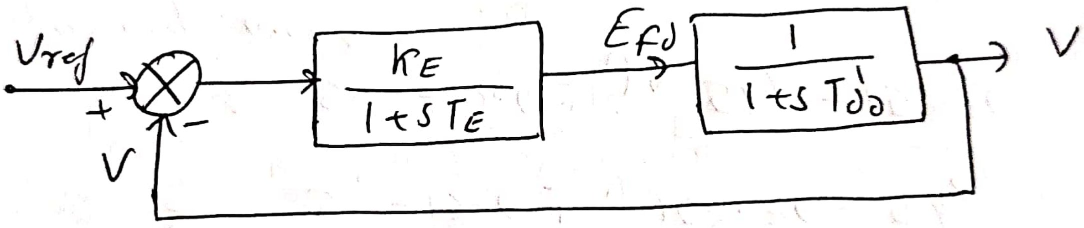
(a) Given

and $T'_{do} = 5\,s$.



⇒ [Note: here pu refers to per unit. $\underline{0\cdot 5\,pu}$ refers to 50% of the rated voltage or quantity]

(b) If the E_{fd} is controlled as shown



Here $G(s) = \left(\frac{K_E}{1+sT_E}\right)\cdot\left(\frac{1}{1+sT'_{do}}\right)$

Here $\boxed{T_E = 0\cdot 04\,s}$

and $H(s) = 1$

∴ Closed loop poles of above system

$1 + G(s)H(s) = 0$

$$\therefore\ s^2 + \underline{25\cdot 2}\,s + 5(1+K_E) = 0 \quad \text{— (1)}$$

→ To determine K_E such that the poles are complex conjugates and with damping ratio 10%.

$$\therefore \quad s = -12.6 \pm j\sqrt{5K_E - 153.76}$$

Comparing with

$$s = \sigma \pm j\omega$$

$$\boxed{\sigma = -12.6} \quad \text{and} \quad \boxed{\omega = \sqrt{5K_E - 153.76}}$$

$\therefore$ Substituting these values in eqn ② we get,

$$\boxed{K_E = 3174.2}$$

blem: 14

Steady state gain = 1. High frequency gain = $\frac{T_1}{T_2} < 1$. So after step is applied, the initial response will be < 1 and then it will reach 1 with time constant T_2. So (c) option is correct.