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ESE - 2018
MAINS EXAMINATION
Questions with Detailed Solutions
ELECTRICAL ENGINEERING
PAPER - II

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PAPER REVIEW

Paper was overall hard, Power systems and Control systems had some questions from our test series. Paper setter mostly concentrated on core subject like Machine, Power Systems and Power Electronics. Electrical Machines got the highest weightage with questions from unexpected areas. Power Electronics is little difficult and overall paper is lengthy.

SUBJECT WISE REVIEW

SUBJECT(S)	LEVEL	Marks
Analog & Digital Electronics	Easy	32
Systems & Signal Processing	Moderate	52
Control Systems	Moderate	84
Electrical Machines	Hard	124
Power Systems	Moderate	104
Power Electronics	Hard	84

Subject Experts,

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SECTION-A

01. (a) A single-phase AC voltage controller is feeding a resistive load of 26. 45Ω from an AC source of 230V, 50 Hz. Compute the firing angle to deliver 1000W to the load. Also compute the p.f. at which this power is delivered. Draw a neat circuit diagram and waveforms of voltage at load terminals with current flowing in the load. (12 M)

Sol: 1-ϕ Voltage controller

$R_{Load} = 26.45\ \Omega$;

$V_m = 230\sqrt{2}$ volt ;

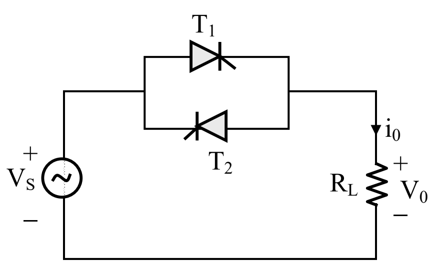
$f = 50$ Hz;

$P_0 = 1000$ W

To find: $\alpha = ?$

p.f. = ?

Circuit diagram



$$V_{0\,rms} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2 \omega t.d\omega t}$$

$$V_{0\,rms} = \frac{V_m}{\sqrt{2\pi}}\left[(\pi-\alpha)+\frac{1}{2}\sin 2\alpha\right]^{\frac{1}{2}}$$

$$P_0 = \frac{V_{0\,rms}^2}{R} = \frac{V_m^2}{2\pi R}\left[(\pi-\alpha)+\frac{1}{2}\sin 2\alpha\right]$$

$$1000 = \frac{\left(230\sqrt{2}\right)^2}{2\pi \times 26.45}\left[(\pi - \alpha) + \frac{1}{2}\sin 2\alpha\right]$$

$$1.5705 = 0.5\sin(2\alpha) - \alpha$$

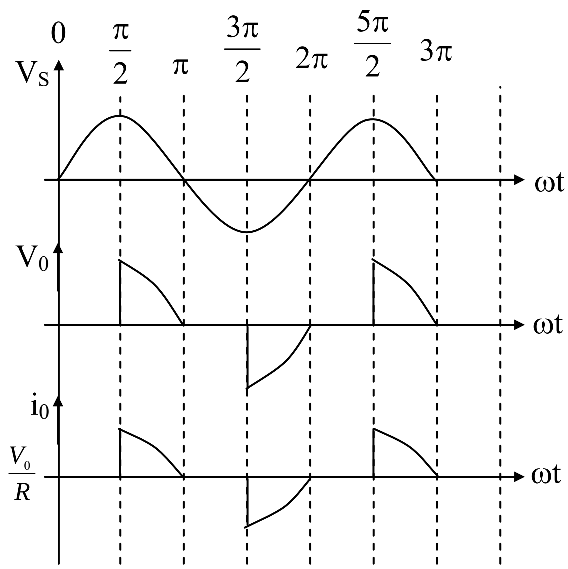
$$\alpha = 90^{o}$$

$$\text{Input pf} = \frac{P_0}{V_{sr} I_{sr}} = \frac{\frac{V_{or}^2}{R}}{V_{sr} \times \frac{V_{or}}{R}} = \frac{V_{orms}}{V_{srms}}$$

$$\text{Input pf} = \frac{1}{\sqrt{\pi}}\left[(\pi - \alpha) + \frac{1}{2}\sin 2\alpha\right]^{\frac{1}{2}}$$

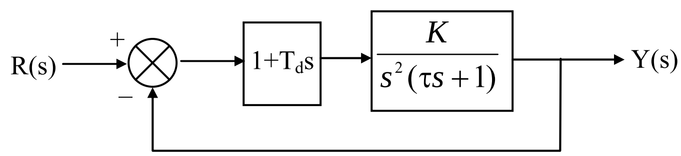
$$\text{Input pf} = \frac{1}{\sqrt{\pi}}\left[\left(\pi - \frac{\pi}{2}\right) + \frac{1}{2}\sin 180\right]^{\frac{1}{2}}$$

$$\text{Input pf} = \frac{1}{\sqrt{\pi}} \times \sqrt{\frac{\pi}{2}} = \frac{1}{\sqrt{2}} = 0.707 \text{ (lag)}$$



01. (b) An open-loop system $G(s) = \frac{1}{s^2(\tau s+1)}$ is placed in cascade with a proportional and derivative controller K(s) = (1+T_ds). If their unity feedback closed-loop system oscillates at a frequency of $\sqrt{2}$ rad/second, find the ranges/values of the system and controller parameters, i.e., ranges/values of K, T_d and τ. **(12 M)**

Sol: **Given data:** $G(s) = \frac{K}{s^2(\tau s+1)}$; $G_C(s) = (1 + T_d s)$; $\omega_n = \sqrt{2}$ rad/sec



CE = 1 + G(s)G_C(s) = 0

$$1+\frac{K(1+T_d s)}{s^2(\tau s+1)} = 0$$

$$\tau s^3 + s^2 + KT_d s + K = 0$$

s^3	τ	KT_d
s^2	1	K
s^1	$\frac{KT_d - K\tau}{1}$	
s^0	K	

$$KT_d - K\tau = 0$$

$$T_d = \tau$$

$$AE = s^2 + K = 0$$

$$s = \pm j\sqrt{K}$$

$$\omega_n = \sqrt{K} = \sqrt{2} \text{ rad/sec (given)}$$

$$\therefore \quad K = 2$$

$T_d = \tau$ any value T_d will gives $\omega_n = \sqrt{2}$ rad/sec

01. (c) Determine the mechanical time constant of rotor of an electrical machine in terms of its moment of inertia j kg-m^2 and windage cum friction coefficient *f* N-m/rad/s. Also explain the method to determine mechanical time constant experimentally in laboratory. (12 M)

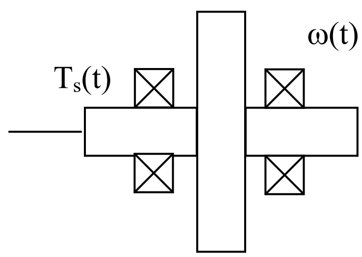
Sol: Given data:

Moment of inertial = J kg-m^2

Windage cum frinction coefficient of rotor = f Nm/rad/sec

The equation of motion of a mechanical system is in genral on ordinary differential equation.

Consider a motor attached to a shaft with friction coefficient f N-m/rad/s



The motor applies torque $T_s(t)$ which is zero for $t < 0$ and increases to a step T_0 at $t = 0$. The shaft inertia is J.

The system equation of motion is

$$J\frac{d\omega}{dt} + f\omega = T_s(t) \quad \text{……….} (1)$$

$$\Rightarrow \quad \frac{J}{f}\dot{\omega} + \omega = \frac{1}{f}T_s(t)$$

Solution of above equation is

$$\omega(t) = \underset{\substack{\uparrow \\ \text{Homogeneou term.}}}{\omega_n(t)} + \underset{\substack{\uparrow \\ \text{forced term.}}}{\omega_f(t)}$$

Homogeneous term is due to the initial conditions of the system. Homogeneous response can be found as a solution of the equation $\frac{d\omega}{dt} + \frac{f}{J}\omega = 0$.

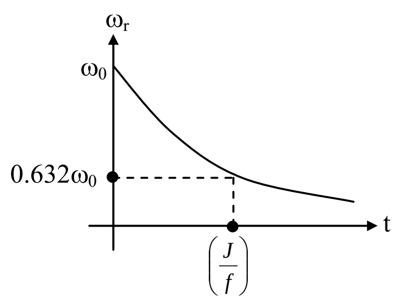
The solution is $\omega_n(t) = Ae^{-t/(J/f)}$. The rotor constant $\tau = \dfrac{J}{f}$.

To find the mechanical time constant:

Run the machine has a motor on no load, under rated conditions and switch off the supply. If the supply is switched off at t = 0, for t ≥ 0, we have $J\dfrac{d\omega_r}{dt} + f\omega_r = 0$ with $\omega_r\,(t = 0) = \omega_0$.

Then $\omega_r(t) = \omega_0 e^{-t/(J/f)}$.

Note the speed ~ time after switching of the motor and plot the $\omega_r \sim t$ curve.



When $t = \dfrac{J}{f}$, speed will be $\omega_0 \times e^{-1} = 0.632\omega_0$

So, simply finding the time t for speed = 0.632 ω_0 gives $\dfrac{J}{f}$, the mechanical time constant.

01. (d) An electric train running between two stations A and B, 10 km apart and maintained at voltages 550V and 500 V respectively, draws a constant current of 600 A. The resistance for both go and return conductors is 0.04 Ω/km. Find the point of minimum potential between the stations, the voltage at point and currents drawn from both the stations at that point

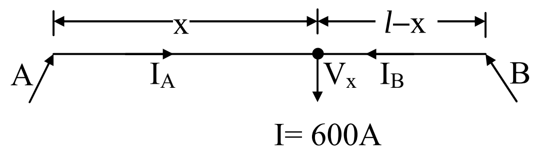
(12M)

Sol: An electric train running between two stations 'A' and 'B' with voltages V_A = 550V, V_B =500 V.

Distance between two stations is (l) = 10 km

Train draws a constant current of (I) = 600 A.

The resistance of both go and return conductor, r = 0.04 Ω/km



Let us assume 'x' is the point at which minimum voltage occurs as shown in the figure. Let currents supplied by 'A' and 'B' stations are I_A and I_B respectively such that $I_A + I_B = 600$ A (or) $I_B = 600 - I_A$

Now, $V_x = V_A - I_A r.x$

$= 550 - I_A(0.04x)$ ……….. (1)

$V_x = V_B - I_B\, r(l - x)$

$= 500 - (600 - I_A)\,(0.04l - 0.04x)$

$V_x = 500 - (600 - I_A)(0.4 - 0.04x)$ ……… (2)

From (1) and (2)

$550 - I_A(0.04x) = 500 - (600 - I_A)(0.4 - 0.04x)$

$= 500 - 240 + 24x + 0.4I_A - 0.04x(I_A)$

$550 - 500 + 240 - 24x = 0.4I_A$

Now,

$$I_A = \frac{290 - 24x}{0.4}$$

From equation (1), $V_x = 550 - I_A(0.04x)$

$$= 550 - (0.04x)\left(\frac{290 - 24x}{0.4}\right)$$

$= 550 - 0.1x(290 - 24x)$

$V_x = 550 - 29x + 2.4x^2$

To get minimum value of V_x , $\dfrac{dV_x}{dx} = 0$

$-29 + 4.8x = 0$

$x = 6.0417$ km

So, minimum voltage occurs at a distance of 6.0417 km from station 'A'.

Minimum voltage value, $V_x = 550 - 29x + 2.4x^2$

$$= 550 - (29 \times 6.0417) + 2.4 \times (6.0417)^2$$

$$= 462.396 \text{ V}$$

Current supplied by station 'A', $I_A = \dfrac{290 - 24x}{0.4} = 362.498$ A

Current supplied by station 'B', $I_B = 600 - I_A = 237.5$ A

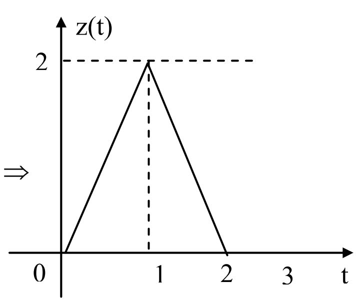
01. (e) The continuous time Fourier transform (CTFT) of a square pulse defined by $x(t) = 1$ for $-0.5 \le t \le 0.5$ is given by

$$X(\omega) = \frac{\sin\left(\frac{\omega}{2}\right)}{\frac{\omega}{2}}$$

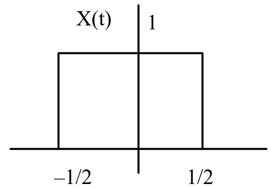
Use the properties of CTFT and synthesize the equation, and find the CTFT of the following signals $y(t)$ and $z(t)$: (12 M)

$$y(t) = \begin{cases} 2, & \text{for } 0 \le t < 1 \\ -2, & \text{for } 1 \le t \le 2 \\ 0, & \text{elsewhere} \end{cases}$$

Z(t) ⇒



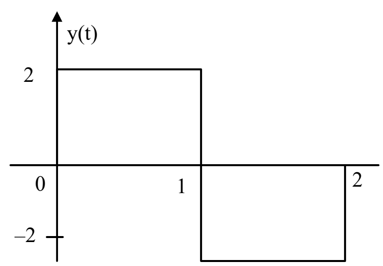
Sol: (a)



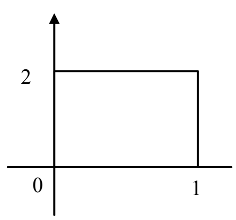
$$x(t) = rect(t) \leftrightarrow \frac{2}{\omega}\sin\frac{\omega}{2}$$

$$y(t) = 2\ ;\ 0 \le t \le 1$$

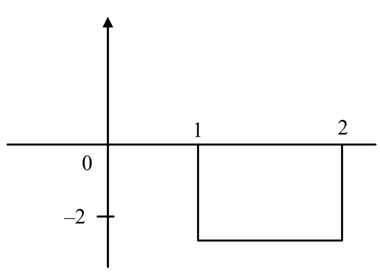
$$-2\ ;\ 1 \le t \le 2$$



$Y(t)$ should be expressed interms of



$$= 2\text{rect}\left(t - \frac{1}{2}\right)$$



$$= -2\text{rect}\left(t - \frac{3}{2}\right)$$

$$\therefore y(t) = 2\text{rect}\left(t - \frac{1}{2}\right) - 2\text{rect}\left(t - \frac{3}{2}\right)$$

$$rect(t) \leftrightarrow \frac{2}{\omega}\sin\frac{\omega}{2}$$

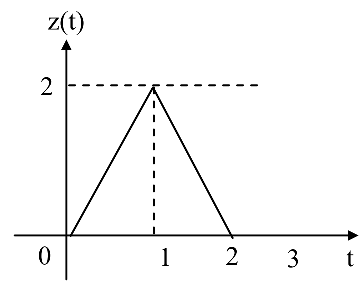
$$rect\left(t - \frac{1}{2}\right) \leftrightarrow e^{-j\omega/2}.\frac{2}{\omega}\sin\frac{\omega}{2}$$

$$rect\left(t - \frac{3}{2}\right) \leftrightarrow e^{-j3\omega/2}.\frac{2}{\omega}\sin\frac{\omega}{2}$$

$$\therefore\ y(\omega) = \frac{4}{\omega}\sin\frac{\omega}{2}\left[e^{-j\omega/2} - e^{-3j\omega/2}\right]$$

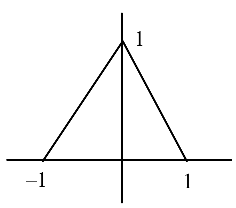
(b)

Z(t) ⇒



Rect (t) ×rect (t) = tri (t)

Tri(t)



$$z(t) = 2tri(t-1)$$

$$tri(t) \leftrightarrow \frac{4}{\omega^2}\sin^2\left(\frac{\omega}{2}\right)$$

$$tri(t-1) \leftrightarrow e^{-j\omega}.\frac{4}{\omega^2}\sin^2\left(\frac{\omega}{2}\right)$$

$$z(\omega) = \frac{8}{\omega^2}e^{-j\omega}.\sin^2\left(\frac{\omega}{2}\right)$$

02. (a) A single-phase full bridge inverter is used to produce a 50 Hz voltage across a series R-L load (R = 10Ω and L = 20 mH) using bipolar PWM. The DC input to the bridge is 380 V, the amplitude modulation ratio ma = 0.8 and frequency modulation ratio m_f = 21. Consider dominant harmonics to be frequency dominant and its nearby side frequencies (both sides). Assume normalized Fourier coefficient for ma = 0.8 to be 82% for dominant harmonic frequency and 22% for the nearby side frequencies.

Determine

(i) amplitude of 50 Hz component of output voltage and current;

(ii) power absorbed by the load resistor;

(iii) THD of the load current.

Also compare the amplitude of 50 Hz component of output voltage with square wave and quasi-square wave output. (20 M)

Sol: 1–ϕFB VSI: output frequency = 50Hz

R = 10Ω V_{dc} =380V

L = 20mH $m_a = 0.8$; $m_f = 21$

(i) $\hat{V}_{01} = m_a \times V_{dc} = 0.8 \times 380 = 304V$

$$z_1 = \sqrt{R^2 + X_L^2} = \sqrt{(10)^2 + (100\pi \times 20 \times 10^{-3})^2} = 11.81\Omega$$

$$\hat{I}_{01} = \frac{\hat{v}_{01}}{Z_1} = \frac{304}{11.81} = 25.74\,A$$

(ii) side frequencies = $m_f \pm 2$ = 21+2 = 23

21 –2 =19

$$(\hat{V}_0)_{19} = 380 \times 0.22 = 83.6V \; at\, 950Hz$$

$$(\hat{V}_0)_{21} = 380 \times 0.82 = 311.6V \; at\, 1050Hz$$

$$(\hat{V}_0)_{23} = 380 \times 0.22 = 83.6V \; at\, 1150Hz$$

$$z_{19} = \sqrt{10^2 + (2\pi \times 950 \times 20 \times 10^{-3})^2} = 119.798\Omega$$

$$z_{21} = \sqrt{10^2 + (2\pi \times 1050 \times 20 \times 10^{-3})^2} = 132.325\Omega$$

$$z_{23} = \sqrt{10^2 + \left(2\pi \times 1150 \times 20 \times 10^{-3}\right)^2} = 144.858\Omega$$

$$\hat{I}_0,19 = \frac{\hat{V}_{0,19}}{Z_{19}} = \frac{83.6}{119.798} = 0.6978A$$

$$\hat{I}_0,21 = \frac{\hat{V}_{0,21}}{Z_{21}} = \frac{311.6}{132.325} = 2.355A$$

$$\hat{I}_0,23 = \frac{\hat{V}_{0,23}}{Z_{23}} = \frac{83.6}{144.858} = 0.5771A$$

$$I_{0r} = \sqrt{I_{01}^2 + I_{019}^2 + I_{021}^2 + I_{023}^2}$$

$$= \sqrt{\left(\frac{25.74}{\sqrt{2}}\right)^2 + \left(\frac{0.6978}{\sqrt{2}}\right)^2 + \left(\frac{2.355}{\sqrt{2}}\right)^2 + \left(\frac{0.5771}{\sqrt{2}}\right)^2}$$

$= 18.28$A

$$\therefore P_0 = I_{or}^2 R = (18.28)^2 \times 10 = 3.34\ \text{kW}$$

(iii) $\mathrm{I}_{01} = \dfrac{25.74}{\sqrt{2}} = 18.2\text{A}$

$$THD = \sqrt{\frac{I_{or}^2 - I_{01}^2}{I_{01}^2}} \times 100 = 9.386\%$$

For comparison:

Square wave operation: $\left(\hat{V}_{01}\right) = \dfrac{4}{\pi} V_{dc} = \dfrac{4}{\pi} \times 380 = 483.83V$

Quasi Square operation:

$2d = 0.8\pi = 144°$

$$\hat{V}_{01} = \frac{4}{\pi} V_{dc} \sin(d) = \frac{4}{\pi} \times 380 \times \sin(72^o) = 460.15\ \text{V}$$

02. (b) A 3-phase, 6-pole, 460 V, 50 Hz induction generator operates at 480 V. The generator has its rated output power of 20 kW. It is driven by a turbine at a speed of 1015 r.p.m. The generator has the following electrical parameters:

$R_1 = 0.2\ \Omega$ $R_2 = 0.15\ \Omega$ $R_{sh} = 320\ \Omega$

$X_1 = 1.2\ \Omega$ $X_2 = 1.29\Omega$ $X_M = 42\ \Omega$

Find the active power delivered by the generator and reactive power it requires from the system to operate. (20 M)

Sol: Given $P = 6$; frequency (f) = 50 Hz

$$\text{Synchronous speed } N_s = \frac{120 \times 50}{6} = 1000 \text{ rpm}$$

Rotor speed (Prime mover speed) $N_r = 1015$ rpm

$$\text{Slip } (s) = \frac{1000 - 1015}{1000} = -0.015$$

Equivalent circuit parameter

$R_1 = 0.2\ \Omega$; $R_2' = 0.15\ \Omega$

$R_{sh} = 320\ \Omega$; $X_1 = 1.2\ \Omega$

$X_2' = 1.29\ \Omega$; $X_M = 42\ \Omega$

Operating voltage V = (480)V

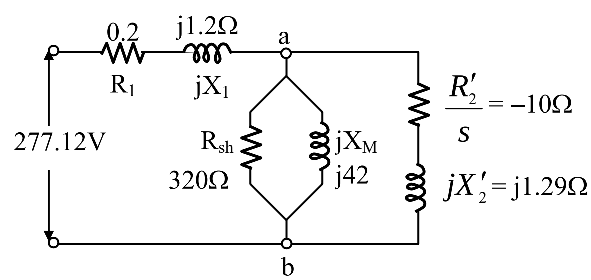
Assuming stator winding connected in star $V_1/\text{ph} = \dfrac{480}{\sqrt{3}} = 277.12\text{V}$

$$\frac{R_2'}{s} = \frac{0.15}{-0.015} = -10\ \Omega$$

Impedance across ab

$Z_{ab} = 320 \| j42\Omega \| (-10 + j1.29)$

$= -9.15 + j3.5$



Impedance across the source

$= 0.2 + j1.2 - 9.15 + j3.5$

$= -8.95 + j4.7\ \Omega$

$= 10.1\angle 152.3^\circ\ \Omega$

$$\text{Input current } I_L = I_1 = \frac{\frac{V_1}{ph}}{Z_{eq}} = \frac{277.12\angle 0}{10.1\angle 152.3}$$

$= 27.4\angle -152.3$

$= 27.4\angle -152.3$ A

Active power (P) = $\sqrt{3} \times V_L I_L \cos\phi$

$= \sqrt{3} \times 480 \times 27.4 \times \cos 152.3$

$= -20.1$ kW

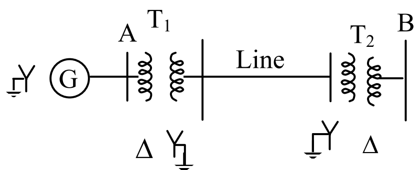
Reactive power (Q) = $\sqrt{3}\, V_L I_L \sin\phi$

$= 10.5$ kVAR

Negative 'P' values, the induction generator is supplying power to the source.

02. (c) (i) Under what condition a single line-to-ground fault at the terminals of a generator can be more severe than a 3-phase symmetrical fault at the same location?

(ii) A 3-phase power system is represented by one-line diagram as shown in the figure below:



The ratings of the equipments are the following:

Generator G: 15 MVA, 6.6 kV, X_1 = 15%, X_2 = 10%

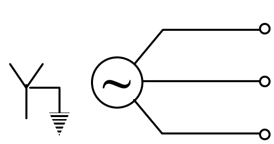
Transformers: 15 MVA, 6.6 kV delta/33 kV star, $X_1 = X_2 = X_0$ = 6%

Line reactance : $X_1 = X_2 = 2\Omega$ and $X_0 = 6\Omega$

Find the fault current for a ground fault on one of the bus bars at B. **(20 M)**

Sol: In case of alternator zero sequence impedance (Z_0) is the leakage impedance of winding itself and it is very low compared to positive and negative sequence impedances of the winding.

If we take a 3-ϕ solidly grounded alternator with sequence impedance Z_1, Z_2, Z_0 as shown below



For a single line to ground fault on phase-a terminals will give the fault current as,

$$I_{f\,LG} = \frac{3E_{a1}}{Z_1 + Z_2 + Z_0}$$, where E_{a1} is prefault voltage

For a 3-ϕ fault at alternator terminals, the fault current is,

$$I_{f\,LLL} = \frac{E_{a1}}{Z_1}$$

Now, $$\frac{I_{f\,LG}}{I_{f\,LLL}} = \frac{3Z_1}{Z_1 + Z_2 + Z_0}$$

As $Z_0 < Z_1$ and generally $Z_2 = Z_1$ from above equation it can be said that $\frac{3Z_1}{Z_1 + Z_2 + Z_0} > 1$

$\Rightarrow I_{f\,LG} > I_{fLLL}$

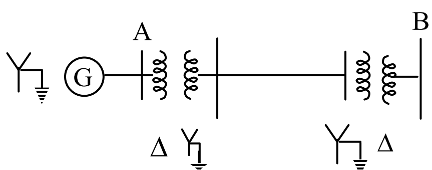
"So LG fault is more severe than LLL fault at alternator terminal provided that the alternator was solidly grounded".

If the alternator neutral is grounded through an impedance then the ratio can be rewritten as,

$$\frac{I_{f\,LG}}{I_{f\,LLL}} = \frac{3Z_1}{Z_1 + Z_2 + Z_0 + 3Z_n}$$

In this case we can't say exactly which fault is severe, it mainly depends on the value of 'Z_n'.

(ii) Given single line diagram,



(Assuming that it it is at no load)

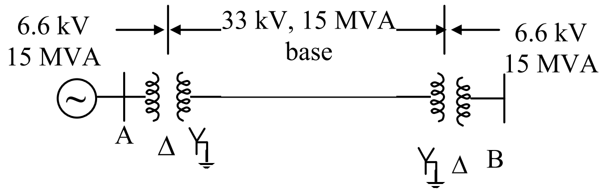
Ratings of apparates:

G : 15 MVA, 6.6 kV, X_1 = 15%, X_2 = 10%

Transformers: 15 MVA, 6.6 kV Δ/33 kV Y, $X_1 = X_2 = X_0$ = 6%

Line: $X_1 = X_2 = 2\ \Omega$, $X_0 = 6\ \Omega$

Let us choose common base as 6.6 kV, 15 MVA at generator location



No need to change the pu reactances of generator and transformers because ratings and base values chosen are identical.

For line:

S_{base} = 15 MVA (3-ϕ), V_{base} = 33 kV(LL)

$$\text{Now, } Z_{\text{base}} = \frac{(V_{base\,LL})^2}{S_{base}(3-\phi)}$$

$$= \frac{33^2}{15} = 72.6\ \Omega$$

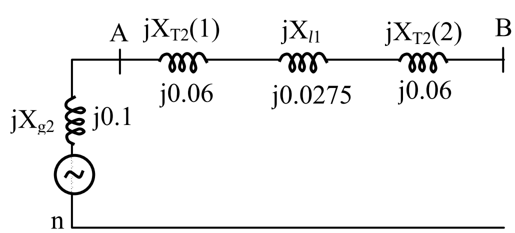
$$X_{l1}\ (\text{pu}) = \frac{X_{\ell_1}(\Omega)}{Z_{base}} = \frac{2}{72.6} = 0.0275 \text{ pu}$$

$$X_{l2}\ (\text{pu}) = \frac{X_{\ell_1}(\Omega)}{Z_{base}} = \frac{2}{72.6} = 0.0275 \text{ pu}$$

$$X_{\ell_o(pu)} = \frac{X_{\ell_o}(\Omega)}{Z_{base}} = \frac{6}{72.6} = 0.0826 \text{ pu}$$

To do single line to ground fault analysis at ‘B’ location, it is need to construct positive, Negative and zero sequence circuits with respect to ‘B’.

Positive sequence network:

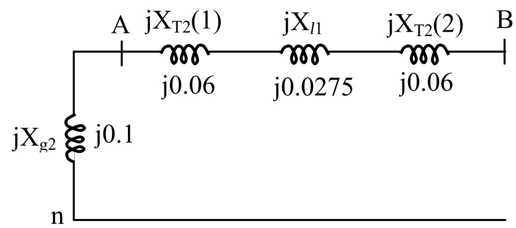


With respect to ‘B’, $Z_{1\text{ eq}} = j0.15 + j0.06 + j0.0275 + j0.06$

$= j0.2975$ pu

Prefault positive sequence thevinin’s voltage, E_{a1} = 1 pu (say)

Negative sequence network:

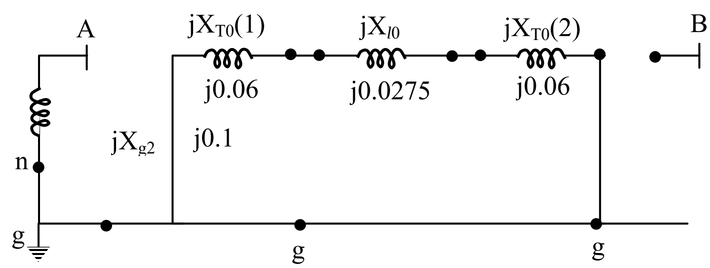


With respect to 'B', $Z_{2eq} = j0.1 + j0.06 + j0.0275 + j0.06$

$= j0.2475$ pu

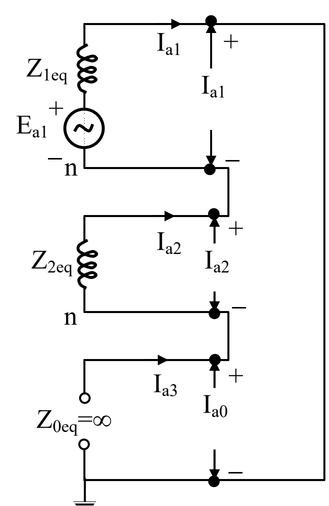
Negative sequence prefault voltage, $E_{a2} = 0$

Zero sequence network:



With respect to 'B' $Z_{0eq} = \infty$

For single line to ground fault at one bus bar on location 'B', the sequence networks connection will be as follows:



Sequence currents, $I_{a1} = I_{a2} = I_{a0} = 0$

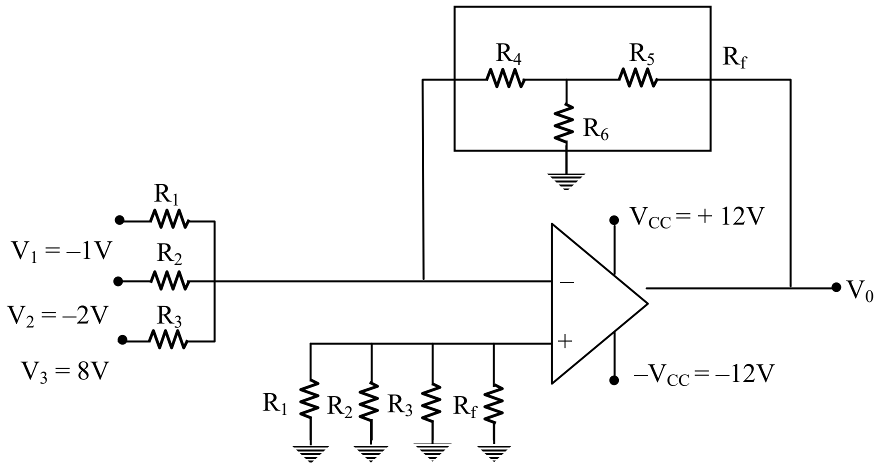
Now, fault current, $I_{f\,LG} = 3.I_{a0} = 0$

Note: For more severe LG fault then 3-ϕ fault. $(Z_1 + Z_2 + Z_{g0} + 3Z_n) < 3Z_1$

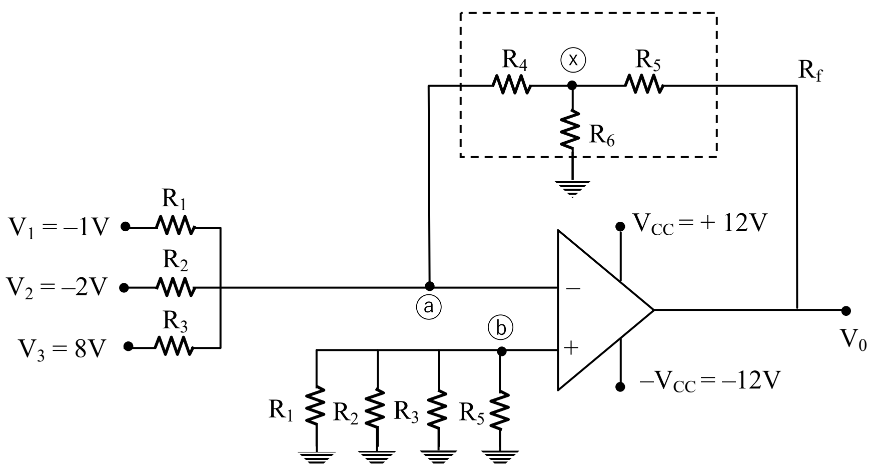
03. (a) For the circuit shown below, calculate the output voltage:

$R_1 = 1\ k\Omega$ $R_2 = 2\ k\Omega$ $R_3 = 3\ k\Omega$

$R_4 = 10\ k\Omega$ $R_5 = 10\ k\Omega$ $R_6 = 100\ k\Omega$



Sol:



Since Op-amp is ideal ($A_{OL} = \propto$)

$V_d = 0$

$V_b = V_a = 0$

Apply KCL ⓐ

$$\frac{-1-V_a}{R_1}+\frac{-2-V_a}{R_2}+\frac{8-V_a}{R_3}=\frac{-V_x}{R_4}$$

$$\frac{-1}{10^3}+\frac{-2}{2\times10^3}+\frac{8}{3\times10^3}=\frac{-V_x}{10\times10^3}$$

$$-1-1+\frac{8}{3}=\frac{-V_x}{10}$$

$$\frac{-6+8}{3}=\frac{-V_x}{10}$$

$$-\frac{20}{3}=V_x$$

$$V_x=-\frac{20}{3}V$$

Apply KCL at ⓧ

$$\frac{-V_x}{R_4}=\frac{V_x}{R_6}+\frac{V_s-V_0}{R_5}$$

$$\frac{-V_x}{10}=\frac{V_x}{100}+\frac{V_x-V_0}{10}$$

$$\frac{-V_x}{10}=\frac{V_x+(V_x-V_0)10}{100}$$

$$-10V_x = 11V_x - 10V_0$$

$$10V_0 = 21V_x$$

$$10V_0 = 21\left(\frac{-20}{3}\right)$$

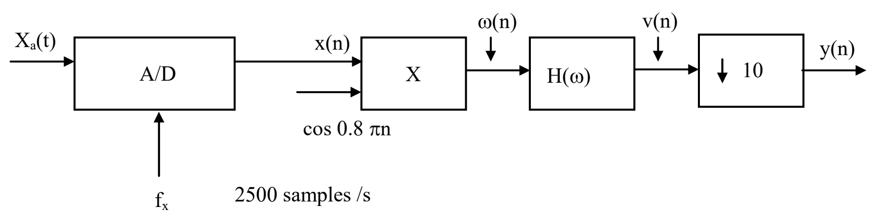
$$= -140\text{ V}$$

$$V_0 = -14\text{ V}$$

As V_0 exceeds the –ve supply voltage of Op-amp so the op-amp operated in –ve saturation region. Then

$V_0 = -12V$

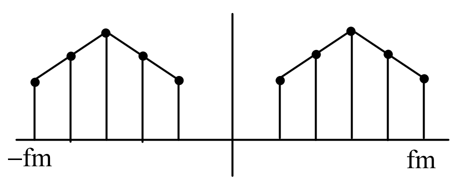
03. (b) A signal x_a (t) is band-limited to the range 900 Hz ≤ f 1100 hz (assume the shape of an isosceles triangle for continuous Fourier transform and $|X_a(f)| = 1$ and f = 1000 Hz]. It is used as an input to the system shown below:



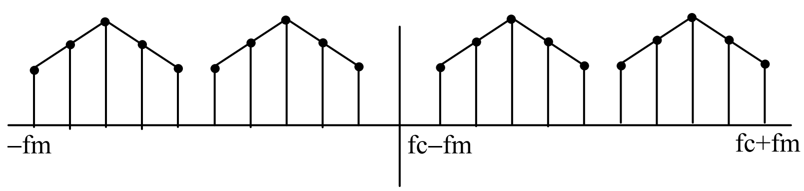
In this system, H(ω) is a low-pass filter with a discrete cut-off frequency equivalent to f_c = 125 Hz (normalized w.r.t. the sample rate at the point in the block diagram). Determine and sketch the spectra of $X(\omega_x)$, $W(\omega_w)$, $V(\omega_v)$ and $Y(\omega_y)$, w.r.t. ω_x, ω_w, ω_v and ω_y respectively for $-\pi < \omega < \pi$. **(20 M)**

Sol: The analog signal is band limited to $900 \le f \le 1100$

The base band spectrum is $X_b(\Omega)$.



After mixing and modulating the final spectrum is



$$X_a(\Omega) = \frac{1}{2}\left[X_b(\Omega - 2000\pi) + X_b\left(\Omega + 2000\pi\right)\right]$$

Because f = 1000 Hz

$$\omega' = \frac{\Omega}{f_x}$$

(ιι) Ω = Frequency of CT domain signal

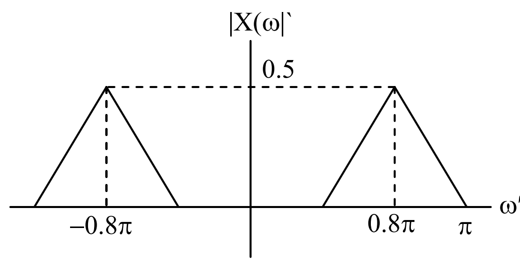
f_x = sampling frequency

$\therefore \qquad X(\omega') = \sum_{q=-\infty}^{\infty} X(\omega' - 2\pi q)$

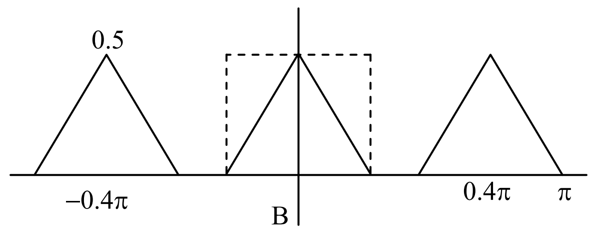
$\therefore$ Normalized frequency, $X(\omega') = \sum_{q=-\infty}^{\infty} \left[X_a(\omega' - 0.8\pi - 2\pi q) + X_b\left(\omega' + 0.8\pi - 2\pi q\right) \right].$

If the modulated signal by cos(0.8π) it causes shifts up and down by 0.8π of each component in spectrum.

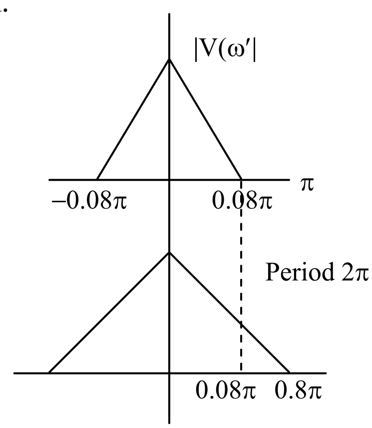
$\therefore$ The spectrum of x(Ω) ↔ X(ω)



$\therefore$ The spectrum of |W(ω)|



If $\omega_n(\Omega)$ is sent through a LPF we can recover the base band signal $X_a(\Omega)$ the down sampling produces the spectrum.



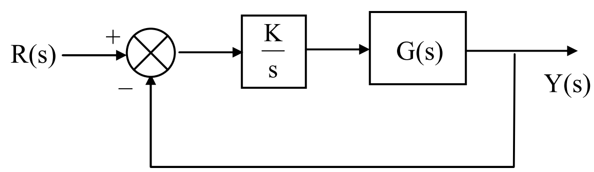
The down sampling expands each 2π periodic repletion of |V(ω′| by a factor with ω′ axis and reduces the gain by factor ‘m’

$$\omega'' = \frac{\Omega D}{Fy} \qquad (D = 10).$$

$$Y(\omega'') = \sum_q X_a\left(\omega'' - q2\pi\right)$$

03. (c) For the system shown in the figure below, the step response of G(s) is given by $(1.5-2e^{-t}+0.5e^{-2t})u(t)$ and K(s) is the integral controller with K(s) = $\frac{K}{s}$. Sketch the approximate root locus of the closed-loop system poles as K varies from 0 to ∞.

Also calculate the real part of poles when K becomes ∞: (20 M)



Sol: Given data:

Step response of G(s) = $(1.5 - 2e^{-t} + 0.5e^{-2t})u(t)$

And K(s) = $\frac{K}{s}$ integral controller

$\therefore$ Impulse response of G(s) = $\frac{d}{dt}(1.5 - 2e^{-t} + 0.5e^{-2t})$

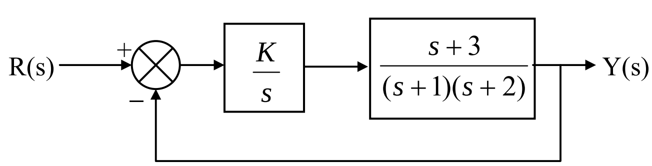
$= 0 + 2e^{-t} - e^{-2t}$

$\therefore$ TF G(s) = $L\left[2e^{-t} - e^{-2t}\right]$

$$= \frac{2}{s+1} - \frac{1}{s+2}$$

$$= \frac{2s+4-s-1}{(s+1)(s+2)}$$

$$= \frac{s+3}{(s+1)(s+2)}$$



Loop TF = $\frac{K(s+3)}{s(s+1)(s+2)}$

$P = 3, Z = 1$

No. of separate RLD branches = 3

No. of asymptotes = $|P - Z| = 2$

$$\text{Centroid } (\sigma) = \frac{0-1-2-(-3)}{3-1} = 0$$

$$\text{Angle of asymptotes } \theta_\ell = \frac{(2\ell+1)\pi}{P-Z} \qquad \ell = 0, 1$$

$\theta_0 = 90^o$, $\theta_1 = 270^o = -90^o$

Root loci starts (K = 0) at s = 0, –1, –2

Root loci ends ($K = \infty$) at s = –3, $s = 0 \pm j\infty$

Break away point

$$\frac{d}{ds}[G_1(s)H_1(s)] = \frac{d}{ds}\left[\frac{s+3}{s(s+1)(s+2)}\right] = 0$$

$$(s^3 + 3s^2 + 2s)(1) - (s+3)(3s^2 + 6s + 2) = 0$$

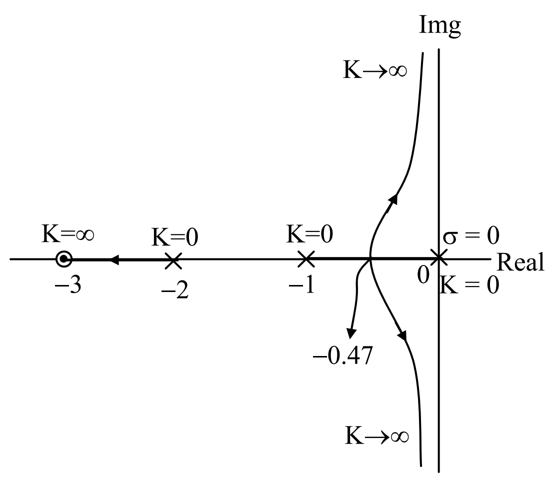
$$s^3 + 3s^2 + 2s - 3s^3 - 6s^2 - 2s - 9s^2 - 18s - 6 = 0$$

$$2s^3 + 12s^2 + 18s + 6 = 0$$

s = – 0.47, s = – 1.65, s = – 3.88

s = –0.47 is only a valid break point

Root locus diagram drawn as shown in below



Real part of the poles when $K \to \infty$ is –3, 0, and 0

ESE / GATE / PSUs - 2019 ADMISSIONS OPEN

CENTER	COURSE	BATCH TYPE	DATE
HYDERABAD - DSNR	GATE + PSUs - 2019	Regular Batch	8th, 22nd July 2018
HYDERABAD - Kukatpally	GATE + PSUs - 2019	Regular Batch	2nd July 2018
HYDERABAD - Abids	GATE + PSUs - 2020	Morning Batch	15th July 2018
HYDERABAD - DSNR	GATE + PSUs - 2020	Morning Batch	22nd July 2018
HYDERABAD - Kukatpally	GATE + PSUs - 2020	Morning Batch	22nd July 2018
HYDERABAD - DSNR	GATE + PSUs - 2020	Evening Batch	22nd July 2018
HYDERABAD - Kukatpally	GATE + PSUs - 2020	Evening Batch	22nd July 2018
HYDERABAD - DSNR	ESE + GATE + PSUs - 2019	Regular Batch	8th, 22nd July 2018
HYDERABAD - Abids	ESE + GATE + PSUs - 2020	Morning Batch	15th July 2018
HYDERABAD - DSNR	ESE + GATE + PSUs - 2020	Morning Batch	22nd July 2018
HYDERABAD - Kukatpally	ESE + GATE + PSUs - 2020	Morning Batch	22nd July 2018
HYDERABAD - DSNR	ESE + GATE + PSUs - 2020	Evening Batch	22nd July 2018
HYDERABAD - Kukatpally	ESE + GATE + PSUs - 2020	Evening Batch	22nd July 2018
HYDERABAD - Abids	ESE - 2019 (PRELIMS) - G.S	Regular Batch	09th July 2018
DELHI	GATE + PSUs - 2019	Regular Batch	22nd July 2018
PUNE	GATE + PSUs - 2019	Weekend Batch	07th July 2018
PUNE	GATE + PSUs - 2020	Weekend Batch	04th Aug 2018
PUNE	ESE + GATE + PSUs - 2020	Weekend Batch	04th Aug 2018
BHUBANESWAR	GATE + PSUs - 2019	Regular Batch	07th July 2018
CHENNAI	GATE + PSUs - 2019	Weekend Batch	07th July 2018
CHENNAI	GATE + PSUs - 2019	Regular Batch	07th July 2018
CHENNAI	GATE + PSUs - 2020	Weekend Batch	07th July 2018
BANGALURU	GATE + PSUs - 2019	Weekend Batch	07th July 2018
BANGALURU	GATE + PSUs - 2020	Weekend Batch	07th July 2018
PATNA	GATE + PSUs - 2020	Weekend Batch	14th July 2018
VISAKHAPATNAM	GATE + PSUs - 2019	Regular Batch	17th July 2018
VISAKHAPATNAM	GATE + PSUs - 2020	Weekend Batch	08th July 2018
TIRUPATI	GATE + PSUs - 2020	Weekend Batch	14th July 2018

FOR BATCH DETAILS VISIT : **www.aceenggacademy.com**

04. (a) (i) What do you mean by grading of cables? What are the methods of grading?

(ii) Derive the condition for minimum value of gradient at the surface of the conductor.

(iii) Determine the economic overall diameter of a single-core cable metal sheathed for a working voltage of 75 kV, if the dielectric strength of the insulating material is 60 kV/cm. (20M)

Sol: Grading of cables:

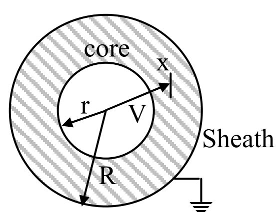
Grading of a cables means distributing the dielectric material such that the difference between maximum and minimum electrostatic stress will be reduced.

By doing this grading, the cable can be operated at higher voltage for a given size of it can be operated at same voltage for a reduced size of cable.

There are two methods of grading:

1. Capacitance grading – Two or more number of dielectric materials are used
2. Intersheath grading – Thin metallic intersheath are kept in the uniform dielectric material. These intersheath are maintained at same voltage levels with the help of auxiliary transformer.

(ii) Condition for minimum voltage gradient on conductor surface:



Let us assume that conductor operates at 'V' voltage and line charge value was +q C/m

At some point 'x' shown in the figure, the electric field intensity is given as

$$E_x = \frac{q}{2\pi\varepsilon x}$$

Now, by point form of KVL, voltage from core to sheath is given as,

$$V = \int_{x=r}^{R} E_x dx$$

$$= \int_{x=r}^{R} \frac{q}{2\pi\varepsilon x}$$

$$V = \frac{q}{2\pi\varepsilon}\left[\ell n(x)\right]_{x=r}^{R}$$

$$V = \frac{q}{2\pi\varepsilon}.\ell n\left(\frac{R}{r}\right)$$

Now, 'E' at any point 'x' will be,

So $q = \dfrac{2\pi\varepsilon.V}{\ell n\left(\frac{R}{r}\right)}$

$$E_x = \frac{q}{2\pi\varepsilon x}$$

$$E_x = \frac{2\pi\varepsilon V}{\ell n\left(\frac{R}{r}\right)} \times \frac{1}{2\pi\varepsilon x}$$

$$E_x = \frac{V}{x.\ell n\left(\frac{R}{r}\right)}$$

On the surface of core, $E_r = \dfrac{V}{r\ell n\left(\frac{R}{r}\right)}$

The value of 'E_r' can be minimized by varying 'r' in which 'V' and 'R' are kept constant.

Min. E_r = min. $\dfrac{V}{r\ell n\left(\frac{R}{r}\right)} \rightarrow \max\left[r\ell n\left(\frac{R}{r}\right)\right] \rightarrow \dfrac{d}{dr}\left[r.\ell n\left(\frac{R}{r}\right)\right] = 0$

$$\ell \times \ell n\left(\frac{R}{r}\right) + r.\frac{1}{\frac{R}{r}} \times \frac{-R}{r^2} = 0$$

$$\ell n\left(\frac{R}{r}\right) = 1 \Rightarrow \frac{R}{r} = e$$

Condition of minimum 'E_r' was $\dfrac{R}{r} = e$ (or) $\dfrac{r}{R} = \dfrac{1}{e}$

(or) r = $\frac{R}{e}$

(or) r = 0.368 R

$\Rightarrow$ Core radius has to be equal to 36.8% at overall radius of cable.

(iii)From the data given,

Working voltage of cable, V = 75 kV

Dielectric strength of insulating material, g = 60 kV/cm

The economical condition is r = 0.368 R

With this condition field intensity on core, $E_r = \frac{V}{0.368R}$

That is g = $\frac{V}{0.368R}$

$$R = \frac{V}{0.368g} = \frac{75}{0.368 \times 60} = 3.396 \text{ cm}$$

Overall diameter of cable, D = 2R = 6.793 cm

04. (b) A 400 V, 50 Hz 6-pole, 960 rpm, Y-connected induction motor has the following parameters per phase referred to stator:

$r_1 = 0.4\Omega$, $r_2' = 0.2\ \Omega$; $x_1 = x_2' = 1.5\ \Omega$; $X_m = 30\ \Omega$

The motor is controlled by the variable frequency inverter at a constant flux of rated value for operation below synchronous speed, while in super-synchronous operation region flux is weakened by keeping voltage constant at rated value. Assume straight line for torque vs. slip characteristics for slip s < s_m (motor region) and s > s_m' (generator region). The connected load on the shaft is constant torque type.

Calculate the inverter frequency and current drawn by the stator when torque on the shaft is half-rated while motoring at 500 rpm. **(20M)**

Sol: Given P = 6; frequency (f) = 50 Hz

Synchronous speed $N_s = \frac{120 \times 50}{6} = 1000$ rpm

Rotor speed $N_r = 960$ rpm

$$\text{Slip (s)} = \frac{1000-960}{1000} = 0.04$$

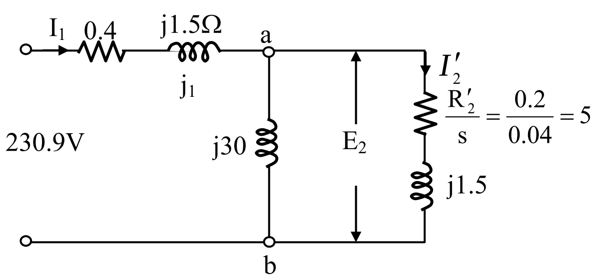
Equivalent circuit parameter

$r_1 = 0.4\ \Omega$; $r_2' = 0.2\ \Omega$

$X_1 = X_2' = 1.5\ \Omega$; $X_M = 30\ \Omega$

Operating voltage V = 400V

$$\text{Operating phase voltage} = \frac{400}{\sqrt{3}} = 230.9\text{ V}$$



Impedance across the source

Impedance across ab

$$= 0.4 + j1.5 + \frac{j30(5+j1.5)}{5+j31.5}$$

$= 4.82 + j3.6$

$$I_1 = I_L = \frac{230.9V}{4.82 + j3.6}$$

$= 30.55 - j22.9$

$= 38.2\angle -36.9^\circ$ A

$$I_2' = \frac{38.2\times 30}{\sqrt{5^2+31.5^2}} = 35.93\text{ A}$$

$$E_2' = 35.93 \times \sqrt{5^2+1.5^2}$$

$= 187.56$ V

Slip speed at rated frequency and rated torque, $sN_s = 0.04 \times 1000 = 40$ rpm

Given that, toque Vs slip characteristic is a straight line for lower slip, therefore slip speed at half rated torque = $\frac{40}{2}$ = 20 rpm

Let K be the ratio of operating frequency to rated frequency

$$K = \frac{f}{f_{rated}}$$

Then rotor speed = $N_r = KN_s$ – slip speed

$$500 = K \times 1000 - 20$$

$$K \times 1000 = 520$$

$$K = 0.52$$

Therefore inverter frequency

$$f = Kf_{rated}$$

$$f = 0.52 \times 50 = 26 \text{ Hz}$$

$$sN_s = 20$$

$$s_{new} = \frac{20}{520} = 0.038$$

$$E'_{2new} = KE'_2$$

$$= 0.52 \times 787.56$$

$$= 97.53 \text{ V}$$

$$\bar{I}_{2new} = \frac{E'_{2new}}{\frac{R'_2}{s_{new}} + jKX'_2}$$

$$= \frac{97.53}{\frac{0.2}{0.038} + j0.52 \times 1.5}$$

$$= \frac{97.53}{5.26 + j0.78} = 18.13 - j2.68$$

$$I_M = \frac{97.53}{j \times 0.52 \times 30} = -j6.25$$

$$I_1 = 18.13 - 2.68j - j6.25$$

$$= 18.13 - j8.93$$

$= 20.2\angle{-26.22}$

$|I_1| = 20.2$ A

04. (c) Why is the waveshape of magnetizing current of a transformer non-linear? Explain the phenomenon of in-rush magnetizing current and derive its expression in terms of α, the angle of the voltage sinusoid at t = 0 and ϕ_r, the residual core flux at t = 0

Use the graph sheet to show non-linearly of current from the assumed ϕ-i diagram of magnetic core of the transformer. (20M)

Sol: The current required to establish the flux in a magnetic circuit is called magnetizing current. For linear magnetization curve, the flux is proportional to magnetizing current.

$\therefore$ Current and flux wave forms are identical.

In practical, the magnetic saturation does occurs and waveform of the flux and magnetizing current are different from each other.

Let us consider only saturation non-linearity, no-hysterisis non-linearity. Applied voltage is taken as sinusoidal the flux set up in the iron core can be obtained from that relation $V_1 = \sqrt{2}\pi N_1\phi_m$. Since V_1 is sine wave the flux also must be sin wave. Now for sinusoidal flux magnetizing current is to be obtained.

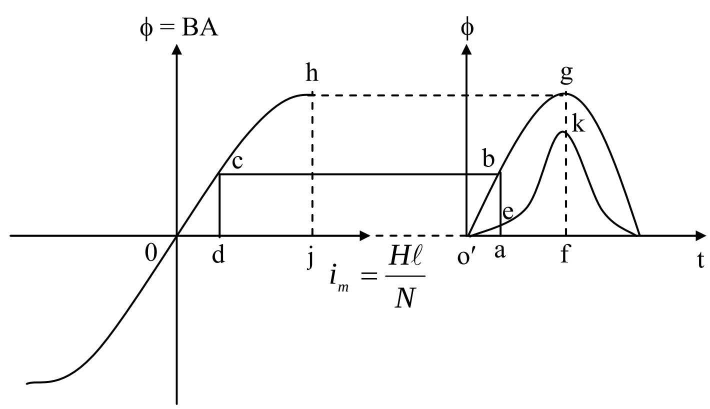


Fig: Wave form magnetizing current when saturation non-linearity is only considered

- For any flux equal to ‘ab’ draw ‘bc’ parallel to oo′ and ‘cd’ perpendicular to oo′ then od = ae is the magnetizing current for setting up the flux ‘ab’.
- For peak flux ‘fg’ draw ‘gh’ parallel to oo′ 2’ and ‘jh’ perpendicular to oo′. Then the oj = fk is the magnetizing current for setting up the peak value flux fg.
- The point ezk lie on the required wave form of magnetizing current. This procedure repeated till sufficient number of points of current waveforms are obtained. The characteristics of this wave form.

(i) It is peaked in nature and is symmetrical about it’s maximum value.

(ii) The flux and currents have their maximum value at the same time.

The phenomenon pertaining to the switching on of an unloaded transformer is referred to as switching in phenomena or inrush phenomena.

According to constant flux linkage theorem, the magnetic flux in the inductive circuit can not change suddenly that is the flux just after closing the switch (i.e., at $t = 0^+$) must be remains equal to the flux just before closing the switch (i.e., at $t = 0^-$).

Suppose there is residual magnetism ϕ_r = ob present in the transformer core. At no load condition if transformer is switched at the instant applied voltage is passing through zero and becomes positive, as per constant flux linkage theorem, the flux just after closing the switch (i.e., at $t = 0^+$) must be equal to the flux before closing the switch (i.e., at $t = 0^-$) which is equal to ϕ_r (residual flux). This can happen only if there is established a constant flux bc = ϕ_{dc} = oα = ϕ_m.

If primary resistance is neglected then ϕ_r and ϕ_{dc} add to the steady state alternating flux ϕ and the resultant core flux is shown with thick line.

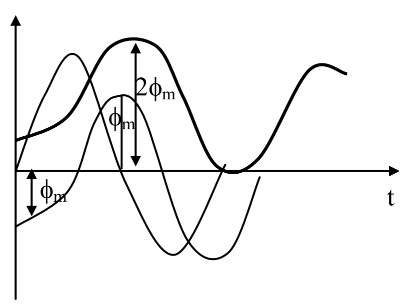


Fig: effect of switching when voltage is zero and residual magnetism ϕ_r is present

Let

v_1 = primary applied voltage at the instant of closing the switch

ϕ_t = core flux at any time t

i_m = magnetizing current

N_1 = primary turns

V_{m1} = maximum value of applied voltage wave

α = the angel which the voltage wave makes with time origin

When the voltage is switched on to the primary of an unloaded transformer, the emf equation for the primary is

$v_1 = V_{m1}\sin(\omega t+\alpha)$

$$= i_m r_1 + N_1\frac{d\phi_t}{dt} \quad \ldots\ldots\ldots(1)$$

Let ϕ_t links all the primary turns, then primary winding inductance L_1 is given by

$$L_1 = \frac{N_1\phi_t}{i_m}$$

Let us assume BH curve is linear $i_m = \dfrac{N_1\phi_t}{L_1}$

Substitute i_m in equation (1)

$$\frac{N_1\phi_t}{L_1}r_1 + N_1\frac{d\phi_t}{dt} = V_{m1}\sin(\omega t+\alpha)$$

$$\left(\frac{r_1}{L_1}+\frac{d}{dt}\right)\phi_t = \frac{V_{m1}}{N_1}\sin(\omega t+\alpha) \quad \ldots\ldots\ldots\ldots\ldots(2)$$

By solving the above equation

$$\phi_t = (\phi_m\cos\alpha \pm \phi_r)\,e^{-\frac{r_1}{L_1}t_1} - \phi_m\cos(\omega t+\alpha) \quad \ldots\ldots\ldots\ldots(3)$$

Here $\phi_m\cos\alpha \pm \phi_r$ represents constant dc flux $\phi_{dc} \pm \phi_r$ which has an exponential decay with time.

$\cos(\omega t + \alpha)$ represent steady state alternating flux of fundamental frequency ω.

If the primary is switched on when applied voltage is passing through is zero when $\alpha = 0$ ϕ_r = positive then,

$v_1 = V_{m1} \sin \omega t$ ....(4)

After half cycle i.e., after $\omega t = \pi$ from the instant when closing the switch.

$$\phi_t = (\phi_m + \phi_r)\, e^{-\frac{r_1}{L_1}\frac{\phi}{\omega}} - \phi_m \cos(\pi)$$

Usually $\omega t_1 >> \pi r_1 \Rightarrow e^{-\frac{r_1}{L_1}\frac{\phi}{\omega}}$ tends to $e^{-0} = 1$

$\therefore$ resultant core flux after half cycle of closing the switch is given

$\phi_{tm} = 2\phi_m + \phi_r$ ....(5)

If the primary resistance is neglected then $\phi_t = \phi_r + \phi_m (1 - \cos\omega t)$

After half cycle $\phi_{tm} = 2\phi_m + \phi_r$ almost double the value of flux is produced in the transformer core. This effect is called doubling effect because core is entered into saturation region to produced almost double the value of flux which demand around hundred times more magnetizing current drawn from supply mains i.e., around five times the full load current. This very high magnetizing current is called magnetic inrush current.

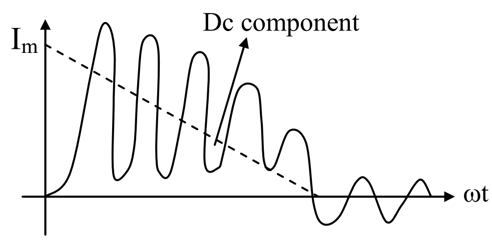


Fig: Magnetic inrush current

Section -B

05. (a) A DC motor has an armature resistance of 0.5 Ω and Kϕ of 3 Vs. The motor is driven by a single-phase thryristorized full converter. The input to the converter is an AC source of 230 V, 50 Hz. The motor is used as a prime mover of a forklift. In the upward direction, the mechanical load is 69 Nm and the triggering angle is $\alpha = 15^{o}$. In the downward direction, the load torque is 180 Nm. Calculate the triggering angle required to keep the downward speed equal in magnitude to upward speed. Assume continuous motor current for all operation. Also calculate the triggering angle to keep the motor at holding position while it was moving upward. (12M)

Sol: During upward motion:

The electromagnetic torque (T_e) is

$$T_e = (K\phi)I_a \qquad \text{……….} (1)$$

Given that $k\phi = 3$ V–S, $r_a = 0.5\Omega$

$$T_e = 69 \text{ Nm}$$

F rom (1) $69 = 3I_a$

$\Rightarrow$ $\mathbf{I_a = 23\ A}$

Now, $V_t = E + I_a r_a$

$$\frac{2V_m}{\pi}\cos\alpha = E + (23\times 0.5)$$

$$\frac{2\times\sqrt{2}\times 230}{\pi}\cos 15° = E + (23\times 0.5)$$

$$\mathbf{E = 188.52\ V}$$

During download direction:

Given that Load Torque = 180 Nm downward speed equal in magnitude to upward speed so, magnitude of back emf(e) is same i.e. E = +188.52

$$T = k\phi\, I_a$$

$$I_a = \frac{180}{3} = 60\text{A}$$

Terminal voltage is

$$V_t = -E + I_a r_a$$

$$\frac{2V_m}{\pi}\cos\alpha = -E + I_a r_a$$

$$\frac{2\sqrt{2}\times 230}{\pi}\cos\alpha = -188.52 + (60\times 0.5)$$

$$\alpha = 139.95$$

$$\alpha \cong 140°$$

Motor at holding position:

Since motor is in holding position, speed is zero. So back emf (E) is Zero

Terminal voltage $V_t = I_a r_a$

Given that it was moving upward, so by taking $I_a = 23A$

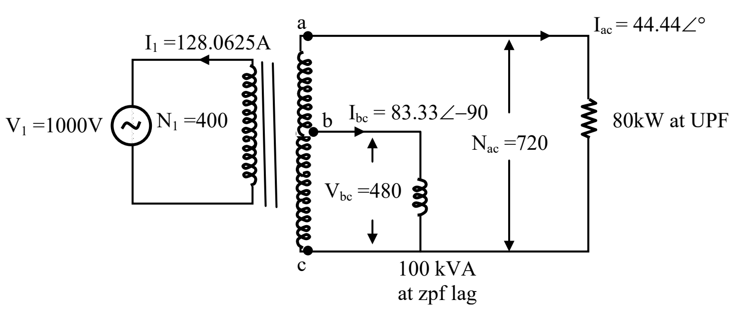
$$\frac{2V_m}{\pi}\cos\alpha = I_a r_a$$

$$\frac{2\sqrt{2}\times 230}{\pi}\cos\alpha = (23\times 0.5)$$

$$\alpha = 86.82°$$

05. (b) The primary side of an ideal transformer (having 400 turns in primary winding and 720 turns in secondary winding) is excited by a 1000 V, 50 Hz AC source. The secondary of the transformer is connected to a resistive load of 80 kW. There is one tapping in secondary winding at 480 turns and this tapping is supplying a pure inductive load of 100 kVA. Determine the primary current and its power factor. (12M)

Sol:



No. of turns in primary winding, $N_1 = 400$ Turns

No. of turns in secondary winding, $N_{ac} = 720$ turns

Supply voltage, $v_1 = 1000V$

$$\text{e.m.f/turn} = \frac{V_1}{N_1} = \frac{1000}{400} = 2.5\text{ V}$$

Voltage across secondary terminal ac, $V_{ac} = \left[\frac{e.m.f}{turn}\right] Nac$

$$= 2.5 \times 720 = 1800V$$

Load current, $I_{ac} = \frac{KVA\,load_{ac}}{V_{ac}} = \frac{80000\angle 0°}{1800\angle 0°} = 44.44\angle 0°$

Load current referred to primary, $I_{ac}^1 = \frac{N_{ac}}{N_1} I_{ac}$

$$= \frac{720}{400} \times 44.44\angle 0° = 80\angle 0°$$

Voltage across secondary terminal, bc, $V_{bc} = \left(\frac{emf}{Turn}\right) N_{bc}$

$$= 2.5 \times 480$$

$$= 1200V$$

Load current, $I_{bc} = \frac{KVA\ load_{bc}}{V_{bc}} = \frac{1000}{1200\angle 0°} = 83.33\angle -90^o$

Load current referred to primary, $I_{bc}^1 = \frac{N_{bc}}{N_1} I_{bc}$

$$= \frac{480}{400} 83.33\angle -90^o$$

$$= 100\angle -90^o$$

Primary current $= I_{ac}^1 + I_{bc}^1$

$$= 80\angle 0 + 100\angle -90^o$$

$$= 128.0625\angle -51.34^o$$

Primary current, $I_1 = 128.0625A$

Primary PF, $\cos\theta_1 = \cos(-51.34) = 0.6247$ lag

2nd method:

$$\text{kVA}_{I/P} = \text{sum of output load KVA}$$
$$= (\text{S load})_{ac} + (S_{load})_{bc}$$
$$= 80\text{KVA} \angle 0 + 100\text{KVA} \angle{-90°}$$
$$= 128.0625 \text{ KVA}\angle{-51.34}$$

Primary current, $I_1 = \dfrac{input\,VA}{V_1} = \dfrac{128.0625\times 10^3}{1000} = 128.0625$

Primary power factor, $\cos\theta_1 = \cos(-51.34) = 0.6247$ lag

05. (c) (i) Obtain an expression for the total average power of a sinusoidal AM wave

$v_C = V_C \sin\omega_C t$

$v_m = V_m \sin\omega_m t$

(ii) An AM transmitter broadcasts a carrier power of 100 kW. Determine the radiated power at the amplitude modulation index of 0.8. (12M)

Sol: (i) Given message signal is v_m and carrier signal is v_C

$v_C = V_C \sin\omega_C t$

General expression of AM signal is given by $S_{AM}(t) = V_C[1 + K_a v_m]\sin\omega_c t$

Power of the modulated signal $S_{AM}(t)$ is

$$P_{Total} = \frac{V_C^2}{2} + \frac{(V_C K_a)^2}{2} P_m$$

When sinusoidal signal given as message signal i.e., $v_m = V_m \sin\omega_m t$

Power of message signal $P_m = \dfrac{V_m^2}{2}$

Now, $$P_{Total} = \frac{V_C^2}{2} + \frac{V_C^2 K_a^2 V_m^2}{4}$$
$$= \frac{V_C^2}{2}\left(1 + \frac{K_a^2 V_m^2}{2}\right)$$

Let P_C be power of carrier signal, $P_C = \dfrac{V_C^2}{2}$

Modulation index (μ) = $V_m K_a$

$\Rightarrow$ $$P_{Total} = P_C\left[1+\frac{\mu^2}{2}\right]$$

(ii) Carrier power (P_C) = 100 kW

Modulation index (μ) = 0.8

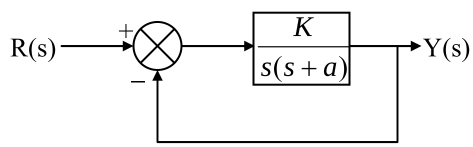
Radiated power (or) total power

$$P_t = P_C\left(1+\frac{\mu^2}{2}\right)$$

$$= 100\times10^3\left(1+\frac{0.8^2}{2}\right)$$

$\therefore$ P_t = 132 kW

05. (d) Given a unity feedback system with $G(s) = \dfrac{K}{s(s+a)}$ as shown in the figure:



(i) Find the values of K and a, when the closed-loop system has K_v = 100 and admits 20% peak overshoot.

(ii) Find the values of K and a, when the closed-loop system has settling time (2% tolerance band) of 2 seconds and admits 10% peak overshoot. (12M)

Sol: Given data:

$$G(s) = \frac{K}{s(s+a)}, \; H(s) = 1$$

(i) K_V = 100 M_P = 20%

$$K_V = \underset{s\to0}{Lt}\, sG(s)$$

$$K_V = \underset{s\to0}{Lt}\, s\frac{K}{s(s+a)} = \frac{K}{a} = 100 \qquad \text{……….} (1)$$

$$M_P = e^{\left[\frac{-\xi\pi}{\sqrt{1-\zeta^2}}\right]} = 20\%$$

$$\zeta = \sqrt{\frac{(\ell n M_p)^2}{\pi^2 + (\ell n M_p)^2}}\Bigg|_{M_P=0.2}$$

$\zeta = 0.46$

$$CE = 1 + \frac{K}{s(s+a)} = 0$$

$s^2 + as + K = 0$ ……….. (2)

Comparing equation (1) and (2)

$s^2 + as + 100a = 0$

$s^2 + as + 100a = s^2 + 2\zeta\omega_n s + \omega_n^2$

$\omega_n = \sqrt{100a}$

$2\zeta\omega_n = a$

$a = 2(0.46)\sqrt{100a}$

$a^2 = 4(0.46)^2(100)a$

$a = 4(0.46)^2\,(100)$

$a = 84.64$

$K = 100a$

$= (100)\,(84.64) = 8464$

$t_s = 2$ sec (2%)

$M_P = 10\%$

$$\zeta = \sqrt{\frac{(\ell n M_p)^2}{\pi^2 + (\ell n M_p)^2}}\Bigg|_{M_P=0.1}$$

$\zeta = 0.6$

$$t_s = \frac{4}{\zeta\omega_n} = 2$$

$$\omega_n = \frac{4}{2(0.6)} = 3.33$$

$$CE = 1 + \frac{K}{s(s+a)} = 0$$

$$s^2 + as + K = s^2 + 2\zeta\omega_n s + \omega_n^2 = 0$$

$K = \omega_n^2 = 11.11$

$K = 11.11$

$a = 2\zeta\omega_n$

$= 2(0.6)(3.33)$

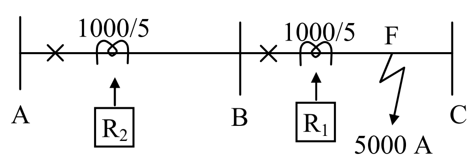
$= 3.994 \approx 4$

$a = 4$

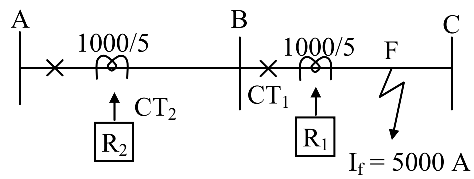
05. (e) Two relay R_1 and R_2 are connected in two sections of a feeder as shown in the following figure. CTs are of ratio 1000/5. The plug setting of relay R_1 is 100% and of R_2 is 125%. The operating time characteristics of the relay is given in the following table:

Operating time characteristics for TMS = 1						
PSM	**2**	**4**	**5**	**8**	**10**	**20**
Operating time (seconds)	**10**	**5**	**4**	**3**	**2.8**	**2.4**

The time multiplier setting of the relay R_1 is 0.3. The time grading scheme has a discriminative margin of 0.5 s between the relays. A three-phase short circuit at F results in a fault current of 5000 A. Find the actual operating time of R_1 and R_2. What is the time multiplier setting (TMS) of R_2? (20M)



Sol:



Plug settling of R_1 and R_2 relays respectively are,

PS_1 = 100% and PS_2 = 125%

Pickup currents of relays are, $I_{P1} = 5$ A

$$I_{P2} = 5 \times 1.25 = 6.25 \text{ A}$$

Now, fault current referred to secondary side CT_2 is

$$i_f = I_f \times \frac{5}{1000}$$

$$= 5000 \times \frac{5}{1000} = 25 \text{ A}$$

As $i_f > I_p$, R_1 operates

For R_1 relays, $PSM_1 = \frac{i_f}{I_{p1}} = \frac{25}{5} = 5$

From characteristics table operating ime of R_1 relay with TMS = 1 was 4S as TMS of R_1 is 0.3

$\therefore$ Operating time R_1 will be, $t_{R_1} = TMS_1 \times (t_{R_1}$ at TMS = 1)

$$= 0.3 \times 4$$

$$= 1.2 \text{ s}$$

Now, operating time of 'R_2' relay with discriminative margin of 0.5s will be $t_{R_2} = 1.2 + 0.5$

$$= 1.7\text{S}$$

For 'R_2' relay, fault current referred to secondary side of CT_2 will be

$$i_f = 5000 \times \frac{5}{1000} = 25 \text{ A}$$

Now, $PSM_2 = \frac{i_f}{I_{p_2}} = \frac{25}{6.25} = 4$

With PSM = 4, operating time of relay from characteristics is 5s at TMS = 1

But actual operating time of R_2 is t_{R_2} = 1.7S

Now, $TMS_2 = \frac{Actual\ operating\ time}{Operating\ time\ at TMS = 1} = 0.34$

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06 (a) A 20 kW, 500 V DC shunt motor (having 90%full-load efficiency) has 40% armature copper losses of its full-load losses. Calculate the resistance values of a 4-section starter suitable for limiting starting current between 120% to 200% of full-load current. Assume field resistance of 250 Ω. (20M)

Sol: 1. 20 W, 500 V dc shunt motor: These ratings mean that the full-load output = 20 kW.

With a full-load efficiency = 90%, full load input = $\frac{20,000}{0.9}$ = 22,222 W.

$\therefore$ Full load losses = 2222 W,

From given data full load armature copper losses = 2,222 × 0.4 = 888.8 W

2. Full-load line current = $\frac{20,000}{0.9\times 500}$ = 44.4 A

Field current (constant) = $\frac{500}{250}$ = 2A

$\therefore$ Full load armature current = 42.4 A

Armature resistance $r_a = \frac{888.8}{42.4^2}$ = 0.49 Ω.

3. The problem specifies starting current. It is assumed that it refers to starting line current.

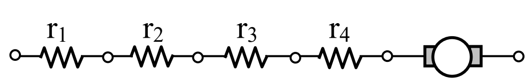
Minimum starting line current = 1.2 × 44.4 = 53.3 A

Maximum starting armature current = 2 × 44.4 = 88.8 A

$\therefore$ Minimum starting armature current = 51.3 A = I_{a2}

Maximum starting armature current = 86.6 A = I_{a1}

4. Design of a 4-section starter:



$$\alpha = \frac{I_{a2}}{I_{a1}} = \frac{51.3}{86.3} = 0.591.$$

Also, $$\frac{500}{r_1 + r_2 + r_3 + r_4 + r_a} = \frac{500}{R_1} = 86.8$$

$\Rightarrow$ $R_1 = 5.76\ \Omega$

We have, $r_1 = R_1(1-\alpha) = 5.76(0.409) = 2.356\ \Omega$.

$r_2 = \alpha r_1 = 0.591 \times 2.356 = 1.392\ \Omega$

$r_3 = \alpha r_2 = 0.591 \times 1.392 = 0.823\ \Omega$

$r_4 = \alpha\ r_3 = 0.591 \times 0.823 = 0.486\ \Omega$

06 (b) (i) Differentiate between characteristic impedance and surge impedance of a line. What do you mean by surge impedance loading (SIL) of a transmission line?

(ii) A three-phase, 50 Hz transmission line is 400 km long. The voltage at the sending end is 220 kV. The line parameters are r = 0.125 ohm/km, x = 0.4 ohm/km and y = 2.8 × 10^{-6} mho/km. Find the sending-end current and receiving-end voltage when there is no load on the line. Make a comment on the value of receiving-end voltage. (20M)

Sol: (i) **Characteristic impedance and surge impedance:**

Characteristic impedance is a basic property medium which is instrument in the propagation of electromagnetic wave through the transmission line. It is the characteristic of the medium through which magnetic field converted into electric field vice versa.

For transmission line, $Z_C = \sqrt{\dfrac{z}{y}} = \sqrt{\dfrac{r + j\omega L}{g + j\omega C}}$

If the line is lossless then r = 0, g = 0. In this case $Z_C = \sqrt{\dfrac{L}{C}}$, which is pure resistive in nature.

This is known as surge impedance of transmission line. That is surge impedance is the characteristic impedance of lossless line.

Surge impedance loading:

It is the amount of power flowing is lossless line when it is terminated with its surge impedance (Z_C) (or) It is the amount of power drawn by the load by matching the load resistance value exactly equal to surge impedance of the line.

During this loading voltage at all the points on line is same, let us say it is rated voltage. The surge impedance loading (SIL) will be given as, SIL = $\dfrac{V_{rated}^2}{Z_C}$

(ii) A 3-ϕ, 50 Hz transmission line of l = 400 km

Sending end voltage, V_S = 220 kV(LL)

The line parameters are, r = 0.125 Ω/km

x = 0.4 Ω/km

y = j2.8 × 10^{-6} mho/km

Series impedance per km, z = r + jx

$= 0.125 + j0.4\ \Omega/\text{km}$

Shunt admittance per km, y = j2.8 × 10^{-6} mho/km

Propagation constant, $\gamma = \sqrt{zy}$

$$= \sqrt{(0.125 + j0.4)(j2.8\times10^{-6})}$$

$$= \sqrt{1.173\times10^{-6}\angle162.64^o}$$

$$= 1.083 \times 10^{-3}\angle81.32^o \text{ per km}$$

$$= (1.634+j10.706) \times 10^{-4} \text{ per km}$$

$$\text{Characteristic impedance, } Z_C = \sqrt{\frac{z}{y}} = \sqrt{\frac{0.125 + j0.4}{j2.8\times10^{-6}}}$$

$$= \sqrt{149670\angle-17.35}$$

$$= 386.89\angle-8.675^o\ \Omega$$

Generalized circuit constants of long line are $A = \cosh\gamma l$

$B = Z_C\sinh\gamma l$

Now, $\gamma l = 0.0654 + j0.4282$

$$e^{\gamma l} = e^{0.0654 + j0.4282}$$

$$= 1.0676\angle24.534^o$$

$$e^{-\gamma l} = \frac{1}{1.0676\angle24.534}$$

$$= 0.9367\angle-24.534^o$$

Now, $A = D = \cos\gamma l$

$$= \frac{e^{\gamma\ell} + e^{-\gamma\ell}}{2} = 0.912\angle 1.707^{o}$$

$$B = Z_C \sinh\gamma l$$

$$= Z_C\left[\frac{e^{\gamma\ell} - e^{-\gamma\ell}}{2}\right]$$

$$= (386.87\angle -8.675^{o})(0.42\angle 81.86^{o})$$

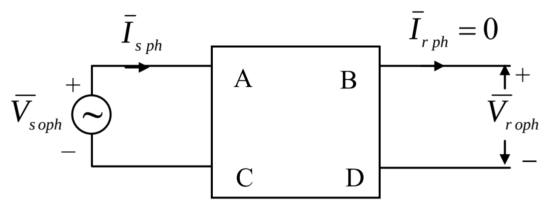
$$= 162.626\angle 73.18^{o}$$

$$C = \frac{1}{Z_C}.\sinh\gamma\ell$$

$$= \frac{1}{(386.87\angle -8.675^{o})}(0.42\angle 81.86)$$

$$= 1.0856\times 10^{-3}\angle 90.535^{o} \text{ mho}$$

The line is operating at no load condition,



Sending end voltage, $V_{sph} = \frac{220}{\sqrt{3}}$ kV = 127 kV

Let V_{sph} taken as reference, $\bar{V}_{sph} = 127\angle 0^{o}$ kV

No load receiving end voltage, $\bar{V}_{rph} = \frac{\bar{V}_{sph}}{A} = \frac{127\angle 0^{o}}{0.912\angle 1.707^{o}}$

$$= 139.25\angle -1.707^{o} \text{ kV}$$

$$|V_{ro}(LL)| = \sqrt{3}\times|V_{rph}|$$

$$= \sqrt{3}\times 139.25 \text{ kV}$$

$$= 241.2 \text{ kV}$$

Sending end current under no load $\bar{I}_{sph} = C.\bar{V}_{rph}$

$$= (1.0856\times 10^{-3}\angle 90.535)(139.25\times\angle -1.707^{o})$$

$$= 151.17\angle 88.828^{o} \text{ A}$$

06. (c) A boost converter is required to have an output voltage of 48 V and supply a load current of 5 A. The input varies from 12 V - 24 V. A control circuit adjusts the duty ratio to keep the output voltage constant. Select the switching frequency to be 200 kHz. Determine a value of inductor such that the variation in inductor current is no more than 40% of average inductor current for all operation. Prescribe a suitable value of capacitor such that output ripple is no more than 2%. (20M)

Sol: Boost Converter:

$V_0 = 48$ V

$I_0 = 5$A

Input voltage V_0 varies from 12 V – 24V

f = 200 kHz

$$T = \frac{1}{200\times10^3} = 5\ \mu s$$

Inductor current ripple $(\Delta I_1) = 0.4 I_{LA}$

Where I_{LA} = Average value of inductor current

For $V_d = 12$ V

$$V_0 = \frac{1}{1-D}V_d$$

$$48 = \frac{1}{1-D}\times 12 \Rightarrow 1 - D = \frac{12}{48} = \frac{1}{4}$$

$$D = \frac{3}{4} = 0.75$$

$$I_{LA} = \frac{I_0}{1-D} = \frac{5}{0.25} = 20 \text{ Amps}$$

$$\Delta I_L = 0.4 \times 20 = 8 \text{ Amps}$$

$$\Delta I_L = \frac{V_d}{L}.T_{on} = \frac{V_d}{L}\times DT$$

$$8 = \frac{12}{L}\times 0.75\times 5\times 10^{-6}$$

$$L = 5.625\ \mu H$$

For $V_d = 24$ V

$V_0 = \frac{V_d}{1-D} \Rightarrow 48 = \frac{24}{1-D}$

$1 - D = \frac{1}{2} \Rightarrow D = \frac{1}{2} = 0.5$

$I_{LA} = \frac{I_C}{1-D} = \frac{5}{0.5} = 10$ A

$\Delta I_L = 0.4 \times 10 = 4$ A

$\Delta I_L = \frac{V_d}{L} \times DT$

$\Rightarrow 4 = \frac{24}{L} \times 0.5 \times 5 \times 10^{-6}$

$\Rightarrow L = 15\ \mu H$

Higher value of inductance is to be considered i.e., 15 μH

If 15 μH inductor is used for 12 V input voltage condition,

Then $\Delta I_L = \frac{V_d}{L} \times DT$

$= \frac{12}{15 \times 10^{-6}} \times 0.75 \times 5 \times 10^{-6}$

= 3 A and it is less than 8 A.

Voltage ripple $(\Delta V_0) = \frac{\Delta Q}{C} = \frac{I_0 \times DT}{C}$

$\Delta V_0 = 2\%$ of V_0

$= 0.02 \times 48 = 0.96$ V

$0.96 = \frac{5 \times 0.75 \times 5 \times 10^{-6}}{C}$

$C = 19.53\ \mu F$

Capacitance is evaluated by considering maximum value of duty cycle.

$\Delta V_0 = 2\%$ of 48V = 0.96 V

$\frac{I_0 DT}{C} = 0.96$

$\Rightarrow \quad C = \frac{5 \times 0.5 \times 5\mu}{0.96} = 13.02\ \mu F$

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07. (a) A full-controlled full-wave bridge AC/DC converter is fed from a single-phase, 230 V, 50 Hz supply, and is in turn feeding to an R-L load (R = 10 Ω and L = 100 mH). The firing angle α = 60°. Investigate whether load current remains continuous or not. Compute r.m.s load current considering only the dominant harmonic, and determine the power absorbed by the load. Also compute voltage ripple factor. (20M)

Sol: 1-ϕ source: 230 V, 50 Hz; $\alpha = 60^o$; R = 10 Ω, L = 100 mH

$$i_0 = \frac{V_m}{\sqrt{R^2+(\omega L)^2}}\left[\sin(\omega t-\phi)-\sin\left((\alpha-\phi)e^{\frac{-R}{\omega L}(\omega t-\phi)}\right)\right]$$

$$\phi = \tan^{-1}\left(\frac{\omega L}{R}\right) = \tan^{-1}\left(\frac{100\pi\times100\times10^{-3}}{10}\right) = 72.34^o$$

i_0 at $\omega t = +\alpha$, i.e., $240^o = \frac{4\pi}{3}$

$$i_0\Big|_{\omega t=240^o} = \frac{230\sqrt{2}}{\sqrt{10^2+\left(100\pi\times100\times10^{-3}\right)^2}}\left[\sin(240-72.34)-\sin\left(60-72.34^o\right)\times e^{-\frac{10}{31.416}}\left(240-72.34\right)\times\frac{\pi}{180}\right]$$

$= 9.866[0.2137 + 0.842] \Rightarrow \neq 0$ hence i_0 is continuous

Dominant harmonic is 2nd harmonic

$$a_2 = \frac{1}{\pi}\int V_m \sin\omega t\cos(2\omega)d\omega t$$

$$= \frac{V_m}{2\pi}\left[\sin 3\omega t - \sin\omega t\right]_{\alpha}^{\pi+\alpha}$$

$$= \frac{V_m}{2\pi}\left[\sin(3\pi+3\alpha)-\sin 3\alpha-\sin(\pi+\alpha)+\sin\alpha\right]$$

$$= \frac{230\sqrt{2}}{2\pi}\left[\sin(720^o)-\sin 180^o-\sin(240)+\sin 60\right]$$

$$= \frac{230\sqrt{2}}{2\pi}\times1.732 = 89.66 \text{ V}$$

$$b_2 = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t\sin(2\omega t)d\omega t$$

$$= \frac{V_m}{2\pi}\left[\cos\omega t - \cos 2\omega t\right]_{\alpha}^{\pi+\alpha}$$

$$= \frac{230\sqrt{2}}{2\pi}\left[\cos(\pi+\alpha) - \cos\alpha - \cos(3\pi+3\alpha) + \cos 3\alpha\right]$$

$$= \frac{230\sqrt{2}}{2\pi}\left[\cos 240 - \cos 60 - \cos 720 + \cos 180\right] = -155.3 \text{ V}$$

$$V_{02} = \sqrt{a_2^2 + b_2^2} = 179.32 \text{ V}$$

$$Z_{22} = \sqrt{10^2 + \left(200\pi \times 100 \times 10^{-3}\right)^2} = 63.62\ \Omega$$

$$I_{02,\,r} = \frac{V_{o2}/z_{22}}{\sqrt{2}} = \frac{179.32}{\sqrt{2}\times 63.62} = 1.993 \text{ A}$$

Average output voltage $V_0 = \frac{2V_m}{\pi}\cos\alpha = \frac{2\times 230\sqrt{2}}{\pi}\times\frac{1}{2} = 103.54$ V

$$I_0 = \frac{V_0}{R} = \frac{103.54}{10} = 10.354 \text{ A}$$

$P_0 = V_0 I_0 = 103.54 \times 10.354 = 1072$ W

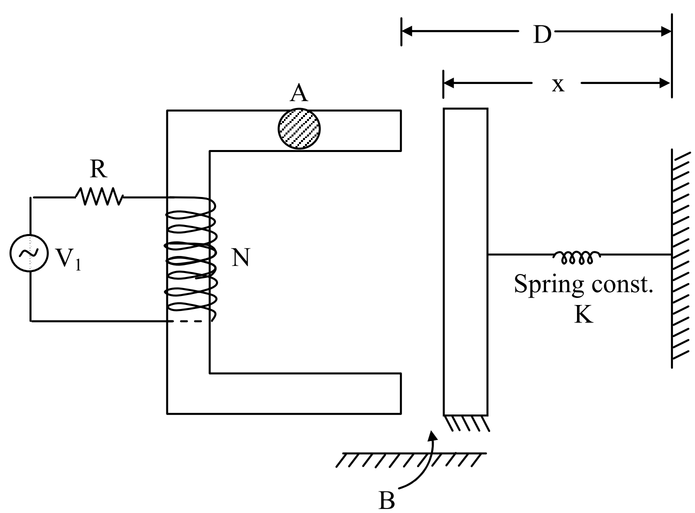
$$V_{or} = \frac{V_m}{\sqrt{2}} = 230 \text{ V}$$

$$RF = \sqrt{\frac{V_{or}^2 - V_o^2}{V_o^2}} = \sqrt{\frac{(230)^2 - (103.54)^2}{(103.54)^2}} = 1.98$$

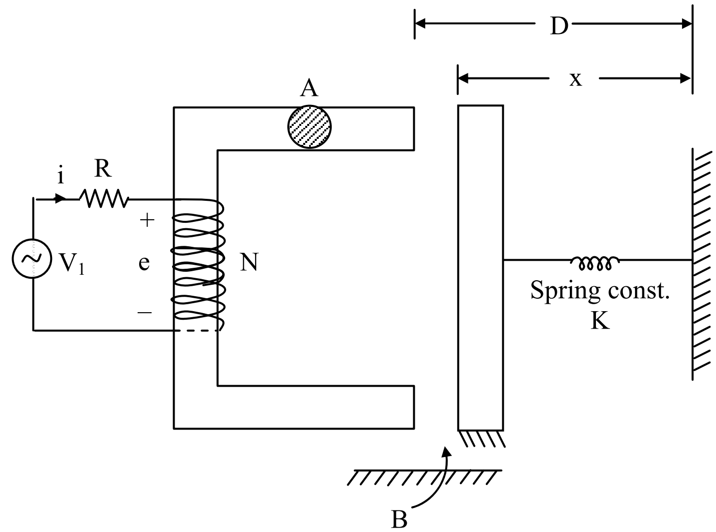
07. (b) For the electromechanical system shown below, the air-gap flux density under steady-state operating condition is given by

$B(t) = B_m \sin \omega t$

Find the instantaneous coil voltage and current along with force of magnetic field origin: **(20M)**



Sol:



Under steady state operation air gap flux density given by,

$B(t) = B_m \sin\omega t$

Induced emf in the coil, $e = \dfrac{d\phi}{dt}$

$$e = \frac{d}{dt}(N\phi)$$

$$= \frac{d}{dt}(N.B(t).A)$$

$$= N.A\,\frac{d\,B(t)}{dt}$$

$$e = N.A\,B_m\,\omega\cos\omega t$$

Expression for emf induced in the direction as shown in figure.

Instantaneous current flow in the coil, $i = \dfrac{v_1 - e}{R}$

$$i = \frac{v_1 - N.A\omega B_m \cos\omega t}{R}$$

Magnetic force, $f_e = -\dfrac{\partial w_{field}}{\partial x}$

Where field energy $w_{\text{field}} = \dfrac{1}{2}L(x)i^2$

Assuming that core body is ideal one ($\mu_r = \infty$), Reluctance of two air gaps, $R_\ell = \dfrac{2(D-x)}{\mu_0 A}$

Inductance of magnetic circuit, $L(x) = \dfrac{N^2}{R_\ell}$

$$L(x) = \frac{\mu_0 N^2 A}{2(D-x)}$$

$$w_{field} = \frac{1}{2}\frac{\mu_0 N^2 A}{2(D-x)}.i^2$$

Force, $f_e = -\dfrac{\partial w_{field}}{\partial x}$

$$= -\frac{1}{2}\frac{\mu_0 N^2 A}{2} i^2 \times \frac{-1}{(D-x)^2} \times -1$$

$$\boxed{f_e = -\frac{1}{2} i^2 \frac{\mu_0 N^2 .A}{2(D-x)^2}}$$

Field energy stored = energy density per unit volume × volume of airgaps

$$w_{field} = \left(\frac{1}{2} \times B \times H\right) \times ((D-x) \times A) \times 2$$

$$= \frac{1}{2}\frac{B^2}{\mu_0}(D-x).A \times 2$$

$$= \frac{B^2}{\mu_0}(D-x)A$$

Force, $f_e = -\dfrac{\partial w_{field}}{\partial x}$

$$= \frac{B^2}{\mu_0} \times A$$

$$\boxed{f_e = \frac{1}{\mu_0} B_m^2 \sin^2 \omega t\, A}$$

07. (c) (i) In case of a circuit breaker, define the terms 'restriking voltage' and 'RRRV' and express their maximum values in terms of system voltage.

(ii) Which circuit breaker is preferred for voltages 132 kV and above?

(iii) In a 132 kV system, the reactance per phase up to the location of circuit breaker is 5 Ω and capacitance to earth is 0.03 μF. Calculate the maximum value of restriking voltage, the maximum value of RRRV and frequency of transient oscillation. (20M)

Sol: Restriking voltage:

The resultant transient voltage which appears across the breaker contacts at the instant of arc extinction

Rate of Rise of Restriking Voltage: (RRRV):

RRRV is the slope of restriking voltage.

Expression for restriking voltage $V_c(t) = V_m(1 \; -\cos_n t)$

Where V_m = per phase maximum value.

The maximum value of restrking voltage occurs at $t = \frac{\pi}{\omega_n} = \pi\sqrt{LC}$

Hence, the maximum value of restriking voltage = $2V_m$

= 2 × peak value of system voltage

Rate of rise of restrking voltage (RRRV) = $\frac{d}{dt}\left[V_m\left(1-\cos\omega_n t\right)\right]$

RRRV = $V_m\omega_n \sin\omega_n t$

The maximum value of RRRV occurs at $_n t = \frac{\pi}{2\omega_n} = \frac{\pi\sqrt{LC}}{2}$

Hence, the maximum value of RRRV= $V_m\omega_n$

(ii) For 132 kV above operation choice of CB is either air blast or SF_6 CB but SF_6 CB has superior arc quenching properties than air blast.

So 132 kV and above operation SF_6 CB is prepared in modern power system.

(iii)Given data:

$X = 2\pi fL = 5\ \Omega$

$L = \dfrac{5}{100\pi} = 15.915$ mH

$C = 0.03\ \mu F$

Active recovery voltage

$$E = K_1K_2V_m\sin\theta$$
$$= 1 \times 1 \times \frac{132}{\sqrt{3}} \times \sqrt{2} \times 1$$
$$= 107.77 \text{ kV}$$

Maximum value of restriking voltage = 2E

$$= 2 \times 107.77 \text{ kV}$$
$$= 215.55 \text{ kV}$$

$$\text{Maximum value of RRRV} = \frac{E}{\sqrt{LC}}$$
$$= \frac{107.77}{\sqrt{15.915\times10^{-3}\times0.03\times10^{-6}}} \text{ kV/sec}$$
$$= \frac{107.77}{21.85}$$
$$= 4.932 \text{ kV/}\mu\text{sec}$$

Frequency of transient oscillations

$$f_x = \frac{1}{2\pi\sqrt{LC}}$$
$$= \frac{1}{2\pi\sqrt{5.915\times10^{-3}\times0.03\times10^{-6}}}$$
$$= 7.283 \text{ kHz}$$

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TOTAL SELECTIONS	CE	ME	EE	E&T
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08. (a) A signal is given by

$x[t] = \cos(28\pi t) + 2\cos(40\pi t) + 3\cos(70\pi t)$

This signal is sampled at 90 samples/s to get discrete-time signal x(n).

(i) Find the periodicity of the individual components in the signal and hence find the periodicity N_0 of the signal x(n).

(ii) Find the harmonic indices $m(0 \le m < N_0)$ of the complex DTFS coefficient D_m, where D_m is non-zero.

(iii) By inspection, write the magnitude of the coefficients $|D_m|$ for the indices found above.

(20M)

Sol:(i) $x(t) = \cos 28\pi t + 2\cos 40\pi t + 3\cos 70\pi t$

The relationship between discrete frequency to the CT domain frequency is

$\Omega = \omega Ts$

$\cos 28\pi t \Rightarrow \omega = 28\pi$ & $f_s = 90$

$$\therefore \Omega = \frac{\omega}{fs} = \frac{28\pi}{90}$$

$$N_1 = \left(\frac{2\pi}{\Omega}\right)K = \frac{2\pi}{\left(\frac{28\pi}{90}\right)}K = \left(\frac{90}{14}\right)K$$

$$N_1 = \left(\frac{45}{7}\right) K \Rightarrow N_1 = 45$$

$\cos 40t \Rightarrow \omega = 40\pi$ & $fs = 90$

$$\Omega = \frac{\omega}{fs} = \frac{40\pi}{90} = \frac{4\pi}{9}$$

$$N_2 = \left(\frac{2\pi}{\Omega}\right)K = \frac{2\pi}{\left(\frac{4\pi}{9}\right)}K = \left(\frac{9}{2}\right)K$$

$\therefore N_2 = 9$

$\cos 70\pi t \Rightarrow \omega = 70\pi$; $fs = 90$

$$\Omega = \frac{\omega}{fs} = \frac{40\pi}{90} = \frac{7\pi}{9}$$

$$N_3 = \left(\frac{2\pi}{\Omega}\right)\text{K} = \frac{2\pi}{\left(\frac{7\pi}{9}\right)}\text{K} = \left(\frac{18}{7}\right)\text{K}$$

$\therefore$ N_3 = 18

$\therefore$ N_0 = LCM (45, 9, 18) = 90

(ii) $x(n) = \dfrac{\cos 14\pi n}{45} + 2\cos\dfrac{4\pi}{9}n + 3\cos\dfrac{7\pi}{9}n$

$\dfrac{N_1}{N_2} = \dfrac{45}{9} = 5 \Rightarrow N_1 = 5N_2$

$\dfrac{N_1}{N_2} = \dfrac{45}{18} = \dfrac{5}{2} \Rightarrow 2N_1 = 5N_3$

$\therefore$ $2N_1 = 10N_2 = 5N_3$

$\therefore$ Harmonic indices are 2, 10, 5

(iii) Magnitude of coefficient are

$|D_2| = 1$; $|D_{10}| = 2$

$|D_5| = 3$

08. (b) For a unity feedback time delay system with open-loop transfer function

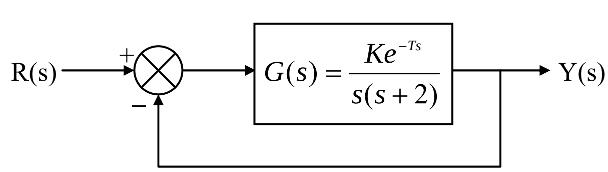
$$G(s) = \frac{Ke^{-Ts}}{s(s+2)}$$

Calculate:

(i) The maximum tolerable value of delay T, when K = 1;

(ii) Phase margin when K = $\sqrt{5}$ and delay T = 0.5 second. **(20M)**

Sol:



i) T_{max} for K = 1 (PM = 0^o, GM = 1 or 0 dB)

$PM = \pi + \angle G(j\omega_{gc})H(j\omega_{gc})$

$$|G(j\omega)H(j\omega)| = \left|\frac{Ke^{-j\omega T}}{j\omega(j\omega+2)}\right|_{\omega=\omega_{gc}} = 1$$

$$= \frac{K}{\omega_{gc}\sqrt{\omega_{gc}^2+4}} = 1$$

$$= \frac{1}{\omega_{gc}\sqrt{\omega_{gc}^2+4}} = 1$$

$$\omega_{gc}^4 + 4\omega_{gc}^2 - 1 = 0$$

Solving $\omega_{gc} = 0.49$

$$PM = \pi + \angle\frac{e^{-j\omega_{gc}T}}{j\omega_{gc}\left(j\omega_{gc}+2\right)} = 0$$

$$= \pi - \left(\omega_{gc}T + \frac{\pi}{2} + \tan^{-1}\frac{\omega_{gc}}{2}\right)\Bigg|_{\omega_{gc}=0.49}$$

$$= \pi - \left[0.49T + \frac{\pi}{2} + 0.24\right]$$

T = 2.71 sec

$\therefore$ T_{max} = 2.71 sec

T < 2.71 sec $\rightarrow$ stable

T = 2.71 sec $\rightarrow$ Marginally stable

T > 2.71 sec $\rightarrow$ unstable

(ii) K = $\sqrt{5}$, T = 0.5 sec

$$\left|\frac{Ke^{-j\omega_{gc}T}}{j\omega_{gc}(j\omega_{gc}+2)}\right| = 1$$

$$\frac{\sqrt{5}}{\omega_{gc}\sqrt{\omega_{gc}^2+4}} = 1$$

$$\omega_{gc}^4 + 4\omega_{gc}^2 - 5 = 0$$

ω_{gc} = 1 rad/sec

$$PM = 180^o + \angle \frac{\sqrt{5}e^{-j\omega_{gc}(0.5)}}{j\omega_{gc}(\omega_{gc}+2)}$$

$$= 180^o - \left[\frac{(\omega_{gc})(0.5)180}{\pi} + 90^o + \tan^{-1}\frac{\omega_{gc}}{2}\right]_{\omega_{gc}=1}$$

$$= 180^o - [28.64 + 90 + 26.57]$$

$$PM = 34.79^o$$

08. (c) Given a system in state space representation as

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix} = \begin{bmatrix}0 & 1\\ 0 & -3\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} + \begin{bmatrix}0\\ 1\end{bmatrix}u$$

$$\mathbf{y} = [1 \quad 0]\begin{bmatrix}x_1\\ x_2\end{bmatrix}$$

(i) Check whether the system is observable or not.

(ii) Find the state transition matrix

(iii) Design a state feedback controller to place closed-loop poles at – 1± 2j. **(20M)**

Sol:
$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix} = \begin{bmatrix}0 & 1\\ 0 & -3\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} + \begin{bmatrix}0\\ 1\end{bmatrix}u$$

$$y = [1 \quad 0]\begin{bmatrix}x_1\\ x_2\end{bmatrix}$$

$$\dot{X} = AX + BU$$

$$Y = CX + DU$$

$$A = \begin{bmatrix}0 & 1\\ 0 & -3\end{bmatrix} \quad B = \begin{bmatrix}0\\ 1\end{bmatrix} \qquad C = [1 \quad 0]$$

(i) To check the system observability

$$M = [C^T \; A^TC^T \; (A^T)^2C^T \; \ldots\ldots]$$

$$= \begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix}$$

Determine of M, $|M| \neq 0$

$\therefore$ System is observable

(ii) State transition matrix

$$\phi(t) = e^{At} = L^{-1}(sI - A)^{-1}$$

$$sI - A = \begin{bmatrix} s & 0 \\ 0 & s \end{bmatrix} - \begin{bmatrix} 0 & 1 \\ 0 & -3 \end{bmatrix}$$

$$= \begin{bmatrix} s & -1 \\ 0 & s+3 \end{bmatrix}$$

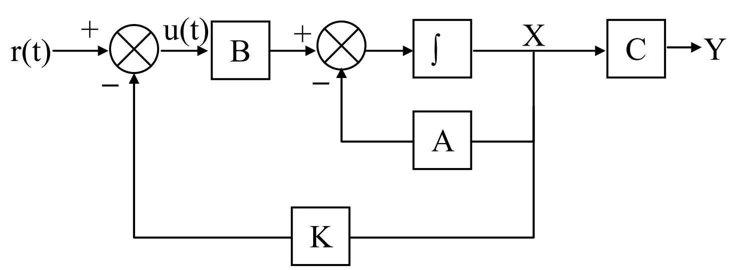
$$(sI-A)^{-1} = \frac{1}{s(s+3)}\begin{bmatrix} s+3 & 1 \\ 0 & s \end{bmatrix}$$

$$= \begin{bmatrix} \frac{1}{s} & \frac{1}{s(s+3)} \\ 0 & \frac{1}{s+3} \end{bmatrix}$$

Apply inverse Laplace transform

$$= \begin{bmatrix} 1 & \frac{1}{3}\left(1-e^{-3t}\right) \\ 0 & e^{-3t} \end{bmatrix}$$

(iii)As the system is completely observable, we can design the state feedback.



$\dot{X}$ = AX + BU

As state feedback 'K' introduced K = [K_1 K_2]

$\dot{X}$ = AX +B[r(t) −KX]

= (A −BK)X + Br(t)

System closed loop poles required to keep at $-1 \pm 2j$

CE equation $= (s + 1)^2 + 2^2 = 0$

$s^2 + 2s + 1 + 4 = 0$

$s^2 + 2s + 5 = 0 \quad \ldots\ldots\ldots.. (1)$

The new characteristic equation

$|sI - (A - BK)| = 0$

$$A - BK = \begin{bmatrix} 0 & 1 \\ 0 & -3 \end{bmatrix} - \begin{bmatrix} 0 \\ 1 \end{bmatrix} \begin{bmatrix} K_1 & K_2 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 1 \\ 0 & -3 \end{bmatrix} - \begin{bmatrix} 0 & 0 \\ K_1 & K_2 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 1 \\ -K_1 & -3-K_2 \end{bmatrix}$$

$$\begin{bmatrix} s & 0 \\ 0 & s \end{bmatrix} - \begin{bmatrix} 0 & 1 \\ -K_1 & -3-K_2 \end{bmatrix}$$

$$= \begin{bmatrix} s & -1 \\ K_1 & s+3+K_2 \end{bmatrix}$$

$|sI - (A-BK)| = 0$

$s(s + 3 + K_2) + K_1 = 0$

$s^2 + (3 + K_2)s + K_1 = 0 \ldots\ldots\ldots\ldots\ldots. (2)$

Comparing equation (1) and (2)

$3 + K_2 = 2$

$K_1 = 5$

$K_2 = -1$

$K_1 = 5$

The state feedback $K = [K_1 \ \ K_2]$

$= [5 \ \ -1]$