BYJU'S
EXAM PREP

GATE 2023

Electrical Engineering

Questions & Solutions

Memory Based

GATE 2023 Electrical Engineering: Major Highlights

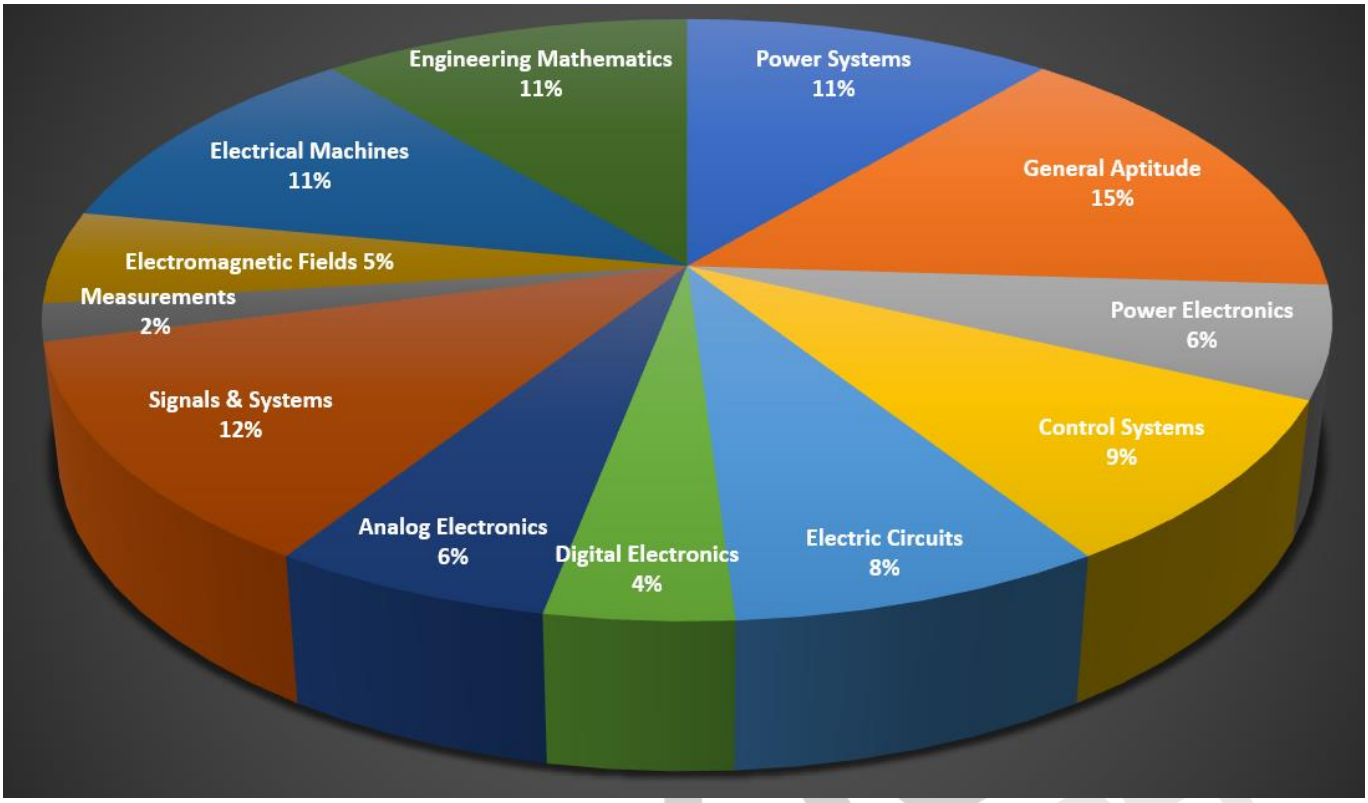
- **Overall Difficulty Level:** Moderate to tough
- **Difficult paper as compared to last year**
- **MSQ weightage:** 8 Qs
- **NAT weightage:** 25 Qs (All 2 Marks)
- **MCQ weightage:** 31 Qs
- Easy to moderate questions from **Machine, Mathematics & Power Systems**
- Conceptual questions from **Network Theory & Signals Systems**
- More numerical type questions
- **Questions from General Aptitude were easy but time consuming**.

GATE 2023 Electrical Engineering: Comparison with last 3 Years' Data

S.No.	Subject Name	2023	2022	2021	2020
1	Power Systems	**11**	8	12	10
2	Power Electronics	**6**	11	9	7
3	Control Systems	**9**	8	8	9
4	Electric Circuits	**8**	7	11	5
5	Digital Electronics	**4**	2	3	3
6	Analog Electronics	**6**	7	6	6
7	Signals & Systems	**12**	8	8	9
9	Electrical & Electronics Measurements	**2**	2	2	7
9	Electromagnetic Fields	**5**	7	5	8
10	Electrical Machines	**11**	12	8	11
11	Engineering Mathematics	**11**	13	13	10
	General Aptitude	**15**	15	15	15
	Total	**100**	**100**	**100**	**100**

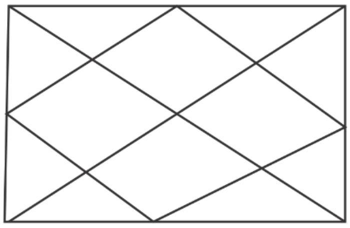
GATE 2023 Electrical Engineering: Subject-Wise Marks Distribution

Subjects	Questions		Total Marks
	1 Mark	2 Marks	
Power Systems	3	4	11
Power Electronics	2	2	6
Control Systems	3	3	9
Electric Circuits	2	3	8
Digital Electronics	2	1	4
Analog Electronics	0	3	6
Signals & Systems	4	4	12
Electrical & Electronic Measurements	0	1	2
Electromagnetic Fields	1	2	5
Electrical Machines	3	4	11
Engineering Mathematics	5	3	1
General Aptitude	5	5	15
Total	**30**	**35**	**100**


Engineering Mathematics 11%
Power Systems 11%
General Aptitude 15%
Electrical Machines 11%
Electromagnetic Fields 5%
Measurements 2%
Power Electronics 6%
Signals & Systems 12%
Control Systems 9%
Analog Electronics 6%
Digital Electronics 4%
Electric Circuits 8%

Section-A: General Aptitude

1. How many triangles are present in the given figure?

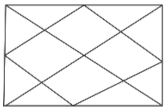


A. 12
B. 16
C. 20
D. 24

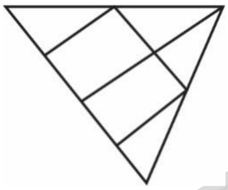
[MCQ - 1 Marks]

Ans. C

Sol.



First half

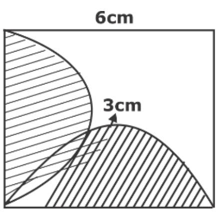


Total triangles = 1 + 2 + 1 + 2 + 2 = 8

∴ So, for second half = 5 more triangles and after overlapped 4 more triangles will come.

∴ Total triangles = 8 + 8 + 4 = 20

2. A required with sides of length 6 cm is given. The boundary of the shaded region is defined by two semi circles whose diameter are the sides of the square as shown, the area of the shaded region is _____cm^2.

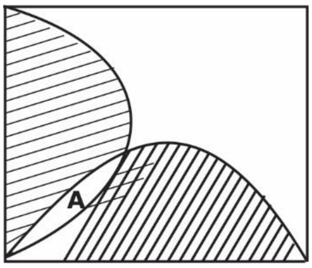


A. 6π
B. 9π
C. 20
D. 18

[MCQ]

Ans. D

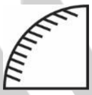
Sol.



Area of shaded = (2 × area of semi-circle) – 2 (unshaded common area)

$$\therefore \text{Area} = \frac{2\pi r^2}{2} - 2A$$

$$= \pi(3)^2 - 2A$$



$$\text{Area of top portion} = \frac{\pi r^2}{4} - \frac{1}{2}(3)(3)$$

$$= \frac{9\pi}{4} - \frac{9}{2}$$

$$\therefore \text{Total unshaded area} = 2\left[\frac{9\pi}{4} - \frac{9}{2}\right]$$

$$\therefore \text{Toal shaded area} = 9\pi - 2 \times 2\left[\frac{9\pi}{4} - \frac{9}{2}\right]$$

$$= 18$$

3. Given a fair six-sided dices where the forces are labelled 1, 2, 3, 4, 5, 6. What is the probability of getting a '1' on the 1^{st} roll of the rice and 4 on the 2^{nd} roll

A. 1/3
B. 1/36
C. 5/6
D. 1/6

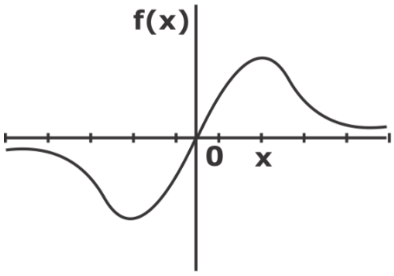
[MCQ]

Ans. D

Sol. Probability of getting ion 1^{st} roll and 4 on 2^{nd} roll

$$= \frac{1}{6} \cdot \frac{1}{6} = \frac{1}{36}$$

4. Which one of the following options represents the given graph.



A. $f(x) = x^2\, 2^{-|x|}$

B. $f(x) = x\, 2^{-x}$

C. $f(x) = |x|\, 2^{-x}$

D. $f(x) = x\, 2^{-|x|}$

[NAT]

Ans. D

Sol. $f(x) = -f(-x)$

Odd symmetry

So, by options,

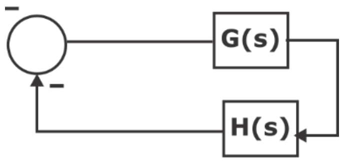
$f(x) = x2^{-|x|}$

$f(-x) = -x2^{-|x|}$

This is only option satisfying even figure.

Section-B: Technical

1. In the Nyquist plot of the open loop transfer function of G(s) H(s) = $\frac{3s+5}{s-1}$ corresponding to feedback loop shown in the figure, the infinite semi-circular arc of the Nyquist contour in s-plane is mapped in to a point at.

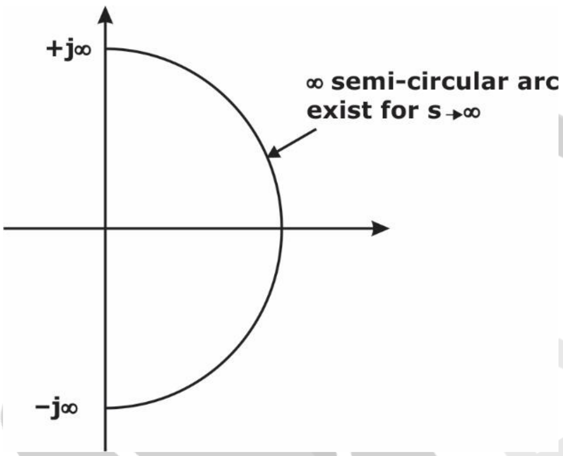


A. G(s) H(s) = 0 B. G(s) H(s) = –5

C. G(s) H(s) = ∞ D. G(s)H(s) = 3

Ans. D

Sol.



So, $\lim_{s\to\infty} G(s)\,H(s)$

$= \lim_{s\to\infty} \frac{3s+5}{s-1} = \frac{3}{1} = 3$

2. Consider a lead compensator of the form $K(s) = \frac{1+\frac{s}{\alpha}}{1+\frac{s}{\beta\alpha}}$ β > 1, α > 0. The frequency at which this compensator produces maximum phase lead is for rad/sec. At this frequency the gain amplification provided by the controller, assuming asymptotic Bode magnitude plot of K(s), is 6 dB the value of α, β respectively.

A. 2,4 B. 3,5

C. 2.66 D. 1,16

[MCQ]

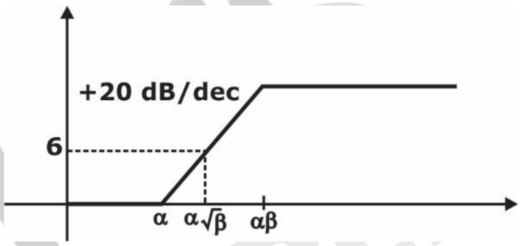
Ans. A

Sol. $K(s) = \frac{1+\frac{\beta}{\alpha}}{1+\frac{\beta}{\alpha\beta}}$

Comer frequency $s = \underset{\text{Zero}}{\underset{\downarrow}{\alpha}}, \quad \underset{\text{Pole}}{\underset{\downarrow}{\alpha\beta}}$

$\omega_n = 4$ = GM of (α, αβ) = $\sqrt{\alpha(\alpha\beta)} = \alpha\sqrt{\beta}$

So, $\alpha\sqrt{\beta} = 4$



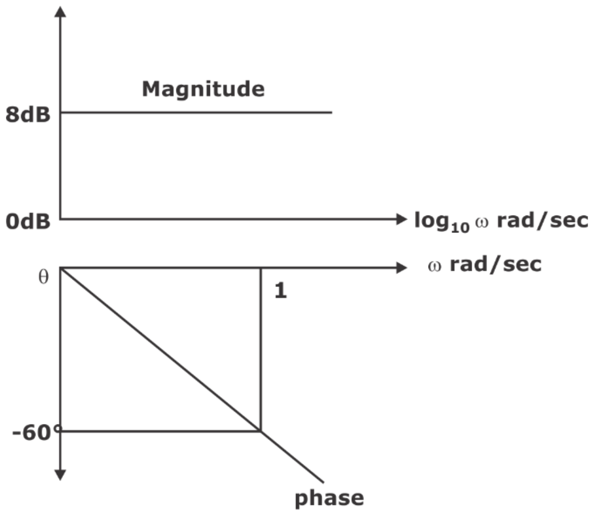
Slope = 20 = $\frac{6-0}{\log\alpha\sqrt{\beta} - \log\alpha} = \frac{6}{\log\sqrt{\beta}}$

$\log\sqrt{\beta} = \frac{b}{20} = 0.3$

β = 4

$\alpha\sqrt{\beta} = 4 \qquad \Rightarrow \alpha = 2$

3. The magnitude and phase plot of an LTI system are shown in the figure. The transfer function of the steering.



A. $2.51\ e^{-0.325}$ B. $2.51\ e^{-1.0475}$

C. $1.04\ e^{-2.5145}$ D. $\frac{e^{-2.514s}}{5+1}$

[MCQ]

Ans. B

Sol. Magnitude = constant

Phase = linear function

So, $G(j\omega) = ke^{-j\omega T}$

$20 \log k = 8$

$k = 2.51$

$\varphi = -\omega T$

$-\frac{\pi}{3} = -(1)T \quad \Rightarrow T = \frac{\pi}{3} = 1.05$

So, $G(j\omega) = 2.51e^{-j1.05\omega}$

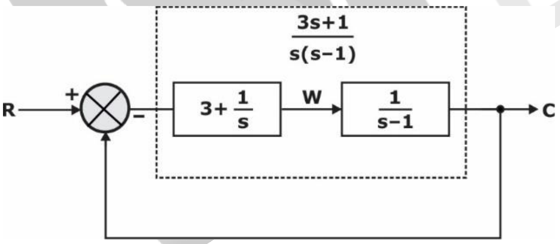
4. Consider a unity gain -ve feedback system consisting of plant $G(s) = \frac{1}{s-1}$ and a proportional integral controller. Let the proportional gain and integral gain is 3 and 1 respectively. For a unit step reference input, the final value of controller output and plant output respectively.

A. 1, −1
B. ∞, −∞
C. −1, 1
D. 1, 0

[MCQ]

Ans. C

Sol.



$$\frac{C}{R} = \frac{3s+1}{s^2+2s+1}$$

$R(s) = 1/s$

Plant output $C(s) = \frac{1}{s}\left[\frac{3s+1}{s^2+2s+1}\right]$

S.S. value $C_{SS} = \lim_{s\to 0} sC(s) = \left(\frac{1}{1}\right) = 1$

Controller output W(s) = ?

$$W \times \frac{1}{s-1} = C$$

$$W = (s-1)C$$

$$W(s) = (s-1) \times \frac{1}{s}\left(\frac{3s+1}{s^2+2s+1}\right)$$

S.S. value $\lim_{s\to 0} sW(s) = (-1)\left(\frac{1}{1}\right) = -1$

5. Consider the state space description of an LTI system with matrices $A = \begin{bmatrix} 0 & 1 \\ -1 & -2 \end{bmatrix}$, $B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$, C = [3, −2], D = 1

For the input, sin (ωt), ω > 0, the value of ω for which the steady state output of the system will be zero, is ________(rounded off to nearest integer).

[NAT - 2 Marks]

Ans. 0

Sol. Given form is CCF model.

$$A = \begin{bmatrix} 0 & 1 \\ -a_v & -a_1 \end{bmatrix} \quad B = \begin{bmatrix} 0 \\ b \end{bmatrix}$$

$$C = C = \begin{bmatrix} C_0 & C_1 \end{bmatrix} \quad D = \begin{bmatrix} d \end{bmatrix}$$

$$\text{So, T.F} = \frac{b(c_1 s + c_0)}{s^2 + a_1 s + a_0} + d$$

$$= \frac{1(-2s+3)}{s^2+2s+1} + 1 = \frac{s^2+4}{(s^2+2s+1)}$$

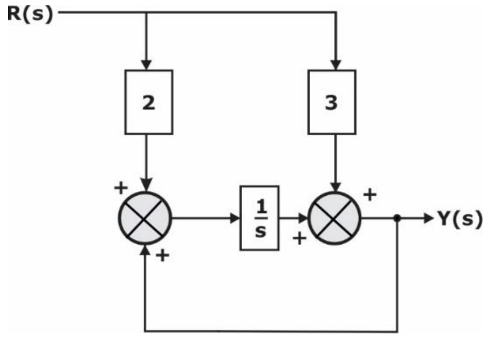
$$T(s) = \frac{s^2+4}{(s+1)^2}$$

$$T(J\omega) = \frac{4-\omega^2}{(1+j\omega)^2}$$

At $\omega = 2$, $|T(J\omega)| = 0$

So, output = 0

6. The block diagram shown in the figure, the transfer function $\frac{Y(s)}{R(s)}$ is



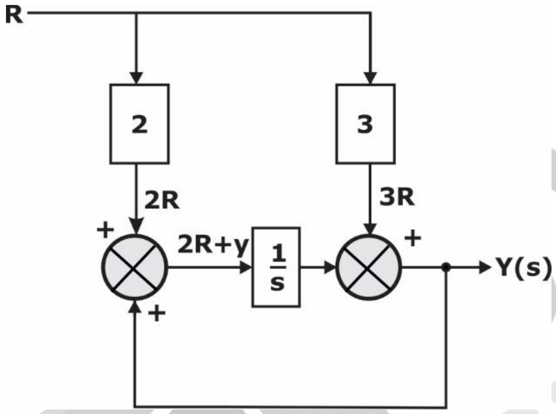
A. $\frac{s+1}{3s+2}$ B. $\frac{3s+1}{s+1}$

C. $\frac{3s+2}{s-1}$ D. $\frac{2s+3}{s+1}$

[MCQ - 2 Marks]

Ans. B

Sol.

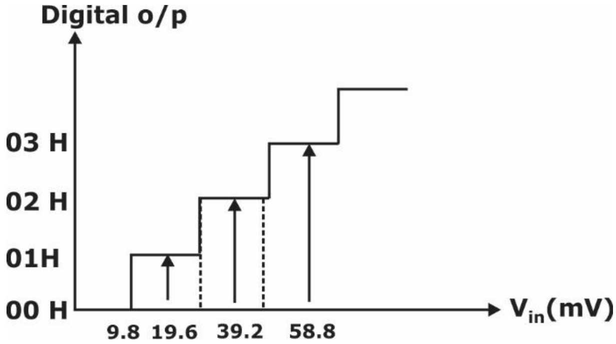


$$y = 3R + \frac{1}{s}(2R + y)$$

$$y\left(1 - \frac{1}{s}\right) = R\left(3 + \frac{2}{s}\right)$$

$$\frac{y}{R} = \frac{3s+2}{s-1}$$

7. An 8 bit ADC converts analog voltage in the range of b_1, 0 to +5V to the correct pending digital code as per the conversion characteristic shown in figure for V_{in} = 1.9922V. Which of the following digital output gives in hex is true?



A. 65 H B. 67 H

C. 66 H D. 64 H

[MCQ - 2 Marks]

Ans. C

Sol. Resolution, $V_{LSB} = \frac{V_{FL}}{2^n - 1} = \frac{5}{2^8 - 1}$

= 0.0196 V

= 19.6 mV

As per graph

$0 < V_{in} < 9.8$, output = 00 H

$9.8 < V_{in} < 19.6$, output = 01 H

$19.6 < V_{in} < 29.4$, output = 01 H

$29.4 < V_{in} < 39.8$, output = 02 H

V_{in} = 1.992 V

$\frac{1.992}{0.0196}$ V = 101.63 > 101.5

So, take (102)

If it is less than 101.5

Take 101

So, $(102)_{10} = (?)_H = (66)_H$

8. A semiconductor switch needed to block the voltage V of only one polarity (v > 0) during OFF state as shown in fig (1) and carry current in both directions during ON state shown in fig (ii) which of the following switch centration will realize the same

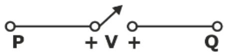


Fig (i)

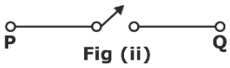
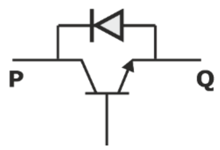
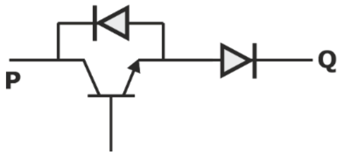


Fig (ii)

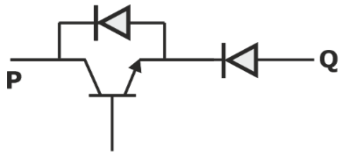
A.



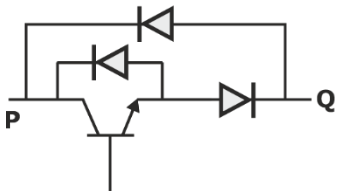
B.



C.



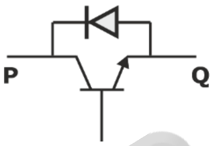
D.



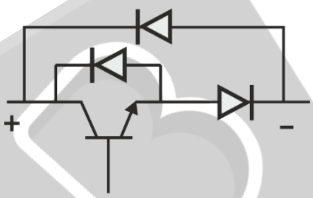
[MSQ]

Ans. A, D

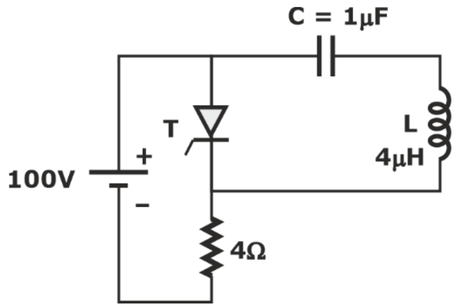
Sol. Option A D are current in option- A & D current can flow in both the direction.



And Blocking voltage shown in Figure.



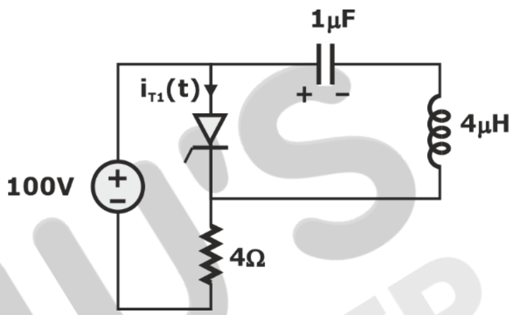
9. The circuit shown in the figure has reached steady state with thyristor 'T' in OFF condition. Assume that the latching & holding currents of the thyristor are zero. The thyristor is turned ON at t = 0 sec. The duration in μsec for which the thyristor would conduct, before it turns OFF, is _______ (around off to 2 decimal)



[NAT]

Ans. 7.33

Sol.



Under steady state capacitor is charged to 100 volt with polarity shown in fig. Let thyristor is fired at t = 0

Current through thyristor will be

$$\frac{V_s}{R} + V_s\sqrt{\frac{C}{L}} \sin\frac{1}{\sqrt{LC}} t$$

$$25 + 50\sin\frac{1}{\sqrt{1L}} t = i_{T1}(t)$$

$i_{T1}(t)$ is zero

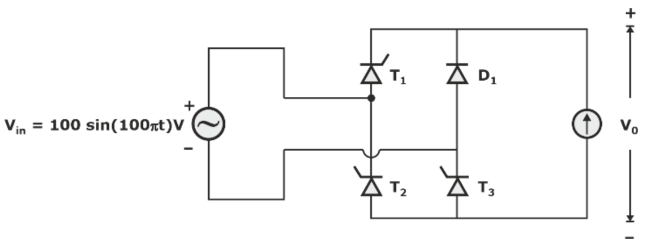
at

$$t = \pi\sqrt{LC} + \frac{\pi}{6}\sqrt{LC}$$

$$= \frac{7\pi}{6}\left[2 \times 10^{-6}\right]\text{sec}$$

$$= \frac{7\pi}{3}\mu\text{sec} = 7.33\,\mu\text{sec}$$

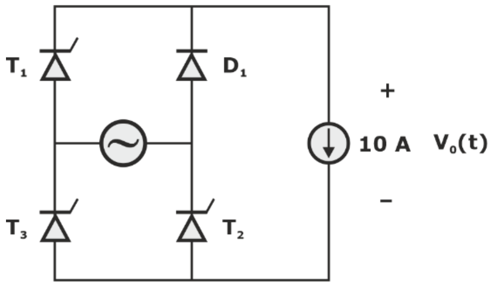
10. The single phase rectifier consisting of 3 thyristors. T_1, T_2 & T_3 and a diode D_1 feed power to a 10 A constant current load. T_1 & T_3 are fired at α =60° & T_2 is fired at α = 240°. The reference for α is the positive zero crossing of V_{in}. The avg voltage V_0 across the load in volts is (round off to 2 decimal)

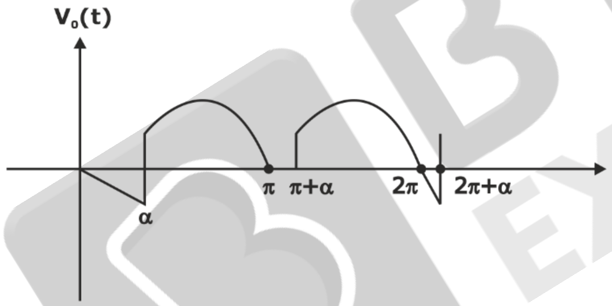


[NAT]

Ans. 39.79

Sol.





$$V_0(t)_{avg} = \frac{1}{2\pi}\left[\int_{\alpha}^{\pi} V_m \sin\omega t\, d(\omega t) + \int_{\pi+\alpha}^{2\pi+\alpha} -V_m \sin\omega t\, d(\omega t)\right]$$

$$\frac{V_m}{2\pi}\left[1+\cos\alpha+\cos\alpha+\cos\alpha\right] = \frac{V_m}{2\pi}\left[1+3\cos\alpha\right]$$

$$V_0(t) = \frac{100}{2\pi}\left(1+\frac{3}{2}\right) = 39.79\,\text{volt}$$

11. The chopper circuit shown in fig. (i) feeds power to a 5A DC constant current source. The switching frequency of chopper is 100 kHz. All the components can be assumed to be ideal. The gate signals of switches S_1 & S_2 are shown in fig. (ii). Average. voltage across the 5 A current source is

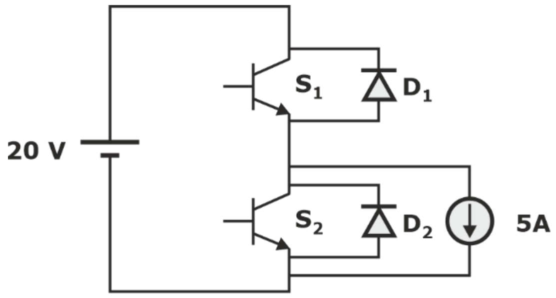


Fig. (i)

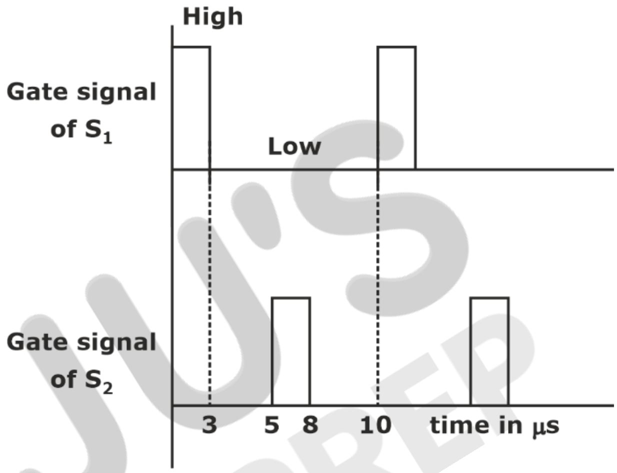


Fig. (ii)

[NAT - 2 Marks]

Ans. 6

Sol.

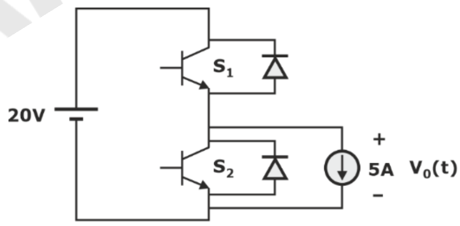
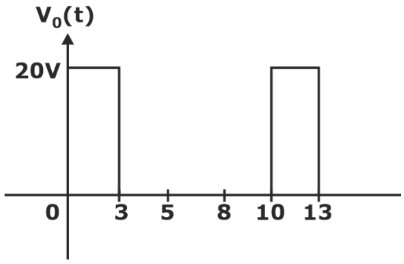
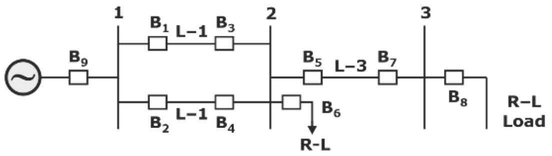


Fig. (i)



$$V_0(t)_{avg} = \frac{(20)(3)}{10} = 6\,\text{volt}$$

12. For the three bus powers system shown in the figures, the trip signal to the circuit breaker km B_2 to B_3 are provided by over current relay R_1 to R_9 respectively. Some of protected for short circuit fault at any part of the system d/w bus 1 and R-L load with isolation of minimum portion of the network using minimum numbers of directional relays is



[MCQ - 2 Marks]

A. R_3 and R_4 are directional over currents relays blocking fault toward bus 2 and R_7 is direction overcurrent relay blocking faults towards bus 3.

B. R_3 and R_4 are directional overcurrent relays blocking fault towards line 1 and line 2 respectively.

C. R_3 and R_4 are directional overcurrent relays blocking fault toward line 1 and line 2.

D. R_3 and R_4 are directional overcurrent relays blocking fault toward line 1 and line 2 Respectively R_7 is directional overcurrent relay blocking faults towards line 3 and R_5 is direction overcurrent relay blocking fault towards bus 2.

[MCQ - 1 Marks]

Ans. C

Sol. Relays which see the current reversal in case of fault should be directional relays.

Also in case of a fault in a line section.

The relay toward the generation side should respond first.

13. A 50Hz, 275 kV line of length 400 km has the following parameter, R = 0.035 Ω/km, L = 1mH/km + 11km; C = 0.01 μF/km the line is represented by nominal-π model with the magnitude of sending end and receiving end voltages of line (directed by V_S and V_R respectively) maintained at 275 kV, the phase angle difference θ between V_S and V_R required for maximum possible active power to be delivered to the receiving end in degree is _____ (rounded off to 2 decimal places)

[NAT - 1 Marks]

Ans. 83.64

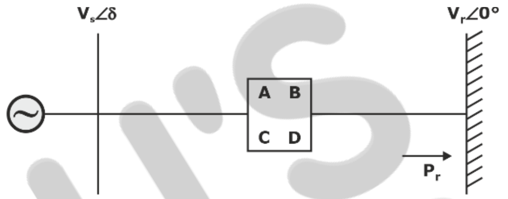
Sol. R = 0.035 r/km

L = 1 mH/km

Nominal -π matter

$|V_s| = |V_r| = 275$ kV

For P_{max}, $\delta = \beta$



$$P_r = \frac{|V_s||V_r|}{|B|}\cos(\beta-\delta) - \frac{|A|}{|B|}|V_n|^2\cos(\beta-\alpha)$$

$$\delta = \theta = \tan^{-1}\frac{125.6}{14}$$

$$= \tan^{-1}(8.97)$$

$\delta = q = 83.638°$

14. The bus admittance (Y_{bus}) matrix of a 3-bus power system is given below:

$$\begin{array}{c} 1 \\ 2 \\ 3 \end{array}\begin{bmatrix} -j15 & j10 & j5 \\ j10 & -j13.5 & j4 \\ j5 & j4 & -j8 \end{bmatrix}$$

Consider that there is no shunt inductor connected to any of the buses, which of the following can not be true?

A. Line charging capacitor of finite value present in line 2-3 only.

B. Line charging capacitor of finite value present in line 2-3 only and shunt capacitor of finite value present in bus 1 only.

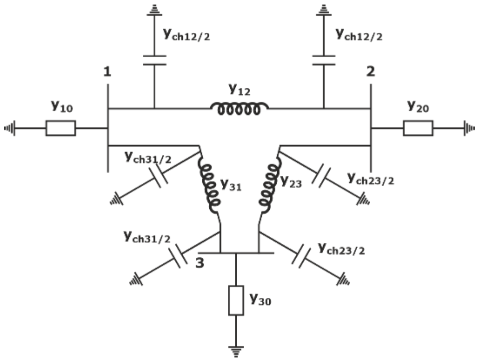
C. line charging capacitor presenting all 3 lines

D. Line charging capacitor of finite value present in line 2-3 only and shunt capacitor of finite value present in bus 3 only.

[MCQ - 2 Marks]

Ans. B, C, D

Sol. Let all buses have shunt capacitors and all lines have all charging capacitance.



$y_{12} = -y_{12} = j_{10} \Rightarrow y_{12} = -j_{10}$

$y_{31} = -y_{31} = j_5 \Rightarrow y_{31} = -j_5$

$y_{23} = -y_{23} = j_4 \Rightarrow y_{23} = -j_4$

$y_{11} = y_{10} + y_{ch12/2} + y_{ch31/2} + (-j_{10}) + (-j_5)$

$= -j_{15}$

$y_{10} + y_{ch12/2} + y_{ch31/2} = 0$

$y_{ch12/2} + y_{ch31/2} = -y_{10}$

Shunt element should be inductor which is not possible.

Hence, $y_{ch12/2}$ and $y_{ch31/2}$ should be zero.

$y_{22} = y_{20} + y_{12} + y_{23} + y_{ch12/2} + y_{ch23/2} =$

$-j13.5$

$y_{ch12/2} + y_{ch23/2} + y_{20} = j0.5$

$y_{ch23/2} + y_{20} = j0.5$

Bus 2 will have some shunt capacitor and line 2-3 will have some line charging capacitance.

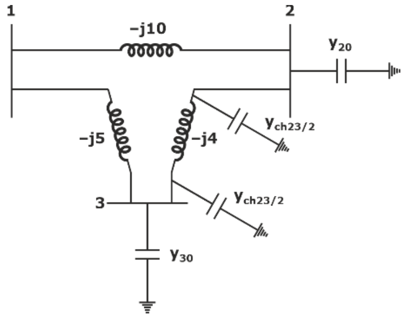
$y_{33} = y_{30} + y_{13} + y_{23} + y_{ch23/2} + y_{ch31/2} =$

$-j8$

$y_{30} + y_{ch23/2} + y_{31/2} + (-j5) + (-j4) = j8$

$y_{30} + y_{ch23/2} + y_{31/2} = j1$

Similarly, bus 3 have same shunt capacitance and line 2-3 will have line charging capacitance.



$y_{20} + y_{ch23/2} = j0.5$

$y_{30} + y_{ch23/2} = j1$

These two equations have infinite solutions.

15. The expressions of fuel cost of two thermal generating units as a function of the respective power generation P_{G1} & P_{G2}

$(P_{G1}) = 0.1\ a\ P^2_{G1} + 40\ P_{G1} + 120$ Rs/hr

$0\ MW \le P_{G1} \le 350\ MW$

$F_2\ (P_{G2}) = 0.2\ P_G^2 + 30\ P_{G2} + 100$ Rs/hr

$0\ MW \le P_{G2} \le 350\ MW$

Where 'a' is a constant. For the given value of 'a' optimal dispatch requires P_{G1} = 175 MW & P_{G2} = 115 MW. With the load remaining unchanged, The value of 'a' increased by 10% and optimal dispatch is carried out. The changes in P_{G1} & the total cost of generation, $F = (F_1 + F_2)$ in Rs/hr will be as follows.

A. Both P_{G1} & F will increase

B. P_{G1} will decrease & F will increase

C. P_{G1} will increase & F will decrease

D. Both P_{G1} & F will decrease

[MCQ - 2 Marks]

Ans. B

Sol.

$$0 \leqslant P_{G1} \leqslant 350\,MW$$

$$F_1\left(P_{G_1}\right) = 0.1aP_{G1}^2 + 40P_{G1} + 120R_s / hr$$

$$F_2\left(P_{G2}\right) = 0.2P_{G_2}^2 + 30P_{G2} + 100R_s / hr$$

$$0 \leqslant P_{G1} \leqslant 350\,MW$$

$$a\begin{cases} P_D = 290, P_{G1} = 175\,MW \\ \qquad\qquad P_{G2} = 115\,MW \end{cases}$$

$$a' = 1.1a\begin{cases} P_D = 290, \; P_{G1} = ? \\ \qquad\qquad\; P_{G2} = ? \end{cases}$$

Changes in P_G, and total cost of generation

$F(F_1 + F_2)$

$$\frac{dF_1}{dPG_1} = 0.2a'P_{G_1} + 40$$

$$\frac{dF_2}{dP_{G2}} = 0.4P_{G2} + 30$$

$$\frac{dF_1}{dP_{G_1}} = \frac{dF_2}{dP_{G_2}}$$

$$0.2aP_{G_1} + 40 = 0.4P_{G_2} + 30$$

$$(0.2 \times 175)a + 40 = 0.4 \times 115 + 30$$

$$a = \frac{36}{0.2 \times 175} = 1.028$$

$a' = 1.013$

$0.2 \times 1.13\ P_{G1} + 40 = P_{G2} + 30$

$P_{G1} + P_{G2} = 290$

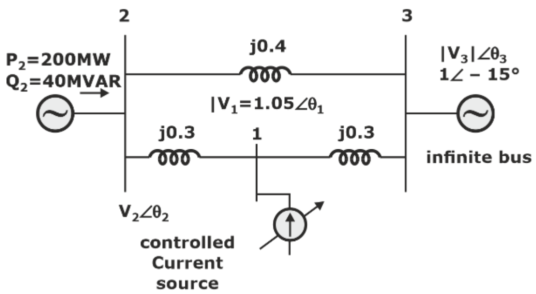
$0.626\ P_{G1} + 10 = 0.4\ (290 - P_{G1})$

$P_{G1} = 169.329$ MW

$P_{G2} = 120.67$ MW

Hence, P_{G1} decreases and F is increase.

16. The three bus power system shown in the figure has one alternator connected to bus 2 , which supplies 200 MW and 40 MVAR power. Bus 3 is infinite bus having a voltage magnitude $|V_3| = 1.0$ pu and angle of $-15°$. A variable current source, $|I| \angle\phi$ is connected as bus 1 and controlled such that the magnitude of bus 1 voltage is maintained at 1.05 pu and phase angle of source current $\phi = \theta_1 \pm \pi/2$, where θ_1, is the phase angle of bus 1. Voltage the three buses can be categorized for load flow analysis as:



A. Bus 1 - slack bus, Bus 2 PV bus, Bus 3 PQ bus

B. Bus 1 - PV Bus, Bus 2 - PQ bus, Bus 3 - Slack bus

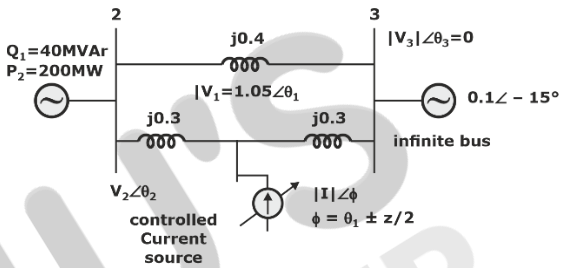
C. Bus 1 - PQ bus, Bus 2 - PQ bus, Bus 3 – Slack bus

D. Bus 1 - PV bus, Bus 2 - PV bus, Bus 3 - Slack bus

[MCQ - 1 Marks]

Ans. B

Sol.



BUS – 1 = PV bus

BUS – 2 = PQ bus

BUS – 3 = sluck bus

PV Bus is a bus which has at least one generator connected and if there is additional voltage control capability its called a special PV Bus. Bus 1 is voltage controlled bus.

Bus- 2 has real and reactive power specified, hence, it is a PQ bus.

Bus 3 is infinite bus. Where voltage magnitude and phase angle is specified hence it is a slack bus.

17. The two bus power system shown in the figure (i) has alternator supplying a synchronous motor load through y-Δ transformer, the positive negative and zero sequence diagram of the system shown in figure (ii), (iii) and (iv) respectively. All reactance in the sequence diagrams are in pu for a bolted line to line fault (fault impedance = 0) between phase b and c at bus 1 neglecting all prefault current the magnitude of fault current (from phase b to c) in pu is ______.

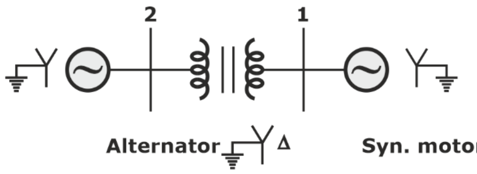


Fig. (1)

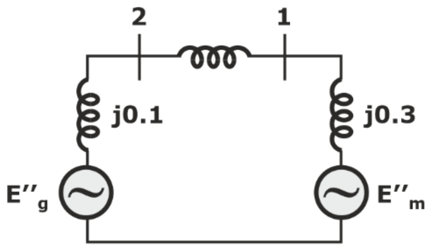


Fig. (2)

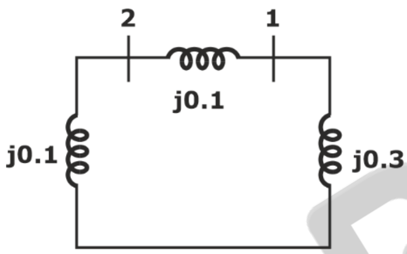


Fig. (3)

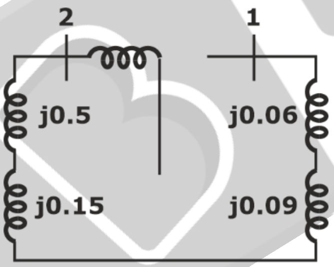


Fig. (4)

[MCQ - 2 Marks]

Ans. B

Sol. In case of line to line fault the ground is not involved, hence zero sequence will not be present.

$$I_f = \frac{-j\sqrt{3}E_a}{Z_{1eq} + Z_{2eq}}$$

$$Z_{1eq} = (j0.1 + j0.1) || j0.3$$

$$= \frac{j0.2 \times j0.3}{j0.2 + j0.3} = \frac{j0.06}{0.5} = j0.12\,\text{pu}$$

$Z_{2eq} = Z_{1eq} = j0.12$

Hence,

$$I_f = \frac{-j\sqrt{3} \times 1}{Z_{1eq} + Z_{2eq}}$$

$$= \frac{-j\sqrt{3} \times 1}{j0.12 + j0.12} = \frac{-j\sqrt{3}}{j0.24}$$

$I_f = 7.22$ pu

18. A 10 pole, 50 Hz, 240V, single phase induction motor runs at 540 rpm while driving rated load. The frequency of induced rotor currents due to backward field is

A. 95 Hz B. 5 Hz

C. 100 Hz D. 10 Hz

[MCQ - 2 Marks]

Ans. A

Sol. Given data of 1-φ induction motor.

$P = 10$

$f = 50$

$V = 240V$

$N_r = 540$ rpm

$f_r = ?$

$$N_s = \frac{120 \times 50}{10} = 600 \text{ rpm}$$

$f_r = s_b f$

$s_b = 2 - s_f$

$$s_f = \frac{N_s - N_r}{N_s} = \frac{600 \times 540}{600} = 0.1$$

$s_b = 2 - 0.1 = 1.9$

$\therefore f_r = 1.9 \times 50 = 95$Hz

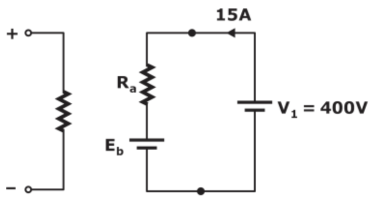
Option (A)

19. A separately excited DC motor rated 400V, 15A 1500 rpm drives a constant torque load at rated speed operating from 400V DC supply drawing rated current. The armature resistance is 1.2Ω. If the supply voltage drops 10% with field current unaltered then the resultant speed of the motor in rpm is____.

[NAT]

Ans. 1342.93

Sol.



Given separately excited motor

$N_1 = 1500$ rpm

$R_a = 1.2\Omega$

$E_{b1} = 400 - 15 \times 1.2 = 382$ Volts

If the voltage drops 10% and, I_f unchanged.

$V_2 = 400 \times 0.9 = 360$ Volts

$\therefore E_{b2} = 360 - I_{a2} \times 1.2$

Since, constant torque load, $T_2 = T_1$

$I_{a2} = I_{a1} = 15A$

$\therefore E_{b2} = 342$ Volts

$N \propto E_b$

$$\frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}}$$

$$\frac{N_2}{1500} = \frac{342}{382}$$

$N_2 = 1342.93$ rpm

20. The following column present various modes of induction machine operation and the range of slip.

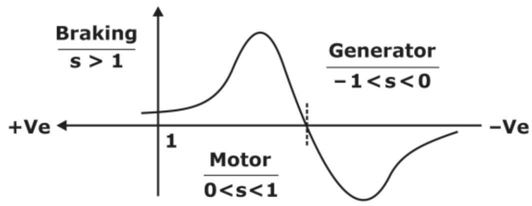
Column-A (Mode of Operation)		Column-B (Range of slip)	
a.	Running in generator mode	p.	From 0.0 to 1.0
b.	Running in motor mode	q.	From 1.0 to 2.0
c.	Plugging in motor mode	r.	From – 1.0 to 0.0

A. a-p, b-r, c-q
B. a-r, b-q, c-p
C. a-q, b-p, c-r
D. a-r, b-p, c-q

[MCQ - 2 Marks]

Ans. D

Sol. The operation range of slip of induction machine.



Option (D) is correct.

21. The four stator conductors (A, A′, B & B′) of a rotating m/c are carrying DC currents of the same value, the directions of which are shown in figure (i) The rotor coils a-a′ and b-b′ are formed by connecting the back ends of conductors a and a′ and b and b′, respectively, as shown in figure (ii) the emf induced in coil a-a′ and b-b′ are denoted by $E_{a-a'}$ and $E_{b-b'}$ respectively. If the rotor is rotated at uniform angular speed ω rad/s in the clockwise direction, then which of the following correctly describes the $E_{aa'}$ and $E_{bb'}$?

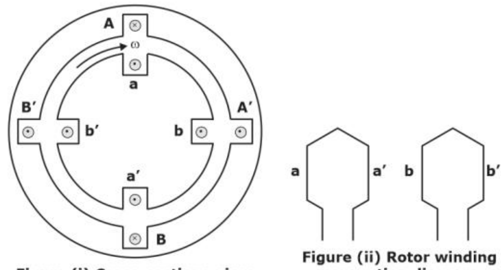


Figure (i) Cross-sectiona view
Figure (ii) Rotor winding connection diagram

A. $E_{aa'}$ and $E_{bb'}$ have finite magnitudes with $E_{aa'}$ leading $E_{bb'}$

B. $E_{aa'} = E_{bb'} = 0$

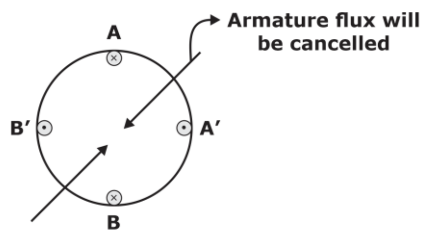
C. $E_{aa'}$ and $E_{bb'}$ have finite magnitudes and are in the same phase

D. $E_{aa'}$ and $E_{bb'}$ have finite magnitudes with $E_{bb'}$ leading $E_{aa'}$

[MCQ - 2 Marks]

Ans. B

Sol. The flux produced by armature coils will be cancelled and hence the EMF induced in the rotor coils will be zero.



22. A three phase 415V, 50 Hz, 6 pole, 960 rpm, 4 HP squirrel cage induction motor drives a constant torque load at rated speed operating form rated supply and delivering rated output. If the supply voltage and frequency are reduced by 20% the resultant speed of the motor in rpm (Neglecting the stator leakage impedance and rotational losses) ___.

[NAT]

Ans. 760 rpm

Sol. As voltage and frequency are reduced by 20%. The ratio of voltage to frequency is constant.

We know, $T_{e_m} = \frac{180}{2\pi N_s} \cdot \frac{SE_2^2}{R_2}$

$= \frac{180}{2\pi N_s} \cdot \frac{N_s - N_r}{N_s} \cdot \frac{E_2^2}{R_2}$

$T_{e_m} \propto \frac{E_2^2}{N_S^2}(N_s - N_r)$

$T_{e_m} \propto \underbrace{\left(\frac{v}{f}\right)^2}_{\text{Constant}}(N_s - N_r)$

$\therefore\ T_{e_m} \propto (N_S - N_r)$

Given constant torque load $T_2 = T_1$

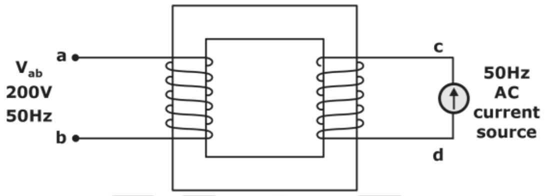
$(N_{s_2} - N_{r_2}) = (N_{s_1} - N_{r_1})$

$= \left(\frac{120 \times 50}{6} - 960\right)$

$= \left[\frac{120 \times 50 \times 0.8}{6} - N_{r_2}\right] = 40$

$N_{r_2} = 760$ rpm

23. When the winding c.d of the single phase, 50Hz, two winding transformer is supplied from AC current source of frequency 50Hz, the rated voltage of 200V (rms), 50Hz is obtained at open circuit terminal a-b. The cross-section area of core 5000 mm² and the average core length transferred by mutual flux is 500 mm. The maximum flux density in the core B_{max} = 1 Wb/m² and the relative permeability of the core material is 5000. The leakage impedance of winding a-b and winding c-d at 50Hz are (5 + j100π × 0.16)Ω and (11.25 + j100π × 0.36)Ω respectively. Considering the magnetizing characteristics to be linear and neglect core loss. The self-inductance of winding a-b in millihenry is ___. (round of 1 decimal places).



[NAT]

Ans. 2.038 Henries

Sol. $E_1 = 4.44 \times f \times \varphi \times N_1$

$E_1 = 4.44 \times f \times B \times A \times N_1$

$200 = 4.44 \times 50 \times 1 \times 5000 \times 10^{-6} \times N_1$

$N_1 = 180.18$ turns

$L_1 = \frac{N_1^2}{\text{Reluctance}} = \frac{N_1^2}{\frac{l_c}{\mu_0\mu_r A}}$

$= \frac{(180.18)^2}{\frac{500 \times 10^{-3}}{4\pi \times 10^{-7} \times 5000 \times 5000 \times 10^{-6}}}$

$L_1 = 2.038$

24. A 3-φ synchronous motor with synchronous impedance of 0.1 + j0.3 per unit per phase has a static stability limit of 2.5 pu. The corresponding excitation voltage in pu is ______ (round off to 2 decimal places).

[NAT]

Ans. 0.4875

Sol. For synchronous motor

$(P_{in})_{max} = \frac{\varepsilon_f V_t}{|z|} + \frac{V_t R}{|z|^2} = 2.5$

$(P_{in})_{max} = 2.5$

$Z_s = 0.1 + j(0.3)$

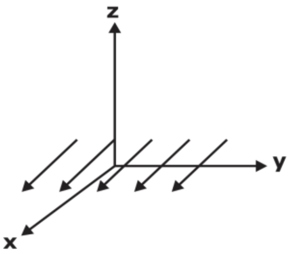
$|Z_s| = \sqrt{0.1^2 + 0.3^2} = 0.32$

$V_t = 1PU$

$$\frac{(\varepsilon_f)(1)}{0.32} + \frac{(1)(0.1)}{(0.32)^2} = 2.5$$

$\varepsilon_f = 0.4875$

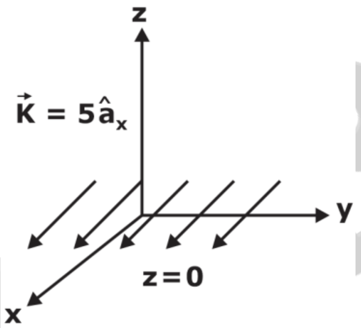
25. At z = 0 surface current sheet is placed with $\vec{K} = 5\hat{a}_x$ A/m, then the magnitude of magnetic field in intensity at (1, 1, 1) is _____.



[NAT]

Ans. +2.5 mA

Sol.



Magnetic field due to infinite charge sheet is given by

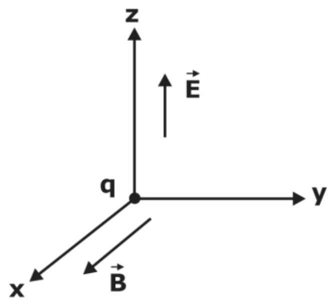
$$\vec{H} = \frac{1}{2}(\vec{K} \times \hat{a}_n)$$

$$= \frac{1}{2}(5\hat{a}_x \times \hat{a}_z)$$

$$= -2.5\,\hat{a}_y$$

Magnitude of $\vec{H}$ will be +2.5 A/m.

26. In the figure, the electric field E and magnetic field B pointed in x and z direction respectively and have constant magnitude. A positive charge 'q' is released from rest from the origin. Which of the following statements is/are correct?



A. The trajectory of the charge will be a circle

B. The charge will progress in the direction of y

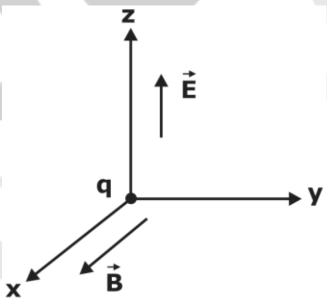
C. The charge will always move on the y-x plane

D. The charge will move in the direction z with constant velocity

[MSQ - 2 Marks]

Ans. B, C

Sol.



Charge is at rest $\vec{V} = 0$

Force on charge due to electric field,

$\vec{F}_E = q\vec{E}$

Force on charge due to magnetic field

$\vec{F}_M = q(\vec{V} \times \vec{B}) = 0$

So, the charge will move the direction of electric field

$\vec{F}_E = ma \neq 0$

$a \neq 0$

$$\frac{dv}{dt} \neq 0$$

The charge will move in direction of z.

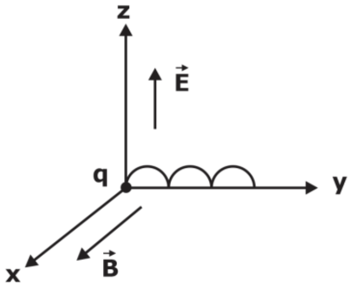
since now the charge is moving, magnetic field will also exist

i.e. $\vec{F}_M = q(\vec{V} \times \vec{B})$

$= q(V\, q(V_0\hat{a}_z \times B_0\hat{a}_x)$

$= qV_0B_0\hat{a}_y$

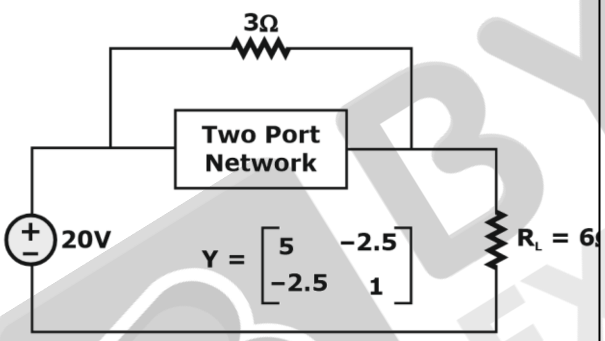
Because of magnetic field it will follow cycloid path in the direction of y.



The charge will move in the x-y plane.

B, C are correct.

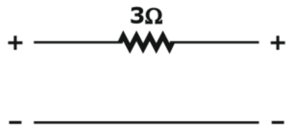
27. Y parameter of linear circuit is given, the power dissipation across load resistor is _______ watt?



[MCQ - 2 Marks]

Ans. 242.69

Sol. For network

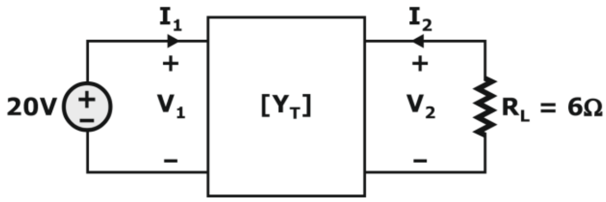


$$[y'] = \begin{bmatrix} 1/3 & -1/3 \\ -1/3 & 1/3 \end{bmatrix}$$

Total y-parameter;

$$[Y_T] = [Y'] + [Y] = \begin{bmatrix} \frac{1}{3} & \frac{-1}{3} \\ \frac{-1}{3} & \frac{1}{3} \end{bmatrix} + \begin{bmatrix} 5 & -2.5 \\ -2.5 & 1 \end{bmatrix}$$

$$[Y_T] = \begin{bmatrix} 5.3 & -2.8 \\ -2.8 & 1.3 \end{bmatrix}$$



$V_1 = 20$ ... (1)

$V_2 = -6I_2$ ... (2)

Also,

$I_1 = 5.3\,V_1 - 2.8V_2$ ... (3)

$I_2 = -2.8V_1 + 1.3V_2$ ... (4)

Put equation 2 in 4

$I_2 = -2.8V_1 + 1.3 \times (-6I_2)$

$8.8\, I_2 = -2.8\, V_1$

$$I_2 = \frac{-2.8}{8.8} \times 20$$

$I_2 = -6.36$ A

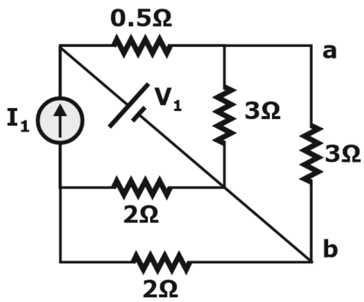
$P = I_2^2\, R_L$

$P = (6.36)^2 \times 6$

$P = 242.69$ W

28. $I_1 = 8A\ V_1 = 8V$

$V_{ab} = ?$



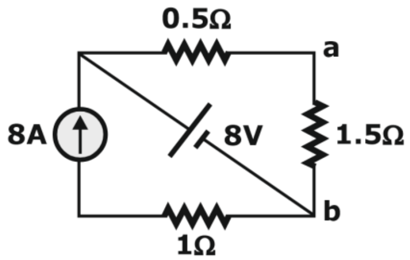
[MCQ - 2 Marks]

Ans. 6

Sol. → 2Ω resistor are in parallel

→ 3Ω resistor are in parallel

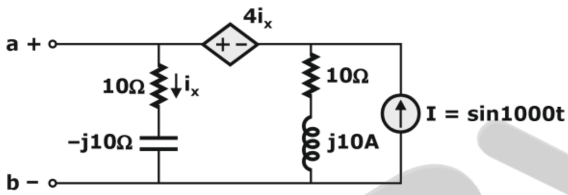
After simplifying,



By voltage division rule

$$V_{ab} = \frac{8 \times 1.5}{0.5 + 1.5} = 6A$$

29. For the circuit shown, if i = sin1000t, the instantaneous value of the Thevenin's equivalent voltage (circuit) across the terminal a – b at time t = 5 ms _______ ? (2 decimal)



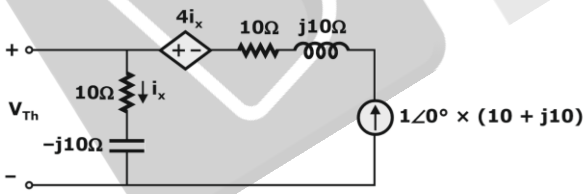
[MCQ - 2 Marks]

Ans. –11.98

Sol. I = sin (1000t)

$= 1\angle 0°$ A

By source transformation,



By KVL,

$-(10 + j10) + (10 + j10 + 10 - j10) I_x - 4I_x = 0$

$16I_x = 10 + j10$

$$I_x = \frac{10 + j10}{16}$$

$v_{Th} = I_x(10 - j10)$

$$V_{Th} = \frac{10 + j10}{16} \times (10 - j10)$$

$$V_{Th} = \frac{200}{16} V$$

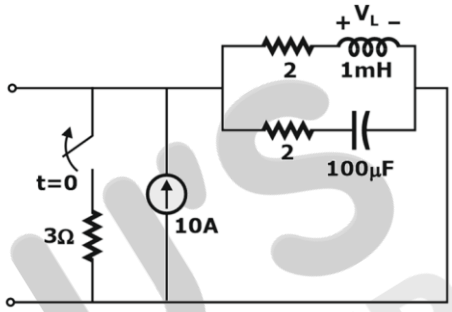
$$V_{Th} = \frac{200}{16} \sin(1000t)$$

By t = 5 ms,

$$V_{Th} = \frac{200}{16} \sin(5)$$

V_{Th} = –11.98 V

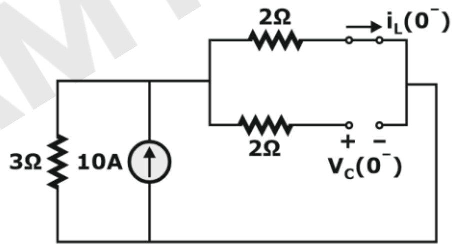
30. Find V_L at t = 0^+?



[NAT]

Ans. 8

Sol. For t = 0^-; inductor behaves as short circuit capacitor behaves as open circuit

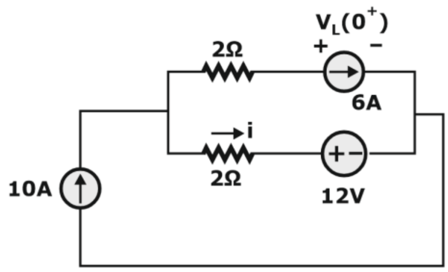


By current division rule,

$$i_L(0^-) = \frac{10 \times 3}{3 + 2} = 6A$$

$V_C(0^-) = 2 \times i_L(0^-) = 2 \times 6 = 12V$

At = 0^+



$V_C(0^+) = V_C(0^-) = 12V$

$i_L(0^+) = i_L(0^-) = 6A$

i = 10 – 6 (KCL)

$i = 4A$

By KVL,

$2 \times i + 12 - V_L(0^+) - 2 \times 6 = 0$

$V_L(0^+) = 2 \times 4 = 8V.$

31. A signal $x(t) = 2\cos(180\pi t)\cos(60\pi t)$ is sampled at 200 Hz & then passed through an ideal low pass filter having cut-off frequency of 100 Hz. The max frequency present in the filtered signal in Hz is ________ (round off to nearest integer)

[NAT]

Ans. 80

Sol. $x(t) = 2\cos(180\pi t).\cos(60\pi t)$

$f_s = 200$ Hz

$x(t) = \cos(240\pi t) + \cos(120\pi t)$

$f_c = 100$ Hz

$f_1 = 120$ Hz $f_2 = 60$ Hz

$nf_s \pm f_m$

$200n \pm 120$	$200n \pm 60$
n = 0 : 120Hz	n = 0; 60 Hz
n = 1 : 320, 80Hz	n = 1; 260, 140Hz

maximum frequency component at output = 80 Hz

32. The Z-transform of a discrete signal x[n] is

$$X(z) = \frac{4z}{\left(z-\frac{1}{5}\right)\left(z-\frac{2}{3}\right)(z-3)} \text{ with ROC} = R$$

Which one of the following statements is true?

A. DTFT of x[n] converges if R is such that x[n] is a right-sided sequence.

B. DTFT of x[n] converge if R is 2/3 < |Z| < 3

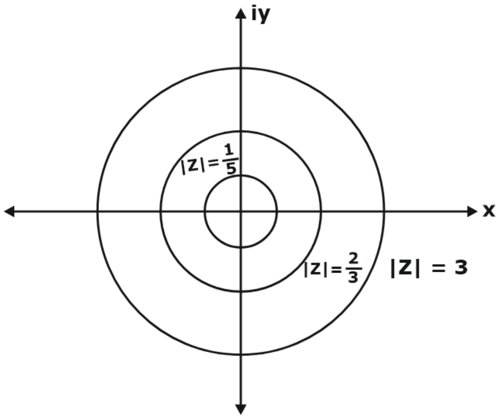
C. DTFT of x[n] converge if R is |Z| > 3

D. DTFT of x[n] converge if R is such that x[n] is a left-sided sequence

[MCQ]

Ans. B

Sol. $Z = \frac{1}{5}, Z = \frac{2}{3}, Z = 3$



For this ROC : $\frac{2}{3} < |Z| < 3$

System is stable as it includes unit circle |Z| = 1

also, DTFT will coverage for this R.O.C.

33. The Fourier transform $X(\omega)$ of the signal x(t) is given by

$X(\omega) = 1$, for $|\omega| < \omega_0$

$X(\omega) = 0$, for $|\omega| > \omega_0$

Which one of the following statements are true?

A. x(0) decrease as ω_0 increase

B. x(t) tends top be an impulse as $\omega_0 \to \infty$

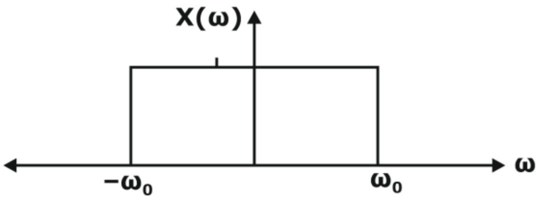
C. At $t = \frac{\pi}{2\omega_0}$, $x(t) = -\frac{1}{\pi}$

D. At $t = \frac{\pi}{2\omega_0}$, $x(t) = \frac{1}{\pi}$

[MCQ]

Ans. B

Sol. $X(\omega) = \begin{cases} 1 & ; |\omega| < \omega_0 \\ 0 & ; |\omega| > \omega_0 \end{cases}$



$$X(\omega) = \text{rect}\left(\frac{\omega}{2\omega_0}\right)$$

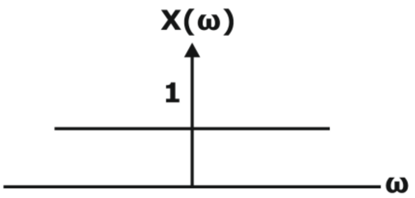
$$x(t) = F^{-1}\{X(\omega)\} = \frac{\sin(\omega_0 t)}{\pi t}$$

(i) $\because\ x(0) = \frac{1}{2\pi}\int_{-\omega_0}^{\omega_0} |X(\omega)|^2 \cdot d\omega$

$$x(0) = \frac{1}{2\pi}\int_{-\omega_0}^{\omega_0} 1 \cdot d\omega = \frac{2\omega_0}{2\pi} = \frac{\omega_0}{\pi}$$

as ω_0 increase then x(0) also increase

(ii) As $\omega_0 \to \infty$ x(t) = impulse signal

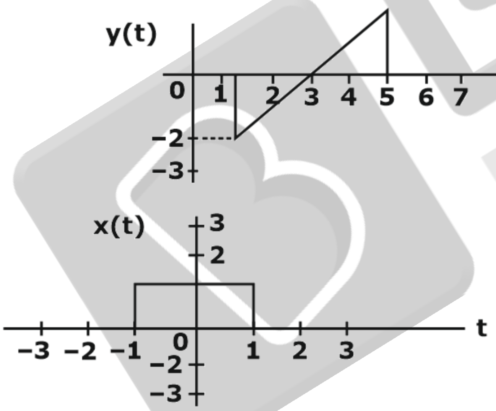


(iii) at

$$t = \frac{\pi}{2\omega_0} \Rightarrow x(t) = \frac{\sin\left(\omega_0 \frac{\pi}{2\omega_0}\right)}{\pi \cdot \frac{\pi}{2\omega_0}} = \frac{2\omega_0}{\pi^2}$$

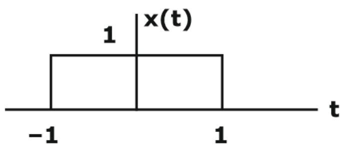
34. For the signals x(t) & y(t) shown in the fig., Z(t) = x(t) * y(t) is max at T_1. Then T_1 in seconds is ___________ (round off to the nearest integer).

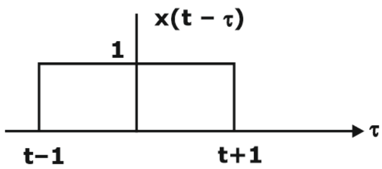
[NAT]

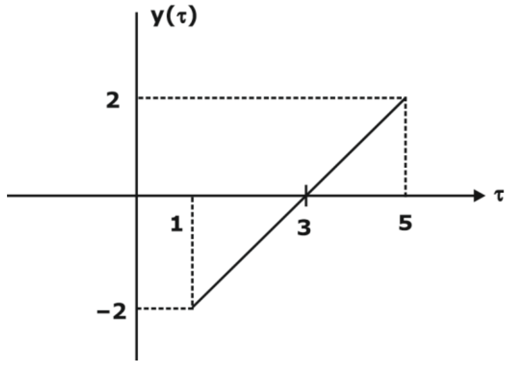


Ans. 4

Sol. Z(t) = x(t) * y(t)







By observation,

Z(t) will be maximum when

t + 1 = 5

t = 4

$\therefore$ for T_1 = t = 4

35. Which of the following statements are true

A. The impulse response 0 < |h[n]| < 1, for all n, then the LTI system is stable.

B. It a discrete time LTI system has an impulse response h(n) of finite duration the system is stable.

C. If an LTI system is casual it is stable

D. A discrete time LTI system is casual and only if its response to a step input u(n) is 0 for n < 0

[MCQ - 2 Marks]

Ans. D

Sol. If h[n] = 0 for n < 0

System is causal

36. The period of discrete time signal x[n] describe by the equation below is

N = ________ Round of to nearest integer

$$x[n] = 1 + 3\sin\left(\frac{15\pi}{8}n + \frac{3\pi}{4}\right)$$
$$-5\sin\left(\frac{\pi}{3}n - \frac{\pi}{4}\right)$$

[MCQ - 2 Marks]

Ans. 48

Sol. $x[n] = 1 + 3\sin\left(\frac{15\pi}{8}n + \frac{3\pi}{4}\right) - 5\sin\left(\frac{\pi}{3}n - \frac{\pi}{4}\right)$

(1) $\Omega_1 = \frac{15\pi}{8}$

$$N_1 = \left(\frac{2\pi}{\Omega_1}\right)\cdot k$$

$$N_1 = \left(\frac{2\pi}{\left(\frac{15\pi}{8}\right)}\right)\cdot k$$

for k = 15

$N_1 = 16$

(2) $\Omega_2 = \frac{\pi}{3}$

$$N_2 = \left(\frac{2\pi}{\Omega_2}\right)\cdot k$$

$$N_2 = \left(\frac{2\pi}{\left(\frac{\pi}{3}\right)}\right)\cdot k$$

$N_2 = 6.k$

For k = 1

$N_2 = 6$

N = LCM (16, 6) = 48

37. For a given vector W = $[1, 2, 3]^T$ the vector normal to the plane defined by $W^Tx = 1$ is

A. $[3, 0, -1]^T$
B. $[1, 2, 3]^T$
C. $[-2, -2, 2]^T$
D. $[3, 2, 1]^T$

[MCQ - 1 Mark]

Ans. B

Sol. $W = \begin{bmatrix}1 & 2 & 3\end{bmatrix}^T = \begin{bmatrix}1\\2\\3\end{bmatrix}$

Let $x = \begin{bmatrix}x\\y\\z\end{bmatrix}$

$\therefore W^T.x = 1$

$$\begin{bmatrix}1 & 2 & 3\end{bmatrix}\begin{bmatrix}x\\y\\z\end{bmatrix} = 1$$

$x + 2y + 3z - 1 = 0$

Let $\varphi = x + 2y + 3z - 1$

$\bar{\nabla}\phi = \hat{i} + 2\hat{j} + 3\hat{k}$

Normal vector to plane $\varphi = [\ 1\ 2\ 3]^T$

38. The following differential equation the numerically obtained value of y(t) at t = 1V is ___________

$$\frac{dy}{dt} = \frac{e^{-at}}{2 + at},\ a = 0.01 \text{ and } y(0) = 0$$

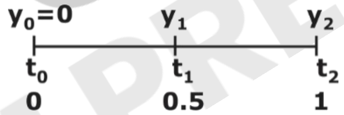
[NAT]

Ans. 0.7462

Sol. $\frac{dy}{dt} = \frac{e^{-at}}{2 + at},$

a = 0.01

$y_0 = 0$



$y_1 = y_0 + hf(t_0, y_0)$

$$y_1 = 0 + 0.5\left(\frac{e^{\circ}}{2 + 0}\right) = \frac{1}{4} = 0.25$$

$y_1 = 0.25$

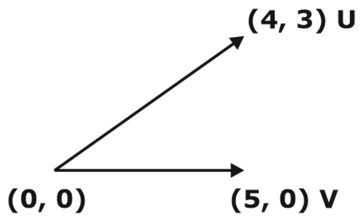
and $y_2 = y_1 + h\,f(t_1, y_1)$

$$y_2 = 0.25 + \frac{e^{-0.01\times 0.5}}{2 + 0.01 \times 0.5}$$

$y_2 = 0.7462 = y(1)$

39. In the figure the vector U and V are related as AU = V by a transformation matrix A.

The correct choice of A is



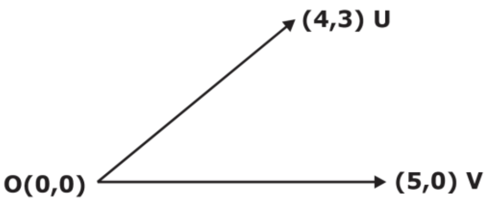
A. $\begin{bmatrix} 4/5 & -3/5 \\ 3/5 & 4/5 \end{bmatrix}$ B. $\begin{bmatrix} 4/5 & 3/5 \\ -3/5 & 4/5 \end{bmatrix}$

C. $\begin{bmatrix} 4/5 & -3/5 \\ 3/5 & -4/5 \end{bmatrix}$ D. None

[MCQ - 2 Marks]

Ans. B

Sol.



$\because$ AU = V

$\begin{bmatrix} a & b \\ c & d \end{bmatrix}\begin{bmatrix} 4 \\ 3 \end{bmatrix} = \begin{bmatrix} 5 \\ 0 \end{bmatrix}$

$4a + 3b = 5$ ...(1)

$4c + 3d = 0$ ...(2)

Checking with options

Option B satisfies equation (1) and (2)

40. Three points in x-y planes are (–1, 0.8), (0, 2.2) (1, 2.8). The value of the slope of the best fit straight line in the least square sense is (Round of two decimals places)

[NAT]

Ans. 1

Sol. x : –1 0 1
y : 0.8 2.2 2.8

$y = a + bx$

N.E.I $\Rightarrow \Sigma y = na + b\Sigma x$

N.E.2 $\Rightarrow \Sigma xy = a\Sigma x + b\Sigma x^2$

x	Y	xy	x^2
–1	0.8	–0.8	1
0	2.2	0	0
1	2.8	2.8	1
$\Sigma x = 0$	$\Sigma y = 5.8$	$\Sigma xy = 2$	$\Sigma x^2 = 2$

$3a + 0 = 5.8 \Rightarrow a = 1.933$

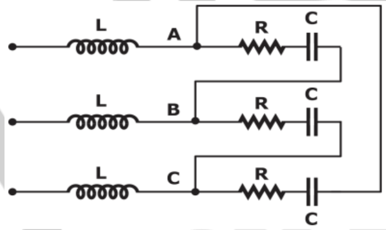
and $2 = 1.933 \times 0 + b \times 2$

$b = 1$

$y = 1.933 + x$

Slope = 1

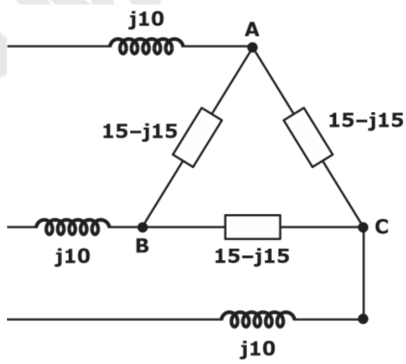
41. A balanced delta connected load consisting of the series connection of one resistor (R = 15Ω) and (C = 212.21μF) in each phase is connected to 3φ, 50Hz, 415V supply terminals through a line having on inductance of L = 31.83mH per phase shown in the figure. Considering the charge in the supply terminal voltage with loading to be negligible, the magnitude of the voltage across the terminals VAB in volts.



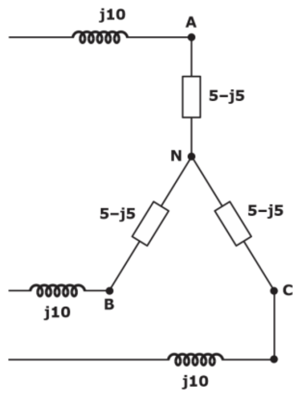
[NAT - 2 Marks]

Ans. A

Sol.



Equivalently we can represent it



Supply phase voltage = $\frac{415}{\sqrt{3}}\angle 0°$

Phase current = $\left[\dfrac{\frac{415}{\sqrt{3}}\angle 0^\circ}{5+j5}\right]$

$V_{AN} = \left[\frac{415}{\sqrt{3}}\angle 0^\circ - \left(\dfrac{\frac{415}{\sqrt{3}}\angle 0^\circ}{5+j5}\right)j10\right]$

$\frac{415}{\sqrt{3}}\angle 0^\circ - \frac{415\sqrt{2}}{\sqrt{3}}\angle -45^\circ = 239.6\angle 90°$

$V_{AN} = 239.6\sqrt{3}\angle 120^\circ$

$= 415\angle 120°$

Line voltage = 415 volts

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GATE 2023 Electrical Engineering: Expected Topper's Marks

- **85+/100 Marks Expected for AIR under 10**
- **77+/100 Marks Expected for AIR under 100**

GATE 2023 Electrical Engineering: Expected Cut-Off

Category	2021	2022	Expected 2023
General	30.3	30.7	26-28 Marks
OBC	27.2	27.6	23-25 Marks
SC/ST	20.2	20.2	16-18 Marks

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