WINTER – 2022 EXAMINATION

Subject Name: Control System and PLC. **Subject Code:** 22531

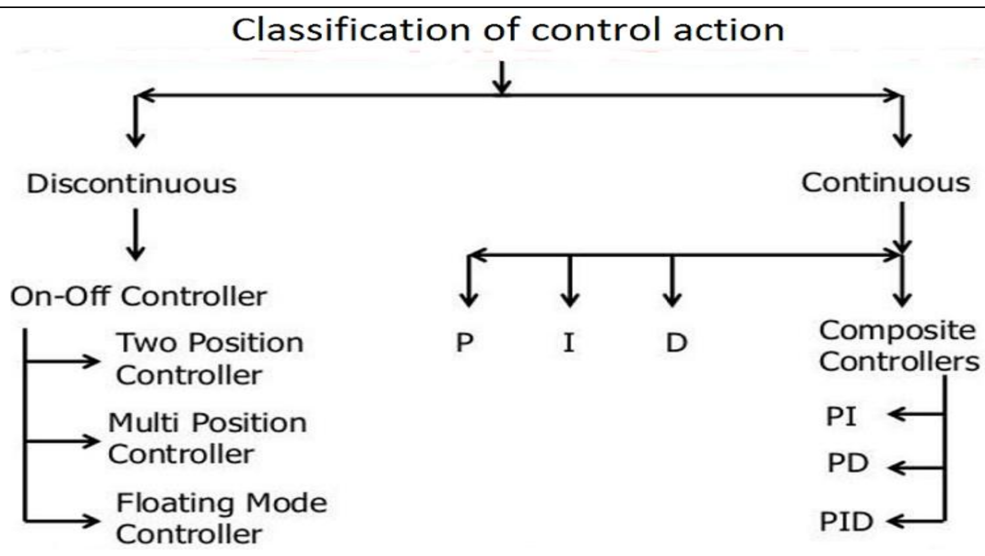
Model Answer

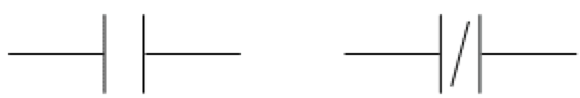
1

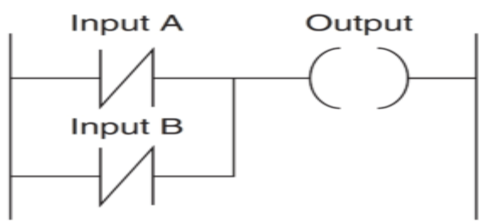
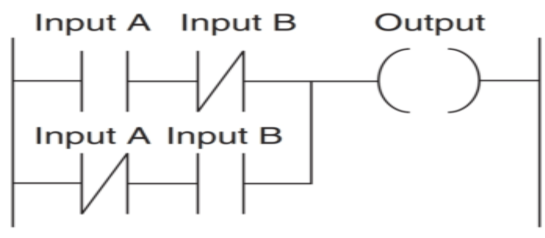
Important Instructions to examiners:

1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more Importance (Not applicable for subject English and Communication Skills.
4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner may give credit for any equivalent figure drawn.
5) Credits may be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer.
6) In case of some questions credit may be given by judgement on part of examiner of relevant answer based on candidate's understanding.
7) For programming language papers, credit may be given to any other program based on equivalent concept.
8) As per the policy decision of Maharashtra State Government, teaching in English/Marathi and Bilingual (English + Marathi) medium is introduced at first year of AICTE diploma Programme from academic year 2021-2022. Hence if the students in first year (first and second semesters) write answers in Marathi or bilingual language (English +Marathi), the Examiner shall consider the same and assess the answer based on matching of concepts with model answer.

Q. No.	Sub Q. N.	Answers	Marking Scheme
1	(A)	**Attempt any FIVE of the following:**	**10- Total Marks**
	(a)	**Define control system and give any two practical examples.**	**2M**
	Ans:	**Control system -** Control system is an arrangement of different physical elements connected in such a manner so as to regulate, direct, command itself or some other system. **Examples** – Traffic lights control system, Washing machine, Lamp, Temperature Control System.	**1M for definition and 1/2M for any example**

	(b)	**Define** **i) Transient response** **ii) Steady state response**	**2M**
	Ans:	**i) Transient response –** After applying input to the control system, output takes certain time to reach steady state. So, the output will be in transient state till it goes to a steady state. Therefore, the response of the control system during the transient state is known as **Transient response**. **Or** The output Variation during the time ,it takes to achieve its final value is called as Transient Response **ii) Steady state response** The part of the time response that remains even after the transient response has zero value for large values of 't' is known as **Steady state response**. Or It is the part of the time response which remains after complete transient response vanishes from the system output. This also can be defined as response of the system as time approaches infinity from the time at which transient response completely dies out.	**1M for each**
	(c)	**State the classification of control actions.**	**2M**
	Ans:		**Correct classification- 2M**

	(d)	**Draw the symbols of NO and NC contacts used in PLC.**	**2M**
	Ans:		**1M for each**
	e)	**List Timer and counter instruction of PLC.**	**2M**
	Ans:	Depending on the time delay and operation, the timers instruction are (i) ON delay timer (ii) OFF delay timer The Counter instructions are (i) Up Counter (ii) Down counter	**1M for each**
	f)	**Define** **i) Poles** **ii) Transfer function.**	**2M**
	Ans:	**Poles :** The values of 's' which makes the transfer function infinity after substitution in the denominator of a transfer function are called poles of the transfer function. **Transfer Function :** It is defined as the ratio of Laplace Transform of output of the system to Laplace Transform of input ,under the assumption that all initial conditions are zero. T(s) = **Laplace transform of output / Laplace transform of input** = C(s) / R(s)	**1M for each**
	g)	**Draw the ladder logic diagram** **i) NAND Gate.** **ii) EX-OR Gate**	**2M**

	Ans:	**NAND Gate.**  **EX-OR Gate** 	**1M each**

Q. No.	**Sub Q. N.**	**Answers**	**Marking Scheme**
2		**Attempt any <u>THREE</u> of the following:**	**12-Total Marks**
	a)	**For the give transfer function** **T.F. =** $\frac{10\,(S+3)}{(S+2)\,(S+1)\,(S+4)}$ **find** **i) Pole's** **ii) Zero's** **iii)Characteristics equations** **iv)Plot Pole's and Zero's in S-plain**	**4M**

Ans:

2 a)

$$T.F = \frac{10(s+3)}{(s+2)(s+1)(s+4)}$$

Poles are the values of s which makes denominator 0.

$s+2=0 \Rightarrow s=-2$

$s+1=0 \Rightarrow s=-1$

$s+4=0 \Rightarrow s=-4$

Poles are $\boxed{-2, -1 \text{ and } -4.}$

ii) Zeros are the values of s for which T.F becomes zero.

$s+3=0 \Rightarrow s=-3$

$\boxed{\text{Zero is } -3}$

iii) Characteristic equation

$(s+2)(s+1)(s+4)=0$

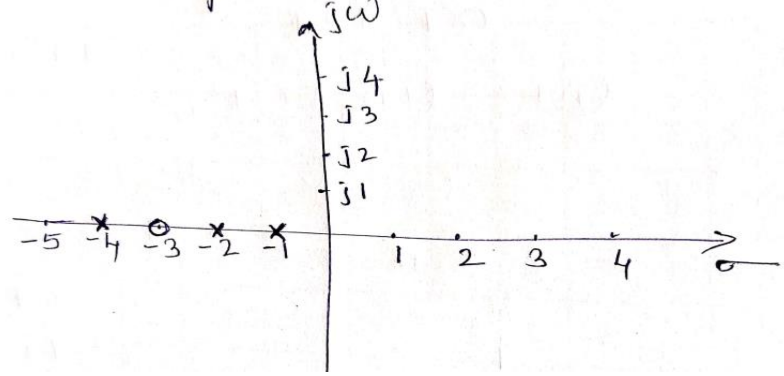
$(s^2+s+2s+2)(s+4)=0$

$(s^2+3s+2)(s+4)=0$

$s^3+4s^2+3s^2+12s+2s+8=0$

$\boxed{s^3+7s^2+14s+8=0}$

Plot in s plane



Each parameter 1M

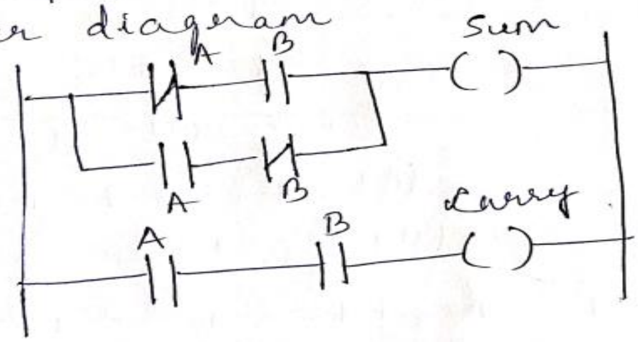
	b)	**State the need of PLC in automation**	**4M**
	Ans:	Need of automation is explained in following points: • To achieve complete control of the manufacturing process. • To achieve consistency in manufacturing. • To improve the product quality and accuracy. • To work in difficult or hazardous atmospheres like nuclear reactors etc. • PLC systems have less wiring and provide a very powerful tool for fault diagnosis. • Documentation can be easily saved in the memory provided in PLC. • To increase productivity. • To quickly change over from one product to another which provides flexibility. • To lower the cost, scrap and rework. • Reduced manpower, PLC systems require high skilled workers for supervision and maintenance. It reduces the requirement of low skilled workers. • Reduction in personal injury or accidents by adding safety interlocks. • Reduction in the cost of product. • Increased profit. • Modules can be easily replaced or upgraded. • In built software timers, counters, relays etc.	**Any 4 points 4M**
	c)	**Draw the ladder logic diagram** **i) Half Adder** **ii) Half Substractor.**	**4M**

Ans:

Half adder Truth Table

A	B	Sum	Carry
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

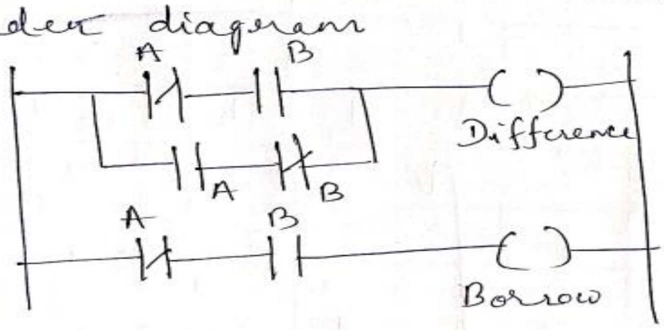
Ladder diagram



Half subtractor Truth Table

A	B	Difference	Borrow
0	0	0	0
0	1	1	1
1	0	1	0
1	1	0	0

Ladder diagram

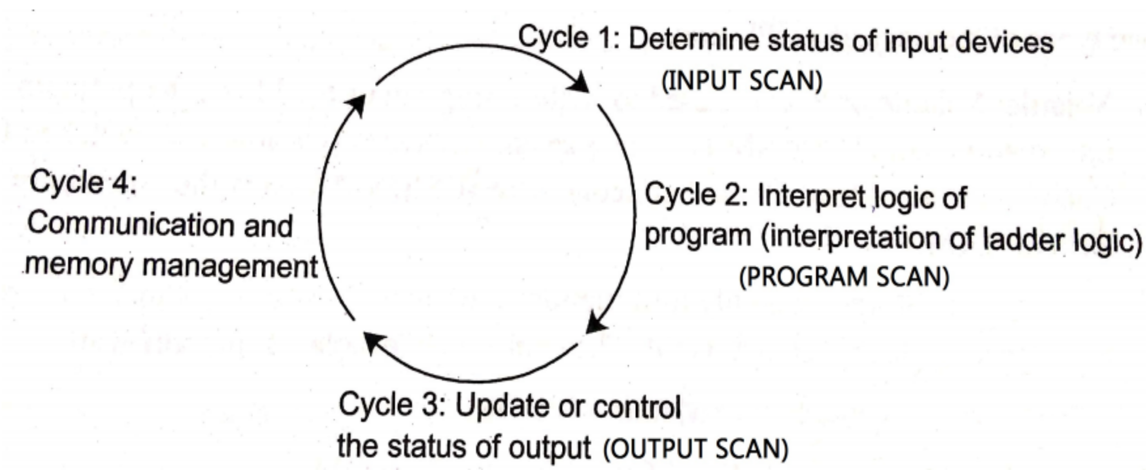


Half Adder 2M

Half Subtractor 2M

d) **Explain scanning cycle of PLC.** **4M**

	Ans:	The SCAN cycle consists of the series of sequential operations that includes the steps as shown in figure below.	**4 points** **4 M**



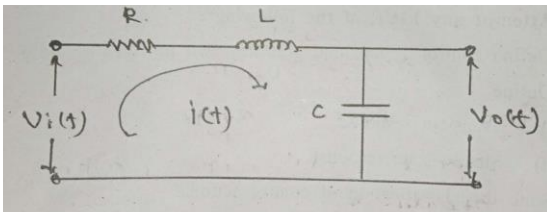
PLC Scanning cycle

• **Input Scan**: During the input scan, the processor scans the status of each input point which is stored in the Input status file by input module.

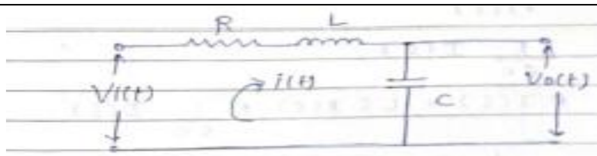
• **Program scan**: After the inputs are read and stored in the input status file, the processor uses this information to solve the user program. During program scan, the processor scans the user program starting at rung 0, from left to right, and evaluates one instruction at a time until output instruction is reached and till the end instruction.The logic ’1’ or ’0’ output states are then placed in the output status file.

• **Output scan**: During output scan processor writes the ON or OFF status of specific output point to the associated output module. Each output status word consists of ON or OFF electrical signals. There is an ON or OFF signal for each output point.

• **Communication and Memory management**: Communication includes updating the handheld programming device or PC monitor screen and sending signals to other PLC’s in the network. Memory management includes updating timers, counters, internal time base and other internal data files.

Q. No.	Sub Q. N.	Answers	Marking Scheme
3		**Attempt any THREE of the following:**	**12- Total Marks**
	a)	**Derive transfer function of following circuit** **Refer Fig.No1**  Fig. No. 1.	**4M**

Ans:



By applying KVL,

Apply KVL to input side,

$\therefore Vi(t) - Ri(t) - L\frac{di(t)}{dt} - \frac{1}{C}\int i(t)\,dt = 0$

By Laplace transform.

$\therefore Vi(s) - R\cdot I(s) - L\cdot s\cdot I(s) - \frac{1}{sC} I(s) = 0$

$$Vi(s) = R\cdot I(s) + LsI(s) + \frac{1}{sC} I s \quad \text{--- (1)}$$

1M

Apply KVL to output side,

$\therefore Vo(t) - \frac{1}{C}\int i(t)\,dt = 0$

By Laplace transform,

$\therefore Vo(s) - \frac{1}{sC} I(s) = 0$

$$\therefore Vo(s) = \frac{1}{sC} I s \quad \text{--- (2)}$$

1M

$TF = \frac{Vo(s)}{Vi(s)}$

$= \frac{\frac{1}{sC} I(s)}{R\cdot I(s) + LsI(s) + \frac{1}{sC} I(s)}$

1M

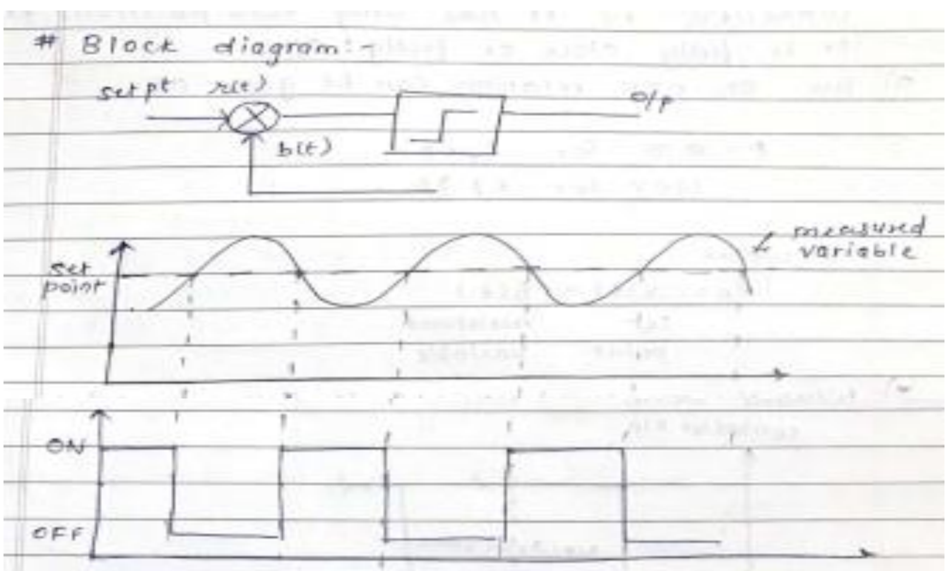
$= \frac{\frac{1}{sC} I(s)}{\left(R + Ls + \frac{1}{sC}\right) I(s)}$

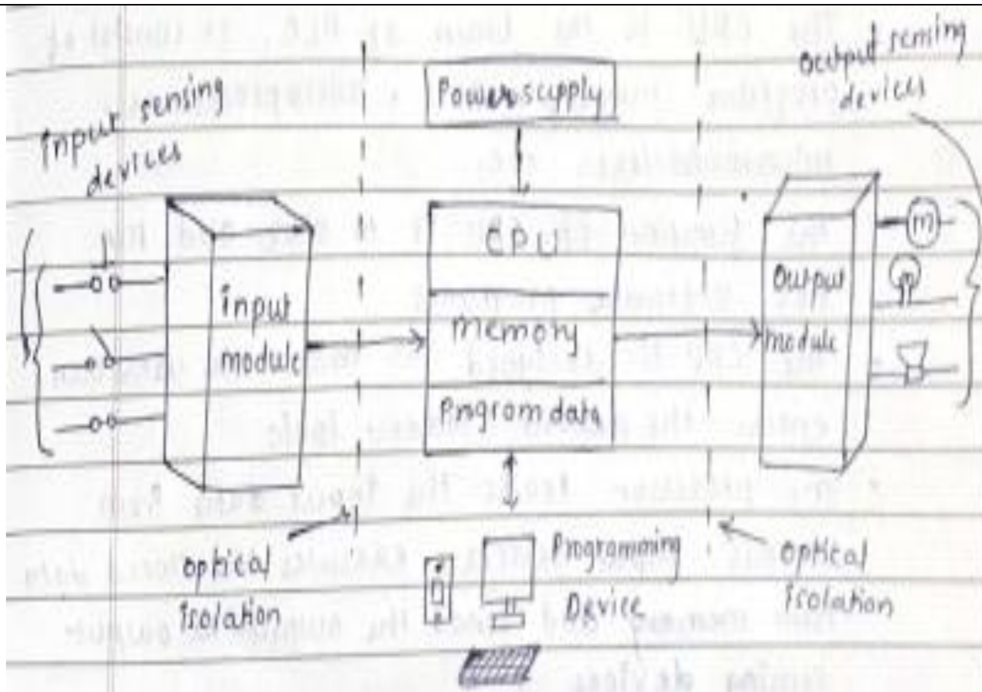
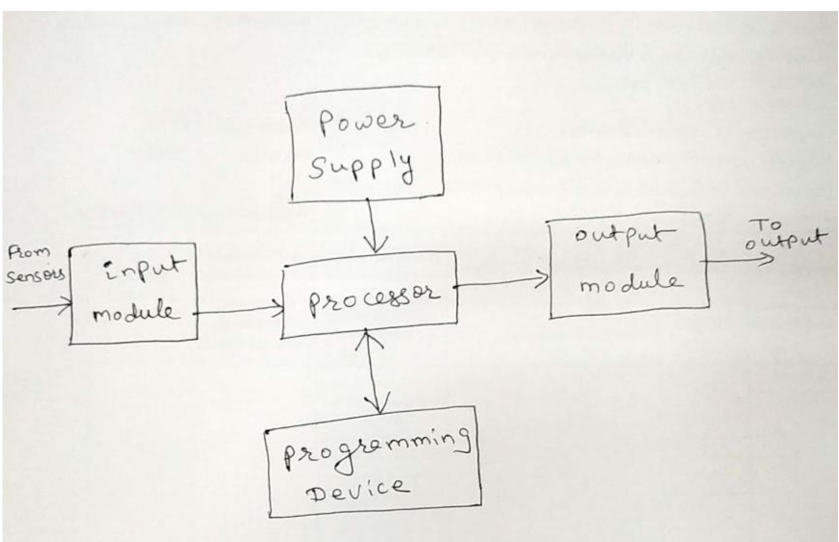
$= \frac{\frac{1}{sC}}{\frac{RsC + Ls^2C + 1}{sC}}$

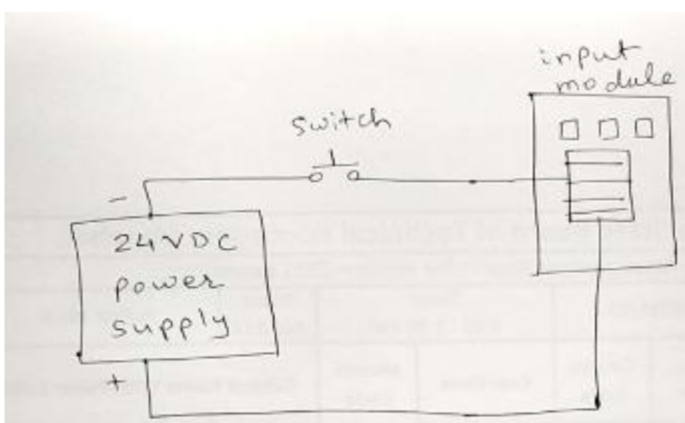
$$\frac{Vo(s)}{Vi(s)} = \frac{1}{RsC + Ls^2C + 1}$$

1M

$\therefore \frac{Vo(s)}{Vi(s)} = \frac{1}{Ls^2C + RsC + 1}$

	b)	**Describe ON – OFF control action with equation and response curve**	**4M**
	Ans:	(1) ON OFF controller is also called as two position Controller. (2) It has to control two positions of control element, either ON or OFF hence this mode is called as ON OFF controller. (3) This controller mode has two possible output states namely 0 % & 100%. Mathematically this can be expressed as P (t) = 0% (OFF) for $ep \leq 0$ 100% (ON) for $ep > 0$ ep = set point – measured variable Where P (t) – Controlled output ep -- Error based on % of span (4) When the measured variable is below set point, the controller output is ON, and output is maximum and when the measured variable is above set point, the controller output is OFF, and output is minimum. 	**2M - Description** **1M – Equation** **1M – Response**

	c)	**Sketch the block diagram of PLC.**	**4M**
	Ans:	 **OR** 	**4M**

	d)	**Explain the sourcing and sinking concept in DC input module**	**4M**
	Ans:	1. Sinking and Sourcing are terms used to describe current flow through a field device in relation to the power supply and the associated input, output point. 2. Solid state input devices with NPN transistors are called "Sinking input device" while input devices with PNP transistor are called "Sourcing input devices". 3. The commonly accepted definition by PLC manufactures about sinking & sourcing input & output circuit is current flows from positive to negative. 4. Basic principle retain to sinking & sourcing circuits.NPN transistors are open collector current sinking devices which interface to a sourcing input module. PNP transistors are open collector, current sources, which interface to a sinking input module. 5. In Fig.1 current flows from positive terminal of 24 volt DC supply to input module then through switch to negative terminal of supply, hence module acts as sinking device for DC supply but sourcing device for switch. 6. In Fig.2 current flows from positive terminal of 24 volt DC supply to switch then input module to negative terminal of supply, as far as input module is concern it act as sinking device for DC switch and sourcing device for 24 volt DC supply.  Fig 1 – Sourcing DC input Module with a sinking switch	**2M- Sinking** **2M- Sourcing**

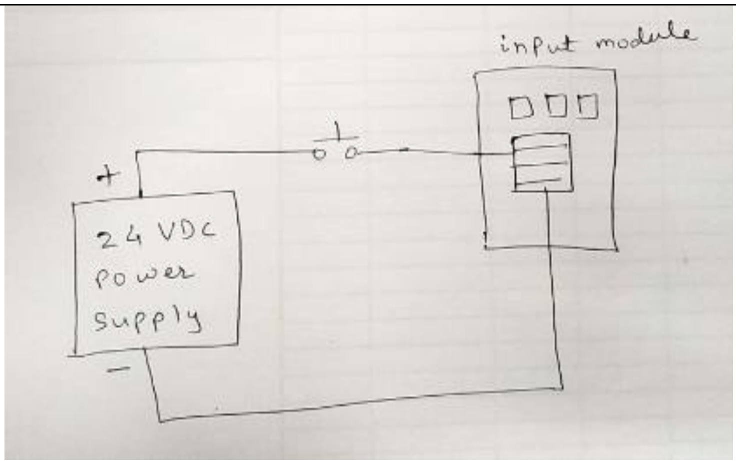
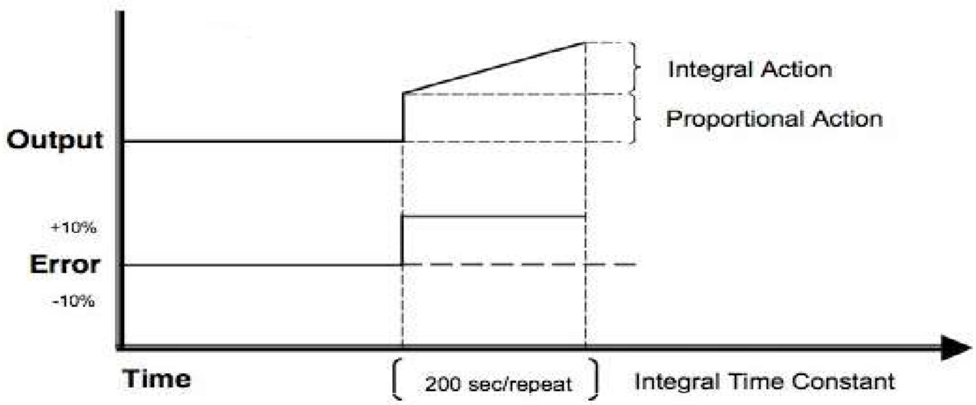


Fig 2 – Sinking DC input module with a Sourcing switch

Q. No.	Sub Q. N.	Answers	Marking Scheme
4		**Attempt any THREE of the following:**	**12- Total Marks**
	(a)	**Explain proportional Integral (PI) controller wit O/P response curve.**	**4M**
	Ans:	1) This is composite control mode obtained by combining the proportional mode and the integral mode. 2) The mathematical expression for such a composite control is P(t) = kp e(t) + kp ki $\int_0^t e(t)dt$ + p(0) Where, p(0)= Initial value of the o/p at t=0 3) one important advantage of this control is that one to one correspondence of proportional mode is available while the offset gets eliminated due to integral mode , the integral part of such a composite control provides a reset of the zero error output after a load change occurs.	**3 M – Explanation** **1M - response**

4) Response of PI mode for direct action of the controller. As the error changes from zero to positive at that instant t1, the controller o/p changes but this change due to proportional mode. As the error changes further the controller o/p increases, but this increase is due to integral mode. And as the error becomes constant, controller o/p remains as it is equal to previous stage.

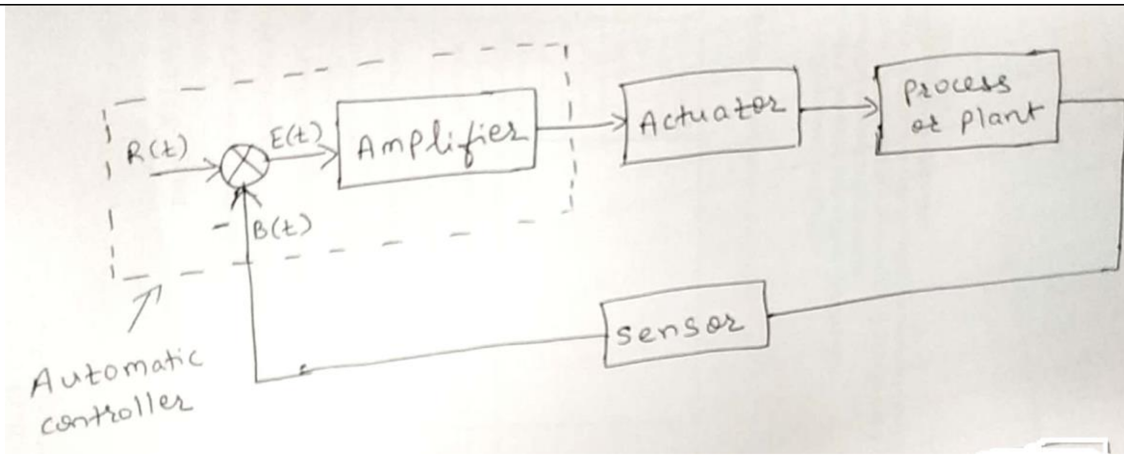


(b) **Distinguish between fixed and modular PLC (any four points).** **4M**

Ans:

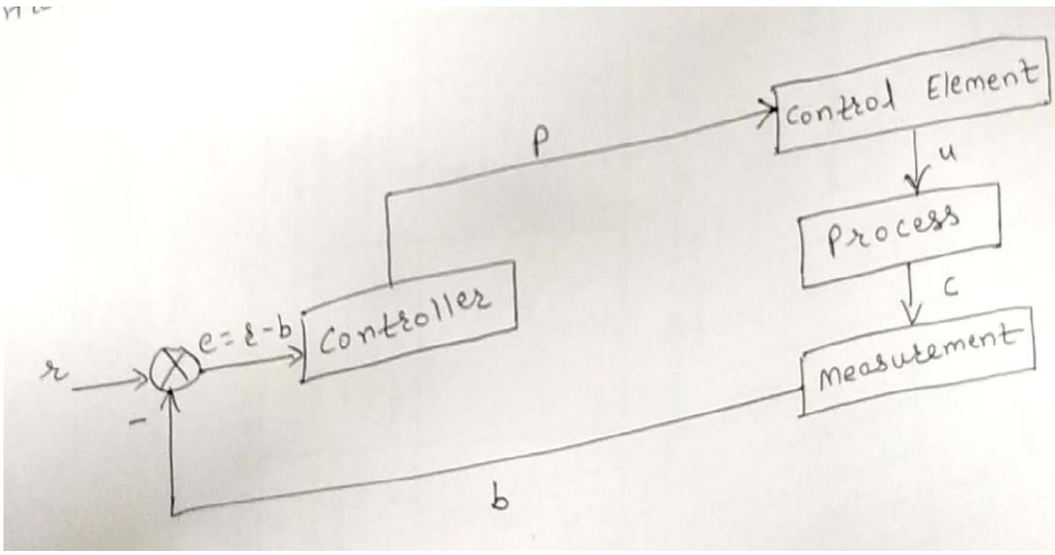
Sr. no.	Fixed PLC	Modular PLC
1.	Elements are fixed on main board of PLC	Elements are mounted on rack
2.	I/O count is 32 or less than 32	I/O count is more than 32
3.	Small in size	Large in size
4.	Low cost	High cost
5.	Easy to install	Installation is complex
6.	Memory capacity is less	Memory capacity is more
7.	It cannot be repaired	It can be repaired

4M (any four points)

	(c)	**Sketch the block diagram of process control system and explain the function of each block**	**4M**
	Ans:	 Explanation: Process control system consists of process or plant ,sensor, error detector, automatic Controller, actuator or control element. 1) **Process or plant**- process means some manufacturing sequence. It has one variable or multivariable output. Plant or process is an important element of process control system in which variable of process is to be controlled. 2) **Sensor/measuring elements** – It is the device that converts the output variable into another suitable variable which can acceptable by error detector Sensor is present in f/b path of close loop system. 3) **Error detector** – Error detector is summing point whose output is an error signal i.e. e(t) = r(t) - b(t) to controller for comparison & for the corrective action. Error detector compares between actual signal & reference i/p i.e. set point. 4) **Automatic controller**- Controller detects the actuating error signal, which is usually at a very low power level, and amplifies it to a sufficiently high level .i.e. means automatic controller comprises an error detector and amplifier. 5) **Actuator or control element** – Actuator is nothing but pneumatic motor or valve, a hydraulic motor or an electric motor, which produces an input to the plant according to the	**1M – Block diagram** **3M - Explanation**

control signal getting from controller

OR



Explanation : The block diagram of process control system consists of the following blocks:-

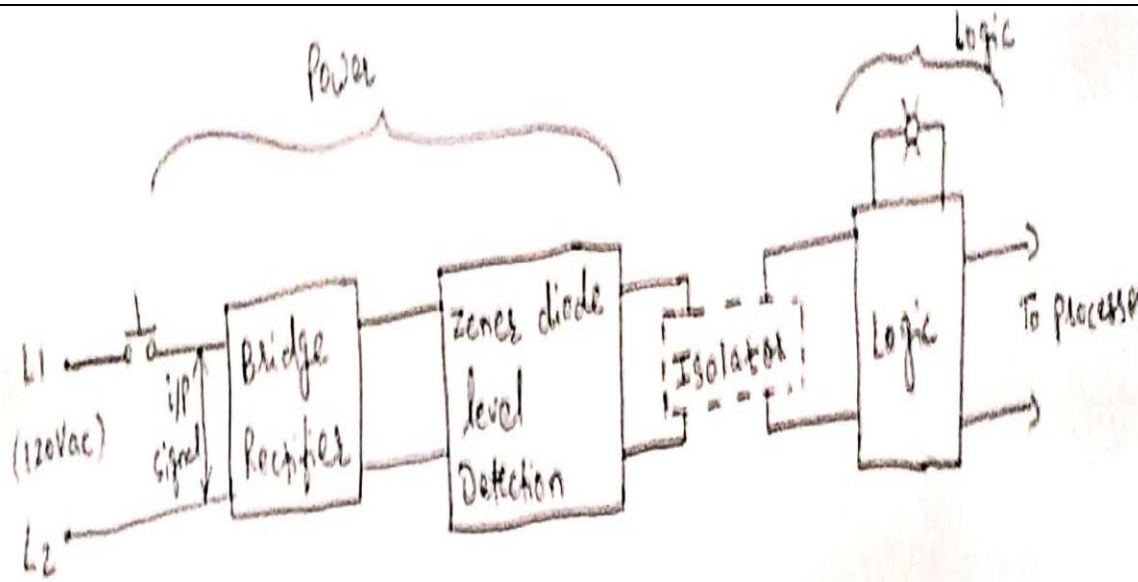
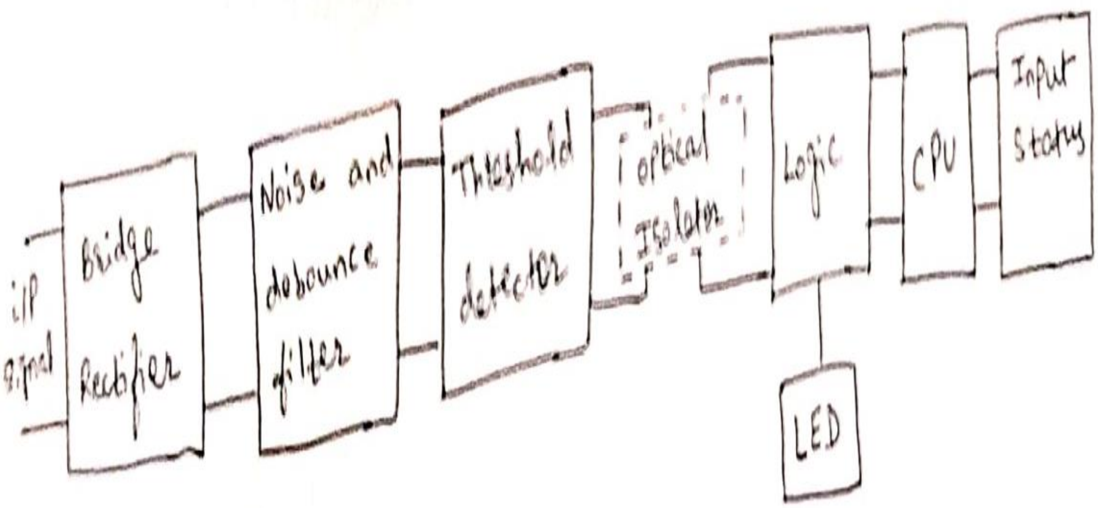
1) Measuring element: It measures or senses the actual value of controlled variable "c" and converts it into proportional feedback variable b.

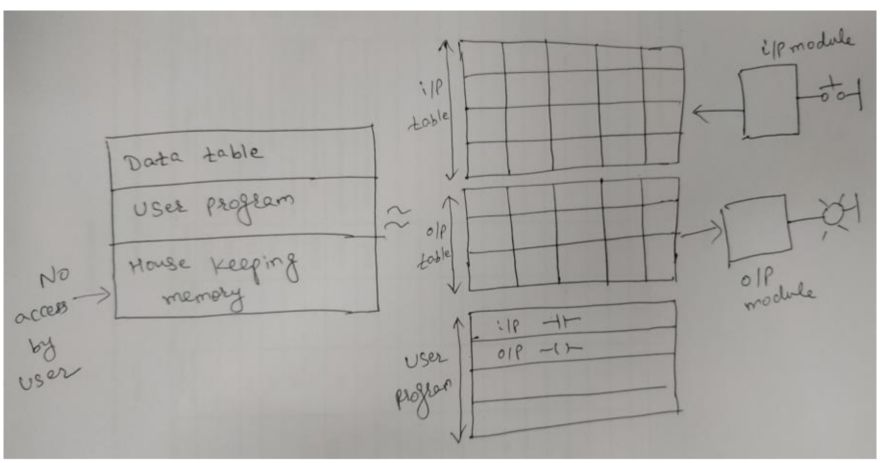
2) Error detector: It receives two inputs: set point "r" and controlled variable "p". The output of the error detector is given by e= r-b. "e" is applied to the controller.

3) Controller: It generates the correct signal which is then applied to the final control element. Controller output is denoted by "p".

4) Final control element: It accepts the input from the controller which is then transformed into some proportional action performed by the process. Output of control element is denoted by "u".

5) Process: Output of control element is given to the process which changes the process variable. Output of this block is denoted by "u".

	(d)	**Draw block diagram of AC discrete input module of PLC.**	**4M**
	Ans:	 **OR** 	**4M – Block diagram**

	(e)	**Explain memory organization of PLC.**	**4M**
	Ans:	1) The term memory organization refers to how certain areas of memory in PLC are used. 2) The memory space can be divided into two categories ie. User Program and Data table. 3) The user program is where the ladder diagram is entered and stored. The data table stores the information needed to carry out user program. This includes such information as the states of input and output devices, time and counter values and so on. 4) The data table can be divided into 3 sections, input image table, output image table and timer and counter storage. 5) Input image table stores the status of digital inputs . if the input is ON, the corresponding bit is set to 1 and if the input is OFF, the corresponding bit is set to 0. 6) Output image table stores the status of digital outputs. If the program calls for specific output to be ON, its corresponding bit is set to 1 and if the program calls for specific output to be OFF, its corresponding bit is set to 0.  	**1M – Diagram** **3M- Explanation**

Q. No.	Sub Q. N.	Answers	Marking Scheme
5.		**Attempt any <u>TWO</u> of the following:**	12- Total Marks
	a)	**For the given differential equation** $\frac{d^2y(t)}{dt^2} + 4\frac{dy(t)}{dt} + 8y(t) = 8x(t)$ **Where y(t) is O/P and x(t) is I/P** **Find, all time response Specification.** **(ξ , T_r, T_p, T_d, T_s, $\%M_p$)**	6M
	Ans:	System differential equation is, $\frac{d^2y(t)}{dt^2} + 4\frac{dy(t)}{dt} + 8y(t) = 8x(t)$ To find TF $\frac{Y(s)}{X(s)}$, take laplace transform from above equation and neglect initial conditions. $s^2Y(s) + 4sY(s) + 8Y(s) = 8X(s)$ $Y(s)[s^2+4s+8] = 8X(s)$ TF $\frac{Y(s)}{X(s)} = \frac{8}{s^2+4s+8}$ comparing this with standard TF of second order system $\frac{\omega_n^2}{s^2+2\xi\omega_n s+\omega_n^2}$ $\omega_n^2 = 8$ $\omega_n = \sqrt{8}$ $\omega_n = 2.83$ rad/sec $2\xi\omega_n = 4$ $\xi\omega_n = \frac{4}{2}$ $\xi = \frac{4}{2\times\omega_n} = \frac{4}{2\times 2.83} = 0.7067$ $\boxed{\xi = 0.7067}$ $\omega_d = \omega_n\sqrt{1-\xi^2} = 2.83\sqrt{1-(0.7067)^2}$ $\boxed{\omega_d = 2.002 \text{ rad/sec}}$	1M for each

$$\theta = \tan^{-1}\left(\frac{\sqrt{1-\xi^2}}{\xi}\right) = \tan^{-1}\left(\frac{\sqrt{1-(0.7067)^2}}{0.7067}\right)$$

$$\boxed{\theta = 45^\circ = \frac{\pi}{4}\ rad}$$

$$\boxed{\theta = 0.785\ rad}$$

$$T_r = \frac{\pi - \theta}{\omega_d} = \frac{3.14 - 0.785}{2.002} = \frac{2.355}{2.002} = 1.176\ sec$$

$$\boxed{T_r = 1.176\ sec}$$

$$T_p = \frac{\pi}{\omega_d} = \frac{3.14}{2.002} = 1.57\ sec$$

$$\boxed{T_p = 1.57\ sec}$$

$$T_d = \frac{1 + 0.7\xi}{\omega_n} = \frac{1 + 0.7(0.7067)}{2.83} = \frac{1.494}{2.83}$$

$$\boxed{T_d = 0.527}$$

$$T_s = \frac{4}{\xi\omega_n} = \frac{4}{0.7067 \times 2.83} = 2\ sec$$

$$\boxed{T_s = 2\ sec}$$

$$\%M_p = e^{-\pi\xi/\sqrt{1-\xi^2}} \times 100$$
$$= e^{-\pi \times 0.706/\sqrt{1-(0.706)^2}} \times 100$$

$$\boxed{\%M_p = 4.33\%}$$

b) **Find out transfer function by using block diagram reduction technique. Refer Fig No 2** **6M**

TF = $\frac{C(S)}{R(S)}$ **= ?**

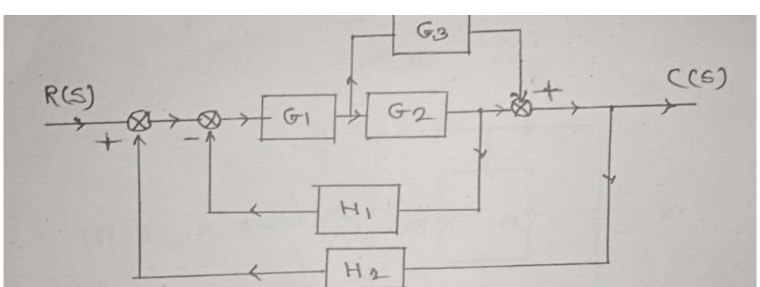
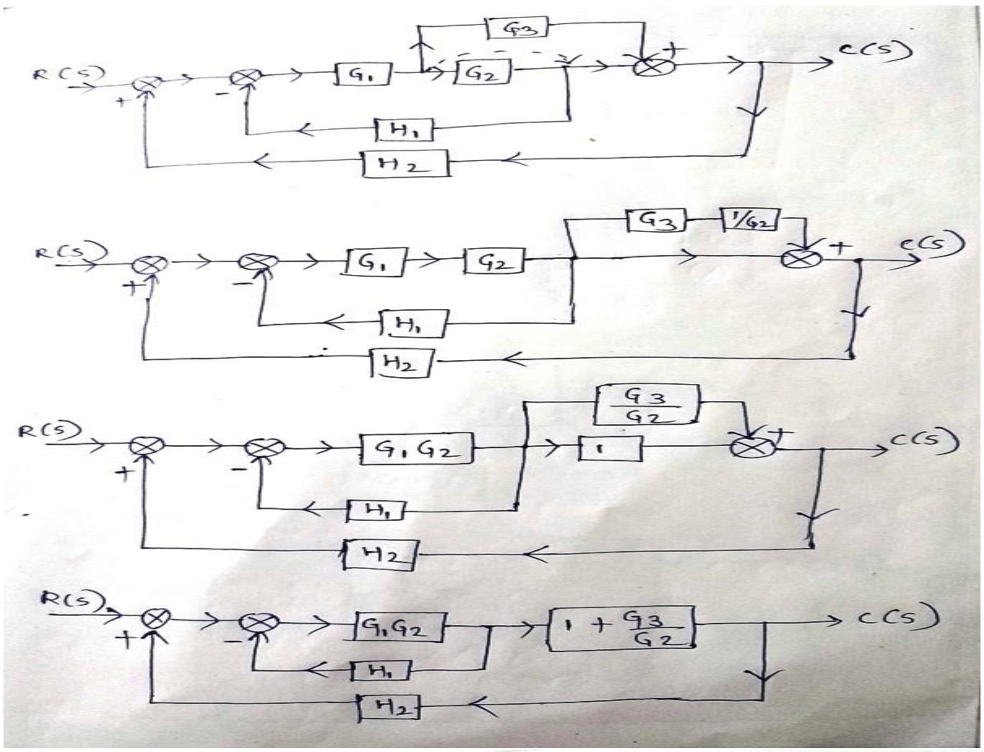


Fig. No. 2.

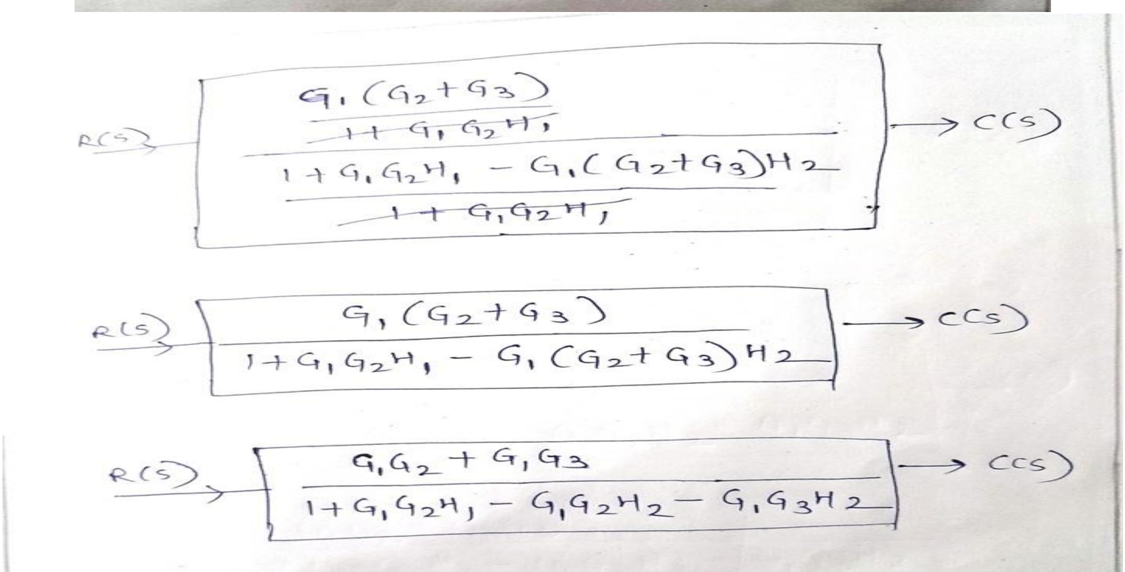
Ans:



1M

1M

1M



1M

$$T.F = \frac{C(s)}{R(s)} = \frac{G_1G_2 + G_1G_3}{1 + G_1G_2H_1 - G_1G_2H_2 - G_1G_3H_2}$$

2M

	c)	**Calculate the range of K for the given unity feedback system to be stable with G(S)** **G(S) =** $\frac{K}{S(S+2)\,(S+4)\,(S+8)}$	**6M**
	Ans:	see below	1M, 4M, 1M

$$G(s) = \frac{K}{s(s+2)(s+4)(s+8)}$$

The characteristic equation is

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

1M

$$\therefore \quad 1 + \frac{K}{s(s+2)(s+4)(s+8)} = 0$$

$$\therefore \quad s(s+2)(s+4)(s+8) + K = 0$$

$$\therefore \quad s^4 + 14s^3 + 56s^2 + 64s + K = 0$$

The Routh's Array is

4M

s^4	1	56	K
s^3	14	64	0
s^2	51.4285	K	
s^1	$\frac{3291.42 - 14K}{51.4285}$	0	
s^0	K		

For system to be stable elements in first column of Routh array must have the same sign i.e no sign change.

From last row $K > 0$

From row of s^1,

$$3291.42 - 14K > 0$$

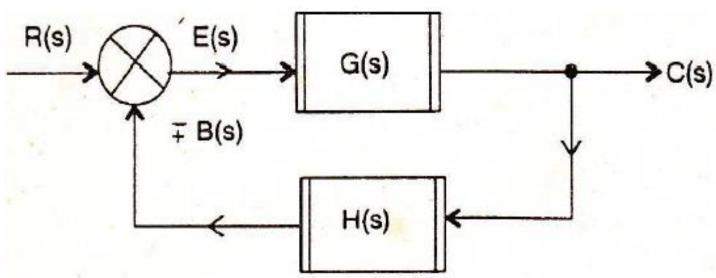
$$3291.42 > 14K$$

$$K < \frac{3291.42}{14} < 235.102$$

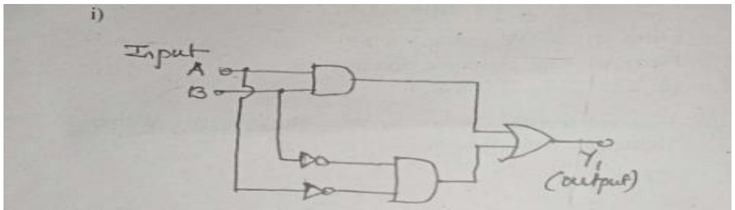
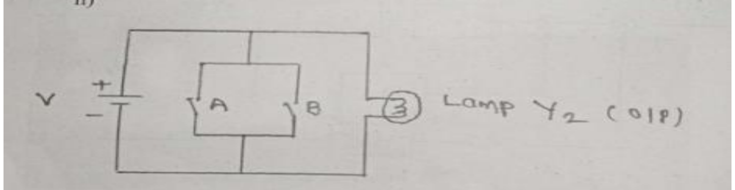
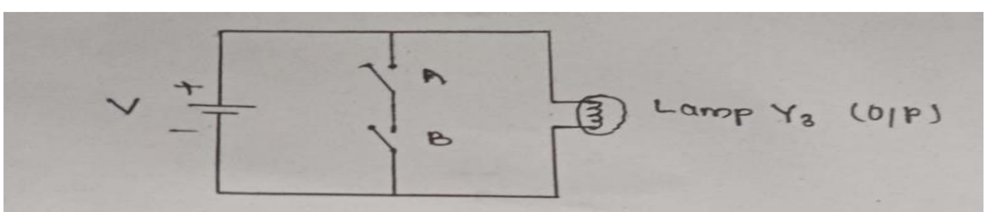
$\therefore$ Range of values of K for stability is

$$0 < K < 235.102$$

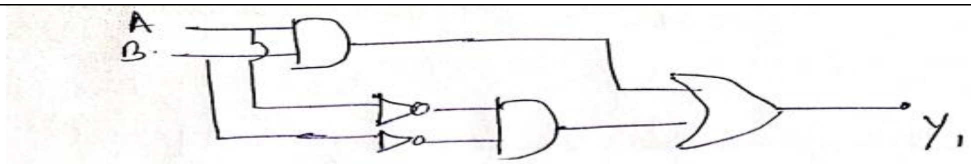
1M

Q. No.	Sub Q. N.	Answers	Marking Scheme
6.		**Attempt any TWO of the following :**	**12- Total Marks**
	a)	**Define transfer function and derive the derivation of transfer function of closed loop control system**	**6M**
	Ans:	TF is defined as the ratio of Laplace transform of Output to that of input under the zero initial condition. Transfer function of the closed loop system with feedback  R(S)= Laplace of reference i/p r(t) C(S)= Laplace of controlled o/p c(t) E(S)= Laplace of error signal e(t). B(S)= Laplace of feedback signal b(t) G(S)= Equivalent forward path transfer function H(S)= Equivalent feedback path transfer function. Referring to this Fig. $E(S)=R(S)\mp B(S)$ ………… (1) $B(S)=C(S)H(S)$ …………….(2) $C(S)=E(S)G(S)$ …………… (3) $E(S)=C(S)G(S)$ ……………… (4) Substituting (2) & (4) in equation (1)	**Defn 2M** **Derivation 4M**

		C(S)G(S)=R(S)∓C(S)H(S) C(S)=G(S)R(S)∓C(S)G(S)H(S) C(S)±C(S)G(S)H(S)=G(S)R(S) C(S)[1±G(S)H(S)]=G(S)R(S) C(S)R(S)=G(S)[1±G(S)H(S)] This is the Transfer Function. For negative feedback, TF=C(S)R(S)=G(S)[1+G(S)H(S)] For positive feedback, TF=C(S)R(S)=G(S)[1-G(S)H(S)]	
	b)	**A unity feedback system has** **G(S) =** $\frac{10\,(S+1)}{S^2\,(S+2)\,(S+10)}$ **Find** **i) Type of system** **ii) Error coefficient k_p, k_v, k_a** **iii) Steady state error e_{ss}, for input r(t) = 1 + 4t + $\frac{t^2}{2}$**	**6M**
	Ans:	$G(s) = \frac{10(s+1)}{s^2(s+2)(s+10)}$ i) Type of the system Comparing the equation in standard form $G(s)H(s) = \frac{K(1+T_1 s)(1+T_2 s)\cdots}{s^j(1+T_a s)(1+T_b s)\cdots}$ where j is the type of system Type = 2 ii) Error coefficients:- $K_p = \lim_{s\to 0} G(s)\cdot H(s) = \lim_{s\to 0} \frac{10(s+1)}{s^2(s+2)(s+10)} = \infty$ $K_v = \lim_{s\to 0} s\cdot G(s)H(s) = \lim_{s\to 0} \frac{s\cdot 10(s+1)}{s^2(s+2)(s+10)} = \infty$ $K_a = \lim_{s\to 0} s^2 G(s)H(s) = \lim_{s\to 0} \frac{s^2(10)(s+1)}{s^2(s+2)(s+10)} = \frac{10}{20} = 0.5$	**i)1M** **ii)3M** **iii)2M**

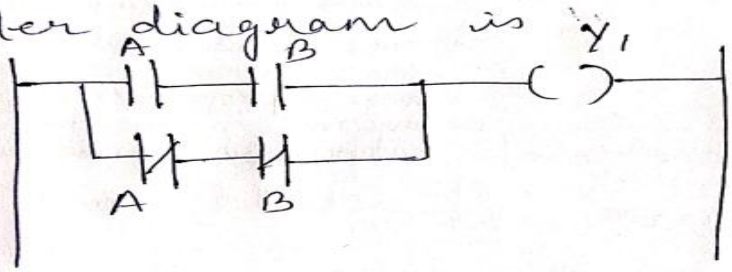
		$K_p = \infty$, $K_v = \infty$, $K_a = 0.5$ Steady state error for input $r(t) = 1 + 4t + \frac{t^2}{2}$ Total steady state error $e_{ss} = e_{ss_1} + e_{ss_2} + e_{ss_3}$ $\frac{A_1}{1+K_p} + \frac{A_2}{K_v} + \frac{A_3}{K_a}$ $= \frac{1}{1+\infty} + \frac{4}{\infty} + \frac{1}{0.5}$ $= 0 + 0 + 2$ $e_{ss} = 2$	
	c)	**Draw the ladder diagram for the following circuits. Refer Fig.No 3, 4 and 5** i)  Fig. No. 3. ii)  Fig. No. 4.  Fig. No. 5.	**6M**

Ans:

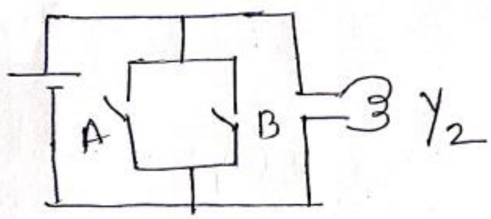


$Y_1 = AB + \overline{A}\,\overline{B}$

Ladder diagram is



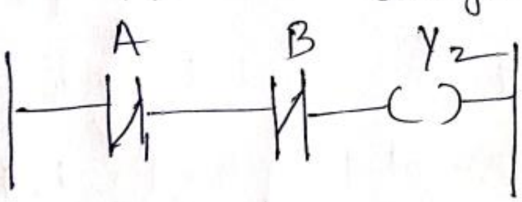
ii)



Truth Table.

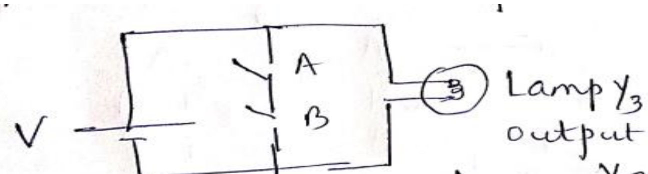
A	B	Y_2
0	0	1
0	1	0
1	0	0
1	1	0

$Y_2 = \overline{A}\,\overline{B}$ Ladder diagram



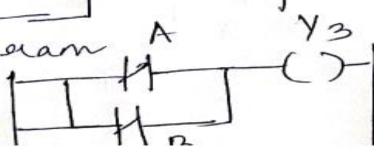
Truth Table

iii)



A	B	Y_3
0	0	1
0	1	1
1	0	1
1	1	0

Ladder diagram



Each circuit 2M