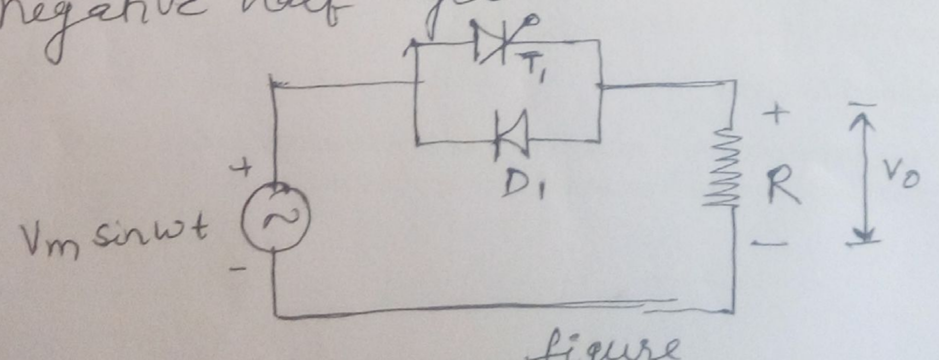
I-Mid Term Examination 2017-18
Advanced Power Electronics
(6EE4A)

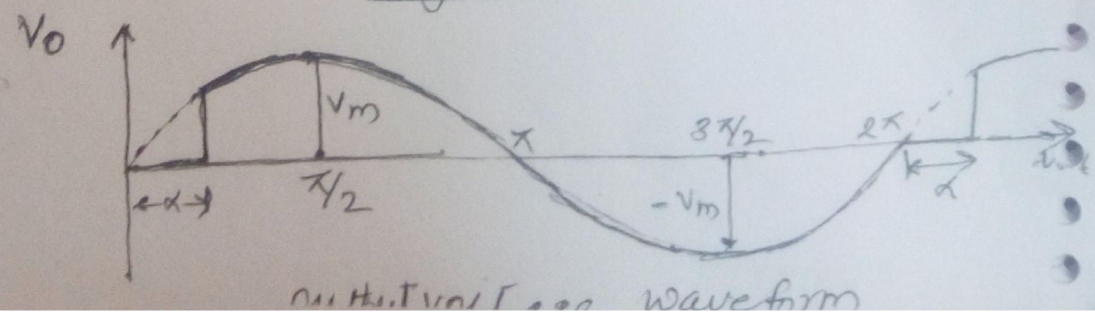
Q No-1 Explain ON-OFF Control & Phase Control of single phase AC voltage controller with R load and determine the r.m.s value of output voltage for ON-OFF control.

Ans. **Phase Angle Control of Single Phase A.C voltage Controller :-** It consist of one thyristor in antiparallel with one diode. When SCR is forward biased during positive half cycle, It is turned ON firing angle α, load voltage at once jumps to $V_m \sin\alpha$, likewise load current becomes $\frac{V_m}{R}\sin\alpha$.

Thyristor get turned off at $\omega t = \pi$ for R load. after $\omega t = \pi$, negative half cycle forward biased diode D_1, Therefore D_1 conductes from $\omega t = \pi$ to 2π. Note that only positive half cycle can be controlled, negative half cycle cannot be controlled.



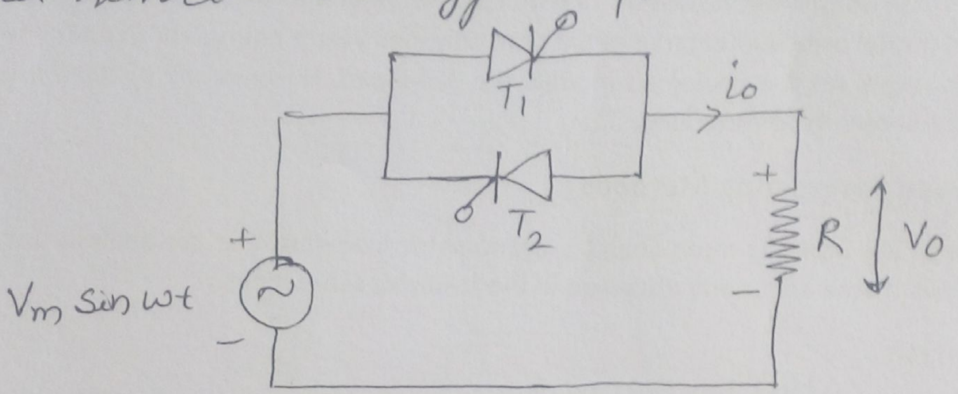
figure



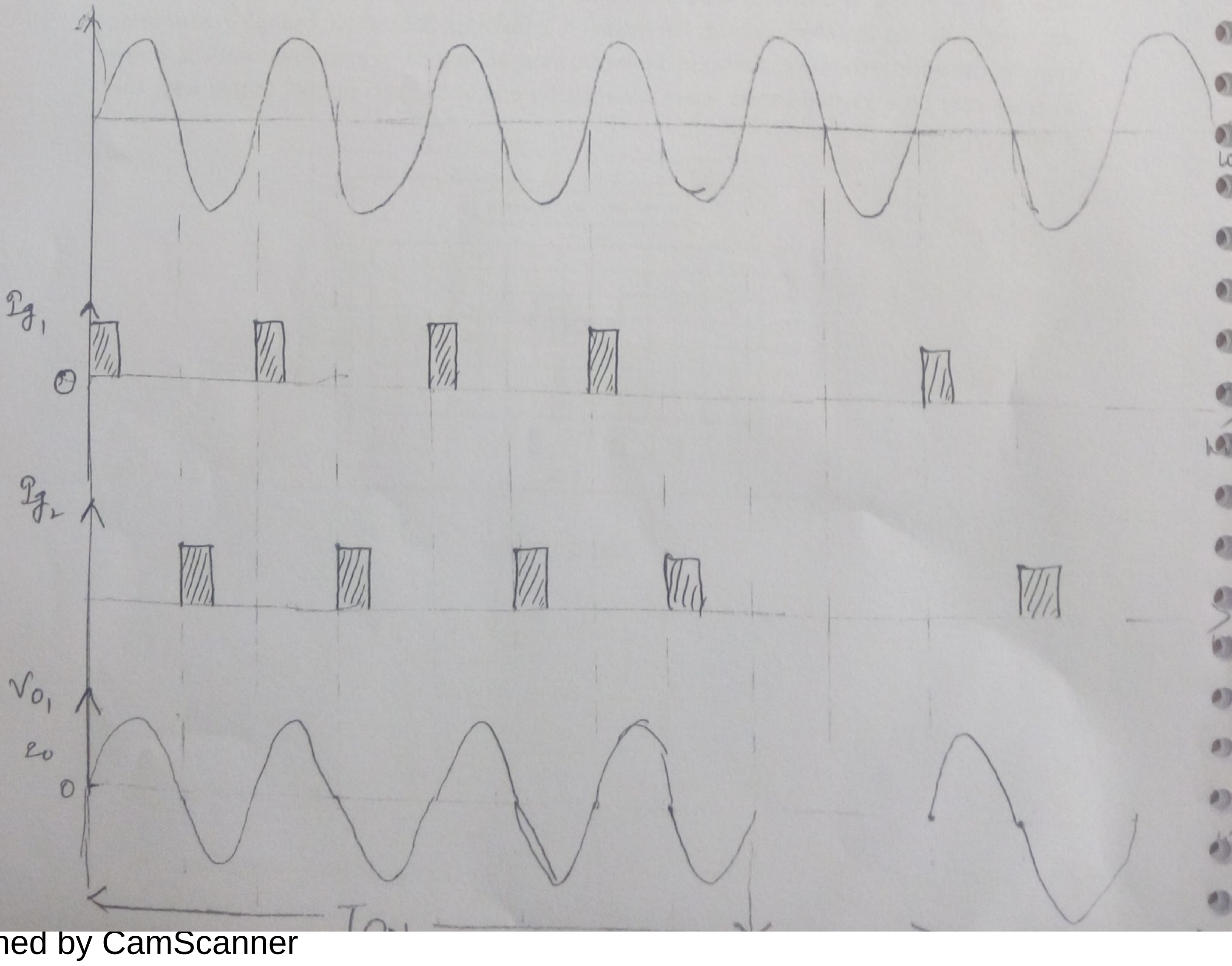
output voltage waveform

Principal of ON-OFF Control:

ON-OFF control also referred to as integral cycle control. In on-off control the thyristor is triggered for some input cycle, i.e. on period (T_{ON}) and remain untriggered for certain input cycle (T_{OFF})



Single-phase full-wave Controller for ON-OFF Control.



The rms value of output voltage (V_{or}) for Sinusoidal supply voltage V_s can be obtained as follows :-

$$(V_{or})^2 = \frac{n}{2\pi(n+m)}\left[\int_0^{2\pi} V_m^2 \sin^2 \omega t\, d(\omega t), \text{ for } 1^{st} \text{ On-cycle} + \int_0^{2\pi} V_m^2 \sin^2 \omega t\, d(\omega t), \text{ for } 2^{nd} \text{ On-cycle} + \cdots + \int_0^{2\pi} V_m^2 \sin^2 \omega t\, d(\omega t), \text{ for } n^{th} \text{ On cycle}\right]$$

$$(V_{or})^2 = \frac{n}{2\pi(n+m)} \int_0^{2\pi} V_m^2 \sin^2 \omega t\, d(\omega t)$$

$$V_{or} = \left[\frac{n}{2\pi(n+m)} \int_0^{2\pi} V_m^2 \sin^2 \omega t\, d(\omega t)\right]^{1/2}$$

$$= \left[\frac{n V_m^2}{2\pi(n+m)} \int_0^{2\pi} \frac{(1-\cos 2\omega t)}{2}\, d(\omega t)\right]^{1/2}$$

$$= \left[\frac{n V_m^2}{4\pi(n+m)} \int_0^{2\pi} (1-\cos 2\omega t)\, d(\omega t)\right]^{1/2}$$

$$= \left[\frac{n V_m^2}{4\pi(n+m)} \times 2\pi\right]^{1/2} \qquad \left(\because \int_0^{2\pi}(1-\cos 2\omega t)\, d(\omega t) = 2\pi\right)$$

$$V_{or} = \left[\frac{n V_m^2}{2(n+m)}\right]^{1/2}$$

$$= \frac{V_m}{\sqrt{2}} \sqrt{\frac{n}{n+m}}$$

$\Rightarrow$ r.m.s value of output voltage

$$\boxed{V_{or} = V_s \sqrt{K}}$$

QNo-2 Explain Three phase A.C voltage Controller with star connected resistive load also draw waveform.

Ans:- Three phase A.C voltage full wave Controller

In single phase a c voltage controlled by Two thyristors connected in parallel in reverse direction. But Three phase A.C voltage can be controlled by connecting three pair of thyristor:

The operation of three phase full wave A.C voltage controller are two types (i) Star connected (ii) Delta connected

Star Connection:-

Each pair of thyristor is connected in series with each phase of three phase load. Three phase controller more power to the load. The current flow to the load is controlled by thyristor T_1, T_3 and T_5 and thyristor T_2, T_4 and T_6 provide return current path. The firing sequence of the thyristor is T_1, T_2, T_3, T_4, T_5, T_6. We may recall that a thyristor will conducts if its anode voltage is higher that that of its cathode. Once a thyristor start conducting, it would be turned off only when it current falls to zero.

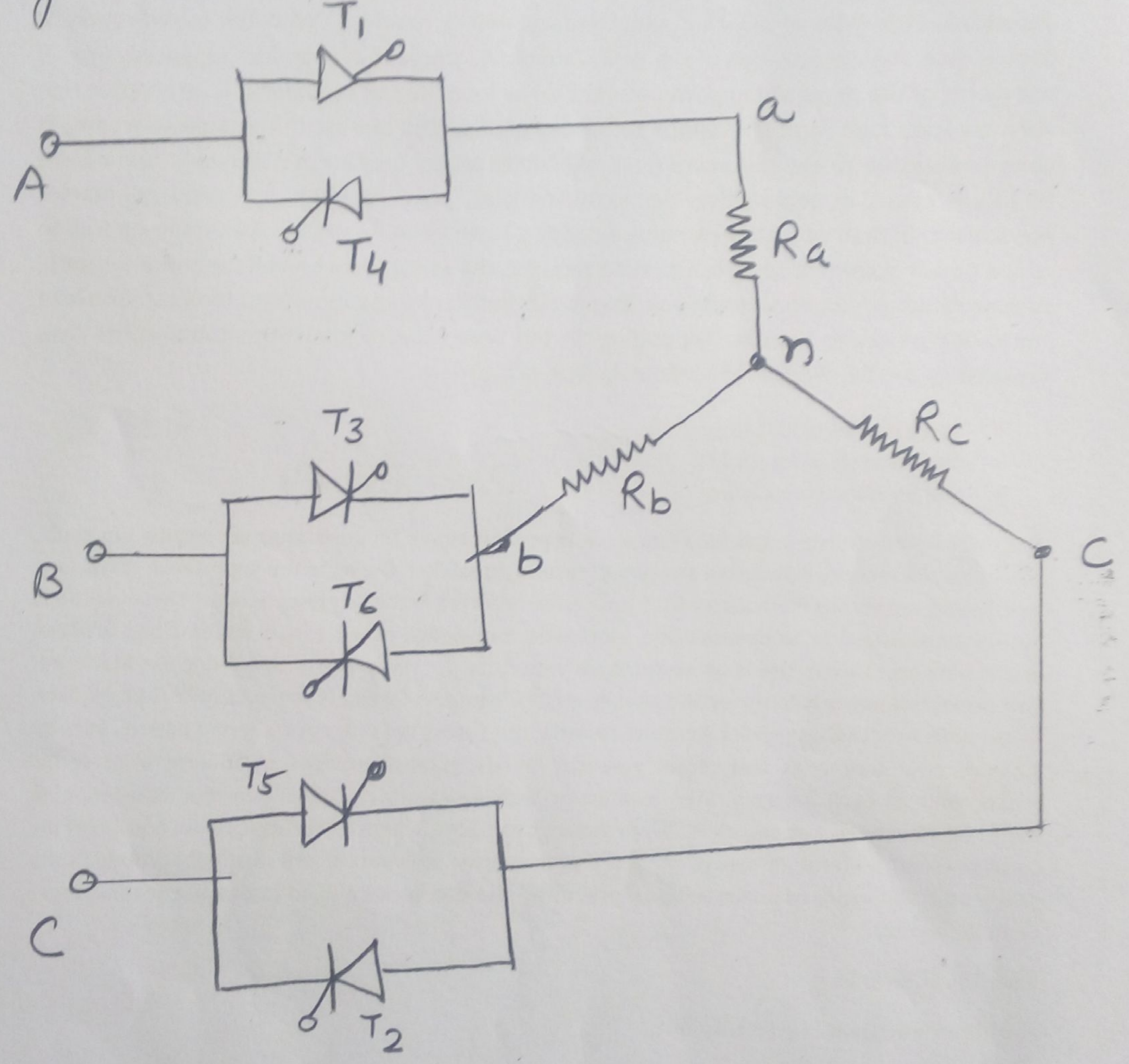


Diagram of Three phase A.C voltage controller.

When Thyristor Conducts Then phase voltag is given by

$\Rightarrow \quad V_A = V_m \sin \omega t$ $\quad \left[V_s = \frac{V_m}{\sqrt{2}}\right]$

$\Rightarrow \quad V_B = V_m \sin\left(\omega t - \frac{2\pi}{3}\right)$ $\quad \left[\frac{2\pi}{3} = 120°\right]$

$\Rightarrow \quad V_C = V_m \sin\left(\omega t - \frac{4\pi}{3}\right)$ $\quad \left[\frac{4\pi}{3} = 240°\right]$

$\Rightarrow V_A = \sqrt{2}\, V_s \sin \omega t$

$\Rightarrow V_B = \sqrt{2}\, V_s \sin\left(\omega t - \frac{2\pi}{3}\right)$

$\Rightarrow V_C = \sqrt{2}\, V_s \sin\left(\omega t - \frac{2\pi}{3}\right)$

We know that. In star Connection.

$\Rightarrow \quad V_L = \sqrt{3}\, V_{ph}$

$\Rightarrow \quad I_L = I_{ph}$.

Then the instantaneous line voltage

when line voltage V_{AB} leads V_A by 30°.

$\Rightarrow \quad V_{AB} = \sqrt{3}\, V_m \sin\left(\omega t + \pi/6\right)$ $\quad \pi/6 = 30$

$\Rightarrow \quad V_{BC} = \sqrt{3}\, V_m \sin\left(\omega t - \pi/2\right)$ $\quad \pi/2 = 90 = 60+30$

$\Rightarrow \quad V_{CA} = \sqrt{3}\, V_m \sin\left(\omega t - 7\pi/6\right)$ $\quad = 180+30 = 210$

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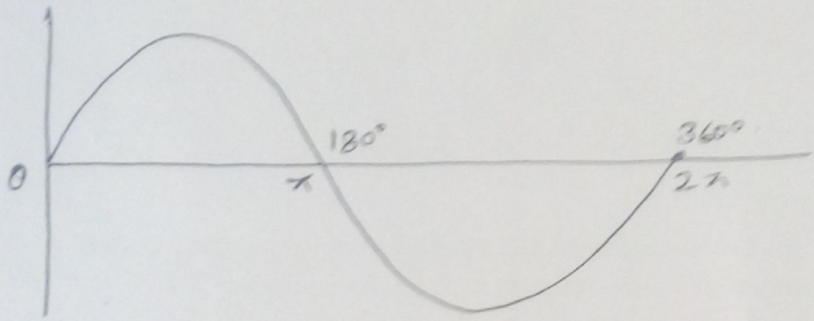


If all thyristor are fired at minimum angle are fired at minimum angle then each thyristor will conducts for the period

⇒ $T_1 = 0$ to $180°$

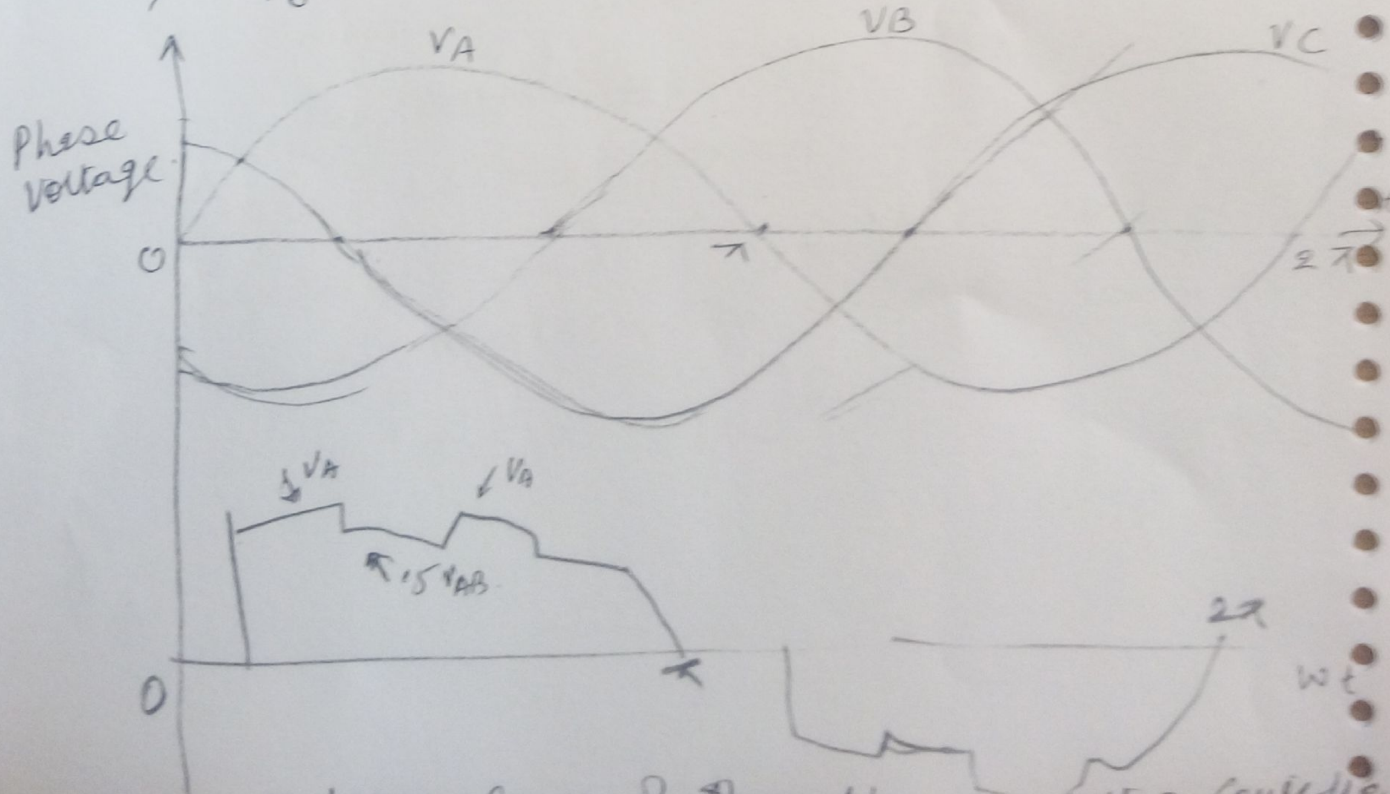
⇒ $T_2 = 60°$ to $240°$

⇒ $T_3 = 120°$ to $300°$

⇒ $T_4 = 180°$ to $360°$

⇒ $T_5 = 240°$ to $60°$ (next cycle)

⇒ $T_6 = 300°$ to $120°$ in next cycle



* Wave forms of three phase A.C voltage controller

The waveform for the input voltages, conduction angles of thyristors, and output phase voltages for $\alpha = 60^\circ$ and $\alpha = 120^\circ$.

For $0 \leq \alpha \leq 60^\circ$, immediately before the triggering of SCR T_1, two thyristor conducts. One SCR T_1 is triggered, three thyristor conducts. A thyristor turned off when it current attempts to reverse. The condition alternate between two and three conducting thyristor.

At any time only two thyristor conduct for $60^\circ \leq \alpha \leq 90^\circ$. For $90^\circ \leq \alpha < 150^\circ$, although two thyristor conduct at anytime. There are periods when no thyristors are ON. For $\alpha \geq 150^\circ$, there is no period for two conducting thyristors and the output voltage becomes zero at $\alpha = 150^\circ$. The range of delay angle is $0 \leq \alpha \leq 150^\circ$.

Q.No-3 An a.c voltage controller has a resistive load of $R = 10\Omega$. The rms input is $V_s = 120V$, 60Hz. The thyristor switch is ON for $n = 25$ cycle and is OFF for $m = 75$ cycles. Determine (a) The rms output voltage (V_o)
(b) input power factor.
(c) current of thyristor.

Ans :- $R = 10\Omega$, $V_s = 120V$, $V_m = \sqrt{2} \times 120 = 169.7V$.

$$k = \frac{n}{n+m} = \frac{25}{25+75} = \frac{25}{100}$$

(a) The r.m.s output voltage.

$$\boxed{V_o = V_s\sqrt{k}}$$

$$= V_s\sqrt{\frac{n}{n+m}} = 120\sqrt{\frac{25}{100}}$$

$$= 60V$$

($\cancel{b}$) r.m.s load current

$$I_o = \frac{V_o}{R} = \frac{60}{10} = 6.0A$$

(b) Input power factor

$$\boxed{P.f = \sqrt{K}}$$

$$= \sqrt{\frac{n}{n+m}} = \sqrt{\frac{25}{100}} = \sqrt{.25}$$

$$= .5$$

Working of single phase to single phase cycloconverter

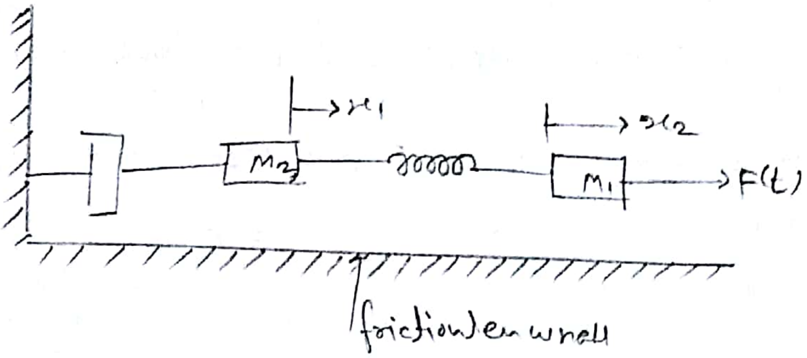
Discontinuous load current:- When point P is positive with respect to O, SCR P_1 is forward biased and triggered at $wt = \alpha$. The load current starts building up in positive direction from point R to point O.. Load current i_0 becomes zero $wt = \beta$ which is greater than π. Thyristor P_1 is naturally commutated at $wt = \beta$ and Thyristor P_1 is reverse biased after π.

After half cycle point Q is positive with respect to O. Now thyristor P_2 is forward bias and triggered at $wt = (\pi + \alpha)$: load current again positive from point R to O. and current flow in the ckt.. At $(2\pi + \alpha)$ P_1 again turned ON. And After P_2, (N_2 should be fired) Thyristor N_2 is gated at $(4\pi + \alpha)$ when point O is positive with respect to Q Now SCR N_2 is forward bias and current flow O to R. When N_2 is triggered. The load current build up in the negative direction.

$f_0 = \frac{1}{4} f_s$

Ans:- 1

Derive state variable model for the system shown in fig.?



∵ So Differential equations are →

$$M_1 \frac{d^2x_1}{dt^2} = F - K(x_1 - x_2)$$

$$F = M_1 \frac{d^2x_1}{dt^2} + K(x_1 - x_2) \quad \text{——— (1)}$$

and

$$M_2 \frac{d^2x_2}{dt^2} = K(x_1 - x_2) - B \cdot \frac{dx_2}{dt}$$

or =

$$M_2 \frac{d^2x_2}{dt^2} + B\frac{dx_2}{dt^2} + K(x_2 - x_1) = 0 \quad \text{——— (2)}$$

These are the Required differential equation.

Q.(2) Explain the advantage and Compare Conventional Control Theory.

Ans:→ 2: Advantage of Modern Control Theory :⇒

(1.) This Approach can be applied to linear | non linear | time-variant time-invariant system.

(2). It is easy to apply when Laplace Transformer can not applied

(3). It is time domain approach.

(4.) This method is suitable for digital Computer computation because this is a time domain approach.

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Comparison between modern control Theory and Conventional Control Theory.

Modern Control Theory	Conventional Control Theory
(1.) Modern control Theory is based on the concept of state.	(1.) It is based on Transfer function Technique.
(2) This can be implemented to linear and Nonlinear systems.	(2.) This can be implemented to linear systems only.
(3.) Modern control Theory is essentially a time domain approach.	(3). Conventional control Theory is a complex frequency domain approach.
(4). It is also for complex tasks with good accuracy.	(4) It is less accurate.
(5) This is also applicable to MIMO (multiple input multiple output systems.)	(5). This is applicable only to single input single output systems.
(6). It also provides information about the internal state of the systems.	(6.) It does not provide any Information about the internal state of the systems.

Q. 3 Construct a state model for a system characterized by the differential equation.

Ans:(3)

$$\dddot{y} + 6\ddot{y} + 11\dot{y} + 6y = u$$

Taking Laplace Transformation.

$$s^3 Y(s) + 6s^2 Y(s) + 11s\, Y(s) + 6\, Y(s) = U(s)$$

$$\frac{Y(s)}{U(s)} = \frac{1}{s^3 + 6s^2 + 11s + 6}$$

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

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

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

$$y(s) = x_1(s) + x_2(s) + x_3(s) \quad \text{—— (1)}$$

<u>where</u> $\Rightarrow x_1(s) = \dfrac{\frac{1}{2}}{s+1} u(s)$

or $s x_1(s) + x_1(s) = \frac{1}{2} u(s)$

Taking inverse Laplace Transform, we get

$$\dot{x}_1 = -x_1 + \frac{1}{2} u$$

$$\dot{x}_1 = -x_1 + 0x_2 + 0x_3 + \frac{1}{2} u \quad \text{—— (2)}$$

$\Rightarrow x_2(s) = \dfrac{-1}{s+2} u(s)$

or $s x_2(s) + 2x_2(s) = -1 u(s)$

Taking inverse Laplace Transform, we get.

$$\dot{x}_2 = -2x_2 - 1u$$

$$\dot{x}_2 = 0x_1 - 2x_2 + 0x_3 - 1u \quad \text{—— (3)}$$

$\Rightarrow x_3(s) = \dfrac{\frac{1}{2}}{s+3} u(s)$

$s x_3(s) + 3x_3(s) = \frac{1}{2} u(s)$

$$\dot{x}_3 = -3x_3 + \frac{1}{2} u$$

$$\dot{x}_3 = 0x_1 + 0x_2 - 3x_3 + \frac{1}{2} u \quad \text{—— (4)}$$

Ans: (4) Define eigen value and eigen vector? Define eigen value and eigen vector of the matrix

$$A = \begin{bmatrix} -2 & 1 & 1 \\ -11 & 4 & 5 \\ -1 & 1 & 0 \end{bmatrix}$$

⇒ The characteristic equation of A is →

$$|A - \lambda I| = 0$$

$$\begin{bmatrix} -2-\lambda & 1 & 1 \\ -11 & 4-\lambda & 5 \\ -1 & 1 & -\lambda \end{bmatrix}$$

$$(-2-\lambda)(-4\lambda+\lambda^2-5) - 1(11\lambda+5) + 1(-11+4-\lambda) = 0$$

$$-\lambda^3 + 2\lambda^2 + 13\lambda + 10 - 11\lambda - 5 - 11 + 4 - \lambda = 0$$

$$-\lambda^3 + 2\lambda^2 + \lambda - 2 = 0$$

$$\lambda^3 - 2\lambda^2 - \lambda + 2 = 0$$

$$\lambda^2(\lambda-1) - \lambda(\lambda-1) - 2(\lambda-1) = 0$$

$$(\lambda^2-\lambda-2)(\lambda-1) = 0$$

$$(\lambda-1)(\lambda+1)(\lambda-2) = 0$$

$$\boxed{\lambda = 1, -1, 2}$$

Thus the three eigen values are $1, -1, 2$

⇒ The matrix equation is, we get -

For $\lambda = 1$ ⇒

$$(A - I)X = 0$$

$$\begin{bmatrix} 3 & 1 & 1 \\ -11 & 3 & 5 \\ -1 & 1 & -1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

$R_2 \to R_2 - \frac{11}{3}R_1, \quad R_3 \to R_3 - \frac{1}{3}R_1$

$$\begin{bmatrix} -3 & 1 & 1 \\ 0 & -\frac{2}{3} & \frac{4}{3} \\ 0 & \frac{2}{3} & -\frac{4}{3} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

$R_3 \to R_3 + R_2$

$$\begin{bmatrix} -3 & 1 & 1 \\ 0 & -\frac{2}{3} & \frac{4}{3} \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\Rightarrow -3x_1 + x_2 + x_3 = 0$$

$$-\frac{2}{3}x_2 + \frac{4}{3}x_3 = 0$$

$$x_2 = 2x_3$$

Let $= 1 = x_2 = 2, x_1 = 1$

$$x_1 = \begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix}$$

for $\lambda = -1$

$$(A + I)X = 0$$

$$\begin{bmatrix} -1 & 1 & 1 \\ -11 & 5 & 5 \\ -1 & 1 & 1 \end{bmatrix} \begin{bmatrix} x_4 \\ x_5 \\ x_6 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

$R_2 \to R_2 - 11R_1, \quad R_3 - R_3 - R_1$

$$\begin{bmatrix} -1 & 1 & 1 \\ 0 & -6 & -6 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_4 \\ x_5 \\ x_6 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

$\Rightarrow \quad -x_4 + x_5 + x_6 = 0$

$-6x_5 - 6x_6 = 0$

$x_5 = -x_6, \quad x_4 = 0$

Let $x_6 = -1$

$x_5 = 1 \qquad x_2 = \begin{bmatrix} 0 \\ 1 \\ -1 \end{bmatrix}$

For $\lambda = 2$

$$(A - 2I)X = 0$$

$$\begin{bmatrix} -4 & 1 & 1 \\ -11 & 2 & 5 \\ -1 & 1 & -2 \end{bmatrix} \begin{bmatrix} x_7 \\ x_8 \\ x_9 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

$R_2 \to R_2 - \frac{11}{4} R_1, \quad R_3 \to R_3 - \frac{1}{4} R_1$

$$\begin{bmatrix} -4 & 1 & 1 \\ 0 & -\frac{3}{4} & \frac{9}{4} \\ 0 & \frac{3}{4} & -\frac{9}{4} \end{bmatrix} \begin{bmatrix} x_7 \\ x_8 \\ x_9 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

$R_3 \to R_3 + R_2$

$$\begin{bmatrix} -4 & 1 & 1 \\ 0 & -\frac{3}{4} & \frac{9}{4} \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_7 \\ x_8 \\ x_9 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

$\Rightarrow \quad -4x_7 + x_8 + x_9 = 0$

$-\frac{3}{4} x_8 + \frac{9}{4} x_9 = 0$

$x_8 = 3x_9$

Let - $x_9 = 1$

$x_8 = 3$

$x_7 = 1$

$$x_3 = \begin{bmatrix} 1 \\ 3 \\ 1 \end{bmatrix}$$

$\Rightarrow$ Thus the required eigenvectors are $\Rightarrow$

$$x_1 = \begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix}, \quad x_2 = \begin{bmatrix} 0 \\ 1 \\ -1 \end{bmatrix}, \quad x_3 = \begin{bmatrix} 1 \\ 3 \\ 1 \end{bmatrix} \text{ Ans} \Rightarrow$$

Q.(5) Write shorts notes.

Ans.(5) (a) Linearity :$\Rightarrow$ A system is said to linear if its output is directly proportional to given input, such as relationship in voltage and current electrical system.

when $V = IR$

or $\boxed{V \propto I}$

$\Rightarrow$ There are two type of Linearity.

(i) superposition principal

(ii) Homogenity principal

(1) superposition principal :$\Rightarrow$ Response to sum of inputs is the same as the sum of the individual Input Response.

Let x_1, x_2 be the inputs to a system and y_1, y_2 the corresponding outputs respectively.

or I $x_1 \rightarrow y_1$

$x_2 \rightarrow y_2$

$\boxed{\text{or } x_1 + x_2 \rightarrow y_1 + y_2}$

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(a) Homogenity principal :⇒ A system is said to be homogeneous if inputs is multiplied by any scalar number and corresponding output is also scaled by the same number.

Let → x_1 is an input to a system and its output is y_1,

$$x_1 \longrightarrow y_1$$

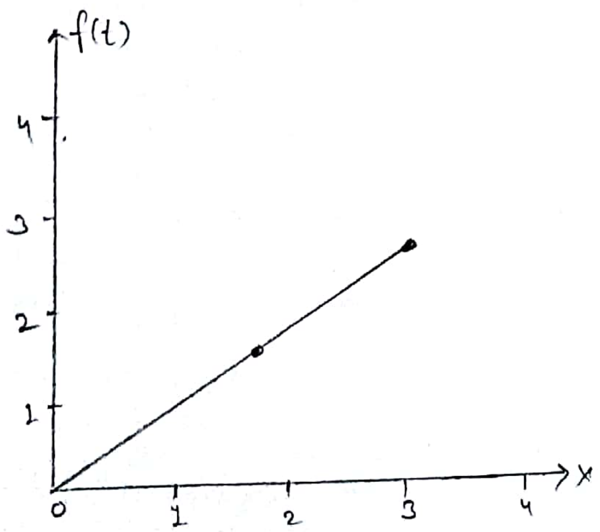
or $\boxed{a x_1 \longrightarrow a y_1}$

⇒ Lets consider a system defined as follows: →

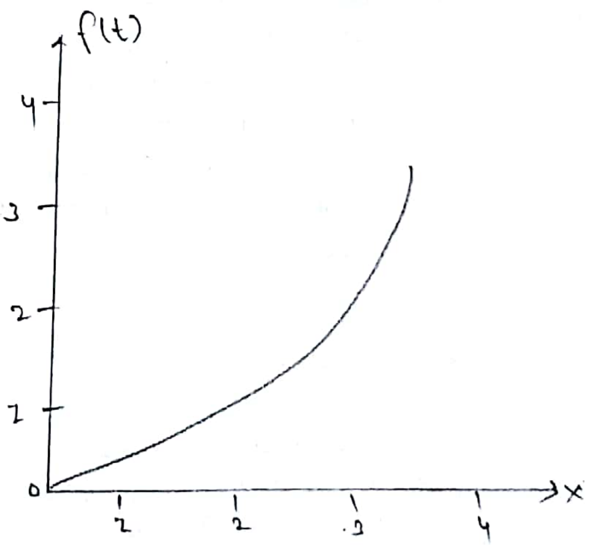
$$y_1(t) = f[x_1(t)]$$

and $y_2(t) = f[x_2(t)]$

$$\boxed{a_1 y_1(t) + a_2 y_2(t) = f[a_1 x_1(t) + a_2 x_2(t)]}$$



(a). Linear system



(b) Non-linear system

(b) Causality :⇒

Causality denotes the relationship between one event called cause and another event called effect, which is the consequence of the first. A casual system is a system that depends only on current and previous inputs. This property is known as causality.

E.g ⇒ of causal system ⇒

$$y(t) = x(t) + x(t-1) + x(t-2) \quad \text{—— (i)}$$

$$y(t) = b_0 x(t) + b_1 x(t-1) + b_2 x(t-2) \quad \text{—— (ii)}$$

$$y(t) = y(t-1) + x(t) \quad \text{—— (iii)}$$

E.g ⇒ of non causal system ⇒

$$y(t) = x(t) + \frac{1}{2}\left[x(t-1) + x(t+2)\right] \quad \text{—— (iv)}$$

$$\boxed{y(t) = x(t) + x(t+1) + x(t+2)} \quad \text{—— (v)}$$

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J.N.I.T. College
Sub ⇒ power system Instrumentation (P.S.I)
I- Mid Term.

Ans-(1) Accuracy and precision :⇒

(I) ⇒ Accuracy :⇒ It is the nearest value with which an Instrument reading approaches the True value of quantity which is being measured. The accuracy can be expressed in terms of limits of errors of inaccuracy.

⇒ There are Three Type of Accuracy ⇒
(i) Point Accuracy
(ii) Accuracy as "Percentage of scale range"
(iii) Accuracy as "Percentage of True value"

(1) Point Accuracy :⇒ In this case, instrument has uniform scale so its accuracy can be expressed in the Term of scale range.

$$\% \text{ Accuracy} = \frac{\text{Measured value} - \text{True value}}{\text{maximum scale value}} \times 100$$

(2). Accuracy as "Percentage of scale range" ⇒ It is the best method to specify in the terms of percentage of True value.

$$\% \text{ Accuracy} = \frac{\text{Measured value} - \text{True value}}{\text{True value}} \times 100$$

(2)

(II) Percision :=> Precision is also used in measurement to describe reproducibility or consistency of results. It gives a fixed value of a quantity. precision is measure of the degree of agreement within a group of measurements.
Precision means is means more the significant figures the greater the precision of measurement.

Ans.(2) Error :=> Error is the difference between True value and measured value. The average value of infinite numbers of measured value is known as True value.

Hence → $\boxed{E_0 = Y - x}$ —— (1)

Where E_0 = absolute error

Y = True value

x = Measured value

Hence - $\%\text{ Error} = \dfrac{\text{Absolute error}}{\text{True value}} \times 100$

$\%\text{ Error} = \dfrac{E_0}{Y} \times 100$

$$\boxed{\%\text{ Error} = \left(\frac{Y - x}{Y}\right) \times 100} \quad \text{—— (2)}$$

(3)

(I) Type of Errors :⇒

There are three types of errors. ⇒

(i) Gross errors
(ii) systematic errors
(iii) random errors.

(I) Gross errors :⇒

Gross errors mainly cover human mistakes in reading instruments, recording and calculating measurment results. These errors change the whole experiment reading calculation due to misreading by experimenter.

(II) systematic Errors :⇒

systematic errors occur due to short comings of the instrument such as defective or worn parts or ageing or effects of the environment on the instrument. systematic errors consider many errors such as instruments errors.

(III) Random errors :⇒

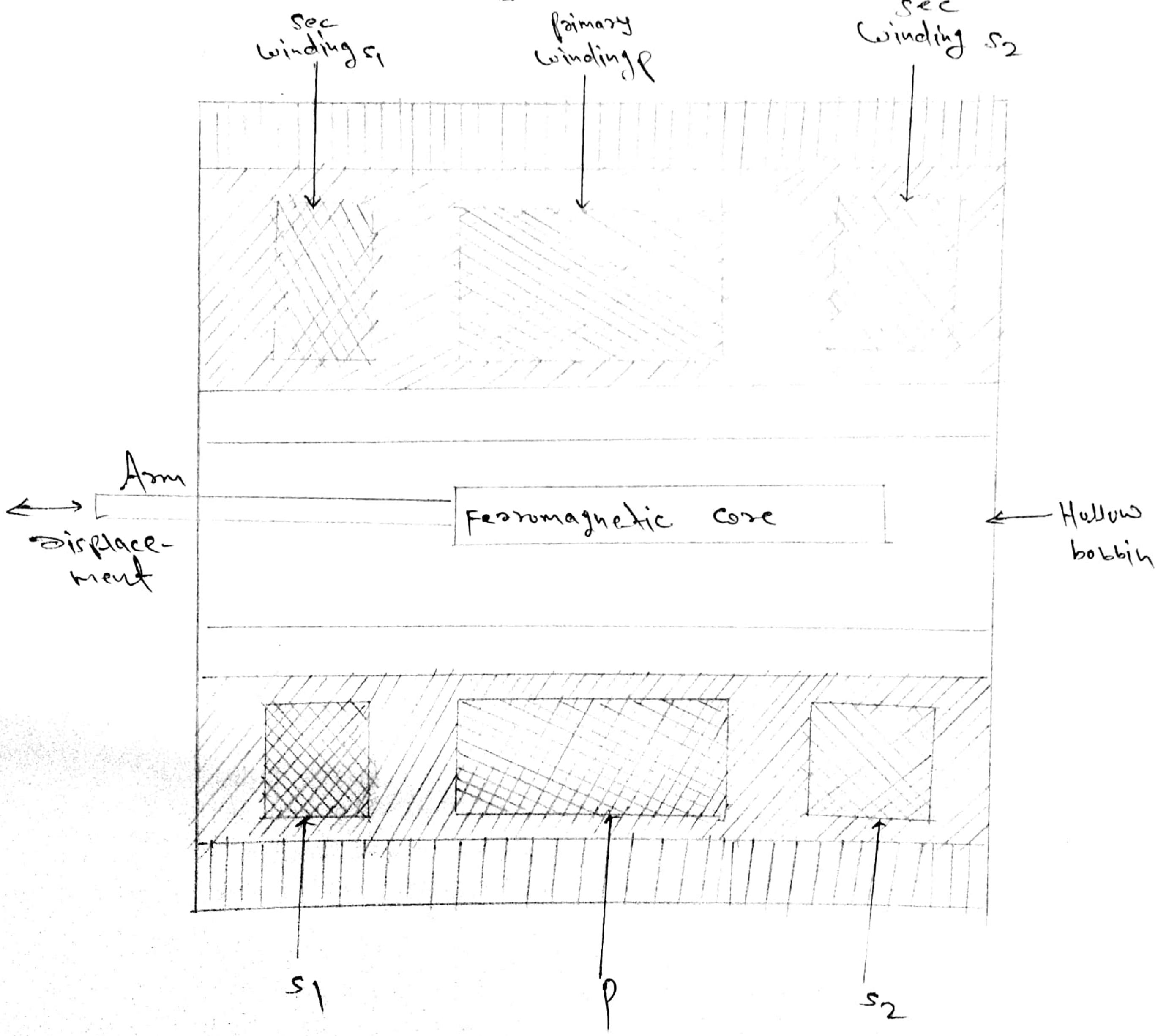
This type of error is found during experimental results. These results show variation from one another even after including all systematic errors. The presence of these type of errors to another are due to a multitude of small factors.

Ans. (4) Electrical Transducers :- A device that converts physical quantity into electrical quantity known as electrical Transducers.

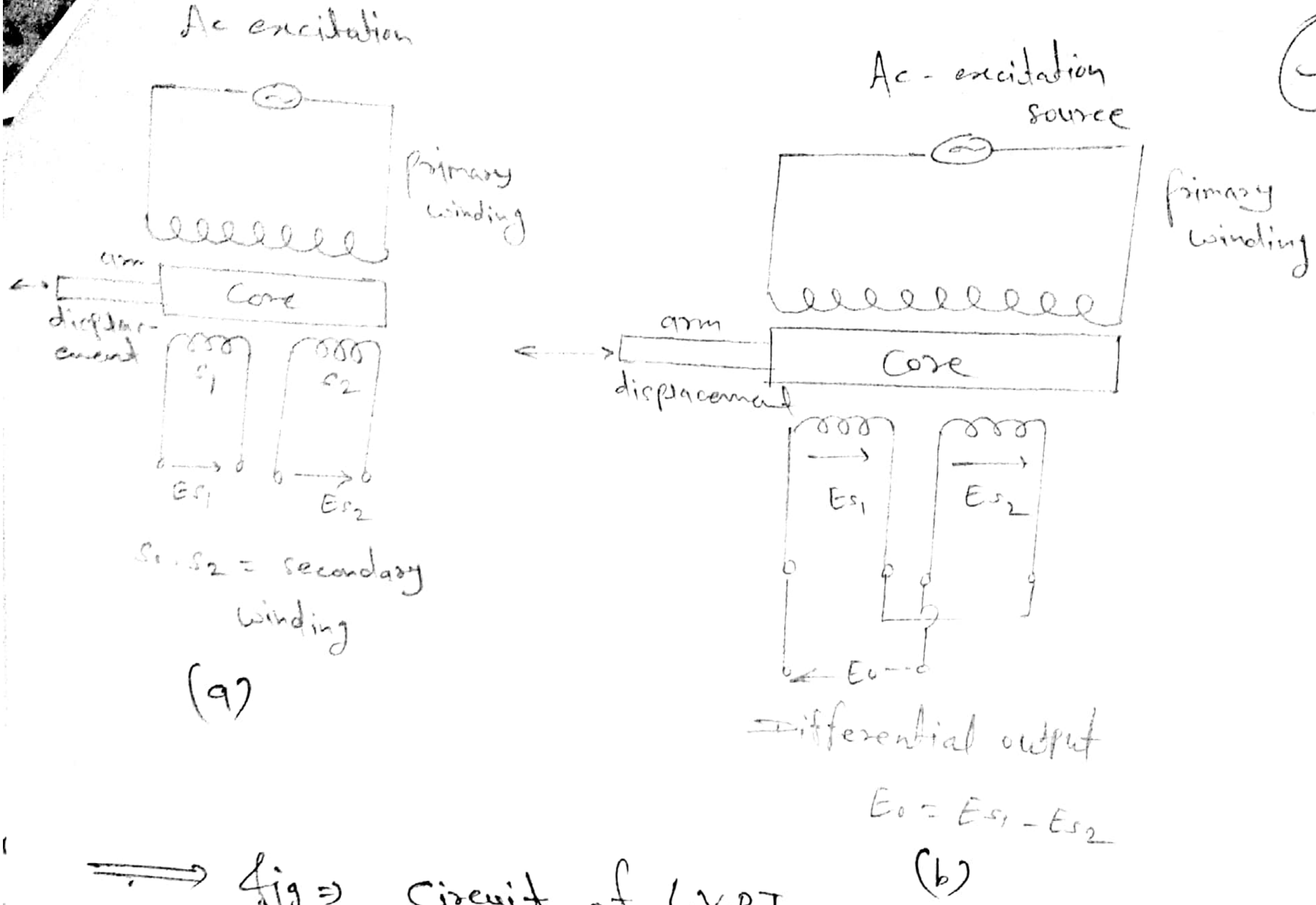
⇒ Example ⇒ LVDT.

⇒ LVDT (Linear variable Differential Transformer) :-

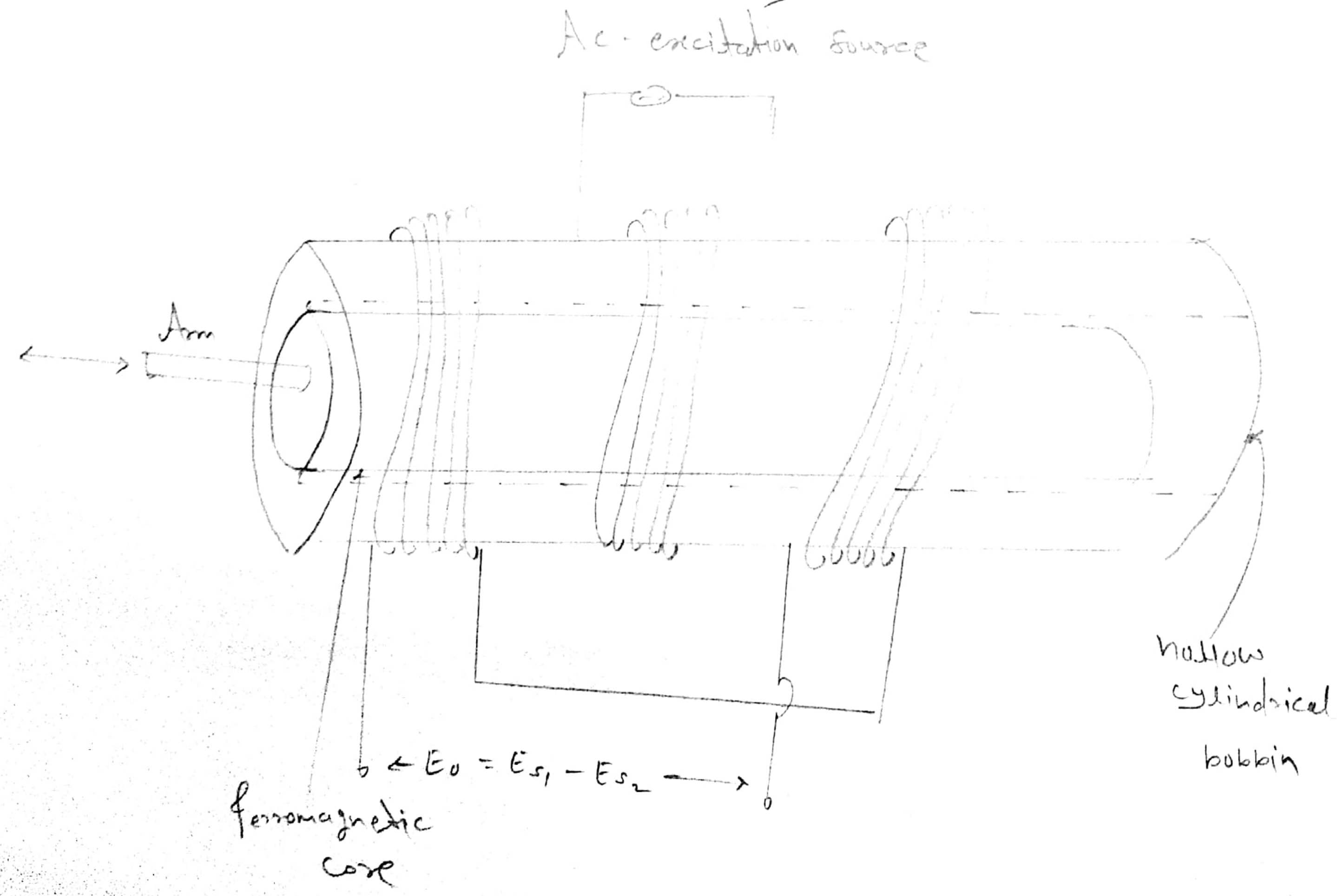
(I) Construction of LVDT :-



⇒ fig ⇒ Linear variable differential Transformer (LVDT)



⟹ fig ⇒ Circuit of LVDT



⟶ fig ⇒ Construction of LVDT

(II) Principle and working of LVDT :⇒

The LVDT works upon the principle of Transformer mutual induction principle.

This principle states that when an ac current flows through the primary winding through an ac - excitation source then an alternating magnetic field is generated due to which an voltage is induced in the secondary winding.

∵ The differential output voltage ⇒

$$\boxed{E_0 = E_{s_1} - E_{s_2}} \quad \text{--- (1)}$$

(III) Advantages :⇒

(i) LVDTs have a very high range for measurement of displacement.

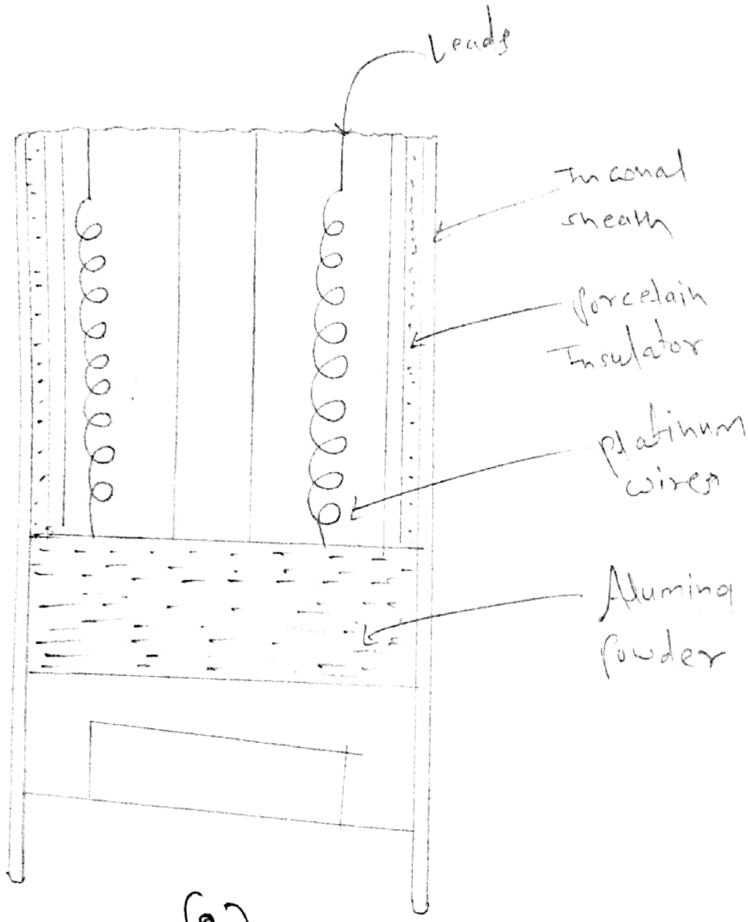
(ii) LVDT possesses a high sensitivity which is typically about 40v/mm.

(iii) They are small and light and maintain

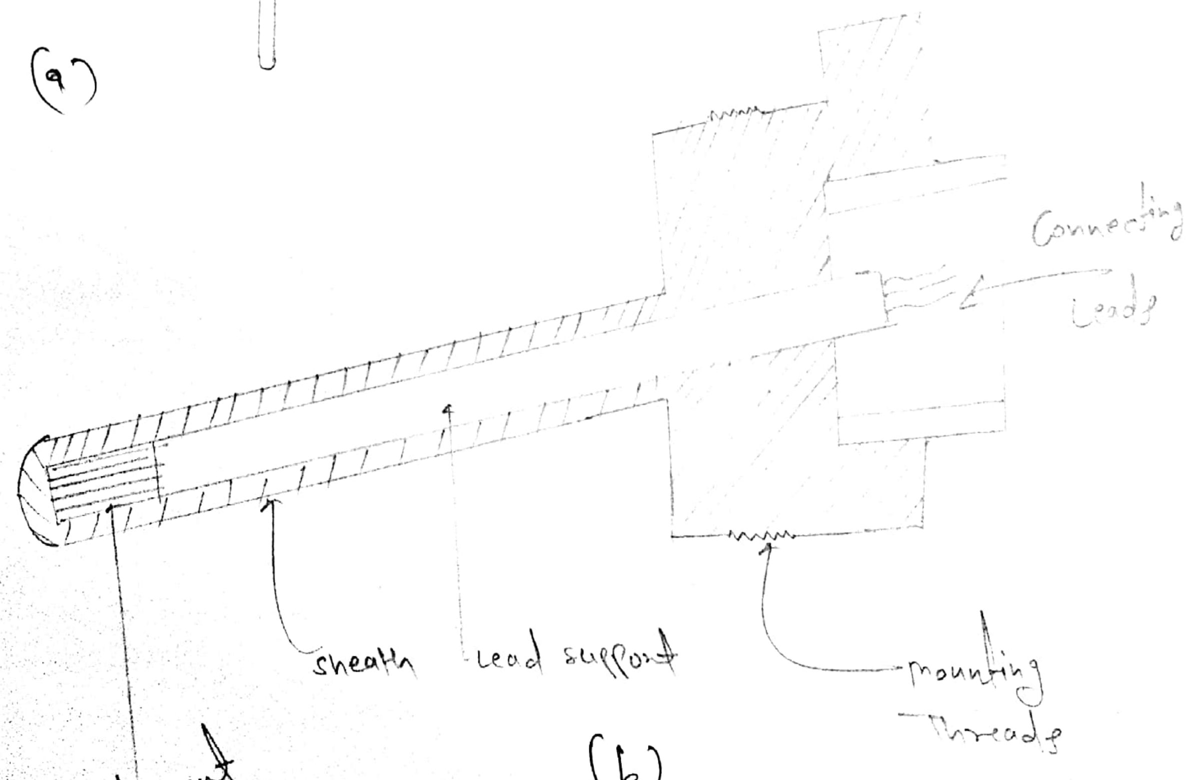
(iv) They consume low power which is less than 1W.

Ans. (5). RTD :⇒

(I) Construction of RTD :⇒



(a)



(b)

⇒ fig ⇒ Resistance Temperature detector (RTD)

(II) Working Principle of RTD

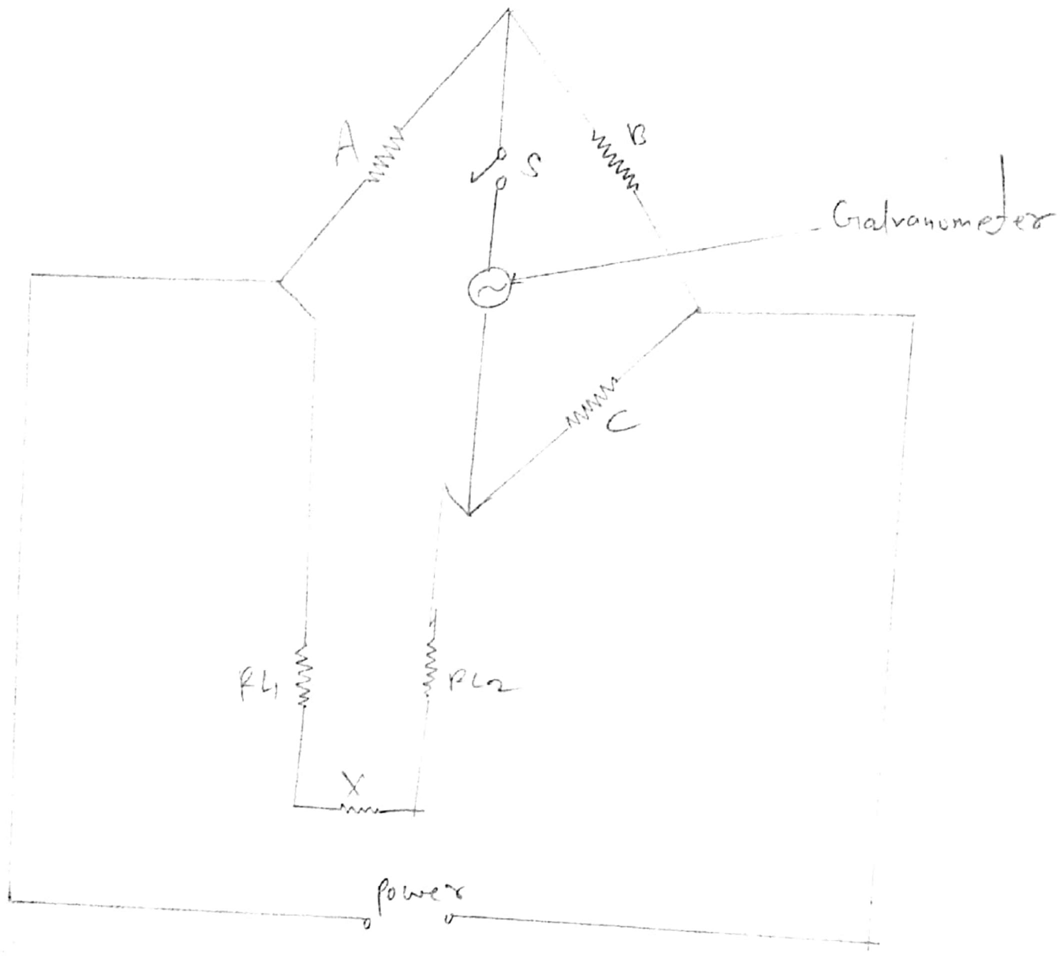


Fig ⇒ RTD Bridge Circuit

⇒ The resistance of certain metals changes with the Temperature change. RTD utilises this property for measurement of the Temperature. With the increase of Temperature, the electrical resistance of the certain increase in direct proportion to the rise of Temperature.

$$\boxed{R = R_0 \left(1 + \alpha_1 T + \alpha_2 T^2 + \text{-----} + \alpha_n T_n^n + \right)} \quad (1)$$

Where R_0 = Resistance at Temperature $T = 0$

α_1, α_2 --- are Constants.

→ The ratio of the Resistance is given by ⇒ (9)

$$\boxed{\frac{A}{B} = \frac{X + R_{L1} + R_{L2}}{C}} \quad (2)$$

(III) Characteristics of RTD :→

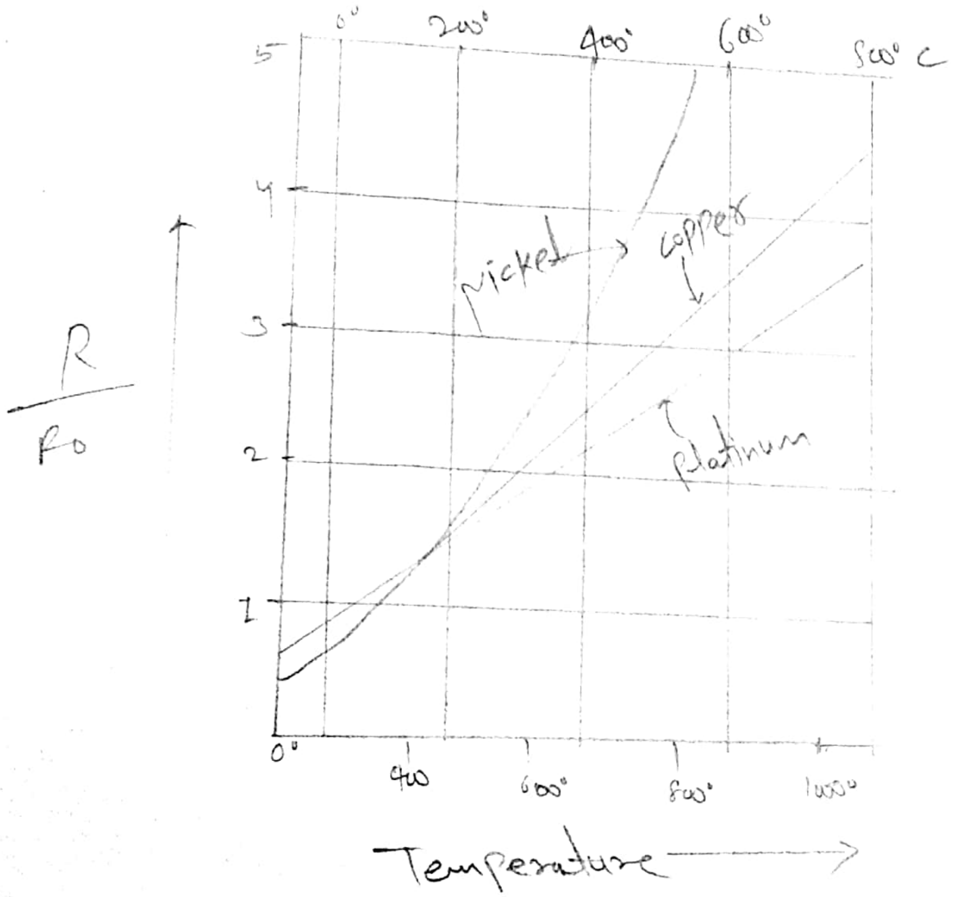


Figure ⇒ Characteristics of the RTD

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JNIT
JAGANNATH GUPTA INSTITUTE OF ENGINEERING & TECHNOLOGY
JAIPUR
II-Mid Term Examination Session 2017-2018
B.Tech …III… Year …VI… Semester

Branch: EE	**Subject: SGT**
Time:	**Subject Code:6EE**
Date:	**Max. Marks: 20**

Note: Attempt any four questions out of five questions.

Q1. Define Wide Area Monitoring in detail.

Ans: Wide Area Measurement Systems (WAMS) is a new term, which has been introduced to power system literatures in late 1980s. Recently, they are commercially available in power systems for purposes of monitoring, operation and control.
To be able to monitor, operate and control power systems in wide geographical area, WAMS combines the functions of metering devices (i.e. new and traditional) with the abilities of communication systems (Junce & Zexiang, 2005). The overall capability of this particular combination is that data of the entire system can be obtained at the same time and the same place i.e. the control center. This data, which are obtained from the entire system, can be used by many WAMS functions, effectively. These facts indicate that nowadays, WAMS has been a great opportunity to overcome power systems' challenges related to the restructuring, deregulation and decentralization.

Wide Area Measurement System (WAMS) was firstly introduced by Bonneville Power Administration (BPA) in the late 1980s (Taylor, 2006). This was resulted from this fact that the Western System Coordinating Council (WSCC) faced a critical lack of dynamic information throughout the 1980s. As a result of this, in 1990, a general plan to address this problem was formed (Cai et al., 2005). Therefore, the Western Interconnection of the North America power system was the first test-bed for WAMS implementation.
In 1995, the US Department of Energy (DOE) and the Electric Power Research Institute (EPRI) launched the Wide Area Measurement System (WAMS) Project. The aim of this project was to reinforce the Western System Dynamic Information Network called WesDINet. Dynamic information provided by WAMS of WesDINet has been very important and useful for understanding the breakups. This dynamic information can also be used for the purpose of avoiding future disturbances. Furthermore, during deregulation and restructuring process, information resources provided by this WAMS were utilized for maintaining the system reliability (Hauer & Taylor, 1998).
Since 1994, phasor measurement units (PMU) have been used in WAMS and they have provided synchrophasor measurements (Cai et al., 2005). It is noted that a complete survey of PMU will be presented in Section 4. Synchrophasor measurements may contribute

previous functions or may introduce some new WAMS functions, which are never achieved previously by conventional measurements. When synchrophasor measurements are used as data resources of a WAMS, such a WAMS will be called PMU based WAMS.

“The WAMS effort is a strategic effort to meet critical information needs of the changing power system”.

In general, a WAMS acquires system data from conventional and new data resources, transmits it through communication system to the control center(s) and processes it. After extracting appropriate information from system data, decisions on operation of power system are made. Occasionally, WAMS may command some actions that are performed by system actuators in remote sites (Shahraeini et al., 2011). All of these facts indicate that WAMS denotes efficient usage of data and data flow to achieve a more secure and a better strategy for the flow of electrical energy.

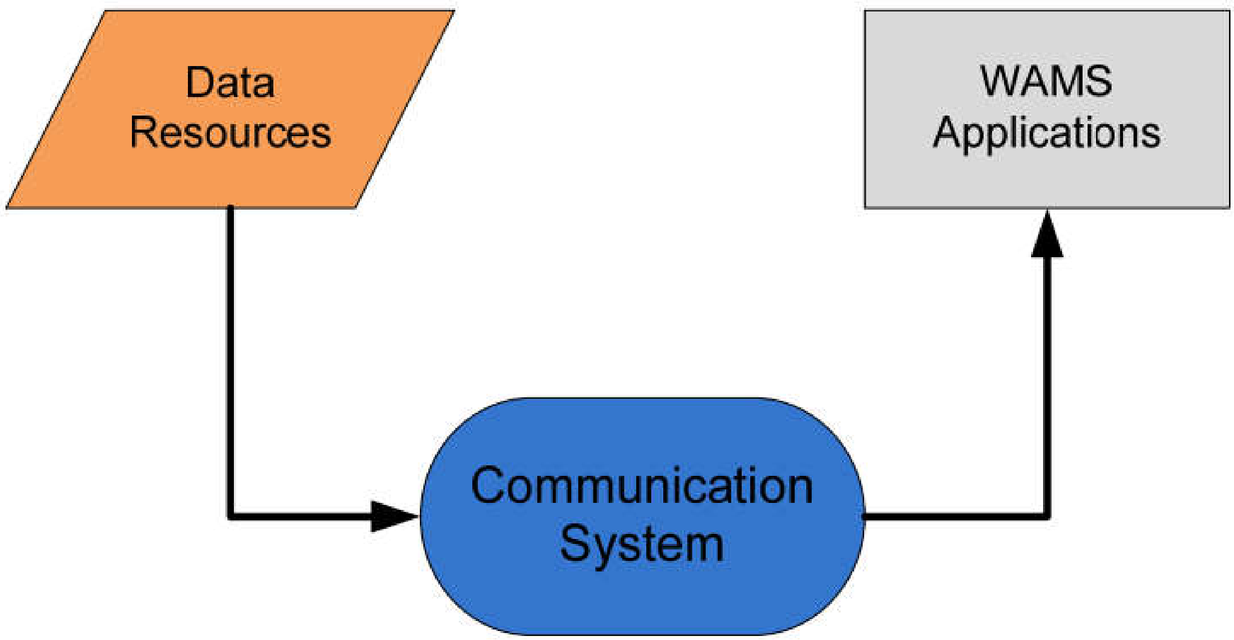


Fig. WAMS Process in Power Systems.

Q2. What is Smart Grid and also explain Smart grid Drivers in detail.

Ans:

Smart Grid :

The electrical grid has been cited as the greatest engineering achievement of the 20th century, but it
now faces new challenges of sustainability, energy security, reliability, etc. Developed countries have

a well-developed grid, and seek to improve it, while developing regions are still expanding their grids.
Over the past decade, the electricity generation, transmission and distribution landscape around the
globe has changed drastically – in the traditional grid of the 20th century there were relatively few
points of power generation or injection and millions of points of power consumption. With rapid proliferation of distributed and renewable generation, the 21st century grid will have numerous points of power injection as well as millions of points of consumption. Electric Vehicle (EV) roll out
has further increased the complexity of the traditional electricity grid. To manage a grid with such
increasing number of intermittent energy sources and EVs, smarter automation and IT systems are
imperative. Peak load management through control of loads (such as through demand response, which can be considered a dynamic form of Demand Side Management, or DSM) has assumed high
priority for electric utilities as there is a growing peak demand, leading to a supply gap during peak
hours of consumption in many parts of the world. Beyond such drivers, increased deregulation, consumer choice for green power, which is inherently variable, and many more factors are giving thrust for the transition to smarter grids that can address all these issues.
A smart grid is an electrical grid with automation, communication and IT systems that can monitor
power flows from points of generation to points of consumption (even down to the appliances level)
and control the power flow or curtail the load to match generation in real time or near realtime. The
increased visibility, predictability, and even control of generation and demand bring flexibility to both
generation and consumption and enable the utility to better integrate intermittent renewable generation and also reduce costs of peak power. If the traditional grid was made secure only through
over-engineering, a smart grid is cost-effective, nimble, responsive, and better engineered for reliabilityandself-healingoperations. The traditional electric grid will need to build additional layers of automation, communication and IT
systems to transform it to a smarter grid. Some of the applications or building blocks of a smart grid
(some of which are already being deployed worldwide, including in India), are:
Supervisory Control and Data Acquisition Systems (SCADA) with Energy Management Systems (EMS) and Distribution Management Systems (DMS)
Enterprise IT network covering all substations and field offices with reliable communication systems

Enterprise Resource Planning (ERP)/Asset Management Systems The first official definition of Smart Grid was provided by the Energy Independence and Security Act of 2007 (EISA-2007), which was approved by the US Congress in January 2007, and signed to law by President George W. Bush in December 2007. Title XIII of this bill provides a description, with ten characteristics, that can be considered a definition for Smart Grid, as follows:

"It is the policy of the United States to support the modernization of the Nation's electricity transmission and distribution system to maintain a reliable and secure electricity infrastructure that can meet future demand growth and to achieve each of the following, which together characterize a Smart Grid: (1) Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid. (2) Dynamic optimization of grid operations and resources, with full cyber-security. (3) Deployment and integration of distributed resources and generation, including renewable resources. (4) Development and incorporation of demand response, demand-side resources, and energy-efficiency resources. (5) Deployment of 'smart' technologies (real-time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices) for metering, communications concerning grid operations and status, and distribution automation. (6) Integration of 'smart' appliances and consumer devices. (7) Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal storage air conditioning. (8) Provision to consumers of timely information and control options. (9) Development of standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid. (10) Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services."

A common element to most definitions is the application of digital processing and communications to the power grid, making data flow and information management central to the smart grid. Various capabilities result from the deeply integrated use of digital technology with power grids. Integration of the new grid information is one of the key issues in the design of smart grids. Electric utilities now find themselves making three classes of transformations: improvement of infrastructure, called the *strong grid* in China; addition of the digital layer, which is the essence of the *smart grid*; and business process transformation, necessary to capitalize on the investments in smart technology. Much of the work that has been going on in electric grid modernization, especially substation and distribution automation, is now included in the general concept of the smart grid.

The drivers for smart grid for different stakeholders in India are:

1. Utilities:

 1 Reduction of T&D losses in all utilities as well as improved collection efficiency
 2. Peak load management – multiple options from direct load control to consumer pricing incentives
 3.Reductionin power purchase cost

4.Better asset management
5.Increased grid visibility
6.Self-healing grid
7.Renewable integration

2. Customers:
    1. Expand access to electricity – "Power for All"
    2. Improve reliability of supply to all customers – no power cuts, no more DG sets and inverters
    3. Improve quality of supply – no more voltage stabilizers
    4. User friendly and transparent interface with utilities
    5. Increased choices for consumers, including green power
    6. "Prosumer" (producer and consumer) enablement
    7. Options to save money by shifting loads from peak periods to off-peak periods

3. Government and Regulators:
    1. Satisfied customers
    2. Financially sound utilities
    3. Tariff neutral system upgrade and modernization
    4. Reduction in emission intensity

    It is evident that the far-reaching goals of the Indian power system can be enabled by smart grids which can help improve the efficiency and optimize performance within the Indian power sector.

Q3 What do you understand by Smart Energy Resources.

Smart Energy Resources can be easily understand with the help of Distributed energy resources are mass-produced, small, and less site-specific. Their development arose out of:

1. concerns over perceived externalized costs of central plant generation, particularly environmental concerns;
2. the increasing age, deterioration, and capacity constraints upon T&D for bulk power;
3. the increasing relative economy of mass production of smaller appliances over heavy manufacturing of larger units and on-site construction;
4. Along with higher relative prices for energy, higher overall complexity and total costs for regulatory oversight, tariff administration, and metering and billing.

Capital markets have come to realize that right-sized resources, for individual customers, distribution substations, or micro-grids, are able to offer important but little-known economic advantages over central plants. Smaller units offered greater economies from mass-production than big ones could gain through unit size. These increased value—due to improvements in financial risk, engineering flexibility, security, and environmental quality—of these resources can often more than offset their apparent cost disadvantages. DG, vis-à-vis central plants, must be justified on a life-cycle basis.Unfortunately, many of the direct, and virtually all of the indirect, benefits of DG are not captured within traditional utility cash-flow accounting.

While the levelized cost of distributed generation (DG) is typically more expensive than conventional, centralized sources on a kilowatt-hour basis, this does not consider negative aspects of conventional fuels. The additional premium for DG is rapidly declining as demand increases and technology progresses, and sufficient and reliable demand may bring economies of scale, innovation, competition, and more flexible financing, that could make DG clean energy part of a more diversified future. Distributed generation reduces the amount of energy lost in transmitting electricity because the electricity is generated very near where it is used, perhaps even in the same building. This also reduces the size and number of power lines that must be constructed.

Grid parity

Grid parity occurs when an alternative energy source can generate electricity at a levelized cost (LCOE) that is less than or equal to the end consumer's retail price. Reaching grid parity is considered to be the point at which an energy source becomes a contender for widespread development without subsidies or government support. Since the 2010s, grid parity for solar and wind has become a reality in a growing number of markets, including Australia, several European countries, and some states in the U.S.

Technologies

Distributed energy resource (**DER**) systems are small-scale power generation or storage technologies (typically in the range of 1 kW to 10,000 kW) used to provide an alternative to or an enhancement of the traditional electric power system. DER systems typically are characterized by high initial capital costs per kilowatt. DER systems also serve as storage device and are often called *Distributed energy storage systems* (DESS).

DER systems may include the following devices/technologies:

- Combined heat power (CHP),[15] also known as *cogeneration* or *trigeneration*
- Fuel cells
- Hybrid power systems (solar hybrid and wind hybrid systems)
- Micro combined heat and power (MicroCHP)
- Microturbines
- Photovoltaic systems (typically rooftop solar PV)
- Reciprocating engines
- Small wind power systems
- Stirling engines
- or a combination of the above. For example, hybrid photovoltaic, CHP and battery systems can provide full electric power for single family residences without extreme storage expenses.

Cogeneration

Distributed cogeneration sources use steam turbines, natural gas-fired fuel cells, microturbines or reciprocating engines to turn generators. The hot exhaust is then used for space or water heating, or to drive an absorptive chiller for cooling such as air-conditioning. In addition to natural gas-based schemes, distributed energy projects can also include other renewable or low carbon fuels including biofuels, biogas, landfill gas, sewage gas, coal bed methane, syngas and associated petroleum gas.

Delta-ee consultants stated in 2013 that with 64% of global sales, the fuel cell micro combined heat and power passed the conventional systems in sales in 2012. 20.000 units were sold in Japan in 2012 overall within the Ene Farm project. With a Lifetime of around 60,000 hours. For PEM fuel cell units, which shut down at night, this equates to an estimated lifetime of between ten and fifteen years. For a price of $22,600 before installation. For 2013 a state subsidy for 50,000 units is in place.

In addition, molten carbonate fuel cell and solid oxide fuel cells using natural gas, such as the ones from FuelCell Energy and the Bloom energy server, or waste-to-energy processes such as the Gate 5 Energy System are used as a distributed energy resource.

Solar power

Photovoltaics, by far the most important solar technology for distributed generation of solar power, uses solar cells assembled into solar panels to convert sunlight into electricity. It is a fast-growing technology doubling its worldwide installed capacity every couple of years. PV systems range from distributed, residential, and commercial rooftop or building integrated installations, to large, centralized utility-scale photovoltaic power stations.

The predominant PV technology is crystalline silicon, while thin-film solar cell technology accounts for about 10 percent of global photovoltaic deployment. In recent years, PV technology has improved its sunlight to electricity conversion efficiency, reduced the installation cost per watt as well as its energy payback time (EPBT) and levelised cost of electricity (LCOE), and has reached grid parity in at least 19 different markets in 2014.

As most renewable energy sources and unlike coal and nuclear, solar PV is variable and non-dispatchable, but has no fuel costs, operating pollution,as well as greatly reduced mining-safety and operating-safety issues. It produces peak power around local noon each day and its capacity factor is around 20 percent.

Wind power

Main article: Wind power

Wind turbines can be distributed energy resources or they can be built at utility scale. These have low maintenance and low pollution, but distributed wind unlike utility-scale wind has much higher costs than other sources of energy.[27] As with solar, wind energy is variable and non-dispatchable. Wind towers and generators have substantial insurable liabilities caused by high winds, but good operating safety. Distributed generation from wind hybrid power systems combines wind power with other DER systems. One such example is the integration of wind turbines into solar hybrid power systems, as wind tends to complement solar because the peak operating times for each system occur at different times of the day and year.

Hydro power

Main articles: Small hydro and Wave power

Hydroelectricity is the most widely used form of renewable energy and its potential has already been explored to a large extent or is compromised due to issues such as environmental impacts on fisheries, and increased demand for recreational access. However, using modern 21st century technology, such as wave power, can make large amounts of new hydropower capacity available, with minor environmental impact.

Modular and scalable *Next generation kinetic energy turbines* can be deployed in arrays to serve the needs on a residential, commercial, industrial, municipal or even regional scale. *Microhydro kinetic generators* neither require dams nor impoundments, as they utilize the kinetic energy of water motion, either waves or flow. No construction is needed on the shoreline or sea bed, which minimizes environmental impacts to habitats and simplifies the permitting process. Such power generation also has minimal environmental impact and non-traditional microhydro applications can be tethered to existing construction such as docks, piers, bridge abutments, or similar structures.

Waste-to-energy

Main articles: Waste-to-energy and Waste-to-energy plant

Municipal solid waste (MSW) and natural waste, such as sewage sludge, food waste and animal manure will decompose and discharge methane-containing gas that can be collected and used as fuel in gas turbines or micro turbines to produce electricity as a distributed energy resource. Additionally, a California-based company, Gate 5 Energy Partners, Inc. has developed a process that transforms natural waste materials, such as sewage sludge, into biofuel that can be combusted to power a steam turbine that produces power. This power can be used in lieu of grid-power at the waste source (such as a treatment plant, farm or dairy).

Energy storage

Main article: Grid energy storage

A distributed energy resource is not limited to the generation of electricity but may also include a device to store distributed energy (DE). Distributed energy storage systems (DESS) applications include several types of battery, pumped hydro, compressed air, and thermal energy storage.Access to energy storage for commercial applications is easily accessible through programs such as Energy Storage as a Service (ESaaS).

PV storage

> Common rechargeable battery technologies used in today's PV systems include, the valve regulated lead-acid battery (lead–acid battery), nickel–cadmium and lithium-ion batteries. Compared to the other types, lead-acid batteries have a shorter lifetime and lower energy density. However, due to their high reliability, low self-discharge (4–6% per year) as well as low investment and maintenance costs, they are currently the predominant technology used in small-scale, residential PV systems, as lithium-ion batteries are still being developed and about 3.5 times as expensive as lead-acid batteries. Furthermore, as storage devices for PV systems are stationary, the lower energy and power density and therefore higher weight of lead-acid batteries are not as critical as for electric vehicles.
>
> However, lithium-ion batteries, such as the Tesla Powerwall, have the potential to replace lead-acid batteries in the near future, as they are being intensively developed and lower prices are expected due to economies of scale provided by large production facilities such as the Gigafactory 1. In addition, the Li-ion batteries of plug-in electric cars may serve as future storage devices, since most vehicles are parked an average of 95 percent of the time, their batteries

could be used to let electricity flow from the car to the power lines and back. Other rechargeable batteries that are considered for distributed PV systems include, sodium–sulfur and vanadium redox batteries, two prominent types of a molten salt and a flow battery, respectively.

Vehicle-to-grid

Future generations of electric vehicles may have the ability to deliver power from the battery in a vehicle-to-grid into the grid when needed.[31] An electric vehicle network has the potential to serve as a DESS.

Flywheels

An advanced flywheel energy storage (FES) stores the electricity generated from distributed resources in the form of angular kinetic energy by accelerating a rotor (flywheel) to a very high speed of about 20,000 to over 50,000 rpm in a vacuum enclosure. Flywheels can respond quickly as they store and feed back electricity into the grid in a matter of seconds.

Q4 What are Facts Devices explain in detail.

Ans:

In conventional AC transmission system, the ability to transfer AC power is limited by several factors like thermal limits, transient stability limit, voltage limit, short circuit current limit etc. These limits define the maximum electric power which can be efficiently transmitted through the transmission line without causing any damage to the electrical equipments and the transmission lines. This is normally achieved by bringing changes in the power system layout. However this is not feasible and another way of achieving maximum power transfer capability without any changes in the power system layout. Also with the introduction of variable impedance devices like capacitors and inductors, whole of the energy or power from the source is not transferred to the load, but a part is stored in these devices as reactive power and returned back to the source. Thus the actual amount of power transferred to the load or the active power is always less than the apparent power or the net power. For ideal transmission the active power should be equal to the apparent power. In other words, the power factor (the ratio of active power to apparent power) should be unity. This is where the role of Flexible AC transmission System comes.

A Flexible AC transmission System refers to the system consisting of power electronic devices along with power system devices to enhance the controllability and stability of the transmission system and increase the power transfer capabilities. With the invention of thyristor switch, opened the door for the development of power electronics devices known as Flexible AC transmission systems (FACTS) controllers. Basically the FACT system is used to provide the controllability of high voltage side of the network by incorporating power electronic devices to introduce inductive or capacitive power in the network.

Types of FACTS Controllers

- **Series Controllers:** Series Controllers consists of capacitors or reactors which introduce voltage in series with the line. They are basically variable impedance devices. Their major task is to reduce the inductivity of the transmission line. They supply or consume variable reactive power. Examples of series controllers are SSSC, TCSC, TSSC etc.

- **Shunt Controllers:** Shunt controllers consist of variable impedance devices like capacitors or reactors which introduce current in series with the line. Their major task is to reduce the capacitivity of the transmission line. The injected current is in phase with the line voltage. Examples of shunt controllers are STATCOM, TSR, TSC, SVC.
- **Shunt-Series Controllers:** These controllers introduce current in series using the series controllers and voltage in shunt using the shunt controllers. Example is UPFC.
- **Series-Series Controllers**: These controllers consist of a combination of series controllers with each controller providing series compensation and also the transfer real power along the line. Example is IPFC.

Types of Series Controllers

- **Thyristor controlled series capacitor (TCSC):** Thyristor controlled series capacitor (TCSC) uses silicon controlled rectifiers to manage a capacitor bank connected in series with a line. This allows utility for transferring more power on a specified line. It generally consists of the thyristors in series with an inductor and connected across a capacitor. It can work in the blocking mode where the thyristor is not triggered and current passes through the capacitor only. It can work in the bypass mode where the current is bypassed to the thyristor and the whole system behaves as a shunt impedance network.

- **Static Series Synchronous Compensators**: SSSC is simply a series version of STATCOM. These are not used in commercial applications as independent controllers. They consist of synchronous voltage source in series with the line such that it introduces a compensating voltage in series with the line. They can increase or decrease the voltage drop across the line.

Parallel Controllers

- **Static Variable Compensators**: Static variable compensator is the most primitive and first generation of FACTS controller. This compensator consists of a fast thyristor switch controlling a reactor and/or shunt capacitive bank to provide dynamic shunt compensation. They generally consist of shunt connected variable impedance devices whose output can be adjusted using power electronic switches, to introduce capacitive or inductive reactance in the line. It can be placed at the middle of the line to increase the maximum power transfer capability and can also be placed at the end of the line to compensate for variations due to load.

Types of SVC are

1. **TSR(Thyristor Switched Reactor)**: It consists of a shunt connected inductor whose impedance is controlled in a gradual manner using a Thyristor switch. The Thyristor is fired at angles of 90 and 180 degrees only.
2. **TSC(Thyristor Switched Capacitor)**: It consists of a shunt connected capacitor whose impedance is controlled in a stepwise manner using a Thyristor. The manner of control using the SCR is same as that of TSR.

3. **TCR(Thyristor Controlled Reactor)**: It consists of a shunt connected inductor whose impedance is controlled by the firing angle delay method of SCR wherein the firing of Thyristor is controlled causing a variation in the current through the inductor.

- **STATCOM(Static Synchronous Compensator)** : It consists of a voltage source which can be a DC energy source or a capacitor or a inductor whose output can be controlled using a Thyristor It is used to absorb or generate reactive power.

Q5. Explain HVDC in detail.

Ans:

Definition: The system which uses the direct current for the transmission of the power such type of system is called HVDC (High Voltage Direct Current) system. The HVDC system is less expensive and has minimum losses. It transmits the power between the unsynchronized AC system.

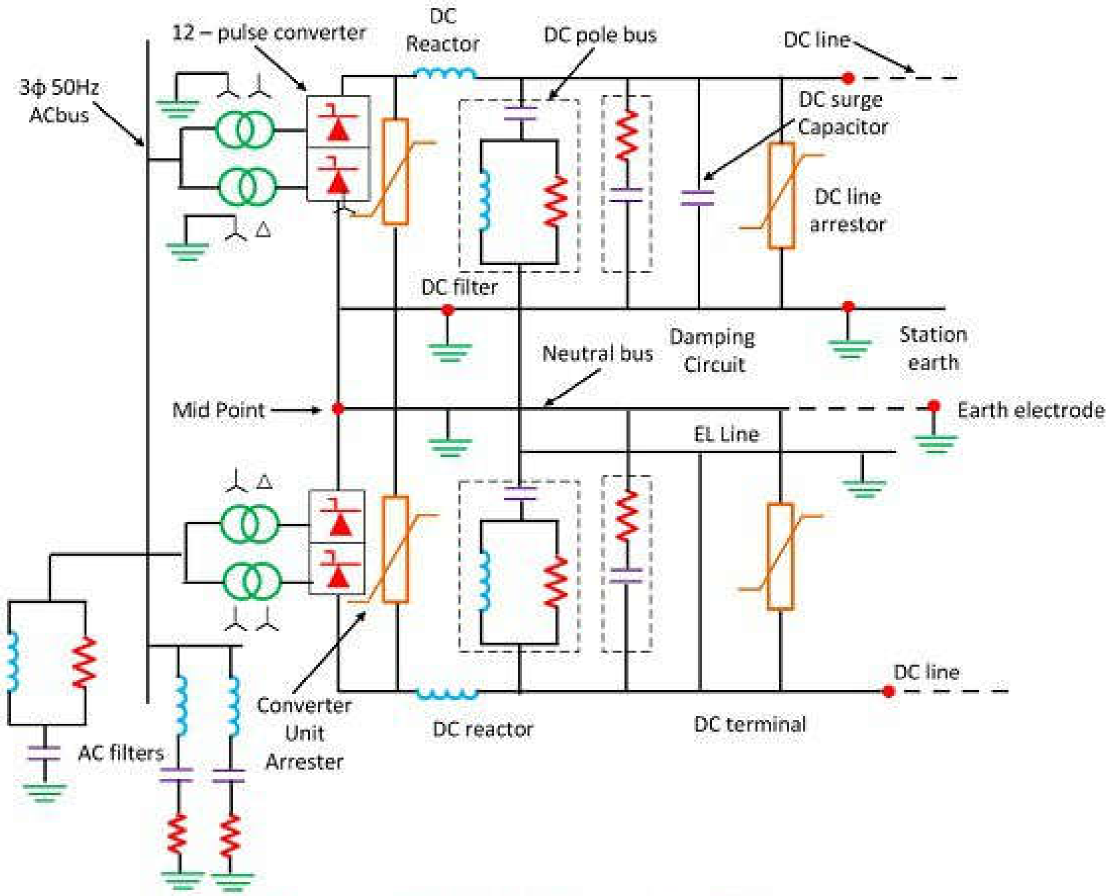
Component of an HVDC Transmission System

The HVDC system has the following main components.

- Converter Station
- Converter Unit
- Converter Valves
- Converter Transformers
- Filters
    - AC filter
    - DC filter
    - High-frequency filter
- Reactive Power Source
- Smoothing Reactor
- HVDC System Pole

Converter Station

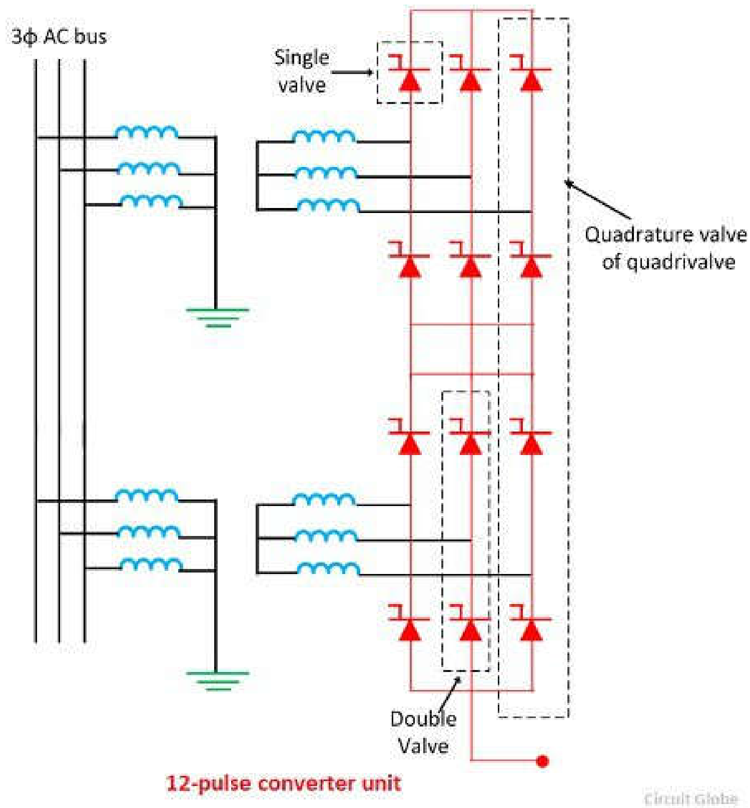
The terminal substations which convert an AC to DC are called rectifier terminal while the terminal substations which convert DC to AC are called inverter terminal. Every terminal is designed to work in both the rectifier and inverter mode. Therefore, each terminal is called converter terminal, or rectifier terminal. A two-terminal HVDC system has only two terminals and one HVDC line.



Schematic Diagram of A typical HVDCconverter Station

Converter Valves

The modern HVDC converters use 12-pulse converter units. The total number of a valve in each unit is 12. The valve is made up of series connected thyristor modules.The number of thyristor valve depends on the required voltage across the valve. The valves are installed in valve halls, and they are cooled by air, oil, water or freon.



Converter Transformer

The converter transformer converts the AC networks to DC networks or vice versa. They have two sets of three phase windings. The AC side winding is connected to the AC bus bar, and the valve side winding is connected to valve bridge.These windings are connected in star for one transformer and delta to another.

The AC side windings of the two, three phase transformer are connected in stars with their neutrals grounded. The valve side transformer winding is designed to withstand alternating voltage stress and direct voltage stress from valve bridge. There are increases in eddy current losses due to the harmonics current. The magnetisation in the core of the converter transformer is because of the following reasons.

- The alternating voltage from AC network containing fundamentals and several harmonics.
- The direct voltage from valve side terminal also has some harmonics.

Filters

The AC and DC harmonics are generated in HVDC converters. The AC harmonics are injected into the AC system, and the DC harmonics are injected into DC lines. The harmonics have the following advantages.

1. It causes the interference in telephone lines.
2. Due to the harmonics, the power losses in machines and capacitors are connected in the system.

3. The harmonics produced resonance in an AC circuit resulting in over voltages.
4. Instability of converter controls.

The harmonics are minimised by using the AC, DC and high-frequency filters. The types of filter are explained below in details.

- **AC Filters –** The AC filters are RLC circuit connected between phase and earth. They offered low impedances to the harmonic frequencies. Thus, the AC harmonic currents are passed to earth. Both tuned and damped filters are used. The AC harmonic filter also provided a reactive power required for satisfactory operation of converters.
- **DC Filters** – The DC filter is connected between the pole bus and neutral bus. It diverts the DC harmonics to earth and prevents them from entering DC lines. Such a filter does not require reactive power as DC line does not require DC power.
- **High-Frequency Filters** – The HVDC converter may produce electrical noise in the carrier frequency band from 20 kHz to 490 kHz. They also generate radio interference noise in the megahertz range frequencies. High-frequency filters are used to minimise noise and interference with power line carrier communication. Such filters are placed between the converter transformer and the station AC bus.