# Control Systems

(8 to 10M)

ESE ⇒ 100M

Obj (20 to 30M) (60 to 70M)

Text Books :-

Gate ① control System Engg → NISE

② control system Engg → Nagrath & Gopal

IES ③ Automatic CS → B.C.KUO

④ control systems : principle & Design : M.Gopal

⑤ Modern control Sys : ogota.

⇒ TF, BD, SFG → 1M or 2M

⇒ Time Domain Analysis → Transient Analysis, → Steady State Analysis (2M)

⇒ Stability → Time Domain tech ⇒ RH | RL; → frequency Domain tech ⇒ BP | NP (4M)

⇒ compensators & controller ×

⇒ State space Analysis → 2M

Control Sys :- objective ⇒ $\boxed{\text{To get desired O/P}}$

⇒ Why we don't get Desired O/P ⇒ Because Noise

⇒ High frequency Noise ⇒ [BW↑ → Noise Amplitude↑]

⇒ High freq noise is eliminated ⇒ By using Low pass filter

⇒ Control systems are desined as Low pass filter.

⇒ Standard form of Sys = $\dfrac{K(1+ST_1)(1+ST_2)\cdots}{S^n(1+ST_a)(1+ST_b)\cdots}$

$\dfrac{1}{S^n} \Rightarrow \dfrac{1}{S} \Rightarrow$ Integrator – Low pass filter.

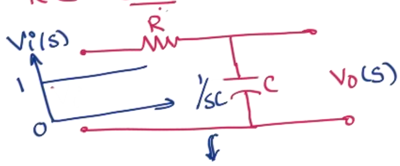
P>Z ⇒ Strictly proper TF

P=Z ⇒ proper TF

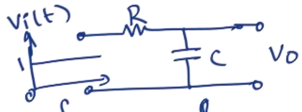
P<Z ⇒ Improper TF

TF :- It is a mathematical equivalent model of the System.

For ex:- RC CKt




$$\frac{V_o(s)}{V_i(s)} = \frac{1/sC}{R + 1/sC} = \frac{1}{sCR+1} = \left(\frac{1}{s\tau+1}\right)$$




$\Longleftrightarrow \left(\frac{1}{sT+1}\right)$

$\downarrow$ MEM $\downarrow$ $V_i(s) = \left(\frac{1}{s}\right)$

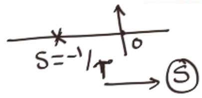
$\downarrow$ MEM $\downarrow$ $\left(\frac{1}{sT+1}\right)$

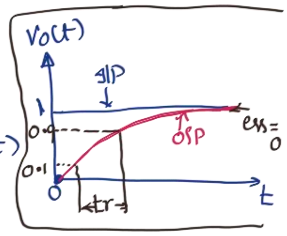
$\Rightarrow \frac{V_o(s)}{V_i(s)} = \left(\frac{1}{sT+1}\right)$

$V_o(s) = \frac{1}{s(sT+1)}$

$V_o(s) = \left(\frac{1}{s} - \frac{T}{sT+1}\right)$

$\xrightarrow{ILT} V_o(t) = \left(1 - e^{-t/T}\right)u(t)$




$\Rightarrow$ BD & SFG :- To find overall TF of the System.

TIME DOMAIN ANALYSIS :- (To Evaluate performance of the System)

- $\rightarrow$ Transient Analysis $\longrightarrow$ Speed
- $\rightarrow$ Steady state Analysis $\longrightarrow$ Accuracy

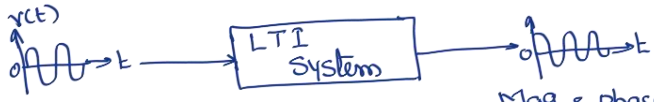
$\delta(t)$ $r(t)$ $\longrightarrow$ TF or MEM SYSTEM $\longrightarrow$ $c(t)$


$t_d, t_r, t_p, t_s$ $\uparrow$ $\rightarrow$ Slow Res

$\%M_p$ $e_{ss}$ $\uparrow$ — Less Accurate

$\uparrow \Rightarrow$ More oscillation

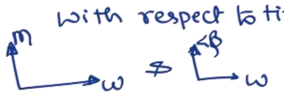
$\rightarrow$ Less Relative (S)




Mag & phase

⇒ o/p does not change with respect to time.

fi




→ frequency response Analysis.

⇒ **Stability:** → $\boxed{\text{To find closed loop system stability}}$

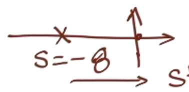
⇒ Prob:- The OLTF of a unity feedback system $G(s) = \left(\frac{10}{s-2}\right)$. The system is

ⓐ Stable ⓑ unstable ⓒ Marginal stable ⓓ conditional stable


→ CL system

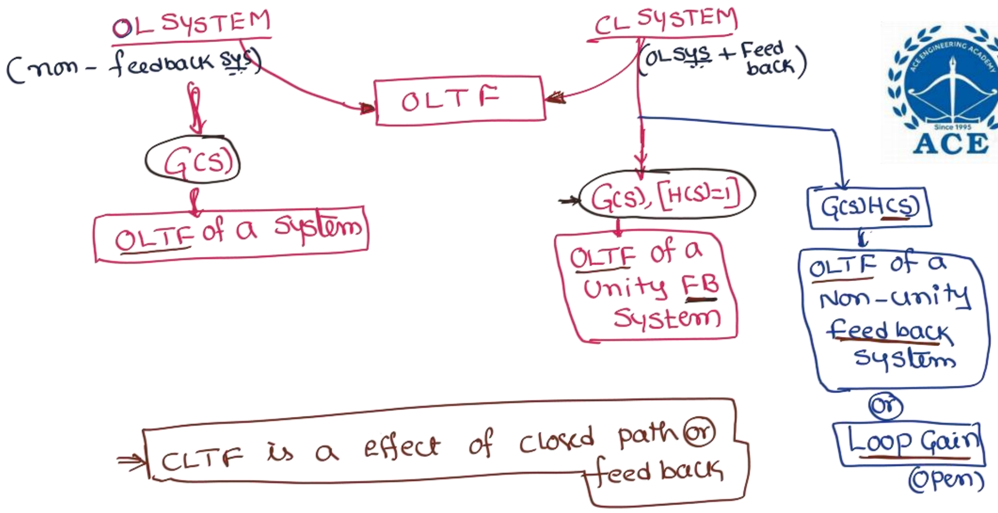
$G(s) = \frac{10}{(s-2)}$, $H(s) = 1$ ⇒ CLTF $\frac{C(s)}{R(s)} = \frac{G(s)}{1+G(s)}$

CLTF $= \frac{10}{(s-2)+10} = \left(\frac{10}{s+8}\right)$



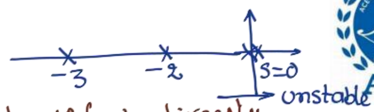

→ Stable.

⇒ Any system, described in terms of OLTF




→ OL system :- It is described as OLTF of a system.

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




→ Open loop poles locations are identified directly.

→ Hence we can find OL stability directly. No stability tech reqd to find OL stability.

⇒ CL System :- It is described as OLTF of a unity FB system.

$$G(s) = \frac{(s+1)}{s^2(s+2)(s+3)}, \quad H(s)=1$$

$$\Rightarrow CLTF \Rightarrow \frac{C(s)}{R(s)} = \frac{(s+1)}{s^2(s+2)(s+3)+(s+1)} = \frac{(s+1)}{\underbrace{(s^4+5s^3+6s^2+s+1)}}$$

→ CL Poles locations can't identified directly. Because find roots of denominator of TF is difficult. Hence reqd a stability tech to find CL stability.

⇒ CL Ⓢ → RH / RL ⇒ Time Domain tech
CL Ⓢ → BP / NP → freq Domain tech

For Complete Analysis ⟶ Best is Time Domain tech.
For stability ⟶ Best is freq Domain tech.

For ex :- $L[g(t-T)] = e^{-sT} \cdot G(s)$ ⇒ [Transportation delay (or) Lag system]

Time Domain tech :-
RH/RL :- Reqd Pole location.

$$e^{-sT} = \left(1 - sT + \cancel{\frac{(sT)^2}{2!}} - \cdots \infty\right)$$ Neglect High order terms.

$$e^{-sT} \simeq (1 - sT)$$ → Approximate Ⓢ condition is obtained.

Freq Domain tech :-
BP / NP :- Reqd Magnitude & Phase.

$$e^{-sT} = e^{j(-\omega T)} \Rightarrow M = 1, \quad \angle\phi = (-\omega T)$$

$$\boxed{\begin{aligned} e^{j(\pm\theta)} &= \cos\theta \pm j\sin\theta \\ M &= \sqrt{\cos^2\theta + \sin^2\theta} = 1 \\ \angle\phi &= \tan^{-1}\left(\frac{\pm\sin\theta}{\cos\theta}\right) = (\pm\theta) \end{aligned}}$$

Here exact magnitude & phase is obtained. Hence exact Ⓢ condition is obtained.

$1^{st}$ priority $\Rightarrow$ NP
- → Stability of all systems.
- → No of CL poles RH-s-plane
- → Range of K for (S)
- → Gm & pm

$2^{nd}$ priority $\Rightarrow$ RL $\Rightarrow$ Nature of the system is Identified

$3^{rd}$ priority $\Rightarrow$ BP $\Rightarrow$ stability of only Minimum phase sys

$4^{th}$ priority $\Rightarrow$ RH $\Rightarrow$ Exact location of pole can't find.

$\Rightarrow$ Compensators & controllers :- To get desired specifications

$\Rightarrow$ Speed ⟶ Lead (or) PD controller (HPF)
$\Rightarrow$ Stability $\Rightarrow$ " " "
$\Rightarrow$ Accuracy $\Rightarrow$ Lag (or) PI controller (LPF)

$\Rightarrow$ Speed, Accuracy & stability
⇓
Lag-Lead compensator (or) PID controller.

State space Analysis :- valid for Dynamic systems

TF Analysis ⟶ Valid only LTI systems

$\Rightarrow$ $\boxed{\text{Dynamic System} \longrightarrow L \mid NL \mid TV \mid TIV}$

i/p → [System] → proper o/p

$\underbrace{\text{System}}_{\text{Group of Physical components}}$

i/p → [control SYSTEM] → Desired o/p

A FAN w/o Blades → Not a system → No proper o/p (No air flow)

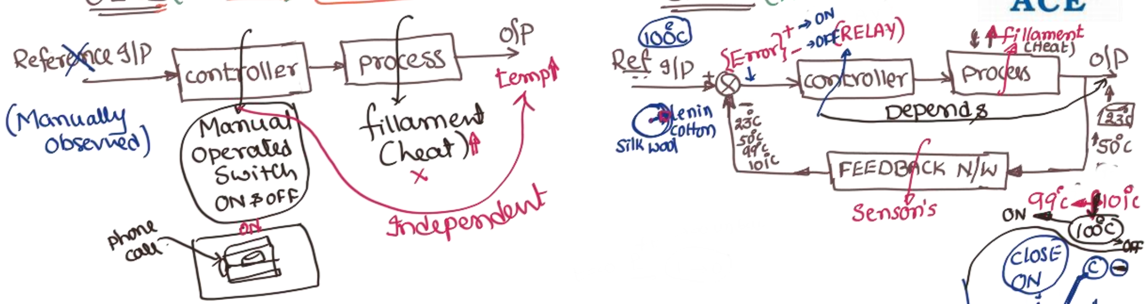
A FAN w/o Regulator → System → proper o/p (air flow)
(May or May not be desired o/p)

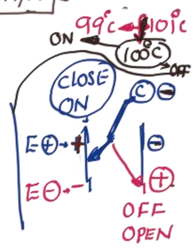
A FAN with Regulator → control system ⇒ Desired o/p.
(Desired air flow)

Control system:- It is a group of physical components arranged in a such away that, it gives the desired o/p, by using controller or regulator to the given i/p.

⇒ Control systems are classified into two ways based on controller action.

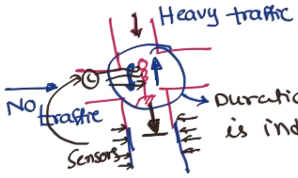
OLCS (Manual) → IRON BOX ← CLCS (Automatic)




⇒ Reference i/p ⇒ want we read from the system [Desired o/p]

Traffic control signal (OL sys)




→ Duration of Traffic light is independent of clearence of traffic (or) Existed traffic

→ OL system :- Human being not included.

⇒ Manual control sys :- closed loop cs → Man ⇒ work like feedback n/w

⇒ CL control systems ⇒ sensor are essential.

OL system :- A system in which, the controller action is independent of o/p. is called open loop system

ex:→ FAN, AIR COOLER, Traffic light, washing machine ... Any system, which is not having provision to select reference i/p and not having sensors.

CL system :- A system in which, the controller action depends on output is called closed loop control system.

Ex → AC, Human Being, Automatic iron Box, refrigirators --- any system which is having sensors & provison to select the reference i/p.

FEEDBACK N/W :- It is a property of the closed loop system which brings the o/p to i/p & compare with reference i/p & Generate error.

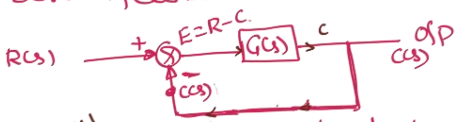
⇒ controller action take place such that, the error becomes the zero.

⇒ Error = 0 means, the system is stable [Bounded i/p] & gives desired o/p.

⇒ feedback n/w consists the sensors.

⇒ Maximum gain of feedback n/w ratio is 1

⇒ The Best feedback is unity negative FB.




E = R − CH

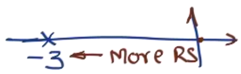
↳ steady state errors are valid for only unity feedback system.

−ve FB ⟶ Improves the relative stability [G(s), H(s) > 0]

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

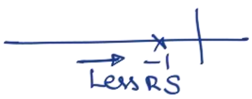

(2nd priority)

H(s) = 1 & (−ve FB) ⟶ $\frac{C(s)}{R(s)} = \frac{G(s)}{1+G(s)} = \frac{1}{S+3}$




(1st priority)

H(s) = 1 & (+ve FB) ⟶ $\frac{C(s)}{R(s)} = \frac{G(s)}{1-G(s)} = \frac{1}{S+1}$




(last priority)