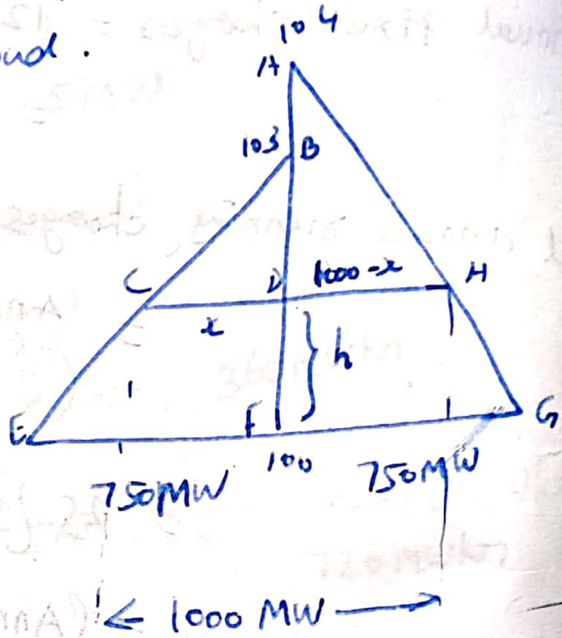
UNIT-2

Real power frequency Control

Problem: 1 Two 750KW alternators operates in parallel. The speed regulation of 1 set 100% to 103% from full load to no load and that of other is 100% to 104%. How will the two alternators share a load of 1000KW and at what load will one machine cease to supply any portion of the load.



Solution:
Total load = 1000KW

Unit I = 3% drop

Unit II = 4% drop

Let x be the power generation of unit I

from similar triangle ΔBCD & ΔBEF

$$\frac{CD}{EF} = \frac{BD}{BF}$$

$$\frac{x}{750} = \frac{3-h}{3}$$

$$x = 750 - 250h \quad \text{--- (1)}$$

from similar triangle ΔADH & ΔAFG

$$\frac{DH}{FG} = \frac{AD}{AF}$$

$$\frac{1000-x}{750} = \frac{4-h}{4}$$

$$1000 - x = 750 - 187.5h$$

$$x = 250 + 187.5h \quad \text{--- (2)}$$

Scanned by CamScanner

equating ① & ②

$$250 + 187.5h = 750 - 250h$$

$$187.5h + 250h = 750 - 250$$

$$h = 1.142$$

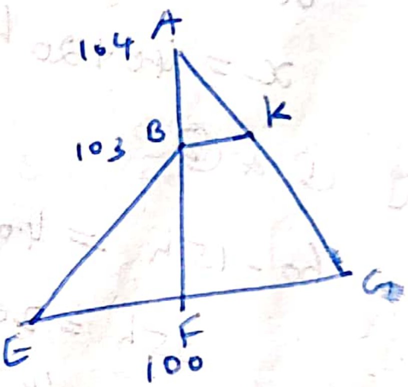
$$x = 750 - 1.142 \times 250$$

$$x = 464.28\,kW$$

$$PG_1 = 464.28\,kW$$

$$PG_2 = 1000 - x = 535.7\,kW$$

machine 1 cease to supply any load when the line DH is shifted to point B. At this point machine 2 will supply load equal to BK



from ΔABK and ΔAFG

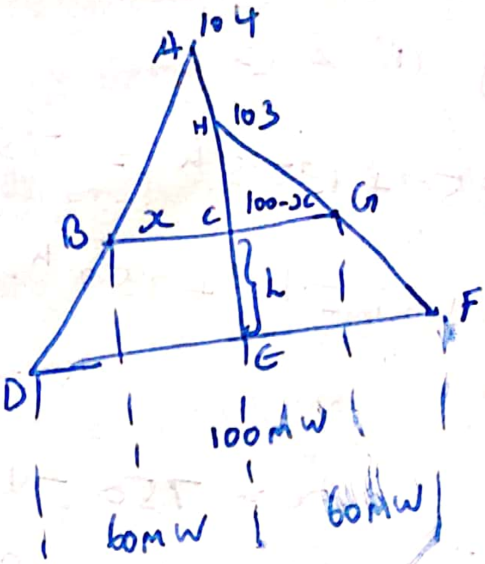
$$\frac{BK}{FG} = \frac{AB}{AF}.$$

$$BK = FG \times \frac{AB}{AF} = 750 \times \frac{1}{4} = 187.5\,kW$$

Problem: 2 Two identical 60MW Synchronous machine operate in Parallel the governor settings on the machine are such that they have 4% and 3% droops no load to full load % speed drops. Determine the load taken by each machine for a total load of 100MW.

a) the load taken by each machine for a total load of 100MW
b) The % no-load speed to be made by the speeder motor If the machines are to share the load equally.

from



ΔABC & ΔADE

$$\frac{BC}{DE} = \frac{AC}{AE}$$

$$\frac{x}{60} = \frac{4-h}{4}$$

$$x = 60 - 15h \quad \text{--- (1)}$$

ΔACG & ΔAEF

$$\frac{100-x}{60} = \frac{3-h}{3}$$

$$x = 40 + 20h \quad \text{--- (2)}$$

equating (1) & (2)

$$60 - 15h = 40 + 20h$$

$$35h = 20$$

$$h = \frac{4}{7}$$

$$x = 60 - 15h = 60 - 15 \times \frac{4}{7} = 51.42\ MW$$

$$P_{G_1} = 51.42\ MW$$

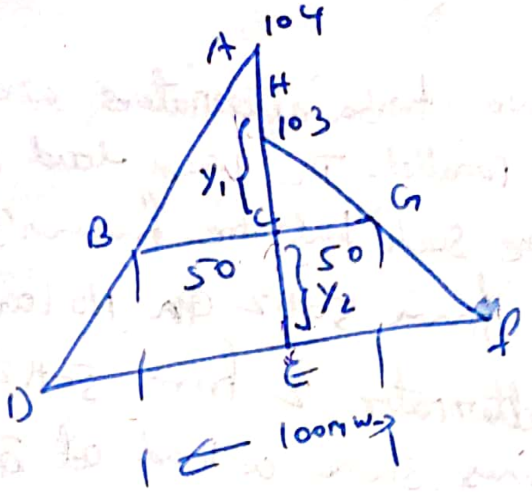
$$P_{G_2} = 100 - 51.42$$

$$= 48.58\ MW$$

ii) If both machines share equally.

$$P_{G_1} = P_{G_2} = \frac{P_D}{2} = 50\ MW$$

$\triangle ABC$ & $\triangle ADG$



$$\frac{BC}{DE} = \frac{AC}{AE}$$

$$\frac{50}{60} = \frac{y_1}{4}$$

$$y_1 = \frac{4 \times 50}{60} = 3.33\%$$

$\triangle HCG$ & $\triangle HEF$

$$\frac{CG}{EF} = \frac{HC}{HE} = \frac{3-CE}{HE}$$

$$\frac{50}{60} = \frac{3-CE}{3} = 3-CE = \frac{50}{60} \times 3$$

$$CE = 3 - \frac{50 \times 3}{60} = 0.5$$

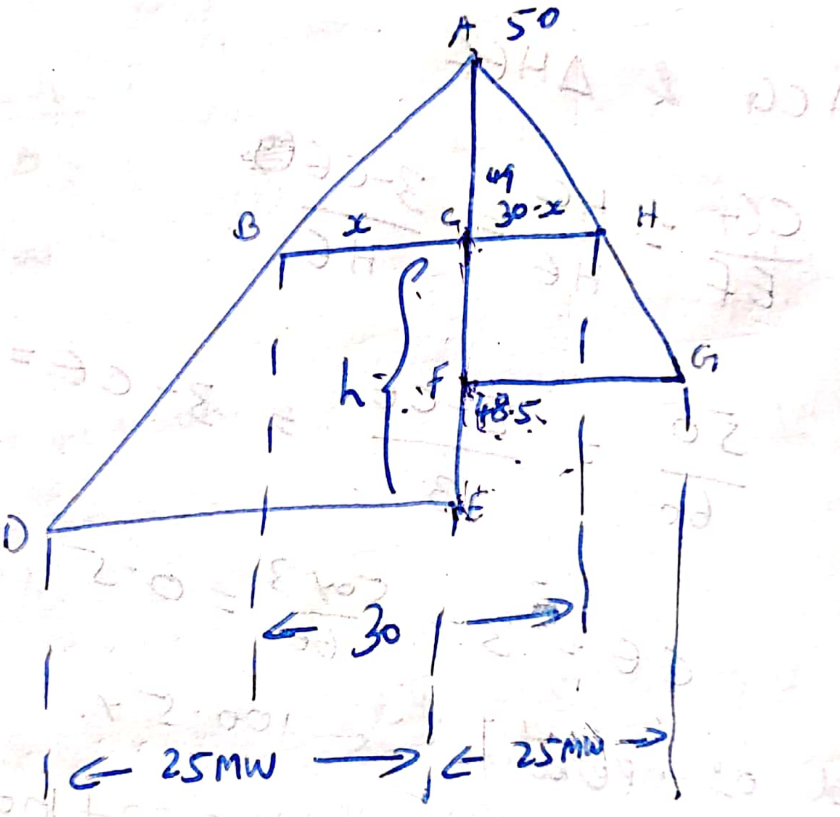
Speed of operation is 100.5%.

$$y_1 + y_2 = 3.33 + 100.5$$

$$= 103.83\%$$

∴ percentage no load speed in the 4% drop machine is 103.83%.

Problem: 3 Two-turbo alternators are rated at 25 MW each. They are running in parallel. The speed-load characteristics of the driving turbines are such that the frequency of alternator 1 drops uniformly from 50 Hz on No load to 48 Hz on full load and that of alternator 2 from 50 Hz to 48.5 Hz a) How will the two machines share a load of 30 MW and find the bus-bar frequency at this load? b) Compute the maximum load that these two units can deliver without overloading either of them



$$\frac{BC}{DE} = \frac{AC}{AE}$$

$$\frac{x}{25} = \frac{2-h}{50-48} = \frac{2-h}{2}$$

$$x = 25 - 12.5h \quad -(1)$$

$$\frac{CH}{FG} = \frac{AC}{AF}$$

$$\frac{30-x}{25} = \frac{AF - FC}{AF}$$

$$\frac{30-x}{25} = \frac{1.5 - (h - 0.5)}{1.5}$$

$$30 - x = 25\left[1 - \frac{h}{1.5} + \frac{0.5}{1.5}\right]$$

$$x = -3.33 + 16.67h \quad -(2)$$

equating ① & ②

$$25 - 12.5h = -3.33 + 16.67h$$

$$29.17h = 28.33$$

$$h = \frac{28.33}{29.17} = 0.971$$

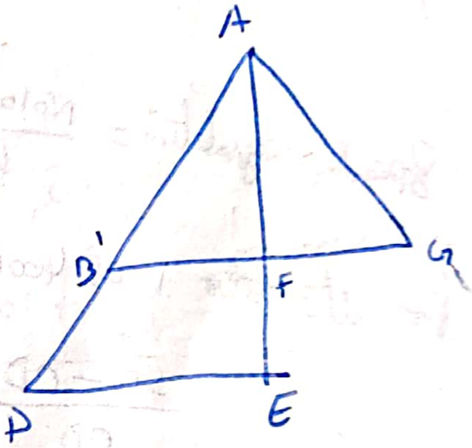
$$x = 25 - 12.5 \times 0.971 = 12.85 MW$$

$$\text{alternator 2} = 30 - x = 30 - 12.85 = 17.15 MW$$

System frequency $f = 48 + h$

$$= 48 + 0.971$$

$$= 48.971 Hz$$



b) full load will first come on alternator 2

full load $= 25 MW$ @ $48.5 Hz$

Extend BC to B'F

$$\frac{B'F}{DE} = \frac{AF}{AE}$$

$$\frac{B'F}{25} = \frac{50 - 48.5}{50 - 48}$$

$$B'F = \frac{1.5}{2} \times 25 = 18.75 MW$$

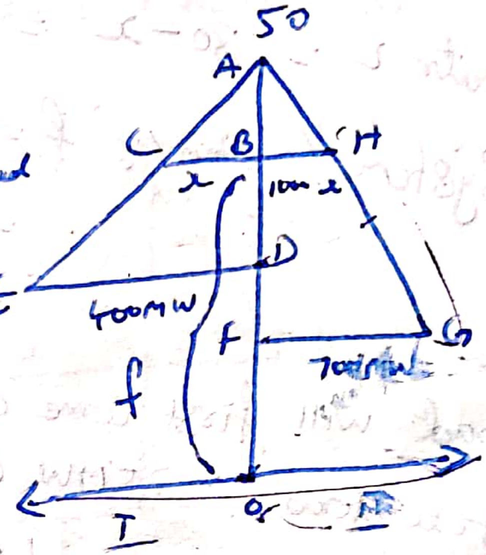
maximum possible load $= 25 + 18.75 = 43.75 MW$

system frequency $= 48.5 Hz$

Scanned by CamScanner

problem:

Two generators rated 400 MW and 700 MW are operating in parallel. The drop characteristics of their governors are 3% and 4% respectively from no-load to full load. Assuming that the governors are operating @ 50 Hz at no load, how would a load of 1000 MW be shared b/w them? What will be the system frequency at this load? Assume linear governor operation. Determine the full load speed for each machine.



Speed regulation = $\dfrac{\text{No load speed} - \text{full load speed}}{\text{full load speed}}$

for alternator 1 of 400 MW

$$\frac{50 - OD}{OD} = 0.03$$

$$50 - OD = 0.03 OD$$

$$50 = 0.03 OD + OD$$

$$50 = 1.03 OD$$

$$OD = 48.544 Hz$$

for alternator 2

$$\frac{50 - OF}{OF} = 0.04$$

$$1.04 OF = 50$$

$$OF = 48.077 Hz$$

Scanned by CamScanner

$\Delta ABC \; \& \; \Delta ADE$

$$\frac{CB}{ED} = \frac{AB}{AD}$$

$$\frac{x}{400} = \frac{50-f}{OA-OD} = \frac{50-f}{50-48.54}$$

$$x = 13736.26 - 27473f \quad \text{--- (1)}$$

$\Delta ABH \; \& \; \Delta AFG$

$$\frac{BH}{FG} = \frac{AB}{AF}$$

$$\frac{1000-x}{700} = \frac{50-f}{50-of} = \frac{50-f}{50-48.077}$$

$$1000-x = 18200.73 - 364.01f \quad \text{--- (2)}$$

equating 1 & 2

$$1000 = 31936.99 - 638.74f$$

$$638.74f = 30936.99$$

$$f = 48.434 \text{ Hz}$$

Load shared by alternator 1 $= 13736.26 - 27473 \times 48.434$

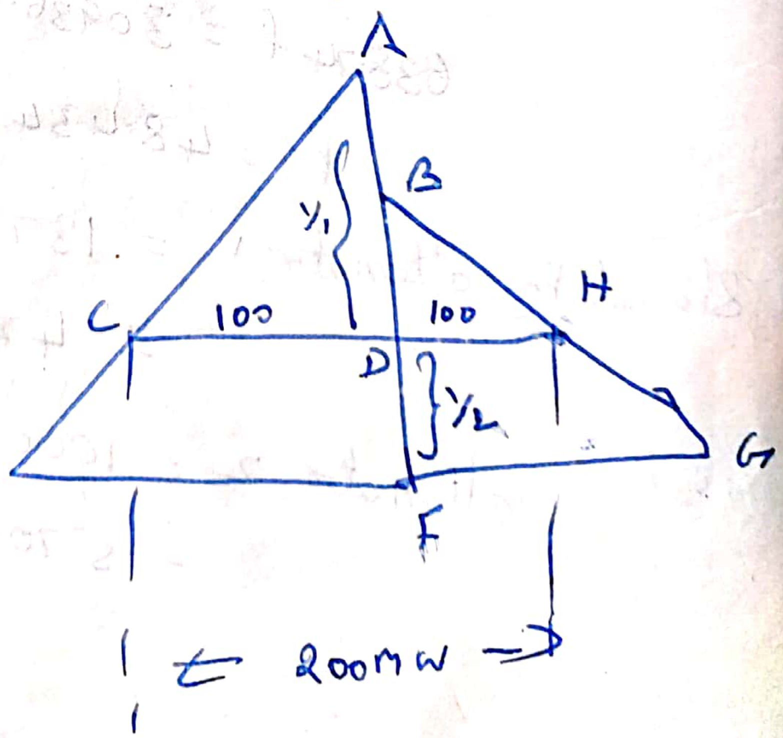
$= 429.88 \text{ MW}$

alternator 2 $= 1000 - 429.88$

$= 570.12 \text{ MW}$

Problem: Two synchronous generators operating in parallel. Their capacities are 300MW and 400 MW. The drop characteristics of their governors are 4% and 5% from no load to full load. Assuming that the generators are operating @ 50Hz at no load how would be a load of 600MW shared b/w them. What will be the system frequency at this load? Assume free governors action.

Problem: Two generators rated @ 120MW and 250MW are operating in parallel. The governor setting on the machines are such that they have 4 percent and 3 percent drops. Determine (i) the load taken by each machine for a total load of 200 MW. ii) The percentage no load speed and rated output of machine 1 to be made by the speeder motor if the machines are to share the load equally. iii) Rated output of machine 1



$$\frac{CD}{CF} = \frac{AD}{AF} = \frac{y_1}{4}$$

$$\frac{100}{120} = \frac{y_1}{4}$$

$$y_1 = \frac{400}{120} = 3.33$$

$$\frac{DH}{FG} = \frac{BD}{BF}$$

$$= \frac{100}{250} = \frac{3-y_2}{3}$$

$$300 = 750 - 250y_2$$

$$y_2 = 1.8$$

The speed of operation $100 + 1.8 = 101.8\%$.

$$y_1 = 3.33$$

$$101.8 + 3.33 = 105.13\%.$$

Total % frequency $= 105.13\%$.

i) Determine rated O/P

$$x_1 \propto 105.13 - 100 \quad \text{--(3)}$$

$$100 \propto 104 - 100 \quad \text{--(4)}$$

$\div$ 3 by 4

$$\frac{x_1}{100} = \frac{5.13}{4}$$

$$x_1 = 128.25 \text{ MW}$$

Load frequency Control of Single area System:

Let ΔP_C be the incremental Control input

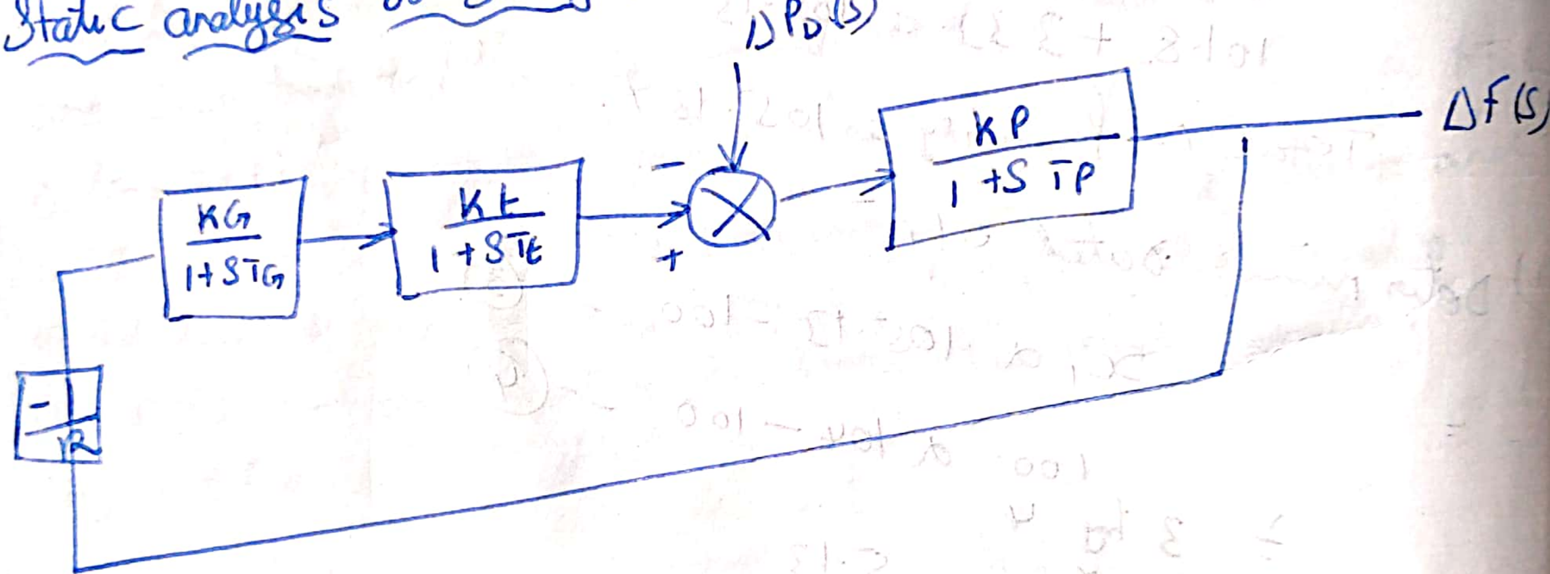
ΔP_D be the incremental disturbance input.

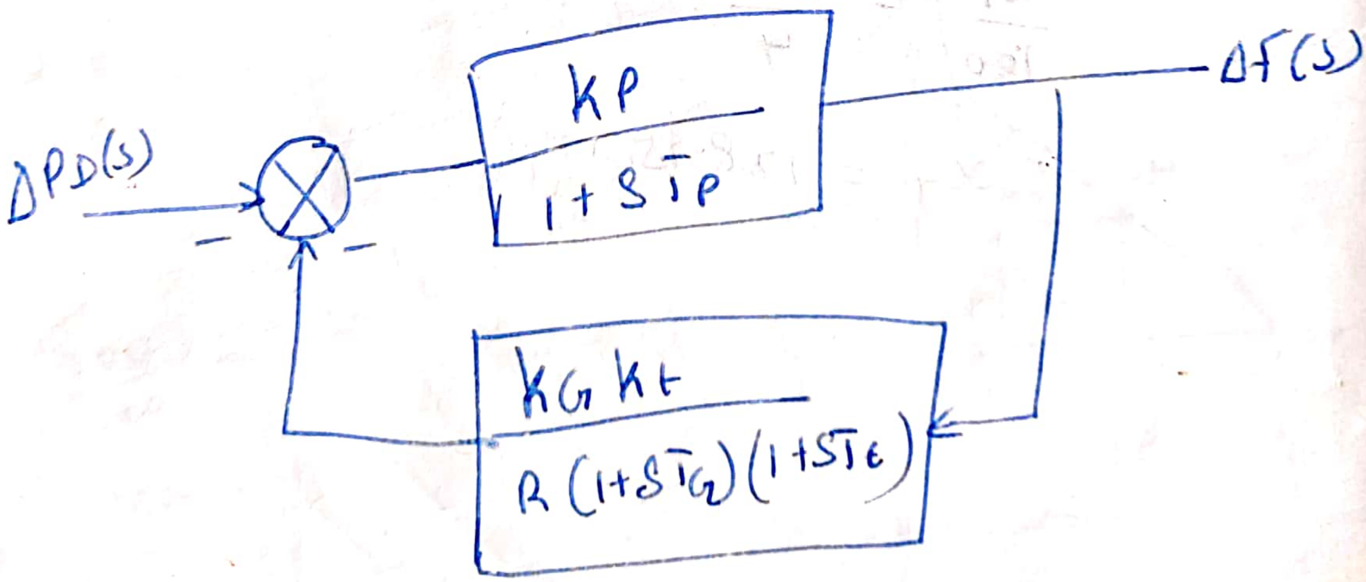
There are two types of responses.

1) Steady State (or) Static response

2) Dynamic State response.

Static analysis or Steady State response of uncontrolled case:



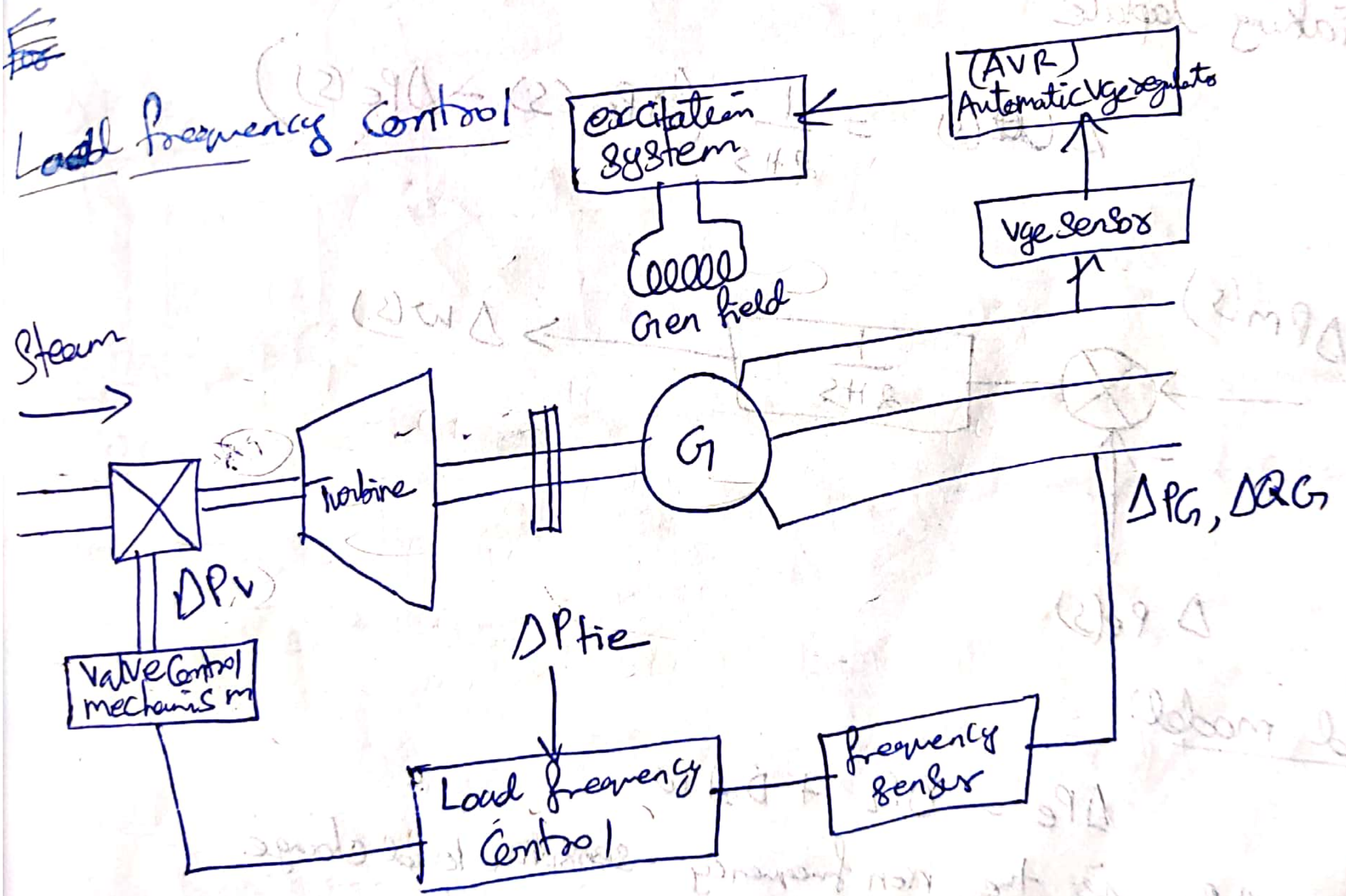


$$\Delta F(s) = \frac{\frac{K_P}{1+sT_P}}{1+\frac{K_P}{1+sT_P}\times\frac{K_G K_t}{R(1+sT_G)(1+sT_t)}}\left[-\Delta P_D(s)\right]$$

$$\boxed{T\cdot f = \frac{G(s)}{1+G(s)H(s)}}$$

$$\Delta F(s) = \frac{K_P}{1+sT_P+\frac{K_P K_G K_t}{R(1+sT_G)(1+sT_t)}}\left[-\Delta P_D(s)\right]$$

Load frequency Control



Generator model

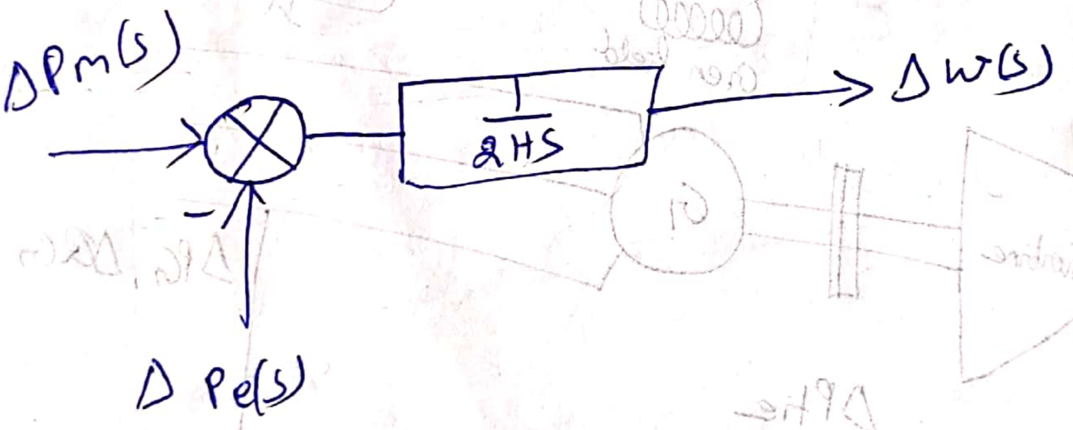
Applying the swing equation of a synchronous machine

$$\frac{2H}{W_s}\frac{d^2\Delta\delta}{dt^2} = \Delta P_m - \Delta P_e$$

$$\frac{d\Delta w}{dt} = \frac{1}{2H}\left(\Delta P_m - \Delta P_e\right)$$

Taking laplace

$$\Delta W(s) = \frac{1}{2HS}\left(\Delta P_m(S) - \Delta P_e(S)\right)$$

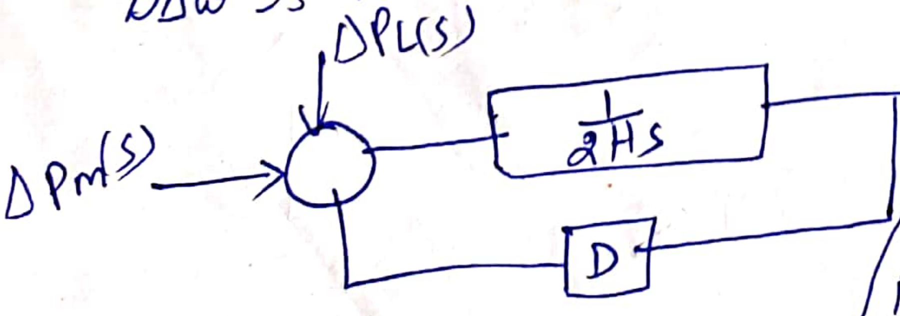


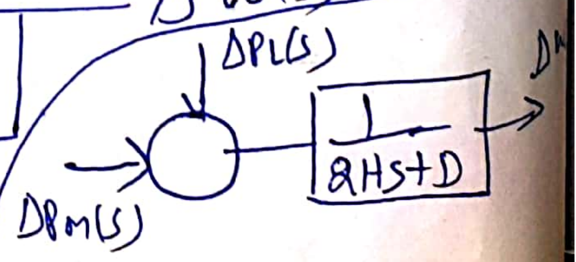
Load model:

$$\Delta P_e = \Delta P_L + D\Delta w$$

ΔP_L is the non frequency-sensitive load change

$D\Delta w$ is the frequency sensitive load change



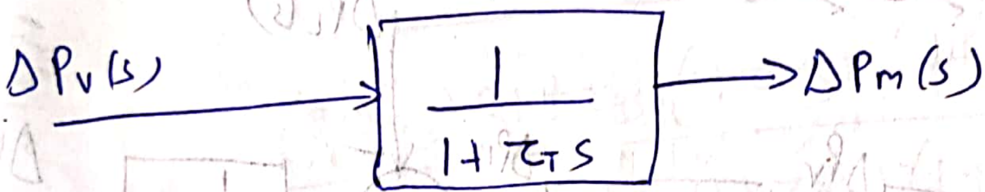


Prime mover model (turbine)

The model for the turbine relates changes in mechanical power output ΔP_m to changes in steam valve position ΔPV

$$G_T(s) = \frac{\Delta P_m(s)}{\Delta PV(s)} = \frac{1}{1+\tau_T s}$$

τ_T time constant is in the range of 0.2 to 2.0 sec



Governor model:

Speed governor mechanism acts as a comparator whose output ΔP_g is the difference b/w the reference set power ΔP_{ref} and the power $\frac{1}{R}\Delta\omega$.

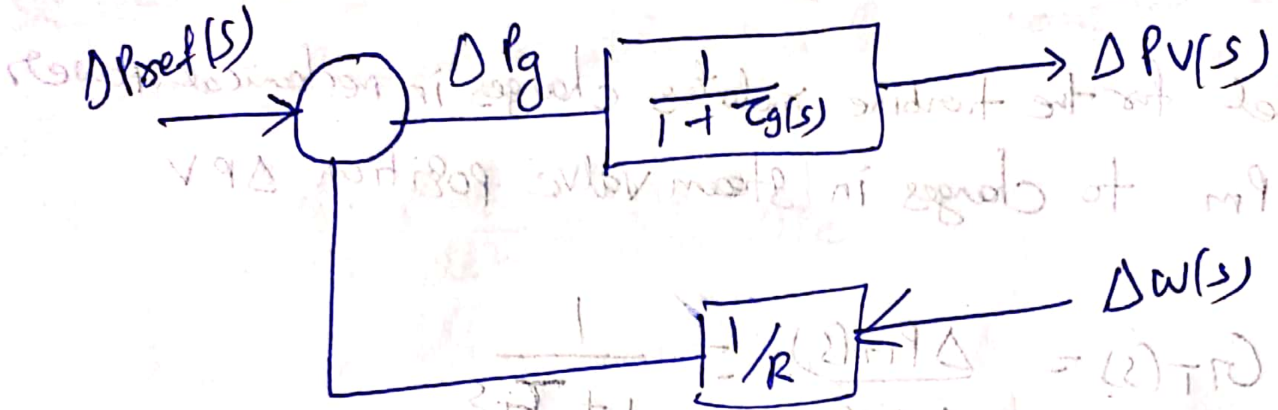
$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\Delta\omega$$

taking laplace

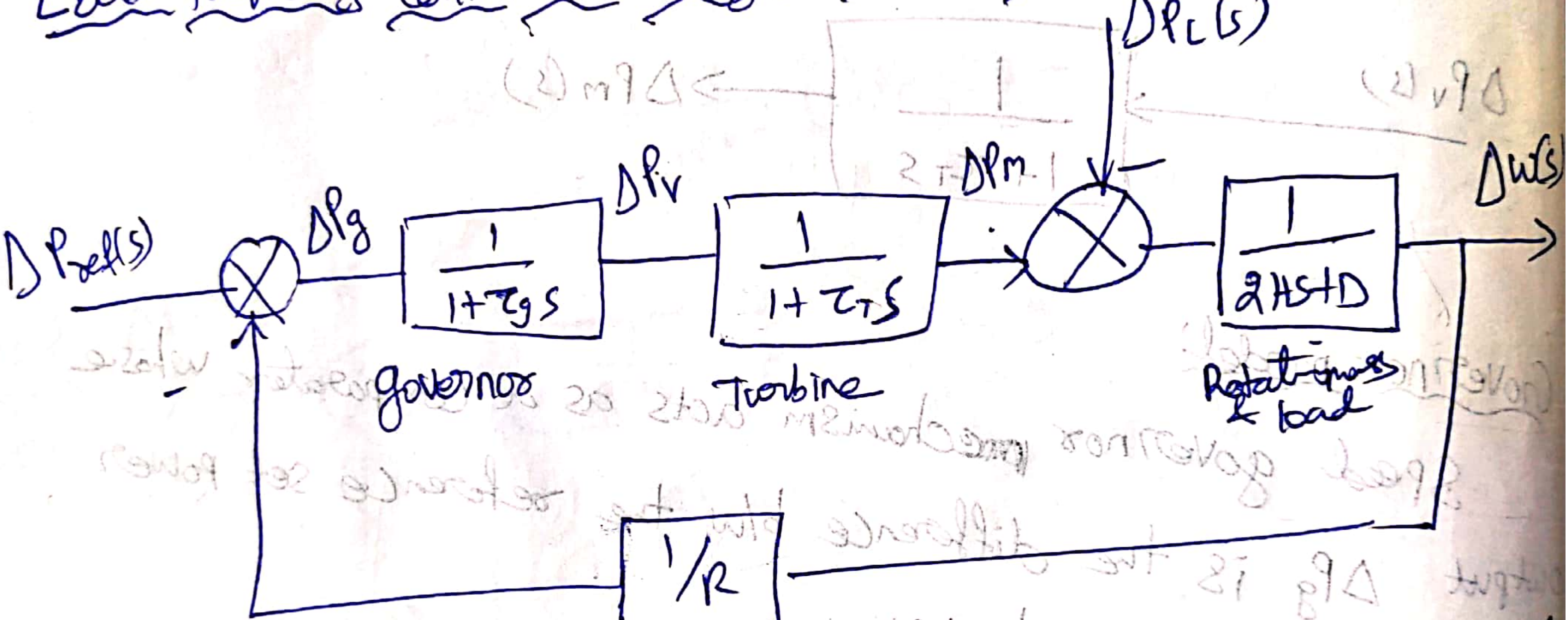
$$\Delta P_g(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta\omega(s)$$

The command ΔP_g is transformed through the hydraulic amplifier to the steam valve position command ΔP_V considering a simple time constant τ_g

$$\Delta P_V(s) = \frac{1}{1+\tau_g}\Delta P_g(s)$$

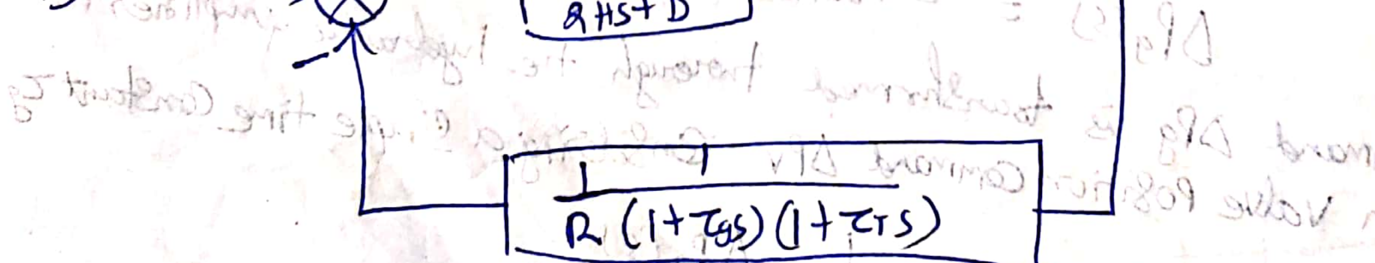


Load frequency control block diagram of an isolated power system.



Static analysis of uncontrolled case or Steady State Response of uncontrolled case

If the $\Delta P_{ref}(s) = 0$



$$\frac{\Delta\omega(s)}{-\Delta P_L(s)} = \frac{G(s)}{1+G(s)H(s)}$$

$$= \frac{\frac{1}{2HS+D}}{1+\frac{1}{(2HS+D)R(1+\tau_g S)(1+\tau_T S)}}$$

$$= \frac{\frac{1}{2HS+D}}{\frac{(2HS+D)R(1+\tau_g S)(1+\tau_T S)+1}{(2HS+D)R(1+\tau_g S)(1+\tau_T S)}}$$

$$= \frac{1}{\cancel{(2HS+D)}} \times \frac{\cancel{(2HS+D)}R(1+\tau_g S)(1+\tau_T S)}{(2HS+D)R(1+\tau_g S)(1+\tau_T S)+1}$$

$$= \frac{\cancel{R}(1+\tau_g S)(1+\tau_T S)}{\cancel{R}(2HS+D)(1+\tau_g S)(1+\tau_T S)+\frac{1}{R}}$$

applying final value theorem -

$$\Delta W_{ss} = \lim_{S\to 0}\left(\frac{1}{D+1/R}\right)(-\Delta P_L)$$

For the case with no frequency sensitive load

$D = 0$

$\Delta w_{ss} = (-\Delta P_L) R$

When several generators with governor speed regulations $R_1, R_2 - - - - R_n$ are connected to the system the steady-state deviation in frequency is given by

$$\Delta w_{ss} = (-\Delta P_L) \frac{1}{D + \frac{1}{R_1} + \frac{1}{R_2} + - - 1/R_n}$$

problem: 2

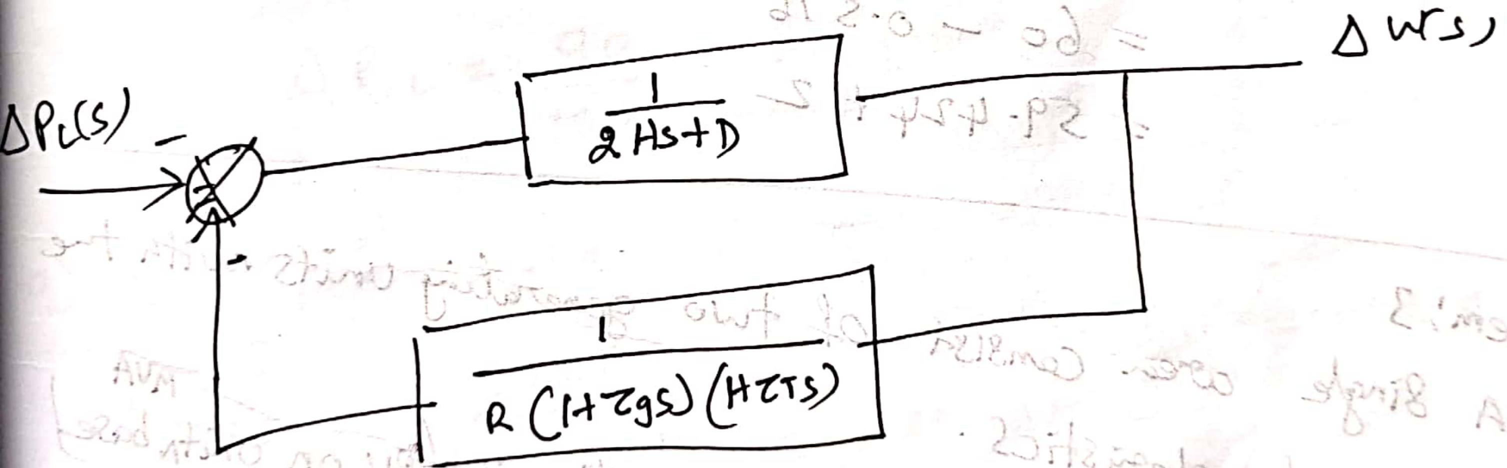
An isolated power station has the following parameters Turbine time constant $\tau_T = 0.5$ sec governor time constant $\tau_g = 0.2$ generator inertia constant $H = 5$ sec Governor speed regulation $= R$ per unit $= 0.05$ per unit. The turbine rated output is 250MW at nominal frequency of 60Hz. A sudden load change of 50MW ($\Delta P_L = 0.2$) perunit occurs

$$\Delta P_L = \frac{50}{250} =$$

find the steady state frequency deviation in Hz

The load varies by 0.8 percent for a 1 percent change in frequency $D = 0.8$

$$\frac{\Delta W(s)}{-\Delta P_L(s)} = \frac{(1+\tau_g s)(1+\tau_T s)}{(2Hs+D)(1+\tau_g s)(1+\tau_T s)+\frac{1}{R}}$$



$$= \frac{(1+0.2s)(1+0.5s)}{(10s+0.8)(1+0.2s)(1+0.5s)+\frac{1}{0.05}}$$

$$= \frac{0.1s^2+0.7s+1}{s^3+7.08s^2+10.56s+20.8}$$

Scanned by CamScanner

apply final value theorem

$$\Delta w_{ss} = \lim_{s \to 0} = \frac{1}{20.8}(-0.2) = -0.0096 \text{ P.U}$$

Thus the steady state frequency deviation

$$\Delta f = (-0.0096)(60) = -0.576$$

The new system frequency

$$f = f_0 + \Delta f$$

$$= 60 - 0.576$$

$$= 59.424 \text{ Hz}$$

Problem: 3

A single area consist of two generating units with the following characteristics.

unit	Rating	speed regulation R (PU on unit MVA base)
1	600 MVA	6%
2	500 MVA	4%

The units are operating in parallel sharing 900 MW at the nominal frequency. Unit 1 supplies 500 MW and unit 2 supplies 400 MW at 60 Hz. The load is increased by 90 MW

a) Assume there is no frequency-dependent load i.e $D=0$ find the steady-state frequency deviation and the new generation on each unit.

b) The load varies 1.5 percent for every 1 percent change in frequency $D=1.5$ find the steady state frequency deviation and the new generation on each unit.

(Select 1000 MVA as base)

$$R_1 = \frac{1000}{600}(0.06) = 0.1 \text{ pu}$$

$$R_2 = \frac{1000}{500}(0.04) = 0.08 \text{ p.u}$$

The per unit load change is

$$\Delta P_L = \frac{90}{1000} = 0.09 \text{ p.u}$$

a) $D = 0$

$$\Delta w_{ss} = \frac{-\Delta P_L}{\frac{1}{R_1}+\frac{1}{R_2}} = \frac{-0.09}{10+12.5} = -0.004 \text{ p.u}$$

The steady state frequency

$$\Delta f = (-0.004)\,60 = -0.24$$

$$f = f_0 + \Delta f = 60 - 0.24 = 59.76 \text{ Hz}$$

Change in generation

$$\Delta P_1 = -\frac{\Delta w}{R_1} = -\frac{-0.004}{0.1} = 0.04 \text{ p.u}$$

$$= 40 \text{ MW}$$

Scanned by CamScanner

$$\Delta P_2 = -\frac{\Delta W}{R_2} = -\frac{-0.004}{0.08} = 0.05 \text{ p.u}$$

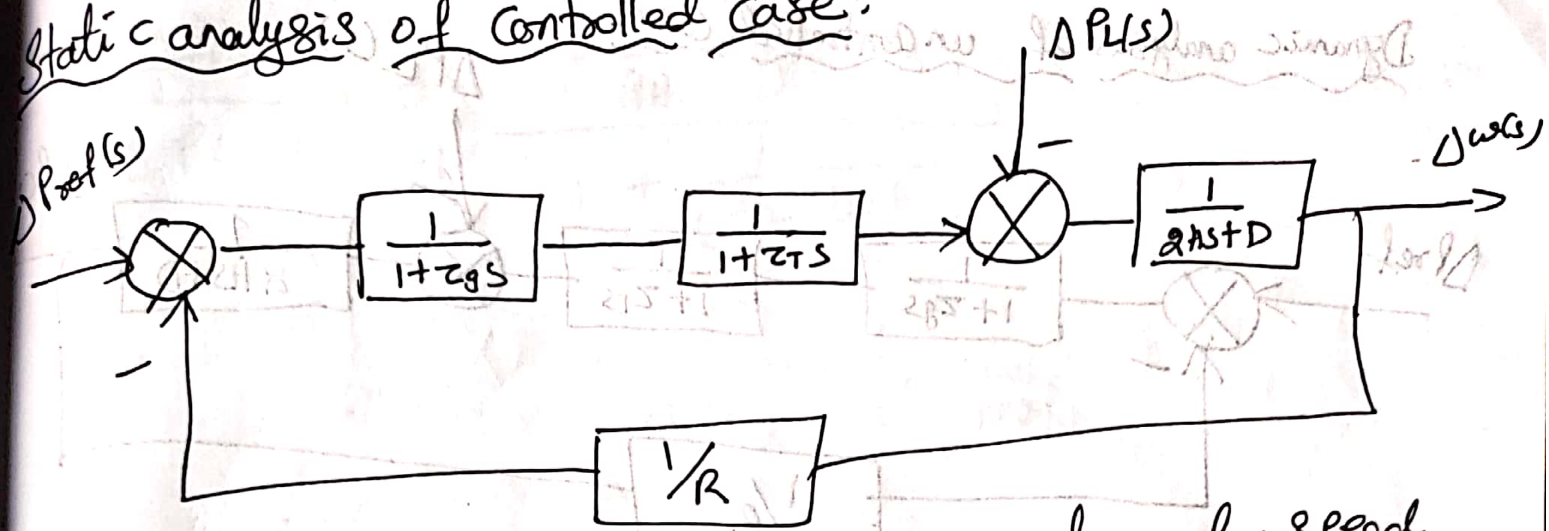
$$= 50 \text{ MW}$$

unit 1 supplies 540 MW

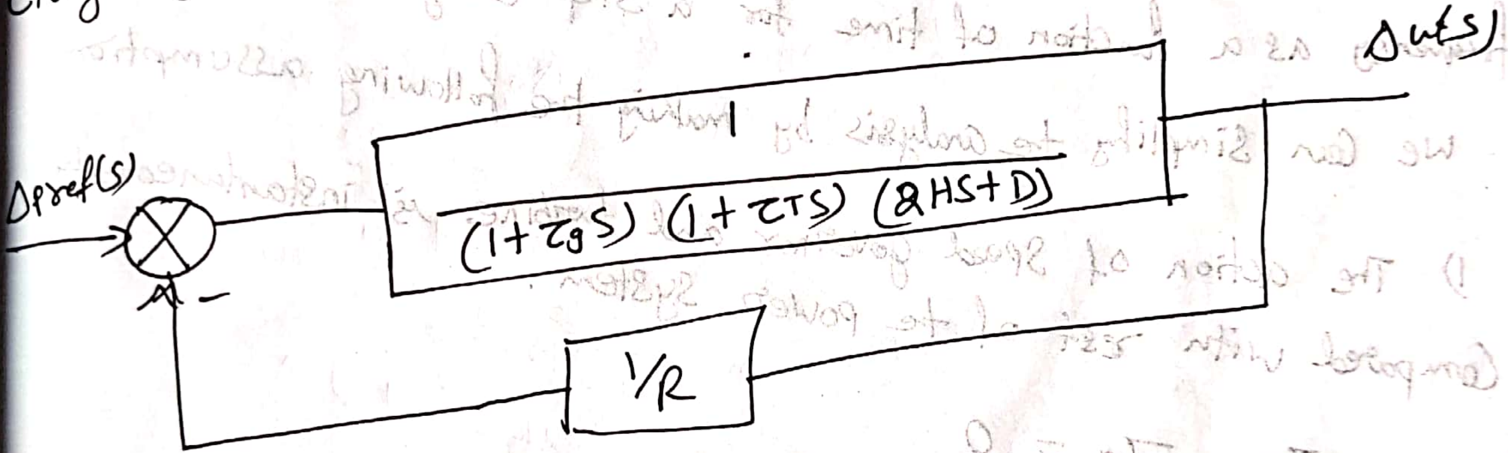
unit 2 supplies 450 MW

new operating frequency 59.76 Hz

Static analysis of Controlled case:



In this case there is a step change ΔPref force for speed changer setting and the load demand remains fixed i.e $\Delta P_L(s)=0$



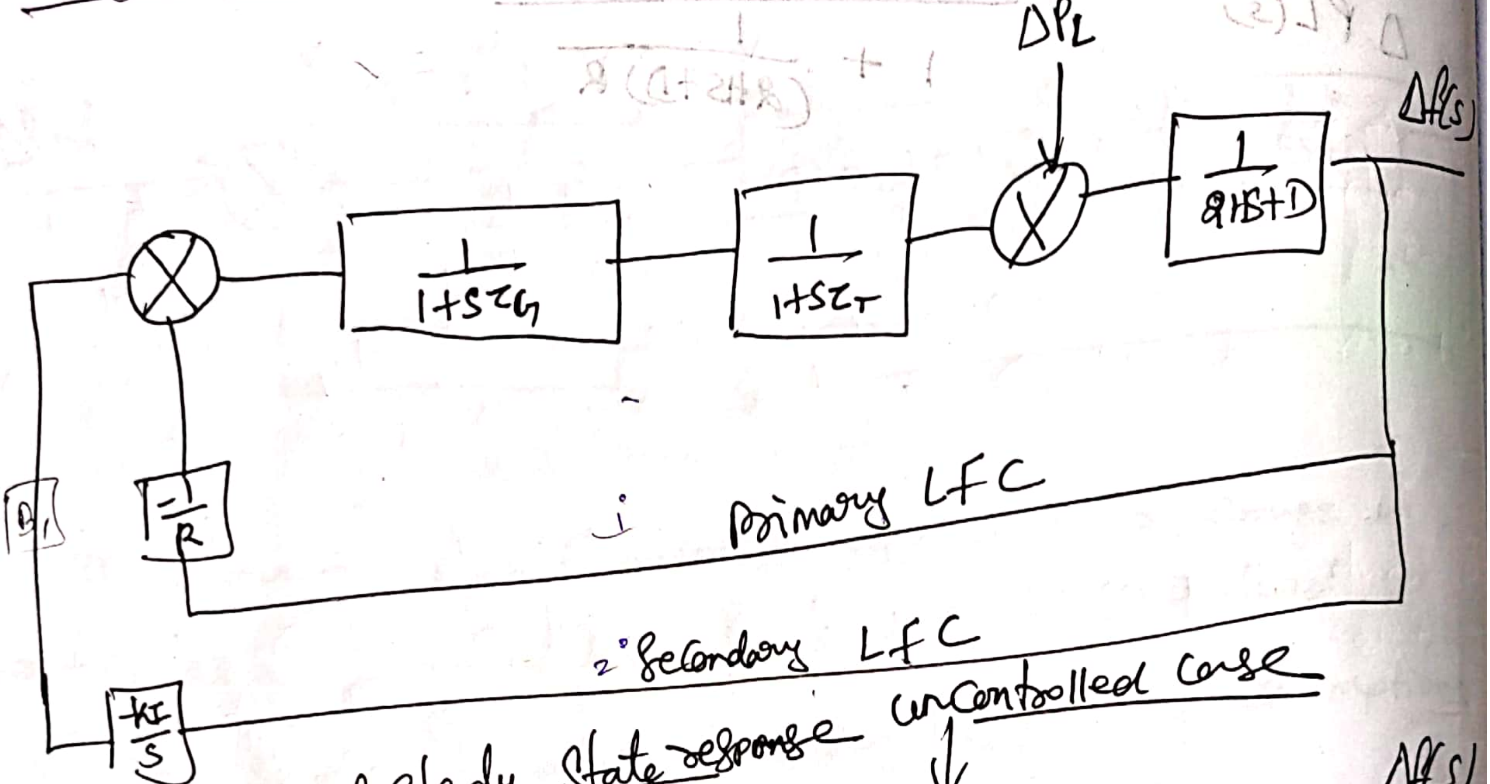
$$\frac{\Delta W(s)}{\Delta Pref} = \frac{1}{(1+S\tau_g)(1+\tau_T S)(2HS+D)+\frac{1}{R}}$$

Applying final value theorem

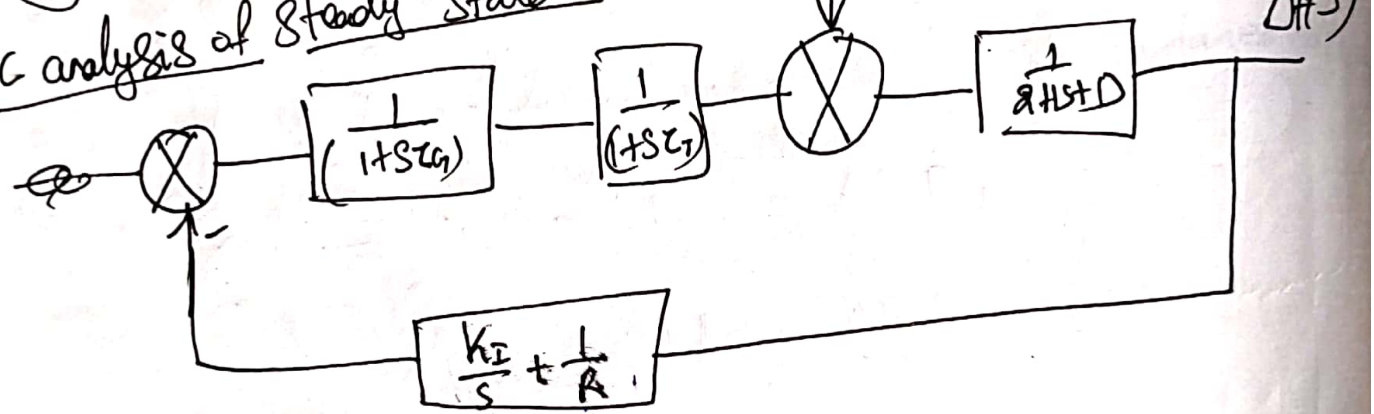
$$\Delta W(s) = \underset{S\to 0}{Lt} = \frac{1}{D+\frac{1}{R}} \Delta Pref$$

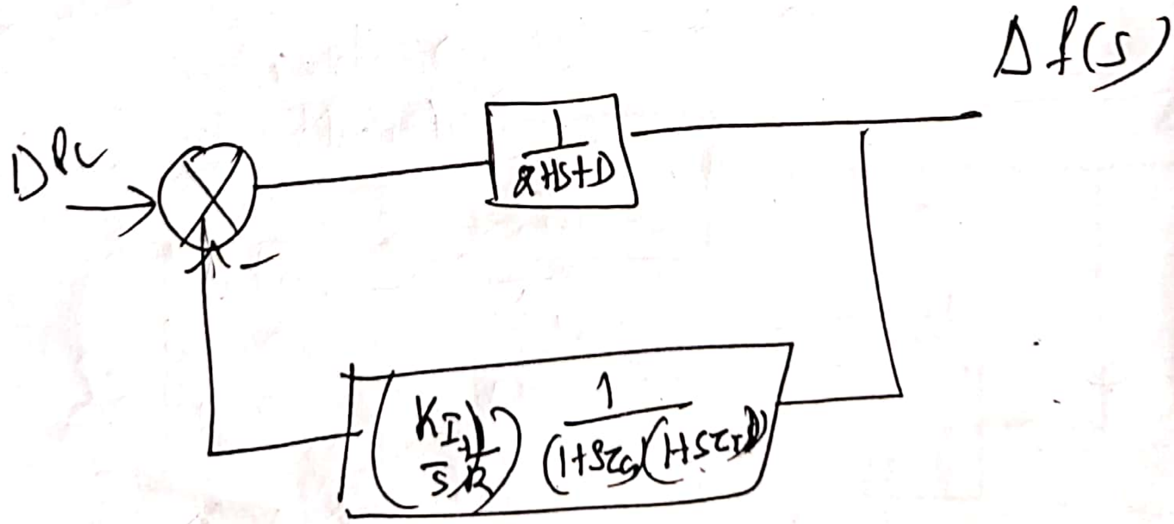
$$\boxed{\Delta W = \frac{1}{D+\frac{1}{R}} \Delta Pref}$$

Integral Control of Single area System



Static analysis of Steady State response uncontrolled case





$$\Delta F(s) = \frac{(1+\tau_g s)(1+\tau_T s)}{\left[(2Hs+D)(1+\tau_g s)(1+\tau_T s) + \frac{K_I}{s} + \frac{1}{R}\right]} \times \frac{\Delta P_{L_1}}{s}$$

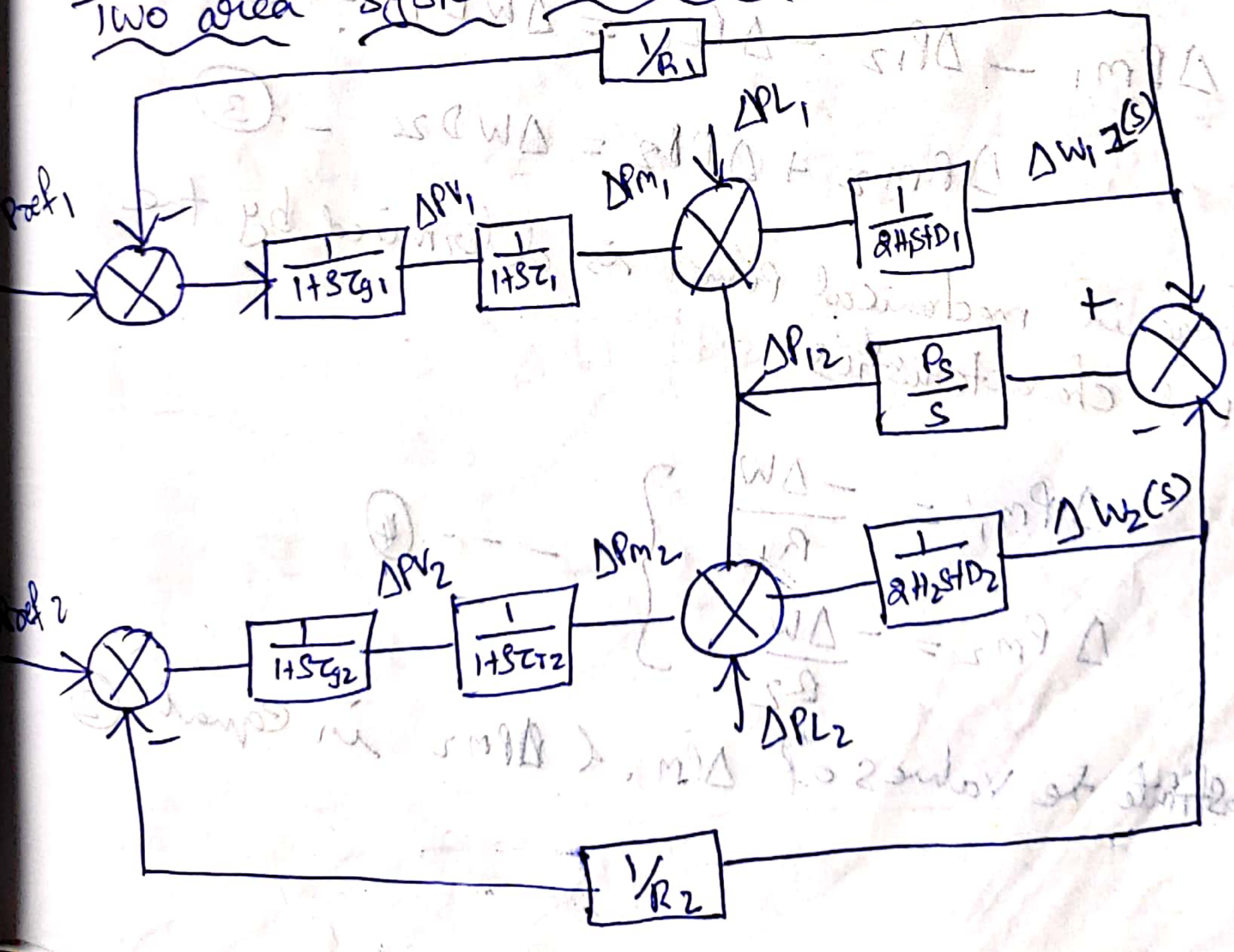
Applying final value theorem

$$\lim_{s \to 0} \Delta f(s) = 0$$

Hence in case of integral control change in frequency is zero.

AGC in the multi area system:

Two area system with only primary LFC loop



The tie-line power deviation takes on the form

$$\Delta P_{12} = P_s(\Delta\delta_1 - \Delta\delta_2)$$

The tie-line power flow appears as a load increase in one area and load decrease in the other area, depending on the direction of the flow. The direction of flow is dictated by the phase angle difference if $\Delta\delta_1 > \Delta\delta_2$ the power flows from area 1 to area 2

Let us consider a load change ΔP_{L1} in area 1. In the steady-state both areas will have the same steady-state frequency deviation

$$\Delta w = \Delta w_1 = \Delta w_2 \quad \text{--- (1)}$$

$$\Delta P_{m1} - \Delta P_{12} - \Delta P_{L1} = \Delta w D_1 \quad \text{--- (2)}$$

$$\Delta P_{m2} + \Delta P_{12} = \Delta w D_2 \quad \text{--- (3)}$$

The change in mechanical power is determined by the governor speed characteristics

$$\left.\begin{aligned} \Delta P_{m1} &= \frac{-\Delta w}{R_1} \\ \Delta P_{m2} &= \frac{-\Delta w}{R_2} \end{aligned}\right\} \quad \text{--- (4)}$$

Substitute the values of ΔP_{m1} & ΔP_{m2} in equat (2)

$$-\frac{\Delta W}{R_1} - \Delta P_{12} - \Delta P_{L1} = \Delta W D_1$$

equation ② is rearranged

$$\Delta P_{12} = \Delta P_{m1} - \Delta P_{L1} - \Delta W D_1 \quad \text{--} ⑤$$

Sub ⑤ in ③

$$\Delta P_{m2} + \Delta P_{m1} - \Delta P_{L1} - \Delta W D_1 = \Delta W D_2 \text{--} ⑥$$

Sub the values of ΔP_{m2} & ΔP_{m1} in eqn ⑥

$$-\frac{\Delta W}{R_2} - \frac{\Delta W}{R_1} - \Delta P_{L1} - \Delta W D_1 = \Delta W D_2$$

$$-\Delta P_{L1} = \Delta W D_2 + \frac{\Delta W}{R_2} + \frac{\Delta W}{R_1} + \Delta W D_1$$

$$= \Delta W \left(D_2 + \frac{1}{R_2}\right) + \Delta W \left(D_1 + \frac{1}{R_1}\right)$$

$$-\Delta P_{L1} = \Delta W \left[\left(D_1 + \frac{1}{R_1}\right) + \left(D_2 + \frac{1}{R_2}\right)\right]$$

$$\Delta W = \frac{-\Delta P_{L1}}{\left(D_1 + 1/R_1\right) + \left(D_2 + \frac{1}{R_2}\right)}$$

$$\boxed{\Delta w = \frac{-\Delta P_{L_1}}{B_1 + B_2}}$$

$$B_1 = \frac{1}{R_1} + D_1$$

$$B_2 = \frac{1}{R_2} + D_2$$

B_1 & B_2 are known as the frequency bias factors

Problem: A two area system connected by a tie-line has the following parameters with base MVA for each area

Area	1	2
Turbine o/p power	2000 MVA	1000 MVA
Nominal frequency	50 Hz	50 Hz
Speed regulation	3%	5%
governor time constant	0.3	0.2
Turbine time constant	0.6	0.4
D	20%	2.5%

Scanned by CamScanner

Two 50Hz power stations are connected by means of interconnected cable so that the stations work in parallel. The following are the data pertaining to the system.

Station	Full load capacity	Speed Regulation	Station load
A	10MW	2.5%	7MW
B	2 MW	4%	2 MW

Calculate the generator o/p of each station power transmitted by the interconnector. and operating frequence.

D_1 & $D_2 = 0$

Change in load = rated − Station load

$= 10 - 7$

$= 3\,MW$

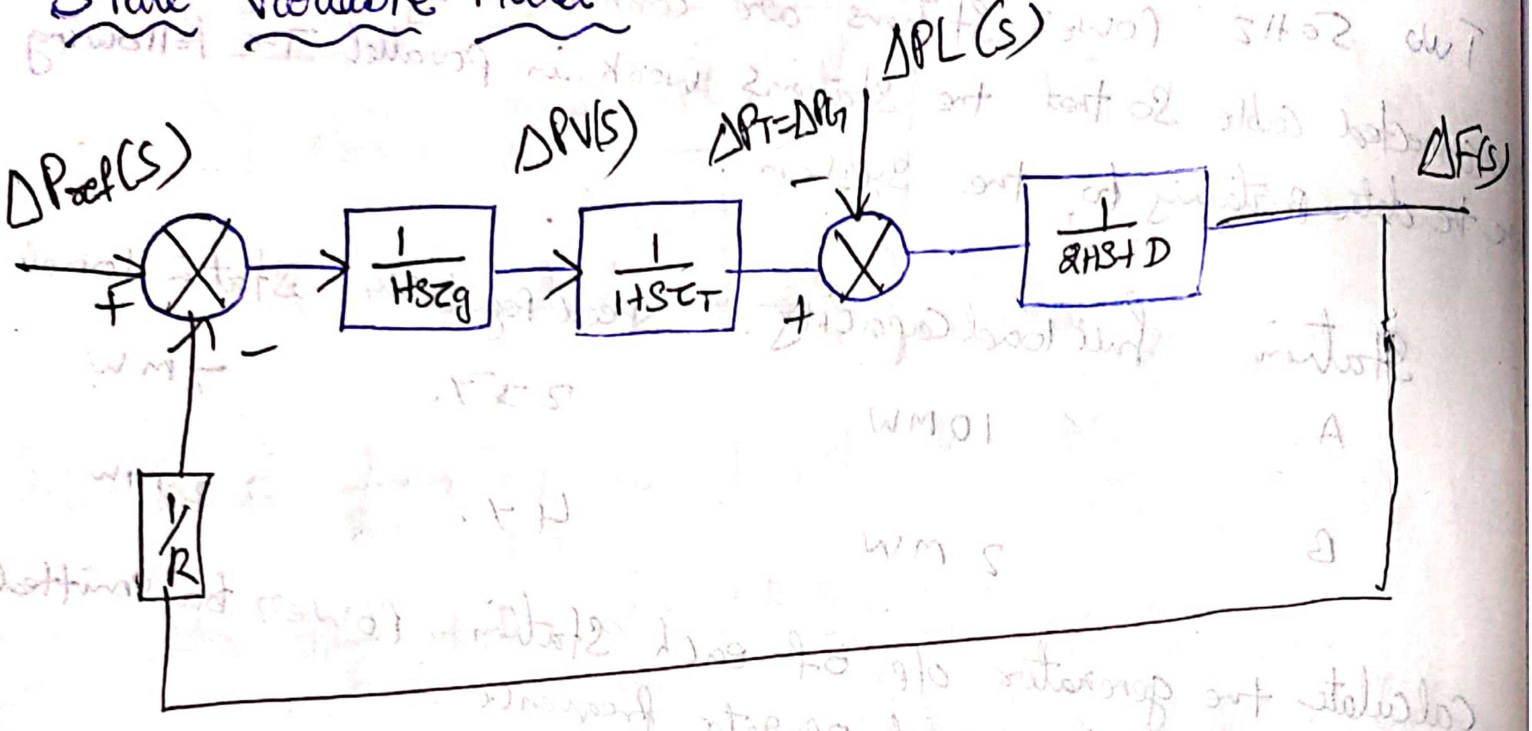
$\Delta P_{L1} = \frac{3}{10} = 0.3\ p.u$

Change in load = rated − Station load

$= 2 - 2$

$\Delta P_{L2} = 0$

State variable model



$$\frac{1}{2HS+D} = \frac{K_P}{1+S\tau_P}$$

Laplace Transform equations

$$\Delta P_V(S) = \frac{1}{1+S\tau_g}\left[\Delta P_{ref}(S) - \frac{1}{R}\Delta F(S)\right] \quad \text{--- (1)}$$

$$\Delta P_T(S) = \frac{1}{1+S\tau_T} \cdot \Delta P_V(S) \quad \text{--- (2)}$$

$$\Delta F(S) = \frac{1}{2HS+D}\left[\Delta P_T(S) - \Delta P_L(S)\right] \quad \text{--- (3)}$$

rewrite the equations 1, 2 & 3

$$\Delta P_V(S) + S\tau_g \Delta P_V(S) = \left[\Delta P_{ref}(S) - \frac{\Delta F(S)}{R}\right] \quad \text{--- (4)}$$

$$\Delta P_T(S) + S\tau_T \Delta P_T(S) = \Delta P_V(S) \quad \text{--- (5)}$$

$$\Delta F(s) + s\tau_P \Delta F(s) = K_P \Delta P_T(s) - K_P \Delta P_L(s) \quad -⑥$$

differentiate

$$\Delta P_V + \tau_g \frac{d(\Delta P_V)}{dt} = \Delta P_{ref} - \frac{\Delta F}{R} \quad -- ⑦$$

$$\Delta P_T + \tau_T \frac{d(\Delta P_T)}{dt} = \Delta P_V \quad -- ⑧$$

$$\Delta F + \tau_P \frac{d(\Delta F)}{dt} = K_P \Delta P_T - K_P \Delta P_L \quad -- ⑨$$

$$S = \frac{d^2}{dt^2} \qquad \int S = \frac{d}{dt}$$

Let us define Control i/p $\Delta P_{ref} = u$

and disturbance factor $\Delta P_L = P$

Sub the values of ΔP_{ref} & ΔP_L in eqns 7 & 9

$$\Delta P_V + \tau_g \frac{d\,\Delta P_V}{dt} = u - \frac{\Delta F}{R}$$

$$\tau_g \frac{d\,\Delta P_V}{dt} = \left(u - \frac{\Delta F}{R} - \Delta P_V\right)$$

$$\frac{d(\Delta P_V)}{dt} = \frac{u}{\tau_g} - \frac{\Delta f}{\tau_g R} - \frac{\Delta P_V}{\tau_g}$$

$$\tau_T \frac{d\,\Delta P_T}{dt} = \Delta P_V - \Delta P_T$$

$$\frac{d\,\Delta P_T}{dt} = \frac{\Delta P_V}{\tau_T} - \frac{\Delta P_T}{\tau_T}$$

$$\tau_p \frac{d\Delta f}{dt} = K_p \Delta P_T - K_p P - \Delta F$$

$$\frac{d\Delta f}{dt} = \frac{K_p \Delta P_T}{\tau_p} - \frac{K_p P}{\tau_p} - \frac{\Delta f}{\tau_p}$$

Let ΔP_V, ΔP_T & ΔF be the state variables

$\therefore$ State vector $X = \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = \begin{pmatrix} \Delta P_V \\ \Delta P_T \\ \Delta F \end{pmatrix}$

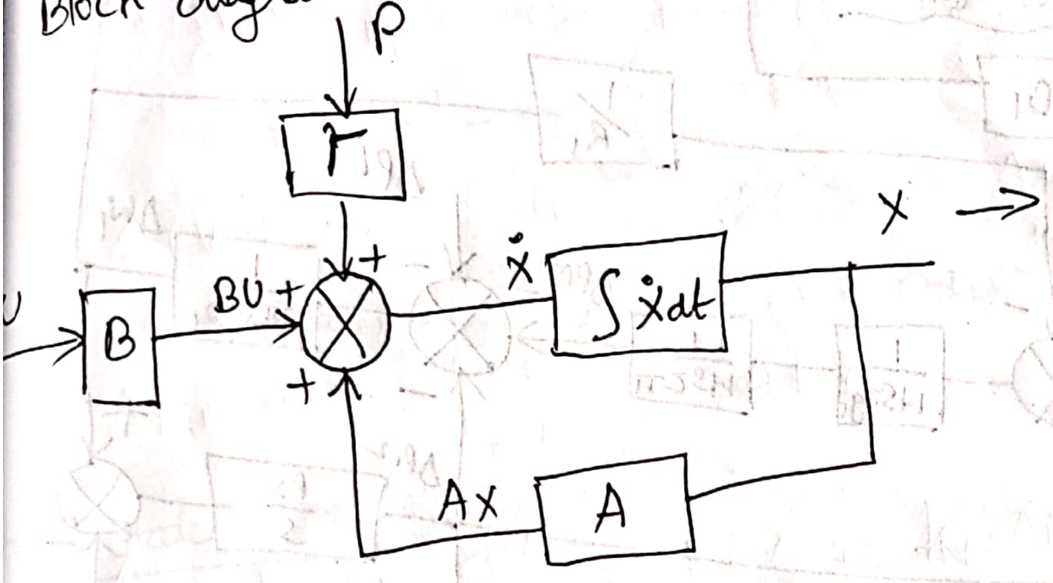
write the equation in state variable from

$$\begin{pmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{pmatrix} = \begin{bmatrix} -\frac{1}{\tau_g} & 0 & -\frac{1}{R\tau_g} \\ \frac{1}{\tau_T} & -\frac{1}{\tau_T} & 0 \\ 0 & \frac{K_p}{\tau_p} & -\frac{1}{\tau_p} \end{bmatrix} \begin{bmatrix} \Delta P_V \\ \Delta P_T \\ \Delta F \end{bmatrix} \pm \begin{bmatrix} \frac{1}{\tau_g} \\ 0 \\ 0 \end{bmatrix} u + \begin{bmatrix} 0 \\ 0 \\ -\frac{K_p}{\tau_p} \end{bmatrix}$$

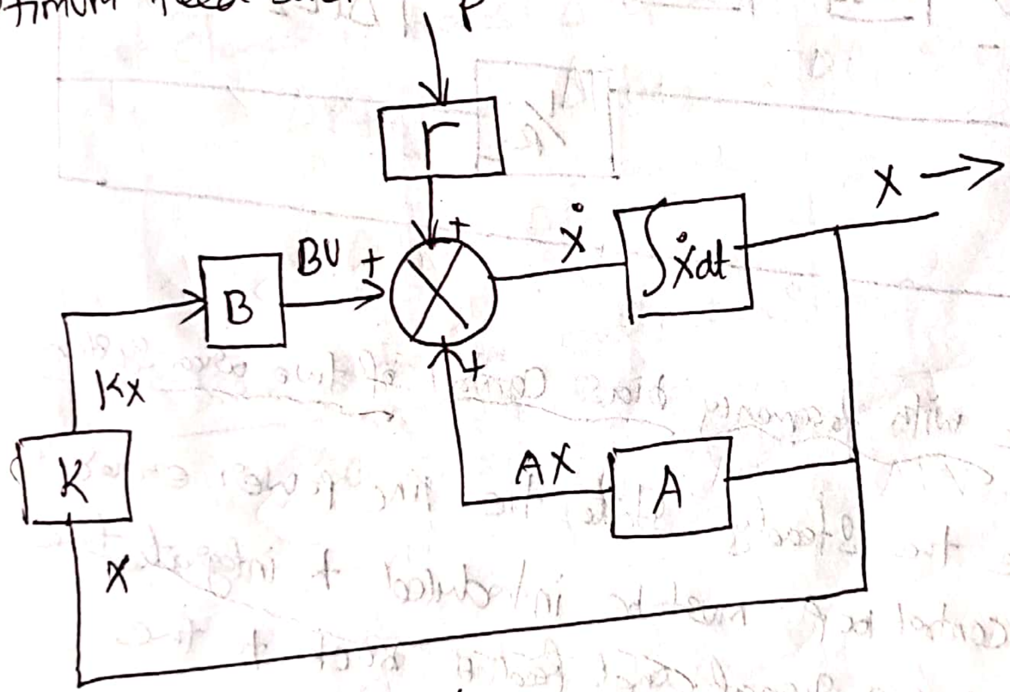
In Compact from

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

Block diagram for linear State model



If we are considering economic dispatch controller the optimum feed back controller



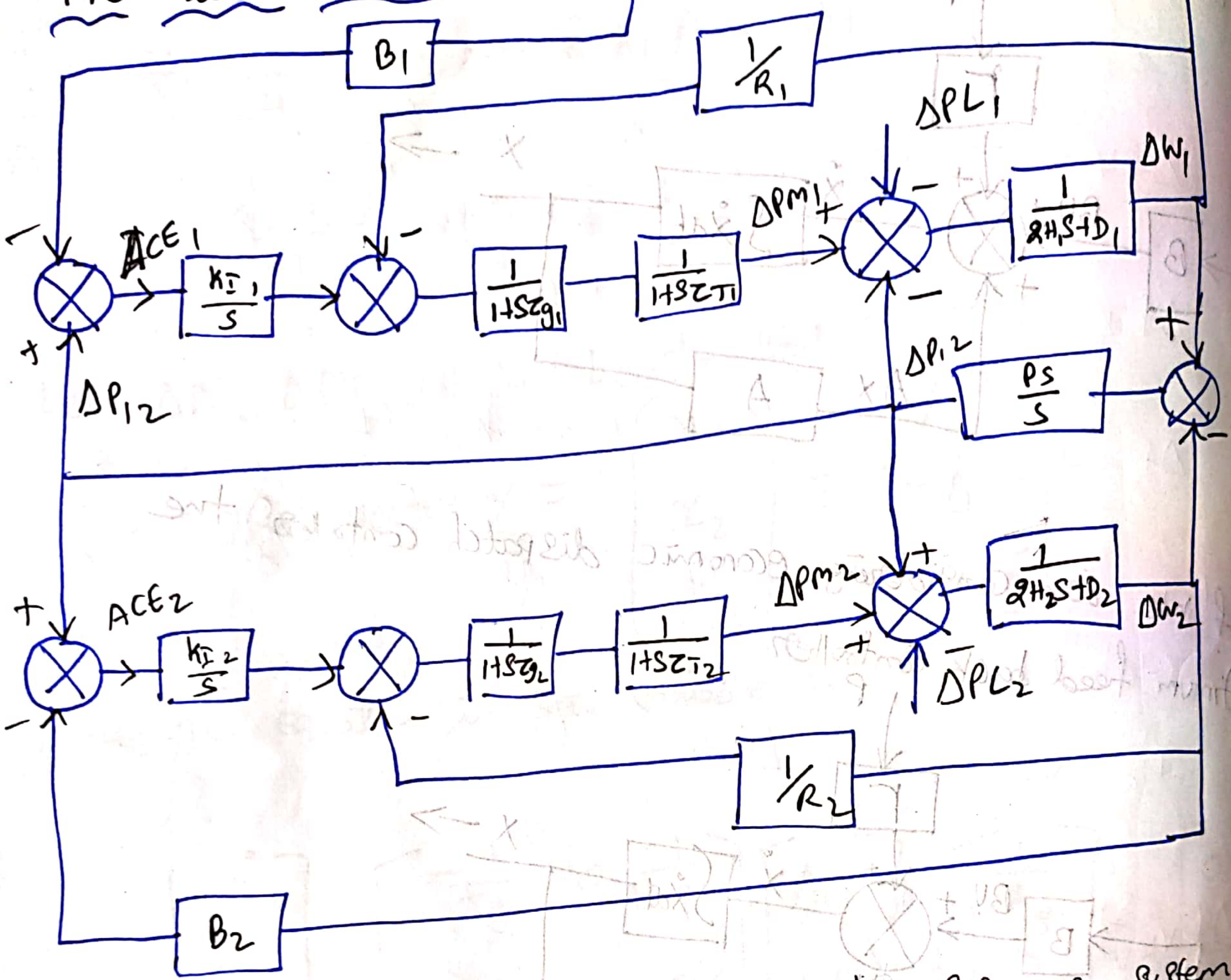
Consider two area System

u be the control force

P be the disturbance force vector

$$u = \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = \begin{bmatrix} \Delta P_{ref_1} \\ \Delta P_{ref_2} \end{bmatrix} \qquad P = \begin{bmatrix} P_1 \\ P_2 \end{bmatrix} = \begin{bmatrix} \Delta P_{C_1} \\ \Delta P_{C_2} \end{bmatrix}$$

Tie line bias Control



Determine of tie line with frequency bias Control of two area system

In order to make the steady state tie line power error to zero another integral control loop must be introduced + integrate the incremental tie line power signal and feed it back to the speed changer.

$$ACE_1 = \Delta P_{tie_1} + b_1 \Delta f_1$$

$$ACE_2 = \Delta P_{tie_2} + b_2 \Delta f_2$$

taking laplace

$$\Delta P_{ref_1} = -K_{I_1} \int (\Delta P_{tie_1} + b_1 \Delta f_1)\, dt$$

$$\Delta P_{ref_2} = -K_{I_2} \int (\Delta P_{tie_2} + b_2 \Delta f_2)\, dt$$

Steady State response:

When Steady State conditions are reached the o/p signals of all integrating blocks will become constant and their i/p signals must become zero

Let step changes in loads ΔP_{L_1} & ΔP_{L_2} be simultaneously applied.

$$\Delta P_{tie_1} = \Delta P_{tie_2} = 0$$

$$\Delta f_1 = \Delta f_2 = 0$$

Tie line bias control of multi area system

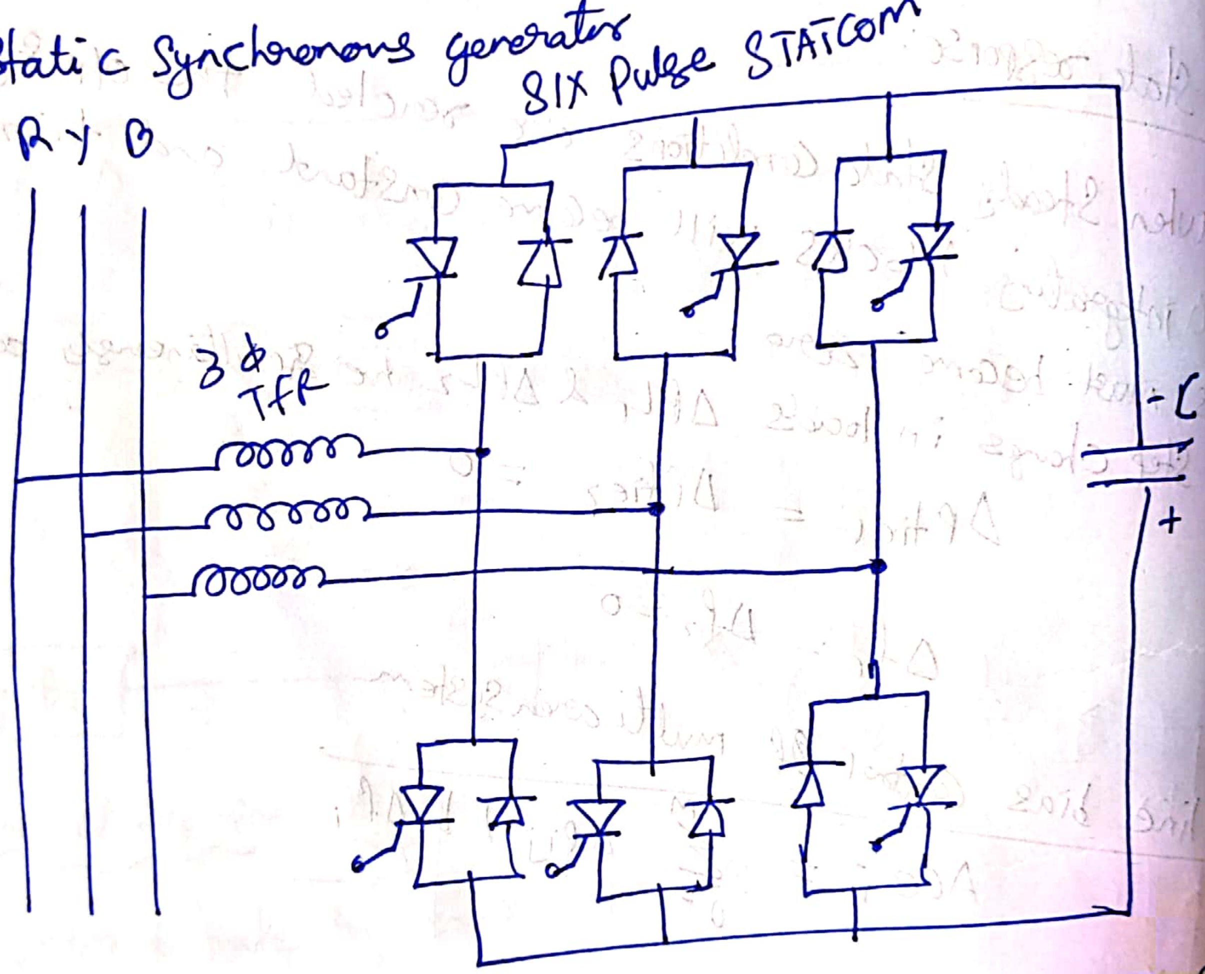
$$ACE_i = \sum_{j=1}^{M} \Delta P_{ij} + b_i \Delta f_i$$

UNIT-3

REACTIVE POWER VOLTAGE CONTROL

Secondary voltage control - STATCOM
(STATIC CONDENSERS)

STATCOM is actually a shunt compensation device - STATCOM is a static synchronous generator



If $E_0 > E_{input}$ current flows through the reactance from the converter to the AC system and converter generates capacitive reactance power

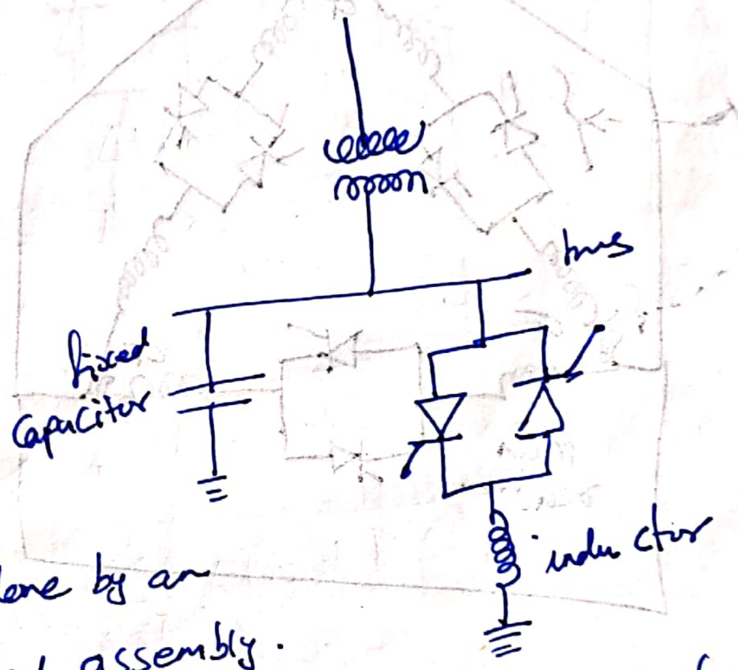
If $E_0 < E_{i/p}$ current flows from AC system to the converter and the converter absorbs inductive reactive power

If $E_0 = E_{i/p}$ the reactive power exchange becomes zero and the STATCOM is in floating state.

The current lags if the inverter vge is less than the system voltage

The current leads if the inverter vge is greater then the system voltage.

Static VAR Compensators



The reactor control is done by an anti parallel thyristor switched assembly. The firing angle of the thyristors governs the voltage across the inductor so the reactor current and reactive power absorption by the inductor can be controlled

Let Q_C be the reactive power charging by the capacitor

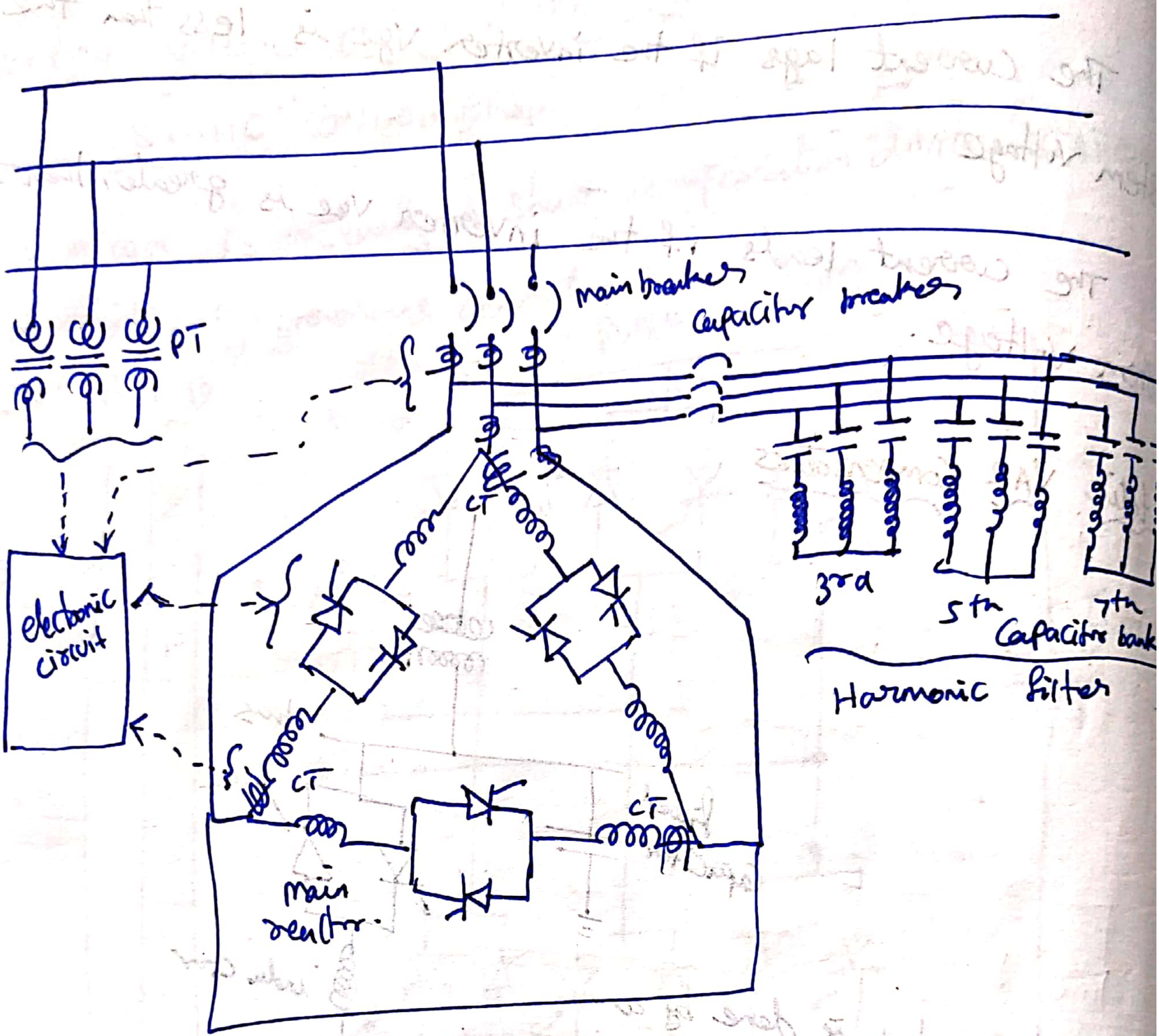
Q_L be the reactive power absorbed by the inductor

Net reactive power injected to the bus $Q = Q_C - Q_L$

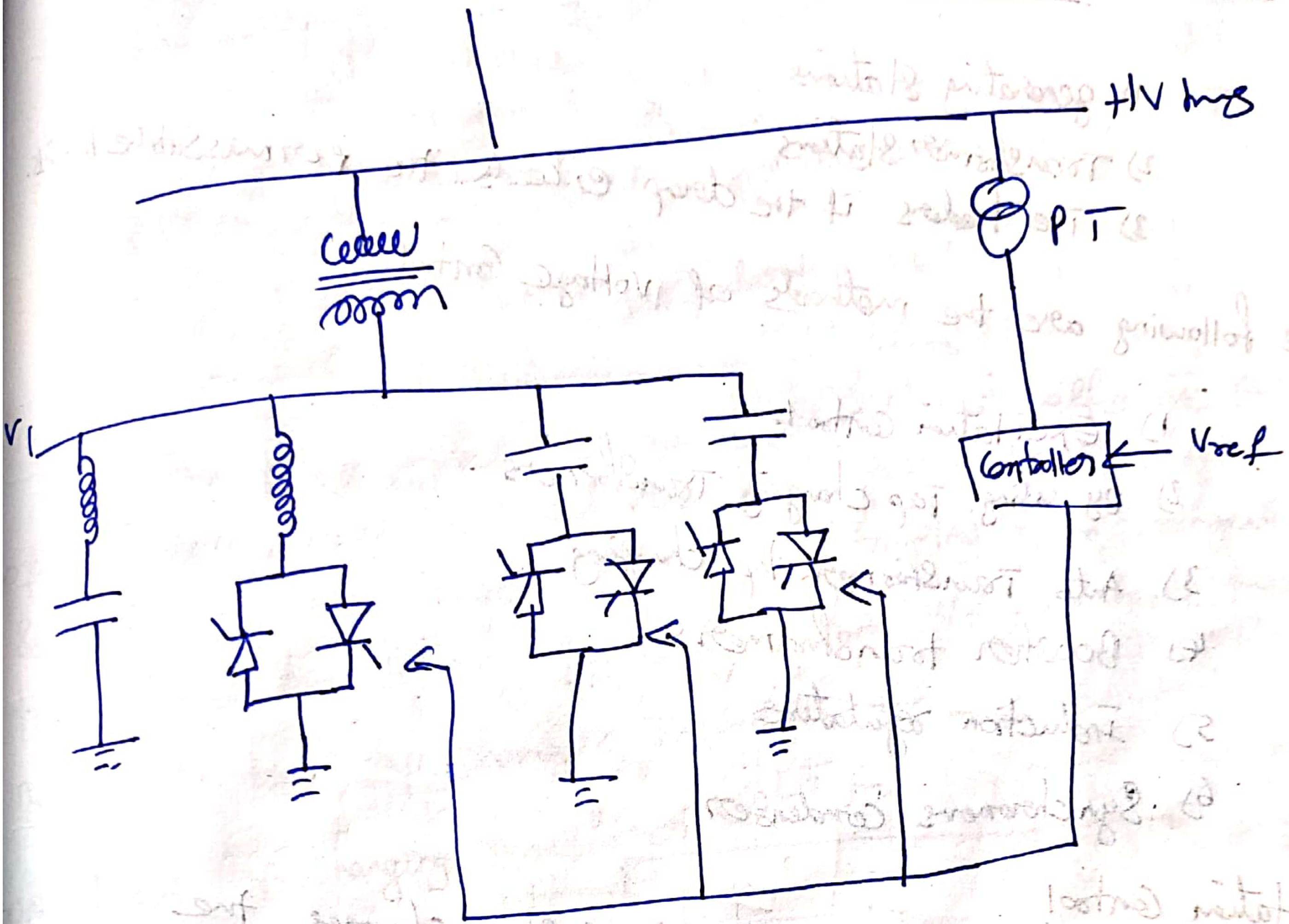
for Light load condition $Q_L > Q_C$

for heavy load condition $Q_C > Q_L$

FC- TCR


main breakers
capacitor breakers
PT
electronic circuit
CT
CT
CT
main reactor
3rd
5th
7th
Capacitor bank
Harmonic filter

TSC - TCR



Location of voltage control equipment

1) generating stations
2) Transformer stations
3) The feeders if the drop exceeds the permissible limit

The following are the methods of voltage control

1) Excitation control
2) By using Tap changing Transformers.
3) Auto Transformer tap changing
4) Booster transformers
5) Induction regulators
6) Synchronous condenser

Excitation control

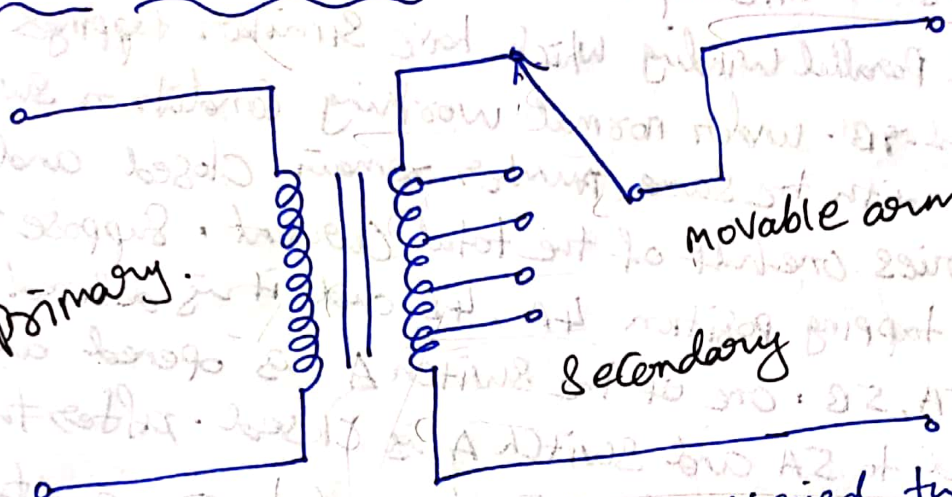
When the load on the supply system changes the terminal voltage of the alternator also varies due to the changed voltage drop in the synchronous reactance of the armature. The voltage of the alternator can be kept constant by changing the field current of the alternator in accordance with the load. This is known as Excitation control method.

TAP changing Transformer

Types of Tap changing Transformer

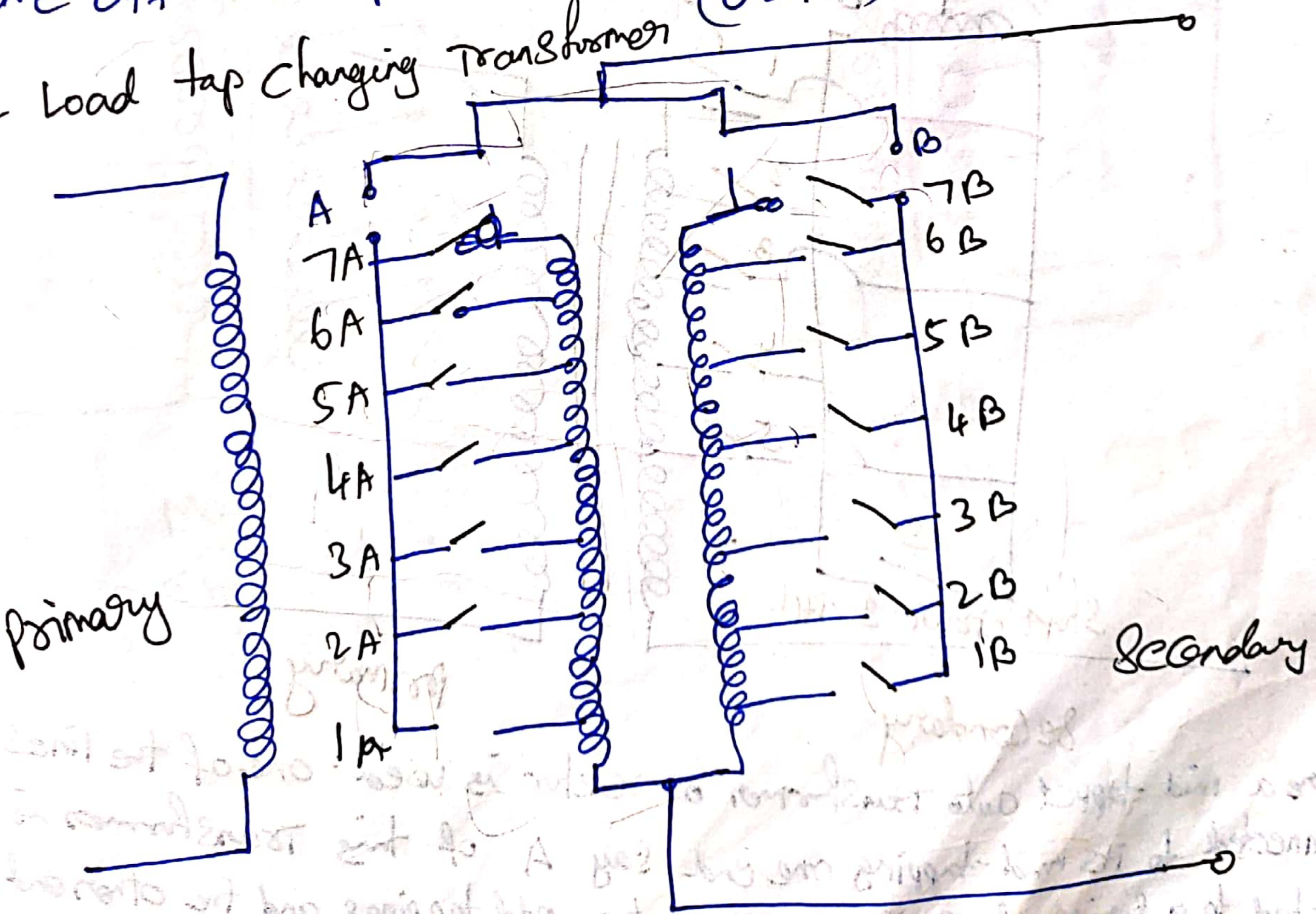
off load tap changing Transformer
ON load tap changing Transformer

off Load tap changing Transformer:



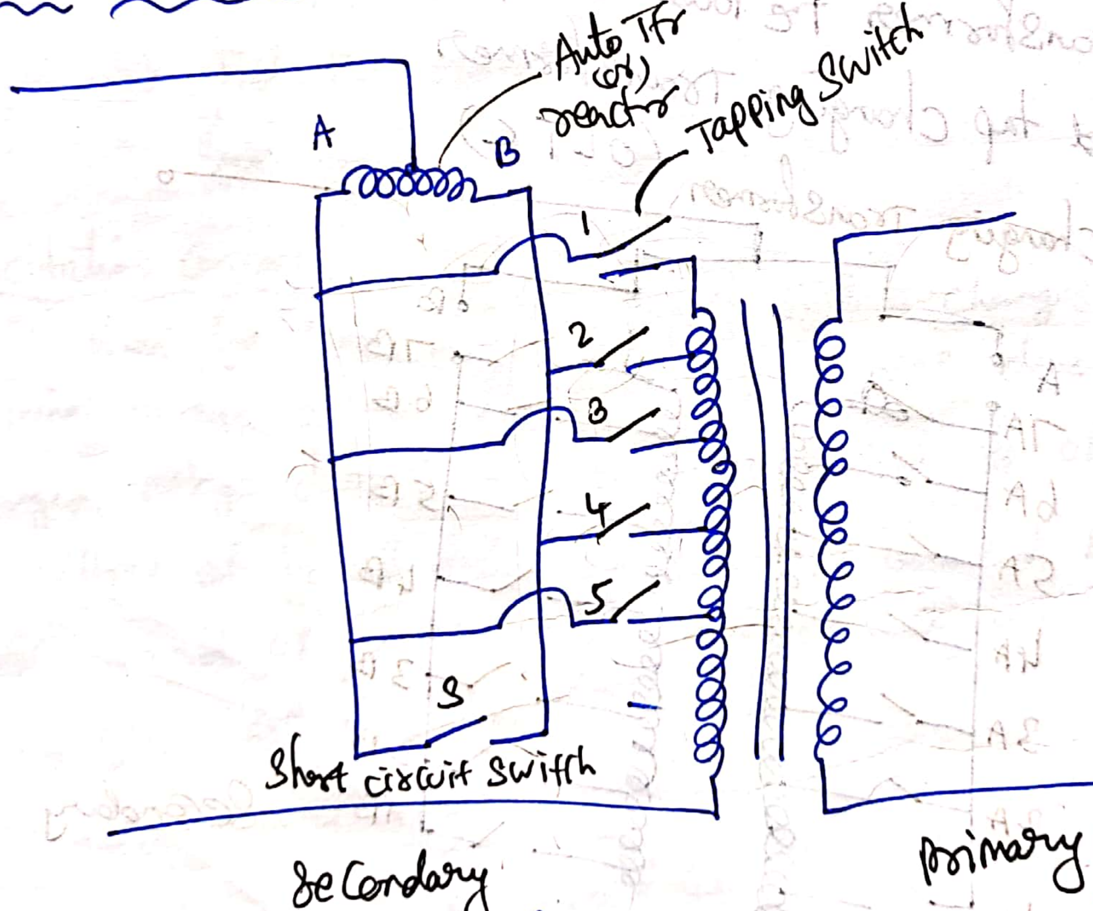
AS the position of the tap is varied the effective number of Secondary turns is varied and hence the output voltage of the Secondary can be changed. When ever a tapping is to changed in this type of transformer the load is kept off and hence the this type of transformer name off Load tap changing Transformer (OLTC)

ON- Load tap Changing Transformer



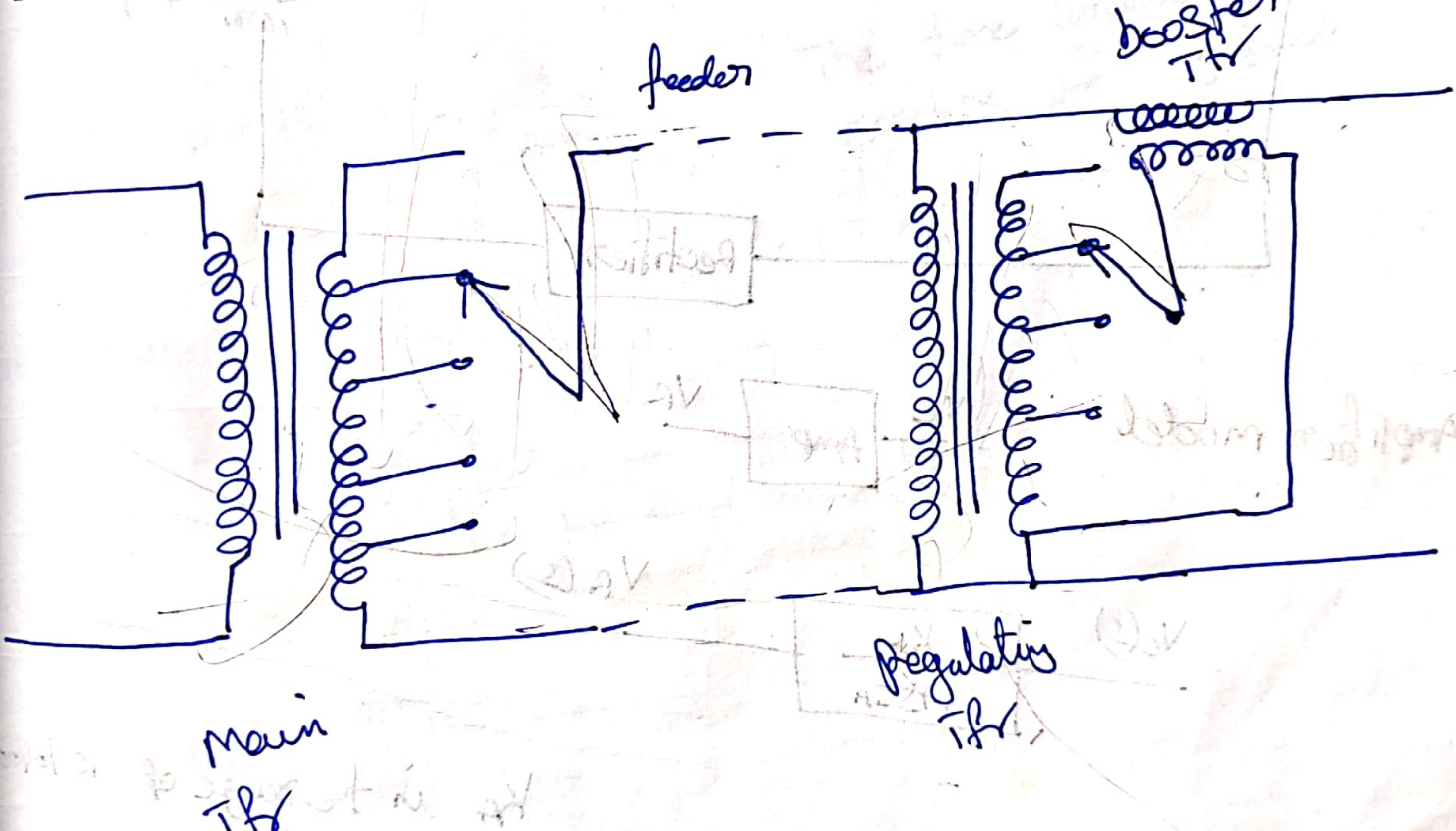
In this system tap changing has normally to be performed on load so that there is no interruption to supply. The secondary consist of two equal parallel winding which have similar tappings 1A --- 5A and 1B --- 5B. under normal working condition switch A & B and tappings with the same number remain closed and each secondary winding carries one half of the total current. Suppose the tfr is working with tapping position 4A, 4B and it is desired to alter its position to 5A, 5B. One of the switch A is opened and the winding is changed to 5A and switch A is closed. After this switch B is opened and the winding is changed to 5B and then switch B is closed. In this way tapping position is changed without interrupting the supply.

Auto Transformer Tap-Changing



Here a mid-tapped auto transformer or reactor is used. One of the lines is connected to its mid-tapping one end say A of this transformer is connected to a series of switches across the odd tappings and the other end is connected to switches across even tappings. A short circuit switch is connected across the auto-transformer and remains in the closed position under normal operation.

Booster Transformer

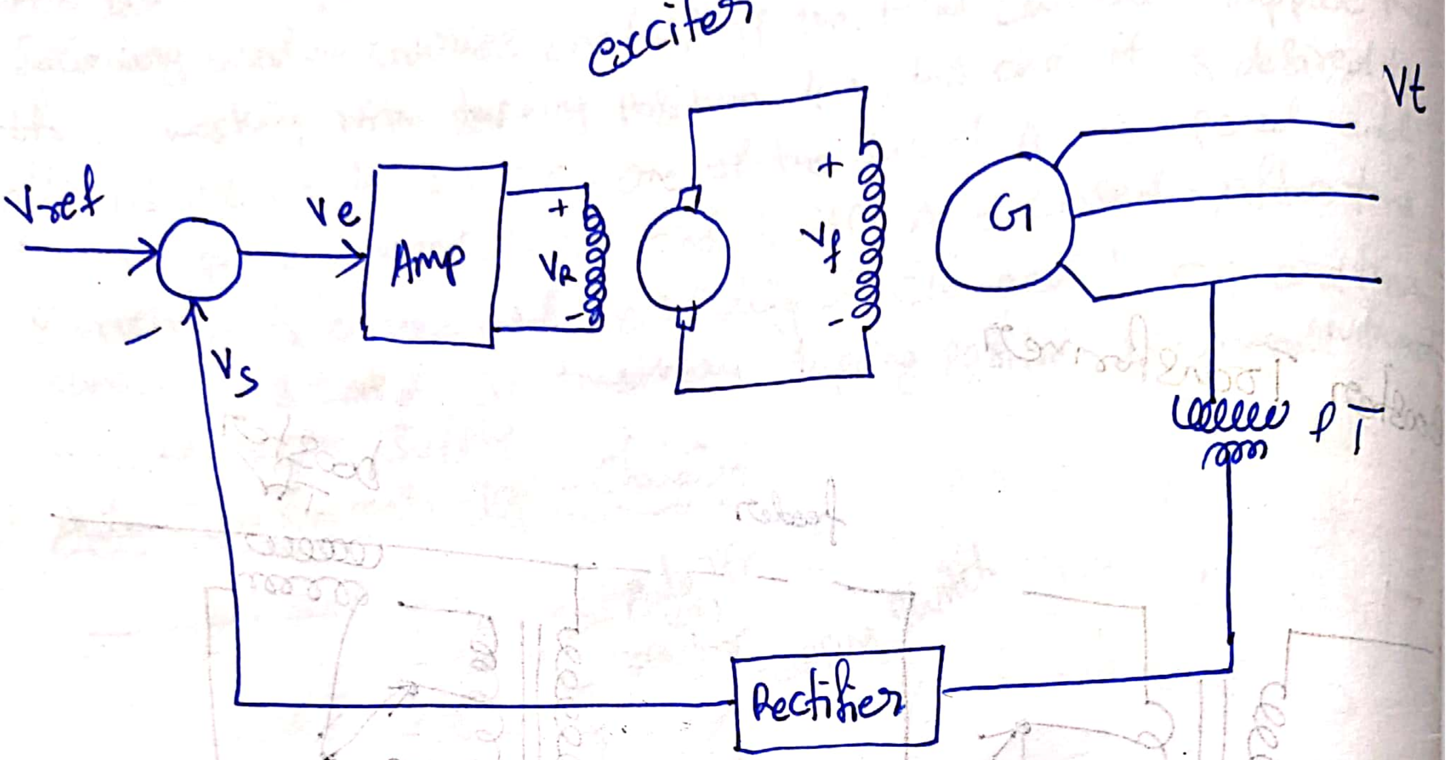


Scanned by CamScanner

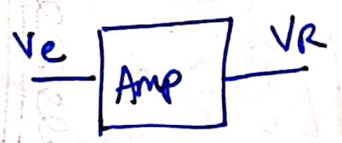
Modelling of Typical excitation system

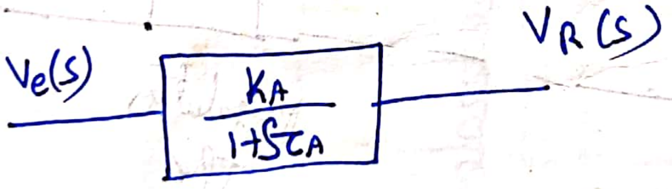
(or)

modelling of Automatic voltage regulator



Amplifier model



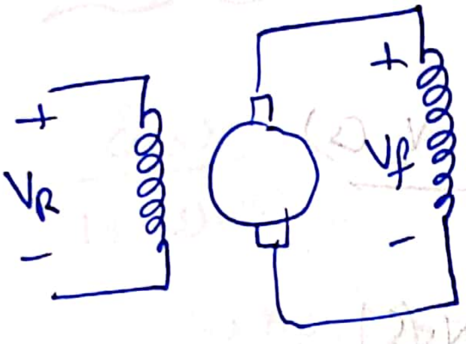


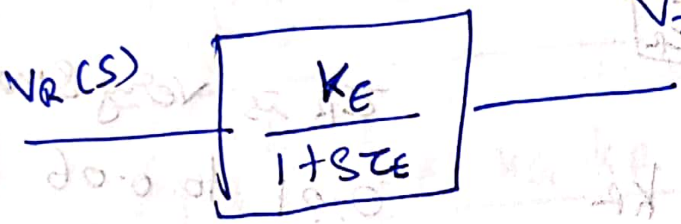
$$\frac{V_R(s)}{V_e(s)} = \frac{K_A}{1+s\tau_A}$$

K_A in the range of 10 to 4

τ_A in the range of 0.02 to 0.1s

Exciter model

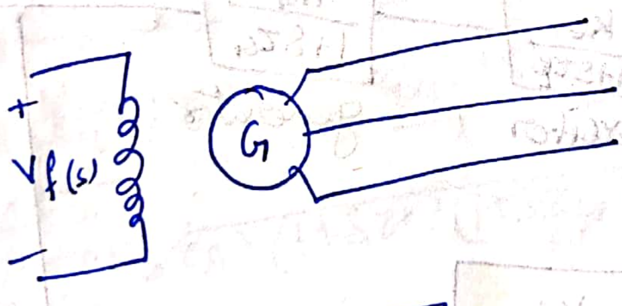


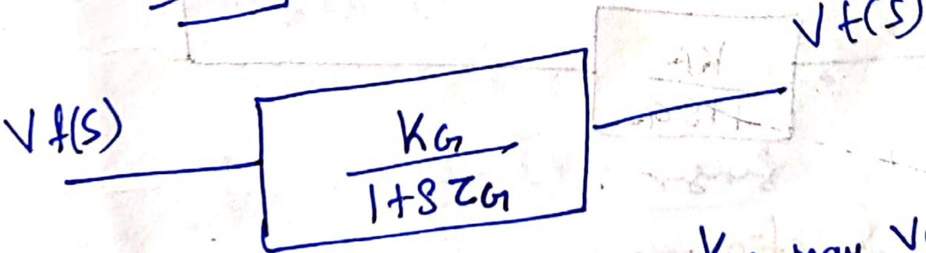


$$\frac{V_F(s)}{V_R(s)} = \frac{K_E}{1+s\tau_E}$$

The time constant of modern exciters are very small

GENERATOR MODEL



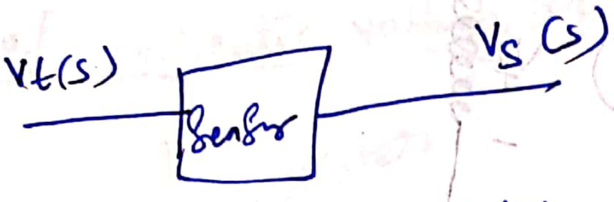


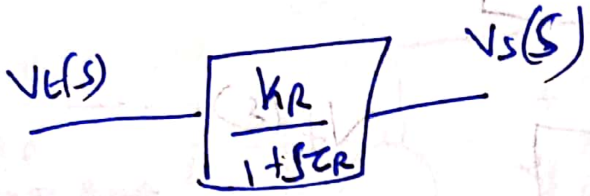
$$\frac{V_t(s)}{V_f(s)} = \frac{K_G}{1+s\tau_G}$$

K_G may vary b/w 0.7 to 1

τ_G may vary b/w 1.0 and 2.0 sec from full load to no-load

Sensor model

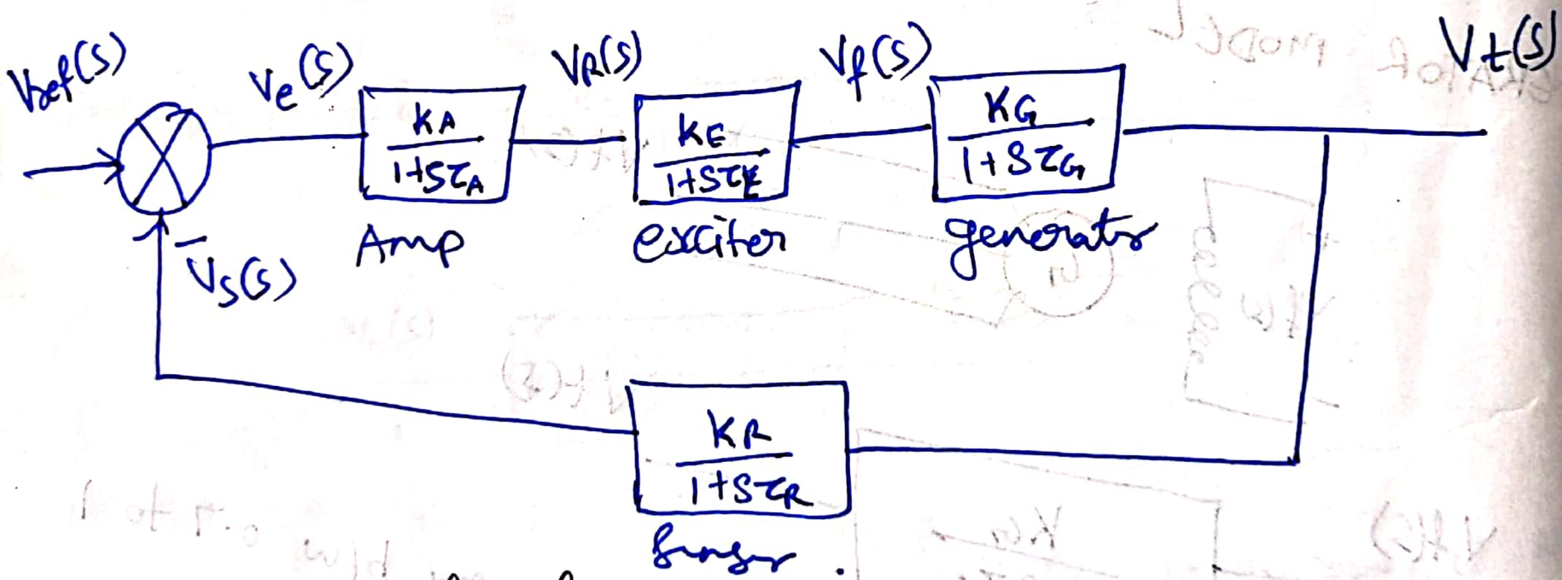




τ_R is very small
0.01 to 0.06 sec

$$\frac{V_s(s)}{V_t(s)} = \frac{K_R}{1+s\tau_R}$$

Block diagram of AVR



Open loop Transfer function.

$$G(s)\,H(s) = \frac{K_A\, K_E\, K_G\, K_R}{(1+s\tau_A)(1+s\tau_E)(1+s\tau_G)(1+s\tau_R)}$$

Closed loop Transfer function:

$$\frac{V_t(s)}{V_{ref}(s)} = \frac{G(s)}{1+G(s)H(s)}$$

$$= \frac{\dfrac{K_A K_E K_G}{(1+s\tau_A)(1+s\tau_E)(1+s\tau_G)}}{1+\dfrac{K_A K_E K_G K_R}{(1+s\tau_A)(1+s\tau_E)(1+s\tau_G)(1+s\tau_R)}}$$

$$= \frac{\dfrac{K_A K_E K_G}{\cancel{(1+s\tau_A)(1+s\tau_E)(1+s\tau_G)}}}{\dfrac{(1+s\tau_A)(1+s\tau_E)(1+s\tau_G)(1+s\tau_R)+K_A K_E K_G K_R}{\cancel{(1+s\tau_A)(1+s\tau_E)(1+s\tau_G)}(1+s\tau_R)}}$$

$$= \frac{K_A K_E K_G (1+s\tau_R)}{(1+s\tau_A)(1+s\tau_E)(1+s\tau_G)(1+s\tau_R)+K_A K_E K_G K_R}$$

for a step i/p $V_{ref}(s) = \frac{1}{s}$

using final value theorem

The values of K_E, K_G, K_R is very small

$$\boxed{V_{tss} = \lim_{s \to 0} s V_t(s) = \frac{K_A}{1 + K_A}}$$

Problem:

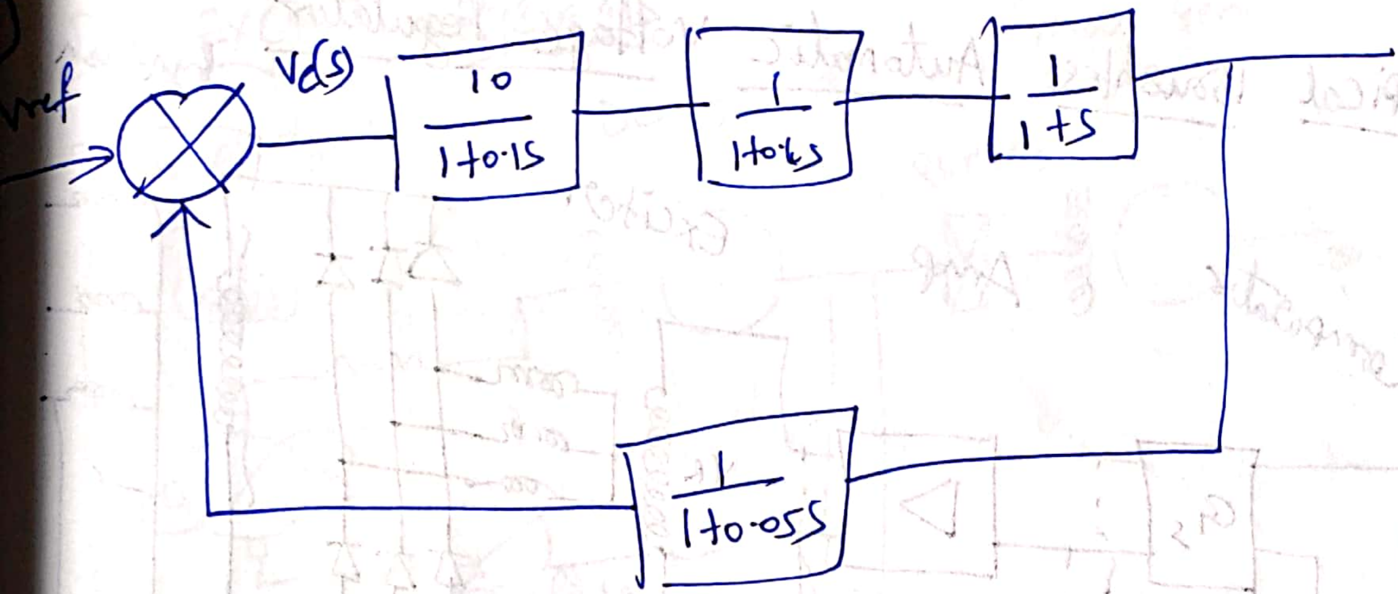
The AVR System of a generator has the following parameter

Amplifier	$K_A = 10$	$\tau_A = 0.1$
Exciter	$K_E = 1$	$\tau_E = 0.4$
Generator	$K_G = 1$	$\tau_G = 1$
Sensor	$K_R = 1$	$\tau_R = 0.05$

1) Draw the block diagram of AVR and write the transfer function of AVR.

2) find the steady state step response

Scanned by CamScanner



$$V_{tss} = \lim_{s \to 0} s V_t(s) = \frac{K_A}{1+K_A}$$

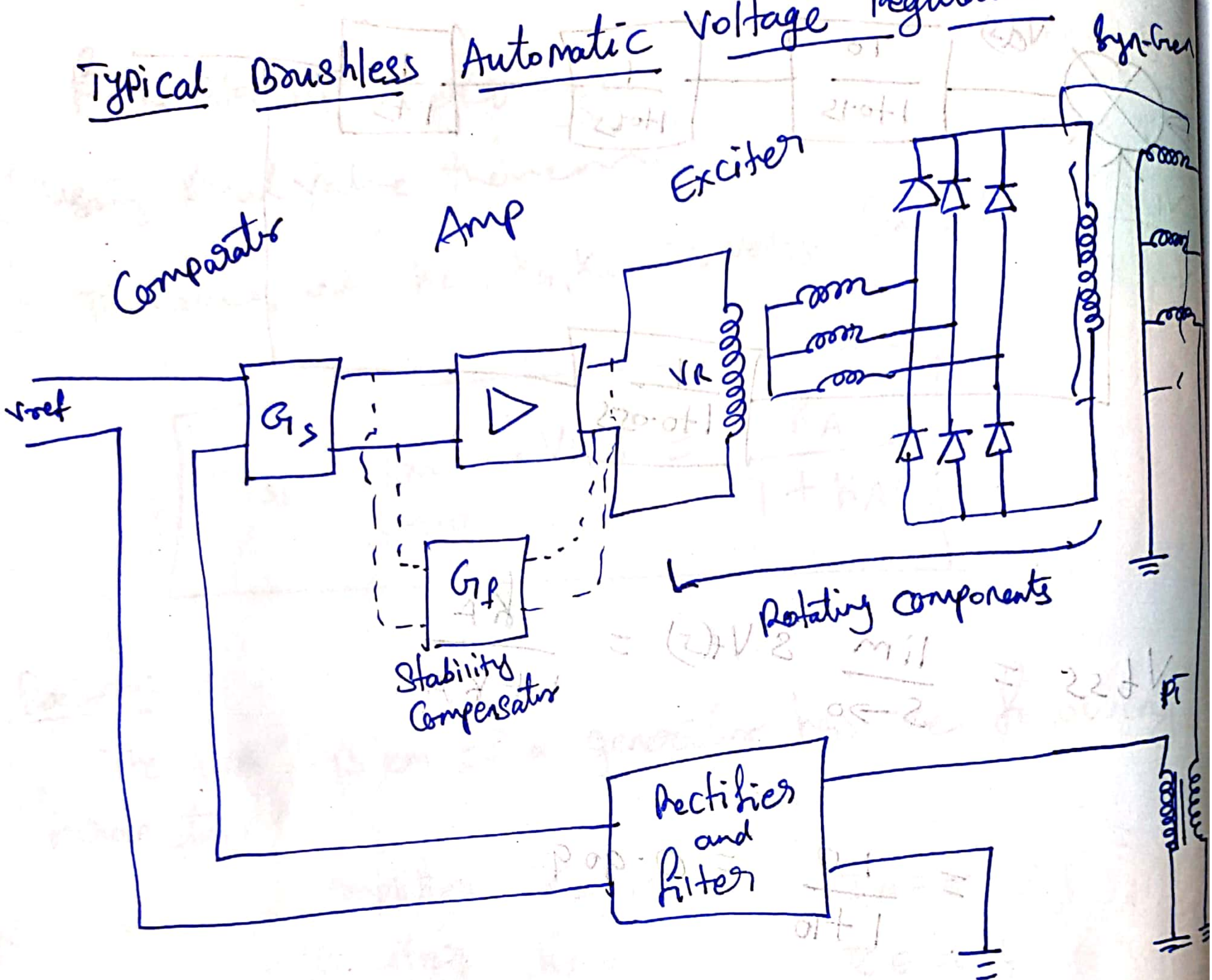
$$= \frac{10}{1+10} = 0.909$$

Stead state error is

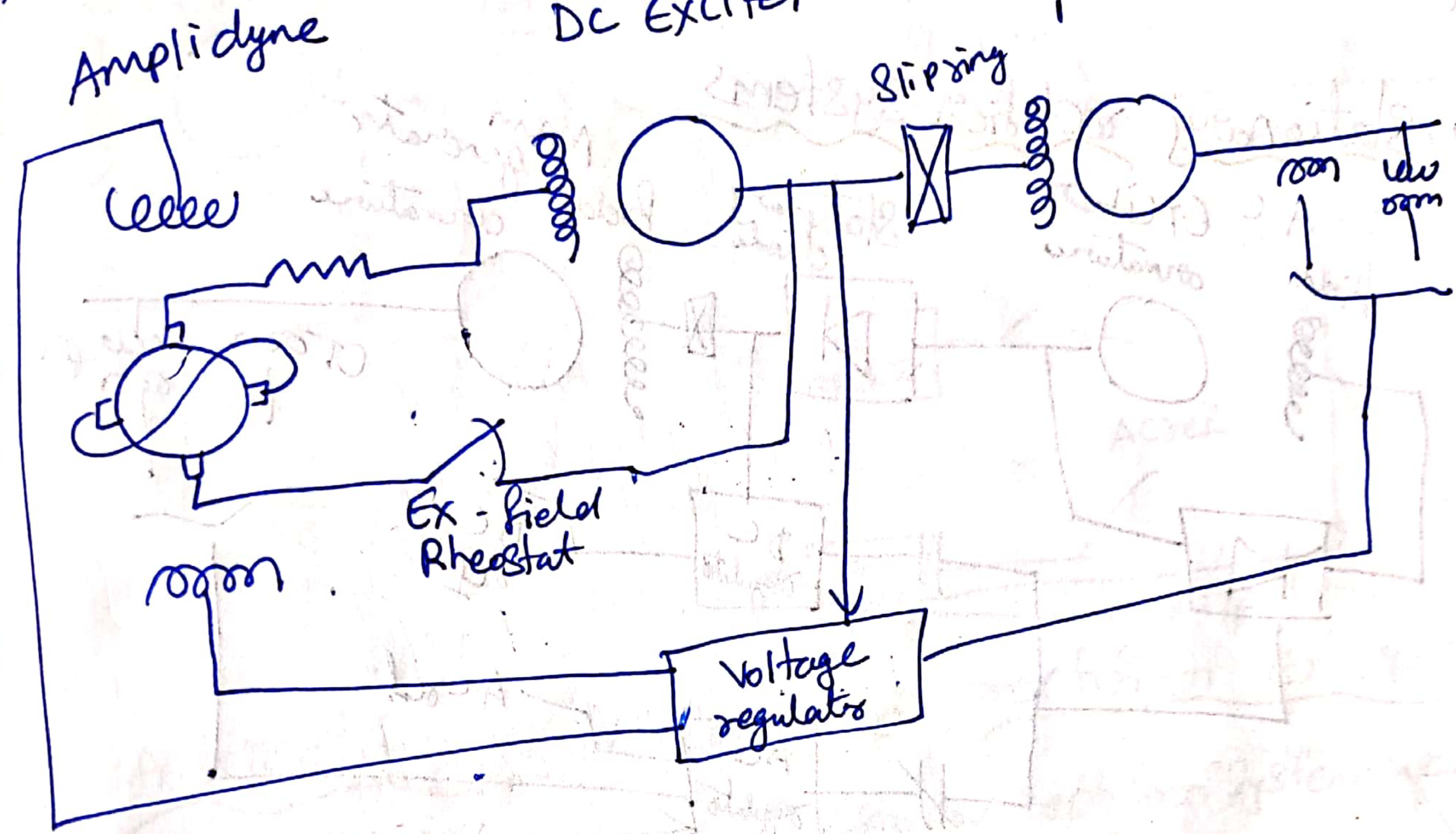
$$V_{ess} = 1.0 - 0.909$$

$$= 0.091$$

Typical Brushless Automatic Voltage Regulator

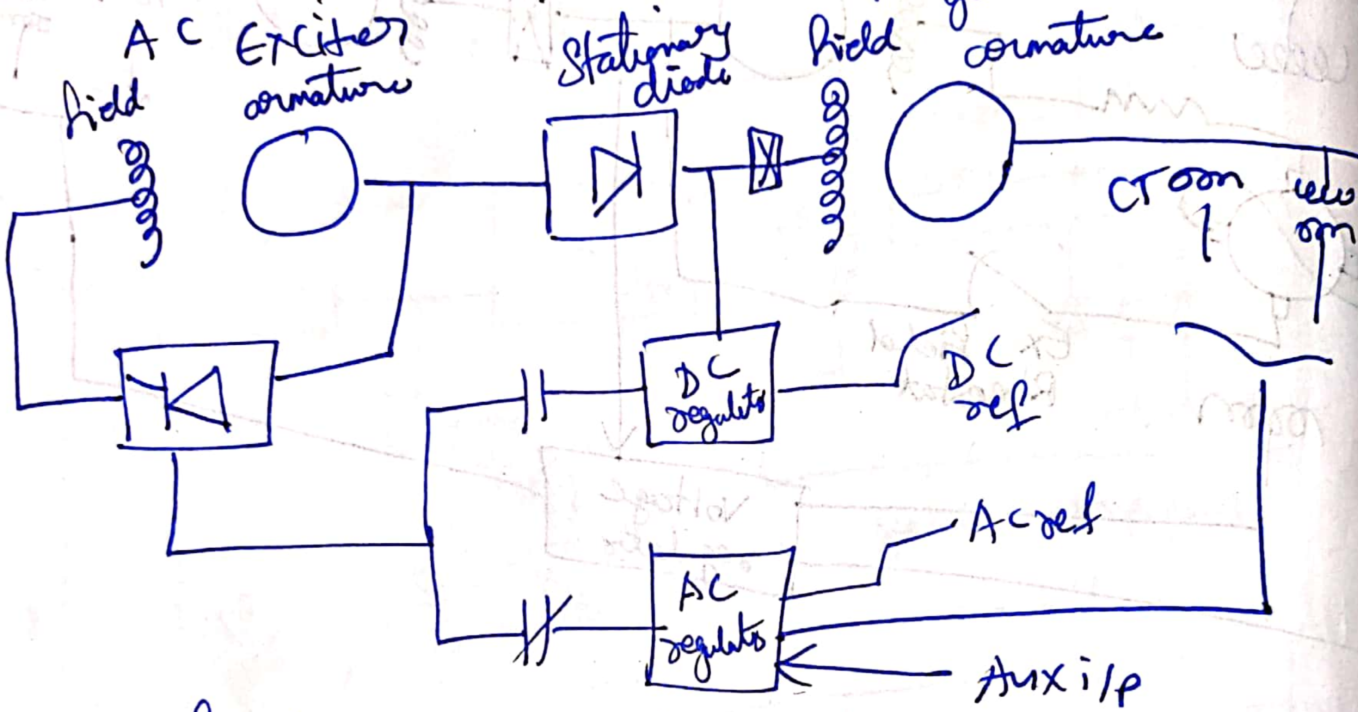


DC Excitation Systems



AC Excitation Systems

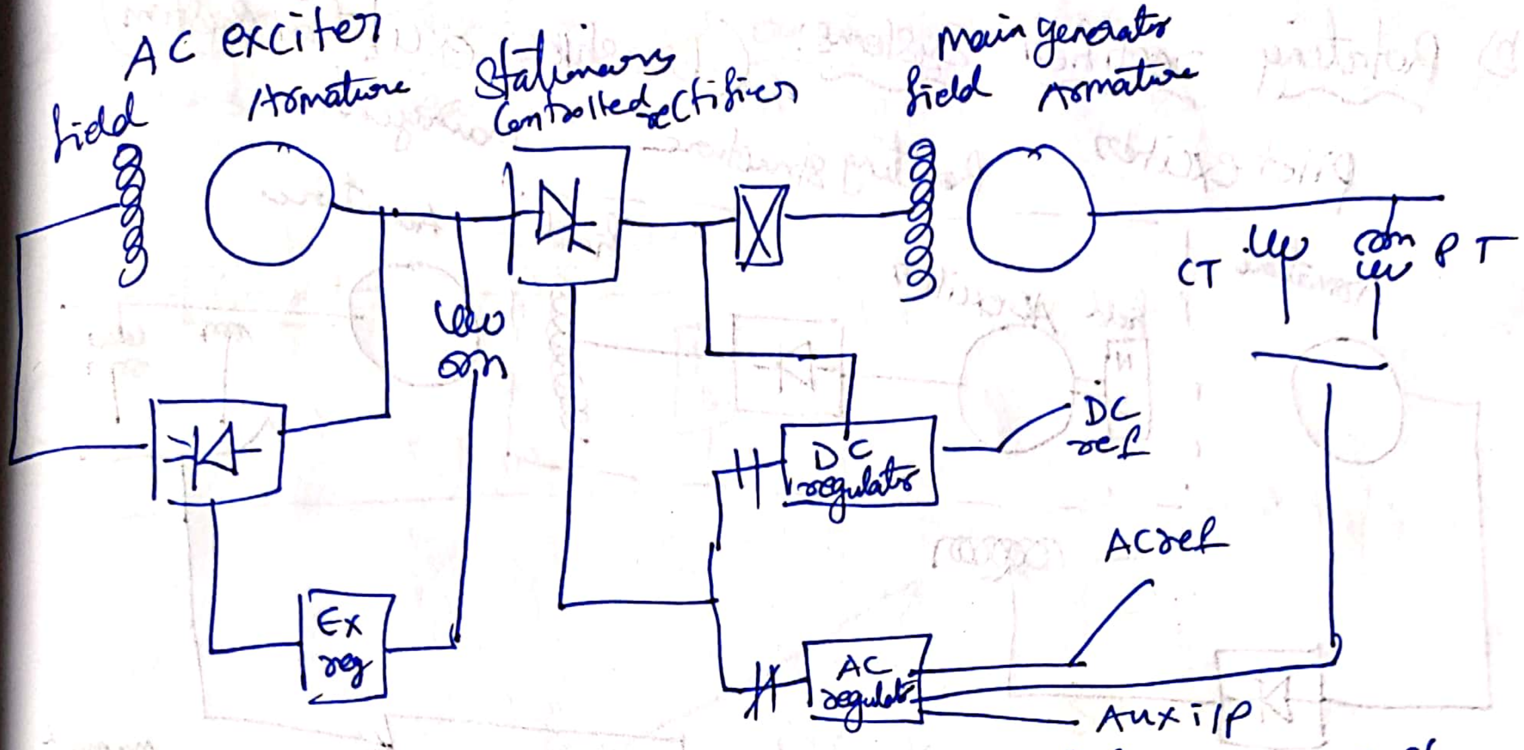
a). Stationary rectifier systems



i) field Controlled alternator rectifier ex. system

With stationary rectifiers the DC output is feed to the field winding of the main generator through slip rings.

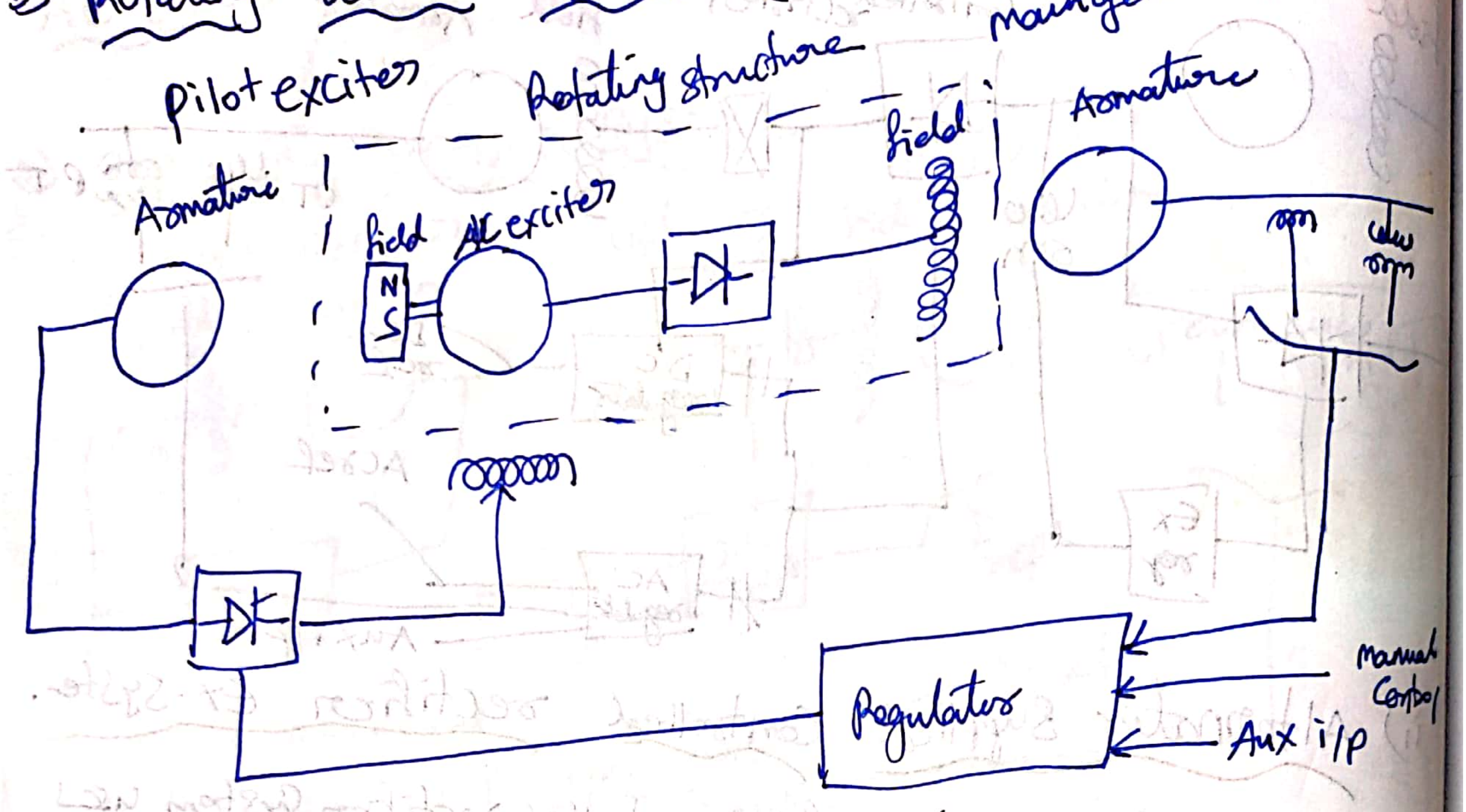
When non-Controlled rectifiers are used the regulator Controls the field of the AC exciter which in turn Controls the Exciter output voltage. The alternator exciter is driven from the main generator rotor. The exciter is self-excited with its field power derived through thyristor rectifiers. The voltage regulator derives its power from the exciter output voltage.



ii) Alternator supplied controlled rectifier Ex-System.

An alternative form of field controlled rectifier system uses a pilot exciter as the source of exciter field power. When controlled rectifiers (Tyristors) are used. The regulator directly controls the DC o/p vge of the exciter. The vge regulator contols the firing of the thyristor. The exciter alternator is self-excited and uses an independent static voltage regulator to maintain its output voltage. Since the tyristors directly control the exciter output this system inherently provides high initial response.

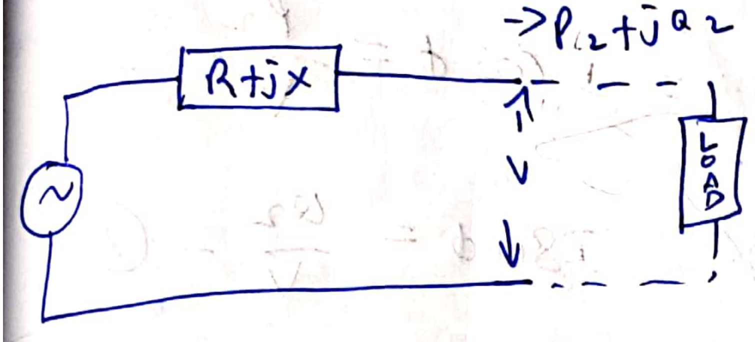
b) Rotating rectifier systems: (Brushless excitation system)

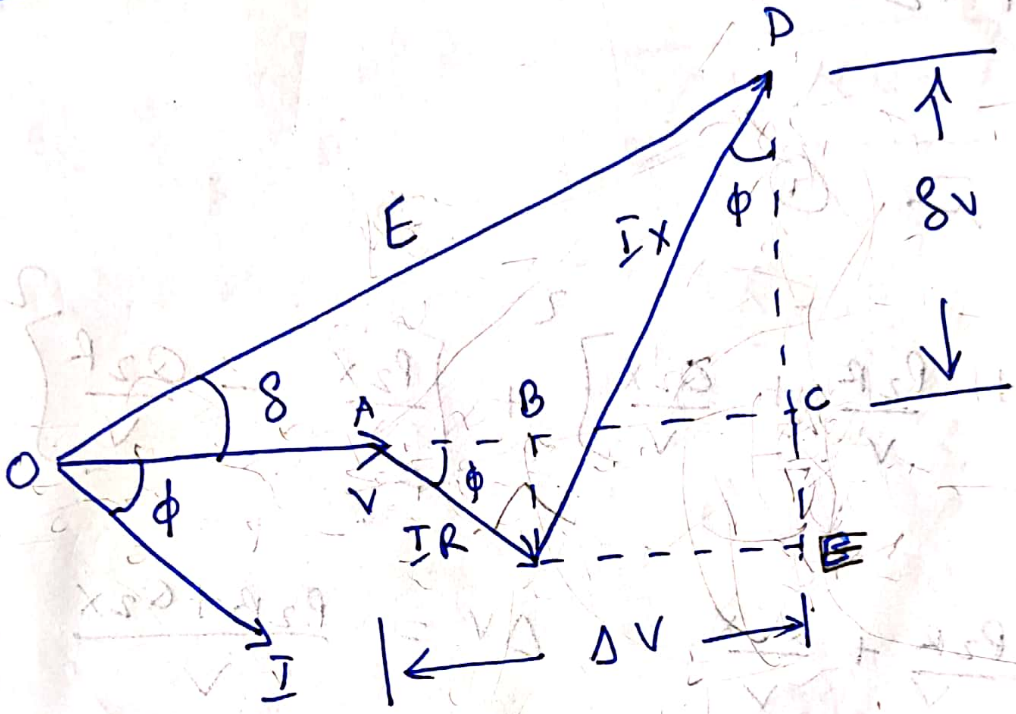


Brushless excitation System

With rotating rectifiers the need for slip rings and brushes is eliminated and the DC output is directly fed to the main generator field. The armature of the AC exciter and the diode rectifiers rotate with the main generator field. A Small AC Pilot exciter with a permanent magnet rotor (NS) rotates with the exciter armature and the diode rectifiers. The rectified o/p of the pilot exciter stator energizes the stationary field of the AC exciter. The voltage regulator controls the AC exciter field which in turn controls the field of the main generator. Such a System is referred to as a brushless excitation system. It was developed to avoid problems with the use of brushes that were perceived to exist when supplying the high field currents of very large generators.

Calculation of Sending end and Receiving end voltages In terms of real and reactive powers in transmission line





phasor diagram

$$OD^2 = OC^2 + CD^2$$

$$E^2 = (OA + AC)^2 + (ED - EC)^2$$

$$E^2 = (V + \Delta V)^2 + (\delta v)^2$$

$$\Delta V = AB + BC \quad = IR\cos\phi + IX\sin\phi$$

$$\delta v = DE - CE \quad = IX\cos\phi - IR\sin\phi$$

$$E^2 = (V + IR\cos\phi + IX\sin\phi)^2 + (IX\cos\phi - IR\sin\phi)^2 \quad -(1)$$

Real Power $P_2 = VI\cos\phi \quad = \quad I\cos\phi = \frac{P_2}{V} \quad -(2)$

Reactive Power $Q_2 = VI\sin\phi \quad I\sin\phi = \frac{Q_2}{V} \quad -(3)$

Sub (3) & (2) in (1)

$$E^2 = \left[V + \frac{P_2R}{V} + \frac{Q_2X}{V}\right]^2 + \left[\frac{P_2X}{V} - \frac{Q_2R}{V}\right]^2$$

$$\Delta V = \frac{P_2R}{V} + \frac{Q_2X}{V} \qquad \Delta V = \frac{P_2R + Q_2X}{V} \quad -(4)$$

$$\delta v = \frac{P_2x - Q_2R}{V} \quad -(5)$$

If $\delta v << (v + \Delta v)$

$$E^2 = \left(V + \frac{P_2R + Q_2X}{V}\right)^2$$

$$E = V + \frac{P_2R + Q_2X}{V}$$

$$E - V = \frac{P_2R + Q_2X}{V} = \Delta V$$

$$\Delta V = \frac{P_2 R + Q_2 X}{V}$$

The arithmetic difference b/w sending end and Receiving end is given by

$$\Delta V = \frac{P_2 R + Q_2 X}{V}$$

If R Resistance of the line is neglected

$$\Delta V = \frac{Q_2 X}{V} \qquad \boxed{\Delta V \propto Q_2}$$

from vector diagram

$$\sin\delta = \frac{CD}{OD} = \frac{\delta v}{E}$$

$$\delta = \sin^{-1}\left[\frac{\delta v}{E}\right]$$

When $X >> R$ $\qquad \delta v = \frac{P_2 X}{V}$ from eq (5)

$$\boxed{\delta v \propto P_2}$$

Hence the flow of power b/w two nodes is determined by the transmission angle δ and the flow of reactive power is determined by the difference b/w sending end and receiving end voltage.