Internal Assesment Test - II

Sub:	POWER SYSTEM OPERATION AND CONTROL							Code:	15EE81
Date:	16/ 04/ 2019	Duration:	90 mins	Max Marks:	50	Sem:	8th	Branch:	EEE

1. With a block diagram representation, explain tie-line bias control of a two area load frequency control.

TIE-LINE BIAS CONTROL FOR TWO-AREA SYSTEM:—

* Since the steady state change in frequency $\Delta f_{ss} \neq 0$, for two-area system, the control adopted should be modified.

* The modified control is called as TIE-LINE BIAS CONTROL.
* The required change in generation (called ACE) represents the shift in area's generation required to restore frequency and net tie-line power. i.e. Δf_{ss} and ΔP_{12ss} must be zero.

Δf	ΔP_{12}	LOAD CHANGE	REQUIRED CONTROL ACTION
↓	↓	$\Delta P_{D_1} = \uparrow$ $\Delta P_{D_2} = 0$	Increase Generation in AREA-1
↓	↑	$\Delta P_{D_1} = 0$ $\Delta P_{D_2} = \uparrow$	Increase Generation in AREA-2
↑	↓	$\Delta P_{D_1} = 0$ $\Delta P_{D_2} = \downarrow$	Decrease Generation in AREA-2
↑	↑	$\Delta P_{D_1} = \downarrow$ $\Delta P_{D_2} = 0$	Decrease Generation in AREA-1

↑ — INCREASE ‖ ↓ — DECREASE

Define Area Control Error of AREA1;

$$ACE_1 = \Delta P_{12} + B_1 \Delta f_1$$

Area Control Error of AREA2;

$$ACE_2 = \Delta P_{21} + B_2 \Delta f_2 \quad [\because \Delta P_{21} = a_{12} \Delta P_{12}]$$

$$ACE_2 = a_{12} \Delta P_{12} + B_2 \Delta f_2$$

For steady state change in frequency and steady state change in tie-line power to be zero

i.e. $\Delta f_{ss} = 0$ and $\Delta P_{12ss} = 0$

The speed changer setting of two areas should be:

$$\Delta P_{C_1} = -K_{i_1} \int ACE_1 \cdot dt$$

$$= -K_{i_1} \int (\Delta P_{12} + B_1 \Delta f_1) \cdot dt$$

Taking Laplace Transform;

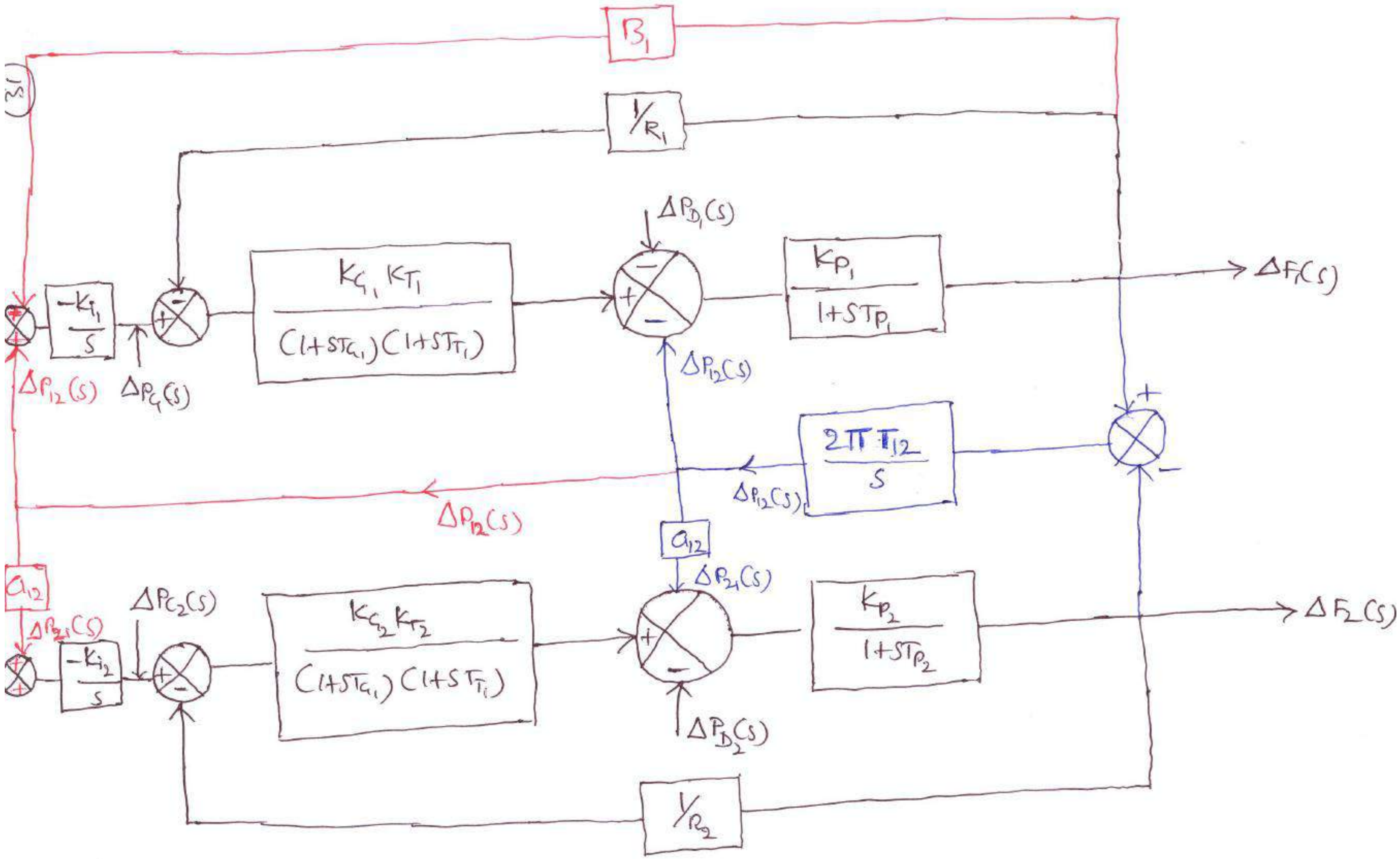
$$\Delta P_{C_1}(s) = -\frac{K_{i_1}}{s} \left[\Delta P_{12}(s) + B_1 \Delta F_1(s) \right] \quad -(7)$$

Similarly $\Delta P_{C_2}(s) = -K_{i_2} \int ACE_2 \cdot dt$

$$= -K_{i_2} \int (a_{12} \Delta P_{12} + B_2 \Delta f_2) \cdot dt$$

Taking Laplace Transform;

$$\Delta P_{C_2}(s) = -\frac{K_{i_2}}{s} \left[a_{12} \Delta P_{12}(s) + B_2 \Delta F_2(s) \right] \quad -(8)$$



TIE-LINE BIAS CONTROL FOR TWO-AREA SYSTEM

STEADY STATE ANALYSIS (STATIC PERFORMANCE) OF TIE-LINE BIAS CONTROL FOR TWO-AREA SYSTEM:—

If $B_1 = D_1 + \frac{1}{R_1}$ and $B_2 = D_2 + \frac{1}{R_2}$, from the steady state analysis of two-area system, we know that,

$$\Delta f_{ss} = \frac{X_2 - a_{12}X_1}{a_{12}B_1 - B_2} \quad \text{and} \quad \Delta P_{12ss} = \frac{B_1 X_2 - B_2 X_1}{B_2 - a_{12}B_1}$$

Then Area Control Error of AREA1 @ steady state:

$$ACE_{1ss} = \Delta P_{12ss} + B_1 \Delta f_{ss}$$

$$= \left[\frac{B_1 X_2 - B_2 X_1}{B_2 - a_{12}B_1}\right] + B_1\left[\frac{X_2 - a_{12}X_1}{a_{12}B_1 - B_2}\right]$$

$$= -X_1$$

Since $\Delta P_{D_1} = X_1$, $ACE_{1ss} = -X_1$

Similarly $ACE_{2ss} = a_{12}\Delta P_{12ss} + B_2 \Delta f_{ss}$

$$= a_{12}\left[\frac{B_1 X_2 - B_2 X_1}{B_2 - a_{12}B_1}\right] + B_2\left[\frac{X_2 - a_{12}X_1}{a_{12}B_1 - B_2}\right]$$

$$= -X_2$$

Since $\Delta P_{D_2} = X_2$, $ACE_{2ss} = -X_2$

$\therefore$ Bias factors are adjusted such that change in load of a particular area should be met by its area.

2. Explain with block diagram modelling of Generator and Load.

GENERATOR - LOAD MODEL :

for incremental change in load demand (ΔP_D), there's going to be change in system frequency (Δf). To get the system frequency back to base frequency ($f^\circ = 50$ Hz), there should be change in generation (ΔP_G)

Define; $\Delta P_G - \Delta P_D$ = the net surplus power (MW) in the system

This surplus power is absorbed in the system in two ways :

1. The surplus power is stored in the rotor in the form of kinetic energy (K.E.) i.e. $\frac{dW}{dt}$

Let, W° = Kinetic energy in the rotor prior to load change.

W = Kinetic energy in the rotor post load change.

f° = System base frequency.

$f^\circ + \Delta f$ = system frequency post load change.

Since the K.E. is proportional to the square of the speed of the generator, we can write

$$W^\circ \propto (f^\circ)^2 \text{ —— } (1)$$

$$W \propto (f^\circ + \Delta f)^2 \text{ —— } (2).$$

$$\frac{(2)}{(1)} \Rightarrow \frac{W}{W^\circ} = \left[\frac{f^\circ + \Delta f}{f^\circ}\right]^2 = \left[1 + \frac{\Delta f}{f^\circ}\right]^2 = 1 + \frac{2\Delta f}{f^\circ}$$

$\because \frac{\Delta f}{f^\circ}$ is small, ignoring $\left(\frac{\Delta f}{f^\circ}\right)^2$

(17)

$$\therefore \frac{dW}{dt} = \frac{2W^\circ}{f^\circ} \cdot \frac{d}{dt} \cdot (\Delta f) \text{ —— } (3).$$

2. The load on the system being mostly motor load, the rate of change of load with respect to frequency can be considered as constant i.e.

Damping coefficient

$$D = \frac{\partial P_D}{\partial f} \text{ —— } (4).$$

Power system parameter.

· The net power surplus at the bus bar is given by

$$\Delta P_G - \Delta P_D = \frac{2W^0}{f^0} \cdot \frac{d}{dt}(\Delta f) + D \cdot \Delta f \quad [\text{from } ③, ④]$$

If H is the inertia constant of the generator in MW-sec/MVA and P is the rating in MVA, then $W^0 = HP$

$$\Delta P_G - \Delta P_D = \frac{2HP}{f^0} \cdot \frac{d}{dt}(\Delta f) + D \cdot \Delta f$$

Dividing throughout by P we get

$$\Delta P_G(p.u.) - \Delta P_D(p.u.) = \frac{2H}{f^0} s\,\Delta F(s) + D\,\Delta F(s) \quad [D \rightarrow D(pu)]$$

$$= \Delta F(s)\left[\frac{2H}{f^0} s + D\right]$$

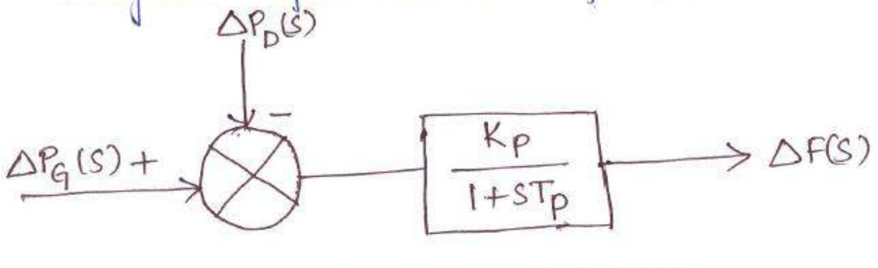
or
$$\Delta F(s) = \frac{\Delta P_G(s) - \Delta P_D(s)}{\left[\frac{2H}{f^0} s + D\right]}$$

$$\frac{\Delta F(s)}{\Delta P_G(s) - \Delta P_D(s)} = \frac{1}{\left[\frac{2H}{f^0} s + D\right]} = \frac{1/D}{\left[1 + \frac{2H}{f^0 D} \cdot s\right]} = \frac{K_p}{1 + sT_p} \quad \text{—— ⑤}$$

where $K_p = \frac{1}{D}$ = power system gain.

$T_p = \frac{2H}{Df^0}$ = power system time constant.

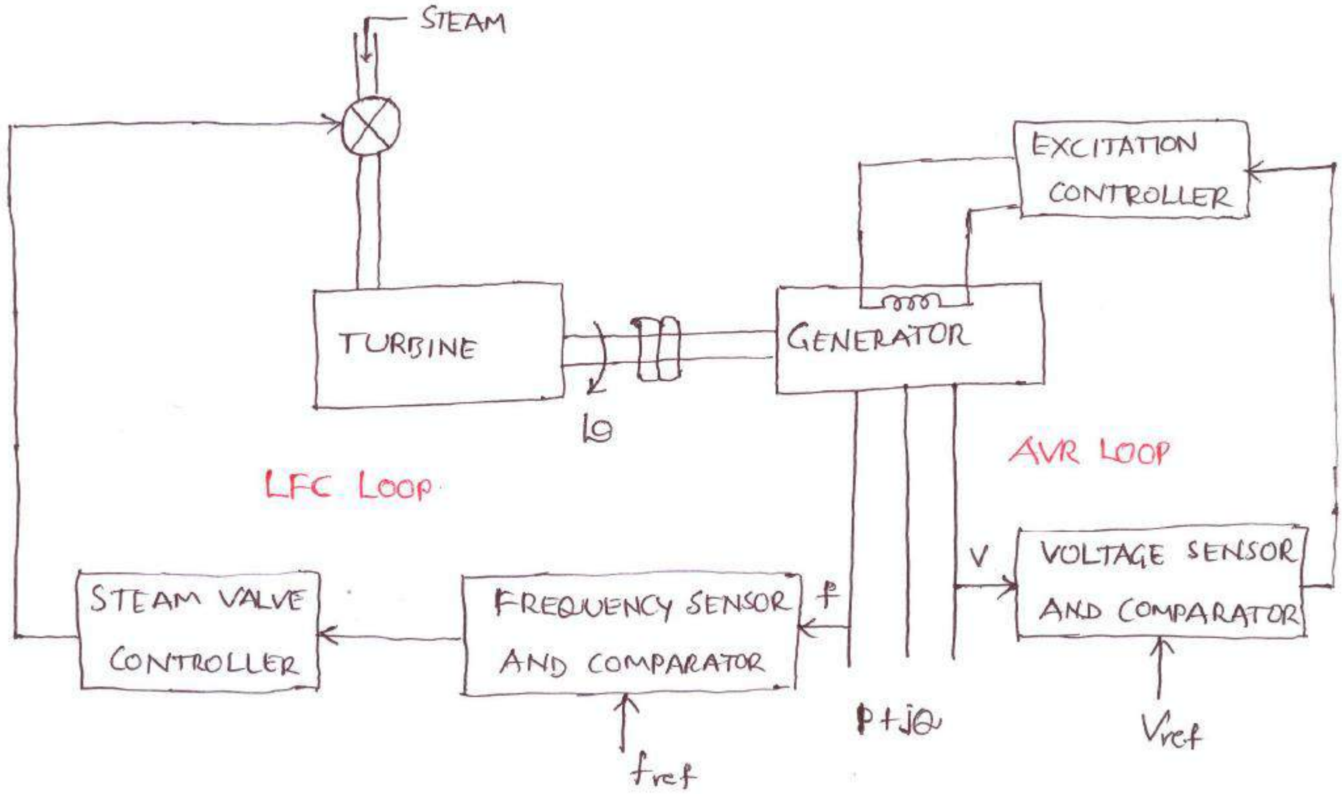
Block diagram representation of ⑤



GENERATOR LOAD MODEL.

3a. Explain basic generator control loops and cross-coupling between control loops.

BASIC GENERATOR CONTROL LOOPS:



SCHEMATIC DIAGRAM OF LOAD FREQUENCY AND EXCITATION VOLTAGE REGULATOR OF A TURBO-GENERATOR

The two control loops are:

The two control loops are:

- Control of turbine input also called as:
  - → Load Frequency Control (LFC)
  - → Automatic Generation Control (AGC)
  - → Automatic Load Frequency Control (ALFC)
  - → MW-f control loop
  - → Power-frequency control loop

— Excitation control (or) MVAR–Voltage (Q–V) Control ②

CROSS – COUPLING BETWEEN CONTROL LOOPS:

* Active power change is dependent on internal machine angle 'δ' and is independent of bus voltage. Change in angle 'δ' is caused by momentary change in generator speed.
* While ~~bo~~ bus voltage is dependent on machine excitation and therefore on reactive power generation 'Q' and is independent of machine angle 'δ'.
* Therefore, load frequency and excitation voltage controls are non-interactive and can be modelled, analysed independently.
* Excitation voltage control is fast acting in which the major time constant is that of generator field.
* Power-frequency control is slow acting with major time constant contributed by the turbine and generator moment of inertia. This time constant is much larger than that of the generator field.
* Thus the transients in excitation voltage control vanish much faster and do not affect the dynamics of power frequency control.

3b. Mention functions of AGC.

Objectives of AGC:

* Sustaining frequency as close as possible to the specified range
* Maintenance of appropriate level of interchange power.
* Maintenance of economic unit's generation.

4a. Two machines operate in parallel to supply a load of 400 MW, the capacities of the machines are 200 MW and 500 MW. Each has a droop characteristic of 4%. Their governors are adjusted so that frequency is 100% on Full Load. Calculate the load supplied by each unit and the frequency at this load. The system frequency is 50 Hz.

$\Delta P_L = 400MW \mid R_1 = R_2 = 0.04 \mid P_{1RATE} = 200MW \mid P_{2RATE} = 500MW$

* @100% Load = 200MW+500MW = 700MW, they are supposed operate @50Hz.
* But we have connected just $\Delta P_L = 400MW$ across generators. So operating frequency is going to be greater than 50Hz.

System Regulation; $R_{SYS} = \frac{\Delta f}{\Delta L} = \frac{1}{\frac{P_{1RATE}}{R_1} + \frac{P_{2RATE}}{R_2}} = 0.0000571 \ Hz/MW$

Change in frequency $\Delta f = R_{SYS} * \Delta L = 0.0228 Hz$.

$\therefore$ Frequency @400MW load $= f^\circ + \Delta f = 50.0228 Hz$.

$$\Delta P_1 = \frac{\Delta f}{R_1} * P_{1RATE} = 114MW$$

$$\Delta P_2 = \frac{\Delta f}{R_2} * P_{2RATE} = 285MW$$

CHECK $\boxed{\Delta P_L = \Delta P_1 + \Delta P_2}$

4b. Determine primary ALFC loop parameters for control area having the following data.Total rated capacity, Pr = 2000 MW; Inertia Constant, H = 5.0 S; Frequency f_0 = 50 Hz, Normal Operating Load, P_D = 1000 MW.

Assume that the load frequency dependency is linear, meaning that the load would increase 1% for 1% frequency change.

$$\partial P_D = 1\% \text{ of } 1000 = 10 \text{ MW}$$

$$\partial f = 1\% \text{ of } 50 = 0.5 \text{ Hz}.$$

$$D = \frac{\partial P_D}{\partial f} = \frac{10}{0.5} = 20 \text{ MW/Hz} = \frac{20}{2000} = 0.01 \text{ pu MW/Hz}.$$

$$K_p = 1/D = 100 \text{ Hz/pu MW} \text{ — Power system gain}$$

$$T_p = \frac{2H}{f^0 D} = 20 \text{ Sec.} \text{ — power system time constant}$$

$$G_p(s) = \boxed{\frac{K_p}{1+sT_p} = \frac{100}{1+20s}}$$

Power System Transfer Function

5. A single area consists of two generators as follows:
G_1 = 200 MW, R = 4% (on machine base)
G2 = 400 MW, R = 5% (on machine base)
They are connected in parallel and share a load of 600 MW in proportion to their rating, at 50 Hz. 200 MW of load is tripped. What is the generation to meet the new load if D=0. What is the frequency at new load? Repeat for D = 1.5 pu.

Choose a base of 200 MW. D=0

$R_1 = 0.04$ pu (on 200MW base)

$$R_2 = 0.05 \times \frac{200}{400} = 0.025 \text{ pu (on 200 MW base)}$$

$$\Delta P_L = -200\text{MW (decrease)} = -1\text{pu}$$

$$\Delta\omega_M = \frac{-\Delta P_L}{\frac{1}{R_1}+\frac{1}{R_2}} = \frac{-(-1)}{\frac{1}{0.04}+\frac{1}{0.025}} = 0.01538 \text{ pu}$$

Frequency at new load $= 1.01538$ pu
$= 50.769$ Hz

$$\Delta P_1 = \frac{-\Delta f}{R_1} = \frac{-0.01538}{0.04} = -0.3845 \text{ pu}$$

$= -0.3845 \times 200$
$= -76.9$ MW

$P_1 = 200 - 76.9 = 123.1$ MW

$$\Delta P_2 = \frac{-\Delta f}{R_2} = \frac{-0.01538}{0.025} = -0.6152 \text{ pu}$$
$= -123.04$ MW

$P_2 = 400 - 123.04 = 276.96$ MW

$P_1 + P_2 = P_L = 400$ MW.

Now $D = 1.5$

$$\Delta\omega_M = \frac{-\Delta P_L}{\frac{1}{R_1} + \frac{1}{R_2} + D} = \frac{1}{\frac{1}{0.04} + \frac{1}{0.025} + 1.5} = 0.01504 \text{ pu}$$

Frequency at new load $= 1.01504$ pu
$= 50.752$ Hz

$$\Delta P_1 = \frac{-0.01504}{0.04} \times 200 = -75.2 \text{ MW}$$

$P_1 = 200 - 75.2 = 124.8$ MW

$$\Delta P_2 = \frac{-0.01504}{0.025} \times 200 = -120.32 \text{ MW}$$

$P_2 = 279.68$ MW

$D\Delta\omega =$ increase in load due to frequency change

$= 1.5 \times 0.01504$

$= 0.02256$ pu

$= 0.02256 \times 200$

$= 4.512$ MW

$P_1 + P_2 = 404.5$ MW

$= P_L + D\Delta\omega$

The sum of the two generators should meet the load plus any increase in load because of frequency.

6. Obtain an expression for steady state change in system frequency $\Delta \mathbf{f}_{ss}$ for a step change in the load demand. Assume free governor operation.

CASE(i): [FREE GOVERNOR OPERATION]

Let the speed changer setting be fixed i.e. $\Delta P_C = 0$ and the load demand changes. This is known as free governor operation.

Let the load on the system be changing in a step manner.

$$\therefore \Delta P_D(s) = \frac{\Delta P_D}{s} \quad \left[\because \text{Laplace Transform of step function is } 1/s\right]$$

Now the mathematical model for the above block diagram (Primary ALFC) with $\Delta P_c(s) = 0$.

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

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

$$S\Delta F(S) = - \frac{\left(K_P/1+ST_P \right)}{\left[1 + \frac{1}{R} \cdot \frac{K_G}{1+ST_G} \cdot \frac{K_T}{1+ST_T} \cdot \frac{K_P}{1+ST_P} \right]} \cdot \Delta P_D$$

From final value theorem;

The steady state change in system frequency;

$$\Delta f_{ss} = \underset{S \to 0}{SF(S)} = - \frac{K_P}{\left[1 + \frac{1}{R} \cdot K_G K_T K_P \right]} \cdot \Delta P_D$$ $\boxed{\text{Let } K_G \cdot K_T = 1}$

$$= - \Delta P_D \cdot \left[\frac{K_P}{1 + \frac{1}{R} \cdot K_P} \right]$$

$$\Delta f_{ss} = - \Delta P_D \left[\frac{1}{\frac{1}{R} + \frac{1}{K_P}} \right] \qquad \left[\because K_P = 1/D \right]$$

$$= - \Delta P_D \left[\frac{1}{D + 1/R} \right] \text{ ——— } (1)$$

Define $B = D + \frac{1}{R}$ = frequency Bias

$$\boxed{\Delta f_{ss} = - \frac{1}{B} \cdot \Delta P_D} \text{ ——— } (2).$$

$\therefore$ For rise in Load; $\Delta P_D = +ve \rightarrow \Delta f_{ss} = -ve$.

For fall in load; $\Delta P_D = -ve \rightarrow \Delta f_{ss} = +ve$.