POWER SYSTEM OPERATION AND CONTROL (15EE81)

MODULE – 03

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MODULE – 03:

- **AUTOMATIC GENERATION CONTROL (Continued) (AGC)**
- **AUTOMATIC GENERATION CONTROL IN INTERCONNECTED POWER SYSTEM**

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AUTOMATIC GENERATION CONTROL IN INTERCONNECTED POWER SYSTEM :

- **Let us consider an isolated system, which is equipped only with the primary speed control.**
- **In this isolated system, any change in load will lead to a steady-state frequency deviation depending upon the speed droop (R) of the governor characteristics and frequency dependence of load (D).**
- **All the generators with governor control, will have a change in their generation levels.**
- **To restore the frequency to the nominal value, a supplementary control is used which changes the reference power set point (P_{ref}).**

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AUTOMATIC GENERATION CONTROL IN INTERCONNECTED POWER SYSTEM :

- **This is achieved by changing the power output of prime mover to match with load variations.**
- **Now let us consider a group of generators which are coupled closely will swing together.**
- **They can be replaced by a single equivalent generator.**
- **Such generators are said to be *coherent* and the complete system is called a *control area*.**

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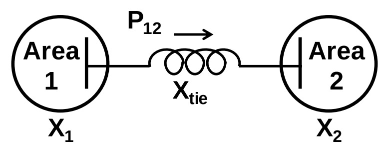
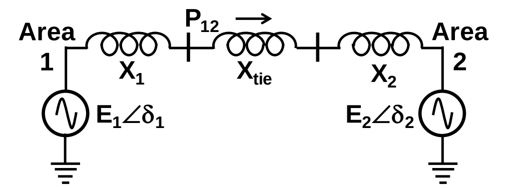
AUTOMATIC GENERATION CONTROL IN INTERCONNECTED POWER SYSTEM :

- When different control areas are connected together, then it is set to be an ***interconnected system***.
- The Automatic Generation Control (AGC) of an interconnected system will have the following objectives.
  - (i) Hold the system frequency close to the nominal value.
  - (ii) To maintain a correct value of power interchange between control areas.
  - (iii) Maintain the generation of each unit at the most economical value.

TIE-LINE CONTROL WITH PRIMARY SPEED CONTROL: (TIE-LINE MODELLING)

- Let us consider a two-area system as shown below.
- The equivalent circuit of this interconnected system is also shown.





- Let us assume a power flow on the tie-line from Area 1 to Area 2 which is considered as positive power flow.

TIE-LINE CONTROL WITH PRIMARY SPEED CONTROL: (TIE-LINE MODELLING)

- Hence, the power flow on tie-line from Area 1 to Area 2 is given by,

$$P_{12} = \frac{|E_1|*|E_2|}{X_{12}} \sin(\delta_1 - \delta_2) \text{ -------------------- (1)}$$

Where, X_{12} is the total reactance between Areas 1 and 2.

$$\therefore X_{12} = X_1 + X_{tie} + X_2$$

E_1 and E_2 are the operating voltages of areas 1 and 2 respectively.

δ_1 and δ_2 are the load or torque angles of areas 1 and 2 respectively.

- Now, let us consider initial operating angles of areas be δ_{10} and δ_{20}.
- Hence, initial power flow is, $P_{12} = \frac{|E_1|*|E_2|}{X_{12}} \sin(\delta_{10} - \delta_{20})$.

$$\therefore \frac{dP_{12}}{d(\delta_1-\delta_2)} = \frac{|E_1|*|E_2|}{X_{12}} \cos(\delta_{10} - \delta_{20})$$

TIE-LINE CONTROL WITH PRIMARY SPEED CONTROL: (TIE-LINE MODELLING)

- Let us linearize the above equation for small variations in parameters.

$$\therefore \frac{\Delta P_{12}}{(\Delta\delta_1-\Delta\delta_2)} = \frac{|E_1|*|E_2|}{X_{12}} \cos(\delta_{10} - \delta_{20})$$

Let $\Delta\delta_{12} = \Delta\delta_1 - \Delta\delta_2$ and $T = \frac{|E_1|*|E_2|}{X_{12}} \cos(\delta_{10} - \delta_{20})$

$$\Rightarrow \frac{\Delta P_{12}}{(\Delta\delta_1-\Delta\delta_2)} = T \qquad \Rightarrow \Delta P_{12} = T * (\Delta\delta_1 - \Delta\delta_2) \text{ ----------- (2)}$$

Where, T = synchronizing torque coefficient

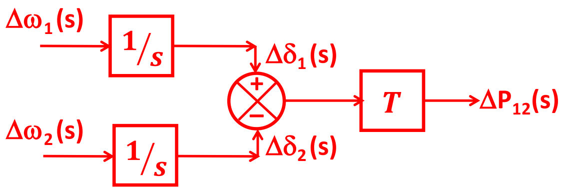
- Also, $\omega_1 = \frac{d\delta_1}{dt}$ and $\omega_2 = \frac{d\delta_2}{dt}$ are angular frequencies in rad/sec of areas 1 and 2 respectively.

$$\Rightarrow \Delta\omega_1 = \frac{d(\Delta\delta_1)}{dt} \qquad \Rightarrow \Delta\omega_1(s) = s\,\Delta\delta_1(s) \qquad \therefore \Delta\delta_1(s) = \frac{1}{s} * \Delta\omega_1(s)$$

Similarly, $\Delta\delta_2(s) = \frac{1}{s} * \Delta\omega_2(s)$

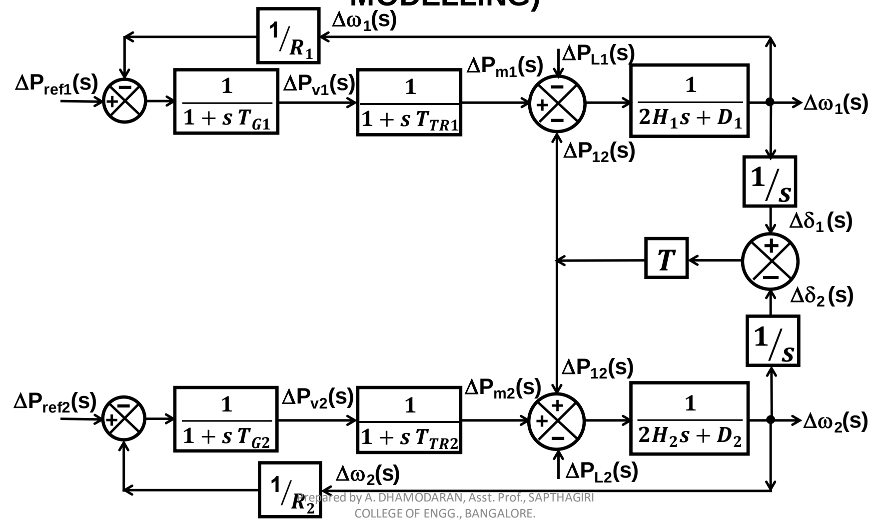
TIE-LINE CONTROL WITH PRIMARY SPEED CONTROL: (TIE-LINE MODELLING)

- From equation (2), the tie-line can be modelled in block diagram as shown.



- With the tie-line model shown above, the block diagram representation of a two-area system with only primary control loop is as shown.
- A positive ΔP_{12} indicates the increase in power flow on tie-line from Area 1 to Area 2.

TIE-LINE CONTROL WITH PRIMARY SPEED CONTROL: (TIE-LINE MODELLING)



TIE-LINE CONTROL WITH PRIMARY SPEED CONTROL: (TIE-LINE MODELLING)

- The block diagram representation of two-area system drawn above is equivalent to load increase in Area 2 and/or load decrease in Area 1.
- Hence, the feedback from ΔP_{12} has a negative sign for Area 1 and positive sign for Area 2.

<u>CHANGE OF LOAD IN AREA 1:</u>

- Let us consider a change in load demand in area 1 only and not in area 2.
- Hence, in area 2 the load demand is considered as constant.
- Upon the change in load demand in area 1, the system reaches a steady-state with a frequency deviation.
- Both areas 1 and 2 have the same steady-state frequency deviation.

TIE-LINE CONTROL WITH PRIMARY SPEED CONTROL: (TIE-LINE MODELLING)

- i.e., $\Delta\omega = \Delta\omega_1 = \Delta\omega_2$ or $\Delta f = \Delta f_1 = \Delta f_2$
- Let us assume the reference power settings of areas 1 and 2 are constant. i.e., $\Delta P_{ref1} = \Delta P_{ref2} = 0$
- Hence, the tie-line and rotating objects exhibit damped oscillations called synchronizing oscillations.

The power balance equation in area 1 is given by,

$$(\Delta P_{m1} - \Delta P_{L1} - \Delta P_{12}) * \left(\frac{1}{2H_1\, s + D_1}\right) = \Delta\omega_1$$

At steady state s → 0, $(\Delta P_{m1} - \Delta P_{L1} - \Delta P_{12}) * \left(\frac{1}{D_1}\right) = \Delta\omega$ $(\because \Delta\omega = \Delta\omega_1)$

$$(\Delta P_{m1} - \Delta P_{L1} - \Delta P_{12}) = D_1 * \Delta\omega \text{ --------------------- (1)}$$

TIE-LINE CONTROL WITH PRIMARY SPEED CONTROL: (TIE-LINE MODELLING)

- Similarly, the power balance equation in area 2 is given by,

$$(\Delta P_{m2} - \Delta P_{L2} + \Delta P_{12}) * \left(\frac{1}{2H_2\, s + D_2}\right) = \Delta\omega_2$$

At steady state s → 0, $(\Delta P_{m2} - \Delta P_{L2} + \Delta P_{12}) * \left(\frac{1}{D_2}\right) = \Delta\omega$ ($\because \Delta\omega = \Delta\omega_2$)

$(\Delta P_{m2} + \Delta P_{12}) = D_2 * \Delta\omega$ ------------------- (2)

($\because \Delta P_{L2} = 0$ i.e., Load demand at area 2 is constant)

- The mechanical power outputs can be given in terms of speed droop of their governors as,

$$R_1 = \frac{-\Delta\omega}{\Delta P_{m1}} \quad \text{and} \quad R_2 = \frac{-\Delta\omega}{\Delta P_{m2}}$$

$$\Rightarrow \Delta P_{m1} = \frac{-\Delta\omega}{R_1} \quad \text{and} \quad \Delta P_{m2} = \frac{-\Delta\omega}{R_2} \text{ ---------------------- (3)}$$

TIE-LINE CONTROL WITH PRIMARY SPEED CONTROL: (TIE-LINE MODELLING)

- Substituting equation (3) in (1) and (2) gives,

(1) ⇒ $\left(\frac{-\Delta\omega}{R_1} - \Delta P_{L1} - \Delta P_{12}\right) = D_1 * \Delta\omega$

$-\Delta P_{L1} - \Delta P_{12} = \left(\frac{1}{R_1} + D_1\right) * \Delta\omega$ ------------------------- (4)

(2) ⇒ $\left(\frac{-\Delta\omega}{R_2} + \Delta P_{12}\right) = D_2 * \Delta\omega$

$\Delta P_{12} = \left(\frac{1}{R_2} + D_2\right) * \Delta\omega$ ----------------------------- (5)

- Substituting equation (5) in (4) gives,

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

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

∴ Steady state frequency deviation $\Delta\omega = \dfrac{-\Delta P_{L1}}{\left(\frac{1}{R_1} + D_1 + \frac{1}{R_2} + D_2\right)} = \dfrac{-\Delta P_{L1}}{(\beta_1 + \beta_2)}$ ----(6)

TIE-LINE CONTROL WITH PRIMARY SPEED CONTROL: (TIE-LINE MODELLING)

- Substituting equation (6) in (5) gives,

The tie-line power flow deviation $\Delta P_{12} = \left(\frac{1}{R_2} + D_2\right) * \dfrac{-\Delta P_{L1}}{\left(\frac{1}{R_1} + D_1 + \frac{1}{R_2} + D_2\right)}$

∴ Tie-line power flow deviation $\Delta P_{12} = \dfrac{-\Delta P_{L1} * \left(\frac{1}{R_2} + D_2\right)}{\left(\frac{1}{R_1} + D_1 + \frac{1}{R_2} + D_2\right)} = \dfrac{-\Delta P_{L1} * \beta_2}{(\beta_1 + \beta_2)}$ --- (7)

- The above equations (6) and (7) gives frequency deviation and tie-line power flow from area 1 to area 2 respectively.
- Where, β_1 and β_2 are composite frequency response characteristics of areas 1 and 2 respectively.

$$\beta_1 = \frac{1}{R_1} + D_1 \quad \text{and} \quad \beta_2 = \frac{1}{R_2} + D_2$$

TIE-LINE CONTROL WITH PRIMARY SPEED CONTROL: (TIE-LINE MODELLING)

CHANGE OF LOAD IN AREA 2:

- Let us consider a change in load demand in area 2 only and not in area 1.
- Hence, in area 1 the load demand is considered as constant.
- Upon the change in load demand in area 2, the system reaches a steady-state with a frequency deviation.
- Both areas 1 and 2 have the same steady-state frequency deviation.
- i.e., $\Delta\omega = \Delta\omega_1 = \Delta\omega_2$ or $\Delta f = \Delta f_1 = \Delta f_2$
- Let us assume the reference power settings of areas 1 and 2 are constant. i.e., $\Delta P_{ref1} = \Delta P_{ref2} = 0$

TIE-LINE CONTROL WITH PRIMARY SPEED CONTROL: (TIE-LINE MODELLING)

- The power balance equation in area 1 is given by,

$$(\Delta P_{m1} - \Delta P_{L1} - \Delta P_{12}) * \left(\frac{1}{2H_1\, s + D_1}\right) = \Delta\omega_1$$

- At steady state s → 0, $(\Delta P_{m1} - \Delta P_{12}) * \left(\frac{1}{D_1}\right) = \Delta\omega$ $\quad (\because \Delta\omega = \Delta\omega_1)$

($\because \Delta P_{L1} = 0$ and Load demand at area 1 is constant)

$$\Delta P_{m1} - \Delta P_{12} = D_1 * \Delta\omega \text{ ------------------------------ (1)}$$

- Similarly, the power balance equation in area 2 is given by,

$$(\Delta P_{m2} - \Delta P_{L2} + \Delta P_{12}) * \left(\frac{1}{2H_2\, s + D_2}\right) = \Delta\omega_2$$

- At steady state s → 0, $(\Delta P_{m2} - \Delta P_{L2} + \Delta P_{12}) * \left(\frac{1}{D_2}\right) = \Delta\omega$ $(\because \Delta\omega = \Delta\omega_2)$

$$(\Delta P_{m2} - \Delta P_{L2} + \Delta P_{12}) = D_2 * \Delta\omega \text{ -------------------- (2)}$$

TIE-LINE CONTROL WITH PRIMARY SPEED CONTROL: (TIE-LINE MODELLING)

- The mechanical power outputs can be given in terms of speed droop of their governors as,

$$R_1 = \frac{-\Delta\omega}{\Delta P_{m1}} \quad \text{and} \quad R_2 = \frac{-\Delta\omega}{\Delta P_{m2}}$$

$$\Longrightarrow \quad \Delta P_{m1} = \frac{-\Delta\omega}{R_1} \quad \text{and} \quad \Delta P_{m2} = \frac{-\Delta\omega}{R_2} \text{ ---------------------- (3)}$$

- Substituting equation (3) in (1) and (2) gives,

(1) ⇒ $\frac{-\Delta\omega}{R_1} - \Delta P_{12} = D_1 * \Delta\omega$

$$-\Delta P_{12} = \left(\frac{1}{R_1} + D_1\right) * \Delta\omega \text{ ------------------------- (4)}$$

(2) ⇒ $\left(\frac{-\Delta\omega}{R_2} - \Delta P_{L2} + \Delta P_{12}\right) = D_2 * \Delta\omega$

$$\Delta P_{12} - \Delta P_{L2} = \left(\frac{1}{R_2} + D_2\right) * \Delta\omega \text{ ---------------------------- (5)}$$

TIE-LINE CONTROL WITH PRIMARY SPEED CONTROL: (TIE-LINE MODELLING)

- Substituting equation (4) in (5),

$$-\left(\frac{1}{R_1} + D_1\right) * \Delta\omega - \Delta P_{L2} = \left(\frac{1}{R_2} + D_2\right) * \Delta\omega$$

$$-\Delta P_{L2} = \left(\frac{1}{R_1} + D_1 + \frac{1}{R_2} + D_2\right) * \Delta\omega$$

∴ Steady state frequency deviation $\Delta\omega = \frac{-\Delta P_{L2}}{\left(\frac{1}{R_1}+D_1+\frac{1}{R_2}+D_2\right)} = \frac{-\Delta P_{L2}}{(\beta_1+\beta_2)}$ - (6)

- Substituting equation (6) in (4),

Tie-line power flow deviation $-\Delta P_{12} = \left(\frac{1}{R_1} + D_1\right) * \frac{-\Delta P_{L2}}{\left(\frac{1}{R_1}+D_1+\frac{1}{R_2}+D_2\right)}$

∴Tie-line power flow deviation $\Delta P_{12} = \frac{\Delta P_{L2} * \left(\frac{1}{R_1}+D_1\right)}{\left(\frac{1}{R_1}+D_1+\frac{1}{R_2}+D_2\right)} = \frac{\Delta P_{L2}\ \beta_1}{(\beta_1+\beta_2)} = -\Delta P_{21}$ --- (7)

- The equations (6) and (7) gives frequency deviation and tie-line power flow deviation from area 1 to area 2 respectively.

TIE-LINE CONTROL WITH PRIMARY SPEED CONTROL: (TIE-LINE MODELLING)

CHANGE OF LOAD IN BOTH AREAS:

- Let us consider a simultaneous change in load demand in both areas 1 and 2.
- Upon the change in load demand in areas, the system reaches a steady-state with a frequency deviation.
- Both areas 1 and 2 have the same steady-state frequency deviation.
- i.e., $\Delta\omega = \Delta\omega_1 = \Delta\omega_2$ or $\Delta f = \Delta f_1 = \Delta f_2$
- Let us assume the reference power settings of areas 1 and 2 are constant. i.e., $\Delta P_{ref1} = \Delta P_{ref2} = 0$

TIE-LINE CONTROL WITH PRIMARY SPEED CONTROL: (TIE-LINE MODELLING)

- **The power balance equation in area 1 is given by,**

$$(\Delta P_{m1} - \Delta P_{L1} - \Delta P_{12}) * \left(\frac{1}{2H_1\, s + D_1}\right) = \Delta\omega_1$$

- **At steady state s → 0,** $(\Delta P_{m1} - \Delta P_{L1} - \Delta P_{12}) * \left(\frac{1}{D_1}\right) = \Delta\omega \ (\because \Delta\omega = \Delta\omega_1)$

$$\Delta P_{m1} - \Delta P_{L1} - \Delta P_{12} = D_1 * \Delta\omega \text{ ---------------------------- (1)}$$

- **Similarly, the power balance equation in area 2 is given by,**

$$(\Delta P_{m2} - \Delta P_{L2} + \Delta P_{12}) * \left(\frac{1}{2H_2\, s + D_2}\right) = \Delta\omega_2$$

- **At steady state s → 0,** $(\Delta P_{m2} - \Delta P_{L2} + \Delta P_{12}) * \left(\frac{1}{D_2}\right) = \Delta\omega \ (\because \Delta\omega = \Delta\omega_2)$

$$(\Delta P_{m2} - \Delta P_{L2} + \Delta P_{12}) = D_2 * \Delta\omega \text{ ------------------- (2)}$$

TIE-LINE CONTROL WITH PRIMARY SPEED CONTROL: (TIE-LINE MODELLING)

- **The mechanical power outputs can be given in terms of speed droop of their governors as,**

$$R_1 = \frac{-\Delta\omega}{\Delta P_{m1}} \quad \text{and} \quad R_2 = \frac{-\Delta\omega}{\Delta P_{m2}}$$

$$\Longrightarrow \ \Delta P_{m1} = \frac{-\Delta\omega}{R_1} \quad \text{and} \quad \Delta P_{m2} = \frac{-\Delta\omega}{R_2} \text{ --------------------- (3)}$$

- **Substituting equation (3) in (1) and (2) gives,**

(1) ⇒ $$\frac{-\Delta\omega}{R_1} - \Delta P_{L1} - \Delta P_{12} = D_1 * \Delta\omega$$

$$-\Delta P_{12} - \Delta P_{L1} = \left(\frac{1}{R_1} + D_1\right) * \Delta\omega \text{ ------------------------ (4)}$$

(2) ⇒ $$\left(\frac{-\Delta\omega}{R_2} - \Delta P_{L2} + \Delta P_{12}\right) = D_2 * \Delta\omega$$

$$\Delta P_{12} - \Delta P_{L2} = \left(\frac{1}{R_2} + D_2\right) * \Delta\omega \text{ --------------------------- (5)}$$

TIE-LINE CONTROL WITH PRIMARY SPEED CONTROL: (TIE-LINE MODELLING)

- **Adding equations (4) and (5) gives,**

$$-\Delta P_{L1} - \Delta P_{L2} = \left(\frac{1}{R_1} + D_1 + \frac{1}{R_2} + D_2\right) * \Delta\omega$$

∴ Steady state frequency deviation $\Delta\omega = \frac{-(\Delta P_{L1} + \Delta P_{L2})}{\left(\frac{1}{R_1} + D_1 + \frac{1}{R_2} + D_2\right)} = \frac{-(\Delta P_{L1} + \Delta P_{L2})}{(\beta_1 + \beta_2)}$ **--- (6)**

- **Substituting equation (6) in (4) gives,**

$$-\Delta P_{12} - \Delta P_{L1} = \left(\frac{1}{R_1} + D_1\right) * \frac{-(\Delta P_{L1} + \Delta P_{L2})}{\left(\frac{1}{R_1} + D_1 + \frac{1}{R_2} + D_2\right)} = \frac{-(\Delta P_{L1} + \Delta P_{L2}) * \left(\frac{1}{R_1} + D_1\right)}{\left(\frac{1}{R_1} + D_1 + \frac{1}{R_2} + D_2\right)}$$

$$\Longrightarrow \ -\Delta P_{12} - \Delta P_{L1} = \frac{-(\Delta P_{L1} + \Delta P_{L2}) * \beta_1}{(\beta_1 + \beta_2)} = \frac{-\Delta P_{L1} * \beta_1}{(\beta_1 + \beta_2)} + \frac{-\Delta P_{L2} * \beta_1}{(\beta_1 + \beta_2)}$$

$$\Longrightarrow \ \Delta P_{12} = \frac{\Delta P_{L1} * \beta_1}{(\beta_1 + \beta_2)} + \frac{\Delta P_{L2} * \beta_1}{(\beta_1 + \beta_2)} - \Delta P_{L1}$$

TIE-LINE CONTROL WITH PRIMARY SPEED CONTROL: (TIE-LINE MODELLING)

$$\Longrightarrow \ \Delta P_{12} = \frac{\Delta P_{L1} * \beta_1 - \Delta P_{L1} * \beta_1 - \Delta P_{L1} * \beta_2}{(\beta_1 + \beta_2)} + \frac{\Delta P_{L2} * \beta_1}{(\beta_1 + \beta_2)}$$

$$\Longrightarrow \ \Delta P_{12} = \frac{-\Delta P_{L1} * \beta_2}{(\beta_1 + \beta_2)} + \frac{\Delta P_{L2} * \beta_1}{(\beta_1 + \beta_2)} = \frac{-\Delta P_{L1} * \beta_2 + \Delta P_{L2} * \beta_1}{(\beta_1 + \beta_2)}$$

∴ Tie-line power flow deviation $\Delta P_{12} = \frac{-\Delta P_{L1} * \beta_2 + \Delta P_{L2} * \beta_1}{(\beta_1 + \beta_2)}$ **------------ (7)**

- **The equations (6) and (7) gives frequency deviation and tie-line power flow deviation from area 1 to area 2 respectively.**

PROBLEMS:

1) A two area system connected by tie-line has the following parameters on a base of 1000 MVA. The units are operating at a nominal frequency of 50 Hz, when there is a sudden increase in load of area 1 by 150 MW. The synchronizing power coefficient T = 2 pu. Draw the block diagram of two-area system with primary speed control.

Parameters	Area 1	Area 2
Speed Regulation	0.05	0.0625
Frequency-sensitive load coefficient	0.6	0.9
Inertia Constant	5.5	5
Governor time constant	0.25 sec	0.3 sec
Turbine time constant	0.5 sec	0.5 sec

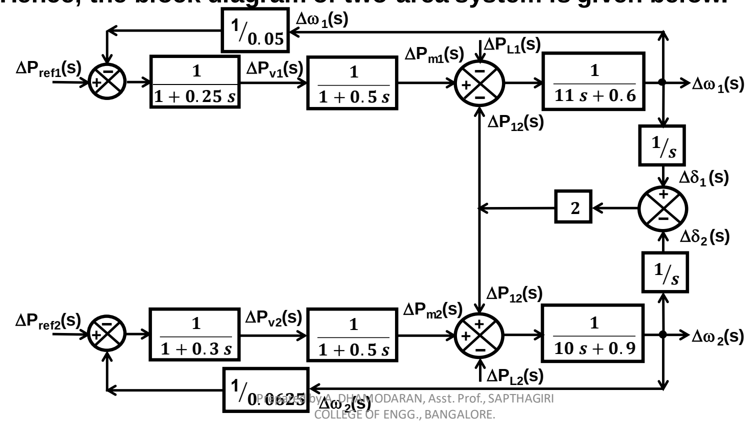
PROBLEMS:

Sol.: Given, R_1 = 0.05 pu, R_2 = 0.0625 pu, D_1 = 0.6 pu, D_2 = 0.9 pu

H_1 = 5.5 sec., H_2 = 5 sec. T_{G1} = 0.25 sec, T_{G2} = 0.3 sec

T_{TR1} = 0.5 sec, T_{TR2} = 0.5 sec. T = 2 pu

Hence, the block diagram of two-area system is given below.



PROBLEMS:

2) Two control areas are connected through a tie-line with the following characteristics.

Area 1: R_1 = 1%, D_1 = 0.8, base MVA = 500

Area 2: R_2 = 2%, D_2 = 1.0, base MVA = 500

A load increase of 100 MW occurs in area 1. What is the new steady-state frequency and the change in tie-line flow if the nominal frequency is 50 Hz? Repeat the same problem if the load change occurs in area 2.

Sol.: Let us select common base MVA = 500

Given, R_1 = 1%=0.01 pu, D_1 = 0.8 pu and R_2 = 2%=0.02 pu, D_2 = 1 pu

$\therefore$ $\beta_1 = (1/R_1) + D_1 = (1/0.01) + 0.8 = 100.8$

and $\beta_2 = (1/R_2) + D_2 = (1/0.02) + 1 = 51$

PROBLEMS:

Case (i): Given, ΔP_{L1} = +100 MW = 0.2 pu

$\therefore$ Steady state frequency deviation $\Delta\omega = \frac{-\Delta P_{L1}}{(\beta_1+\beta_2)} = \frac{-0.2}{100.8+51}$

$\Rightarrow$ $\Delta\omega = -0.001318\ pu = -0.0659\ Hz = \Delta f$

$\therefore$ Steady state frequency $f_1 = \Delta f + f_0 = -0.0659 + 50$

$\Rightarrow$ Steady state frequency f_1 = 49.9341 Hz

Change in tie-line flow $\Delta P_{12} = \frac{-\Delta P_{L1} * \beta_2}{(\beta_1+\beta_2)} = \frac{-0.2*51}{100.8+51}$

$\Rightarrow$ $\Delta P_{12} = -0.0672\ pu = -33.6\ MW$

Since, ΔP_{12} is negative, the power flows from Area 2 to Area 1 through tie-line.

Hence, there is a flow of power of 33.6 MW from Area 2 to Area 1.

PROBLEMS:

Verification:

- Let us verify the power balance in both areas 1 and 2 after the change in load demand.
- For area 1, the power balance is given by,

$$(\Delta P_{m1} - \Delta P_{L1} - \Delta P_{12}) = D_1 * \Delta\omega \text{ ------------------------ (1)}$$

- Change in power generation in area 1 $\Delta P_{m1} = \frac{-\Delta\omega}{R_1} = \frac{0.001318}{0.01}$

$\Rightarrow \Delta P_{m1} = 0.1318$ pu = 65.9 MW

- Hence, in equation (1),

LHS = $\Delta P_{m1} - \Delta P_{L1} - \Delta P_{12}$= 65.9 – 100 + 33.6 = – 0.5

RHS = $D_1 * \Delta\omega = \Delta P_{D1}$ = 0.8 * (– 0.001318)* 500 = – 0.5272

$\therefore$ LHS = RHS. Hence, the power balance is verified.

- For area 2, the power balance is given by,

$$(\Delta P_{m2} + \Delta P_{12}) = D_2 * \Delta\omega \text{ ------------------------------ (2)}$$

PROBLEMS:

- Change in power generation in area 2 $\Delta P_{m2} = \frac{-\Delta\omega}{R_2} = \frac{0.001318}{0.02}$

$\Rightarrow \Delta P_{m2} = 0.0659$ pu = 32.95 MW

- Hence, in equation (2),

LHS = $\Delta P_{m2} + \Delta P_{12}$= 32.95 – 33.6 = – 0.65

RHS = $D_2 * \Delta\omega = \Delta P_{D2}$ = 1 * (– 0.001318)* 500 = – 0.659

$\therefore$ LHS = RHS. Hence, the power balance is verified.

- Further, total change in generation $=\Delta P_{m1} + \Delta P_{m2}$ = 65.9 + 32.95

$\therefore$ Total change in generation = 98.85 MW

- Total change in load= $\Delta P_{L1} + \Delta P_{L2} + \Delta P_{D1} + \Delta P_{D2}$

$= \Delta P_{L1} + 0 + D_1 * \Delta\omega + D_2 * \Delta\omega$

= 100 + (0.8 * (– 0.001318))* 500 + (1 * (– 0.001318))* 500

PROBLEMS:

$\therefore$ Total change in Load = 98.8138 MW

- Hence, Total change in generation = Total change in load

Case (ii): Given, ΔP_{L2} = +100 MW = 0.2 pu

$\therefore$ Steady state frequency deviation $\Delta\omega = \frac{-\Delta P_{L2}}{(\beta_1+\beta_2)} = \frac{-0.2}{100.8+51}$

$$\Rightarrow \Delta\omega = -0.001318\ pu = -0.0659\ Hz = \Delta f$$

$\therefore$ Steady state frequency $f_1 = \Delta f + f_0 = -0.0659 + 50$

$\Rightarrow$ Steady state frequency f_1 = 49.9341 Hz

Change in tie-line flow $\Delta P_{12} = \frac{\Delta P_{L2} * \beta_1}{(\beta_1+\beta_2)} = \frac{0.2*100.8}{100.8+51}$

$$\Rightarrow \Delta P_{12} = 0.13281\ pu = 66.405\ MW$$

Since, ΔP_{12} is positive, the power flows from Area 1 to Area 2 through tie-line.

Hence, there is a flow of power of 66.405 MW from Area 1 to Area 2.

TIE-LINE BIAS CONTROL (FREQUENCY BIAS):

- In an interconnected system, with only a primary loop, an increase of load in any area is met by
  - (i) an increase of generation in both areas.
  - (ii) an associated change in tie-line power and
  - (iii) a reduction in frequency.
- Supplementary controls are provided to restore the balance between generation and load of each area and restore the frequency to a nominal value.
- These supplementary controls are carried out as tie-line bias controls or frequency bias controls.
- In general, there are three modes of operation of interconnected systems can be carried out.

TIE-LINE BIAS CONTROL (FREQUENCY BIAS):

Mode 1) FLAT FREQUENCY MODE:

- In this mode, the control is executed to obtain only a constant frequency but not tie-line power flow.
- Hence, in this mode of operation, the interconnected system responds to only for frequency changes and not for tie-line power flow, then it cannot have control over the power flow through tie-lines.

Mode 2) FLAT TIE-LINE MODE:

- In this mode, the control is executed to maintain the scheduled tie-line interchanges by changing the power generations in each area.
- Hence, in this mode of operation, the interconnected system responds to only for tie-line power changes and not for frequency changes.

TIE-LINE BIAS CONTROL (FREQUENCY BIAS):

Mode 3) FREQUENCY BIAS CONTROL MODE:

- It is a combined control of one of the areas in an interconnected system which responds to both tie-line power changes and frequency changes.

- In an isolated system, an addition of an integral controller stabilizes the frequency deviation to zero.
- But for an interconnected system, the supplementary control should also regulate the tie-line deviation in addition to frequency deviation.

TIE-LINE BIAS CONTROL (FREQUENCY BIAS):

- Hence, to develop such a control, the following points are to be noted in an interconnected system.

(i) If there is a decrease in frequency and an increase in net interchange of power leaving the control area, then the increase in load will be outside the control area.

(ii) If there is a decrease in frequency and a decrease in net interchange of power leaving the control area, then the increase in load will be inside the control area.

(iii) If there is an increase in frequency and an increase in net interchange of power leaving the control area, then the decrease in load will be inside the control area.

(iv) If there is an increase in frequency and a decrease in net interchange of power leaving the control area, then the decrease in load will be outside the control area.

TIE-LINE BIAS CONTROL (FREQUENCY BIAS):

- At any point of time, $\Delta P_{12} = P_{12} - (P_{12})_{sch}$

Where, P_{12} is the actual power flow from area 1 to area 2.

$(P_{12})_{sch}$ is the scheduled interchange of power from area 1 to area 2.

- Hence, the summary of control actions can be listed as follows.

$\Delta\omega$	ΔP_{12}	Load Change	Control action
–	+	$\Delta P_{L1} = 0$ $\Delta P_{L2} = +ve$	Increase P_{G2}
–	–	$\Delta P_{L1} = +ve$ $\Delta P_{L2} = 0$	Increase P_{G1}
+	+	$\Delta P_{L1} = -ve$ $\Delta P_{L2} = 0$	Decrease P_{G1}
+	–	$\Delta P_{L1} = 0$ $\Delta P_{L2} = -ve$	Decrease P_{G2}

TIE-LINE BIAS CONTROL (FREQUENCY BIAS):

- A control signal will be made up of tie-line flow deviation added to frequency deviation weighted by a bias factor.
- This control signal can achieve the desired objective of restoring frequency to a nominal value and holding the tie-line power flow at the scheduled value.
- This control signal is called as **Area Control Error (ACE)** and is defined as follows.

For area 1; $ACE_1 = \Delta P_{12} + \beta_1 * \Delta\omega$ MW -------------------- (1)

For area 2; $ACE_2 = \Delta P_{21} + \beta_2 * \Delta\omega$ MW -------------------- (2)

Where, $\beta_1 = \frac{1}{R_1} + D_1$ and $\beta_2 = \frac{1}{R_2} + D_2$ MW/Hz or MW/0.1Hz

- This control signal ACE actuates changes in reference power set points.

TIE-LINE BIAS CONTROL (FREQUENCY BIAS):

- When the steady state is reached, the tie-line deviations ΔP_{12} and frequency deviations $\Delta\omega$ will be zero.
- An alternate expression commonly used for ACE is,

$ACE_i = (P_i - P_{i,sch}) - 10\,\beta_i\,(f_i - f_{i,sch})$ MW

Where, ACE_i is the Area Control Error of area i.

P_i is the net actual tie-line power interchange from area 'i' in MW.

$P_{i,sch}$ is the scheduled tie-line power interchange of area 'i' in MW.

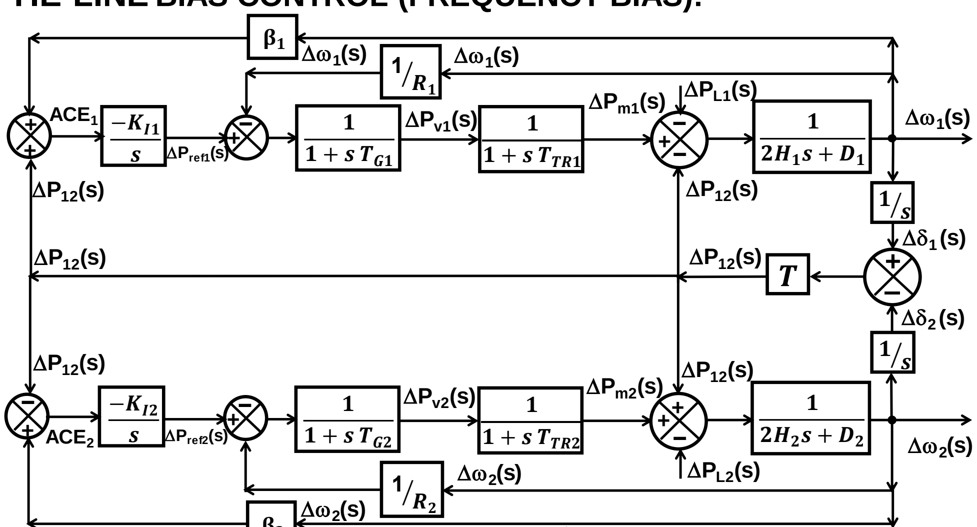
β_i is the area frequency bias in MW/0.1 Hz.

f_i is the actual frequency of area 'i' in Hz.

$f_{i,sch}$ is the scheduled frequency of area 'i' in Hz.

- Hence, the block diagram of simple AGC for a two-area system is shown below.

TIE-LINE BIAS CONTROL (FREQUENCY BIAS):



CHOICE OF BIAS FACTORS:

- The control signals ACE for both areas in a two-area interconnected system are given by,

$ACE_1 = \Delta P_{12} + B_1\,\Delta\omega = 0$ and $ACE_2 = \Delta P_{21} + B_2\,\Delta\omega = 0$

- Under steady state, the tie-line interchanges ΔP_{12} & $\Delta P_{21} = 0$ and frequency deviations, $\Delta f = \Delta\omega = 0$, irrespective of the bias factors B_1 and B_2.
- However, the choice of bias factors will affect the dynamic performance.
- Let us assume a **sudden change in load in area 1**.
- Then, the frequency deviation and tie-line flow deviation in the interconnected system are given by respectively,

$$\Delta\omega = \frac{-\Delta P_{L1}}{\beta_1+\beta_2} \quad \text{and} \quad \Delta P_{12} = \frac{-\Delta P_{L1} * \beta_2}{\beta_1+\beta_2}$$

CHOICE OF BIAS FACTORS:

- Hence, the control signals ACE_1 and ACE_2 for both areas in a two-area interconnected system are given by, ($B_1 = \beta_1$ and $B_2 = \beta_2$)

$$ACE_1 = \Delta P_{12} + B_1\,\Delta\omega = \Delta P_{12} + \beta_1\,\Delta\omega$$
$$= \frac{-\Delta P_{L1}*\beta_2}{\beta_1+\beta_2} + \beta_1\left(\frac{-\Delta P_{L1}}{\beta_1+\beta_2}\right) = \frac{-\Delta P_{L1}(\beta_2+\beta_1)}{\beta_1+\beta_2} = -\Delta P_{L1} \quad \text{and}$$
$$ACE_2 = \Delta P_{21} + B_2\,\Delta\omega = \Delta P_{21} + \beta_2\,\Delta\omega$$
$$= \frac{\Delta P_{L1}*\beta_2}{\beta_1+\beta_2} + \beta_2\left(\frac{-\Delta P_{L1}}{\beta_1+\beta_2}\right) = \frac{\Delta P_{L1}(\beta_2-\beta_2)}{\beta_1+\beta_2} = 0$$

- Thus, only the supplementary control in area 1 will change the load reference point to meet the change in load in area 1.
- The supplementary control of area 2 will not be affected.
- When the bias factors B_1 and B_2 are chosen greater than the corresponding frequency bias factors β_1 and β_2, then the area 2 will pick up generation to correct the frequency deviation.

CHOICE OF BIAS FACTORS:

- However, this would be withdrawn in the steady state.
- But a very high value of bias factors B_1 and B_2 would cause controller instability.
- When the bias factors B_1 and B_2 are chosen much less than the corresponding frequency bias factors β_1 and β_2, then the supplementary control of area 2 will withdraw the generation picked up by the primary speed control.
- But, this would be harmful for frequency recovery.

CHOICE OF BIAS FACTORS:

- Under normal conditions, if each area has enough generation capacity, then the action of AGC in steady state is confined only to the area, where, change in generation/load occurs.
- The tie-line power interchanges are maintained at scheduled values and frequency is maintained constant.
- Under abnormal conditions, if enough generation is not available, then based on AGC signal, the other areas will change the generation levels to meet the generation – load mismatch.
- The frequency and tie-line power interchanges will deviate from scheduled values.
- The participation of each area in frequency regulation is proportional to its available generation capacity.

CHOICE OF BIAS FACTORS:

- If the control signals ACEs of all areas are zero, then the frequency of the system is equal to the scheduled frequency and all tie-line power interchanges are at their scheduled values.

PROBLEMS:

3) Consider two control areas of 50 Hz as interconnected systems. The connected load is 15000 MW in area 1 and 30000 MW in area 2. The generations are 14000 MW and 31000 MW respectively. For both areas D = 1 pu and R = 5%. Area 1 has a spinning reserve of 1000 MW spread over a generation of 5000 MW capacity and area 2 has a spinning reserve of 1000 MW spread over a generation of 10000 MW. Determine the steady state frequency, generation and load of each area and tie-line power flow for the loss of load of 1000 MW in area 1 with no supplementary control.

PROBLEMS:

Sol.: Given that f_0 = 50 Hz. P_{L1} = 15000 MW P_{L2} = 30000 MW

P_{G1} = 14000 MW P_{G2} = 31000 MW $D_1 = D_2$ = 1 pu

$R_1 = R_2$ = 5% SR_1 = 1000 MW SR_2 = 1000 MW

ΔP_{L1} = – 1000 MW

Total generation capacity in Area 1 = $(P_{G1})_{capacity} = P_{G1} + SR_1$

= 14000+1000 = 15000 MW

Total generation capacity in Area 2 = $(P_{G2})_{capacity} = P_{G2} + SR_2$

= 31000+1000 = 32000 MW

Total generation capacity of the system = $(P_{G1})_{capacity}$+ $(P_{G2})_{capacity}$

= 15000 + 32000 = 47000 MW

The base power is taken as the respective area generation capacity and let the base frequency be 50 Hz.

PROBLEMS:

∴ R_1 = 0.05 pu = 0.05 * (50 / 15000) Hz / MW = $1.6667*10^{-4}$ Hz / MW

R_2 = 0.05 pu = 0.05 * (50 / 32000) Hz / MW = $0.78125*10^{-4}$ Hz / MW

Total load on area 1 after change = 15000 – 1000 = 14000 MW

Total load on area 2 = 30000 MW

∴ Base power for load damping constant in area 1 = 14000 MW.

and base power for load damping constant in area 2 = 30000 MW

∴ D_1 = 1 pu = 1 * (14000 / 50) = 280 MW / Hz

D_2 = 1 pu = 1 * (30000 / 50) = 600 MW / Hz

∴ Steady state frequency deviation $\Delta\omega = \frac{-\Delta P_{L1}}{\left(\frac{1}{R_1}+D_1+\frac{1}{R_2}+D_2\right)}$

$$\Rightarrow \quad \Delta\omega = \frac{1000}{\frac{1}{1.6667*10^{-4}}+280+\frac{1}{0.78125*10^{-4}}+600} = 0.050813\ Hz$$

∴ Steady state frequency $f_1 = f_0 + \Delta f$ = 50 + 0.050813 Hz = 50.0508 Hz

PROBLEMS:

∴ Change in power generations in areas 1 and 2 are,

$$\Delta P_{m1} = \Delta P_{G1} = \frac{-\Delta f}{R_1} = \frac{-0.050813}{1.6667*10^{-4}} = -304.8719\ MW$$

$$\Delta P_{m2} = \Delta P_{G2} = \frac{-\Delta f}{R_2} = \frac{-0.050813}{0.78125*10^{-4}} = -650.4064\ MW$$

∴ Change in frequency dependent loads in areas 1 and 2 are,

$\Delta P_{D1} = D_1 * \Delta f$ = 280 * 0.050813 = 14.22764 MW

$\Delta P_{D2} = D_2 * \Delta f$ = 600 * 0.050813 = 30.4878 MW

∴ The new generation and load in two areas are as follows.

<u>Area 1:</u> New Generation $P_{G1}' = P_{G1} + \Delta P_{G1}$

= 14000 – 304.8719 = 13695.1281 MW

New Load $P_{L1}' = P_{L1} + \Delta P_{L1} + \Delta P_{D1}$ = 15000 – 1000 + 14.22764

= 14014.22764 MW

PROBLEMS:

<u>Area 2:</u> New Generation $P_{G2}' = P_{G2} + \Delta P_{G2}$

= 31000 – 650.4064 = 30349.5936 MW

New Load $P_{L2}' = P_{L2} + \Delta P_{L2} + \Delta P_{D2}$ = 30000 + 0 + 30.4878

= 30030.4878 MW

∴ Power balance in Area 1 = $P_{G1}' - P_{L1}'$ = 13695.1281 – 14014.22764

= – 319.09954 MW

Power balance in Area 2 = $P_{G2}' - P_{L2}'$ = 30349.5936 – 30030.4878

= 319.1058 MW

Hence, the deficit in generation in Area 1 will be met by excess in generation in Area 2 through the tie-line power flow from Area 2 to Area 1.

∴ ΔP_{21} = 319.1058 MW

PROBLEMS:

4) Consider two control areas of 50 Hz as interconnected systems. The connected load is 15000 MW in area 1 and 30000 MW in area 2. The generations are 14000 MW and 31000 MW respectively. For both areas D = 1 pu and R = 5%. Area 1 has a spinning reserve of 1000 MW spread over a generation of 5000 MW capacity and area 2 has a spinning reserve of 1000 MW spread over a generation of 10000 MW. The generation carrying spinning reserve is on supplementary control with bias factor setting of 250 MW/0.1Hz for area 1 and 500 MW/0.1Hz for area 2. Evaluate the steady state frequency, generation and load of each area and tie-line power flow for the following contingencies.

PROBLEMS:

(i) Loss of 1000 MW load in area 1.

(ii) Loss of 500 MW generation with part of spinning reserve in area 1

(iii) Loss of 1500 MW generation not carrying spinning reserve in area 1.

(iv) Tripping off the tie-line without change to the interchange of power schedule of the supplementary control.

(v) Tripping off the tie-line with interchange schedule changed to zero.

Sol.: Given that f_0 = 50 Hz. P_{L1} = 15000 MW P_{L2} = 30000 MW

P_{G1} = 14000 MW P_{G2} = 31000 MW $D_1 = D_2$ = 1 pu

$R_1 = R_2$ = 5% SR_1 = 1000 MW SR_2 = 1000 MW

PROBLEMS:

(i) Loss of 1000 MW load in area 1:

Given that the area 1 has a spinning reserve of 1000 MW spread over a generation of 5000 MW capacity.

Hence, the area 1 has a generation capacity of 5000 MW on supplementary control. (Generation of 4000 MW + Spinning reserve of 1000 MW).

With the loss of 1000 MW in area 1, the supplementary control will act to bring ACE_1 to zero. Similarly, the supplementary control in area 2 will bring ACE_2 to zero.

$ACE_1 = \Delta P_{12} + B_1 \Delta f = 0$ $\quad ACE_2 = \Delta P_{21} + B_2 \Delta f = -\Delta P_{12} + B_2 \Delta f = 0$

$\therefore \Delta P_{12} = 0$ and $\Delta f = 0$

Hence, there is no steady state deviation in frequency or tie-line power flow.

PROBLEMS:

(ii) Loss of 500 MW generation with part of spinning reserve in area 1:

Given that the area 1 has a spinning reserve of 1000 MW spread over a generation of 5000 MW capacity.

Hence, the area 1 has a generation capacity of 5000 MW on supplementary control. (Generation of 4000 MW + Spinning reserve of 1000 MW).

For the loss of 500 MW generation in the part of spinning reserve in area 1, %age loss of generation = (500/4000)*100 = 12.5%

Assuming in proportion,

the loss of spinning reserve= 12.5% * 1000 MW = 125 MW.

$\therefore$ Available spinning reserve = 1000 – 125 = 875 MW.

Hence, the loss of 500 MW generation can leave the available spinning reserve to 875 MW which results in no change in tie-line flow and system frequency.

PROBLEMS:

(iii) Loss of 1500 MW generation not carrying spinning reserve in area 1:

- Since, the spinning reserve is 1000 MW in area 1, the loss of 1000 MW can be made up.
- Beyond this, the area 1 can no longer control ACE, i.e., supplementary control of Area 1 will not act.
- But the supplementary control of area 2 will control ACE_2.

Given that, frequency bias factor of area 1, $B_1 = 250$ MW/0.1Hz

$\therefore B_1 = 2500$ MW/Hz

The frequency bias factor of area 2, $B_2 = 500$ MW/0.1 Hz

$\therefore B_2 = 5000$ MW/Hz

Let the base power be power rating of respective area and base frequency be 50 Hz.

PROBLEMS:

(iii) Loss of 1500 MW generation not carrying spinning reserve in area 1:

Load base power for area 1 = P_{L1} = 15000 MW and

for area 2 = P_{L2} = 30000 MW

$\therefore$ Damping constant $D_1 = 1 *(15000/50) = 300$ MW/Hz

Damping constant $D_2 = 1* (30000/50) = 600$ MW/Hz

Since, the total loss of generation is 1500 MW and spinning reserve is 1000 MW, the net change in generation = $\Delta P_{G1} = -1500 + 1000$

$= -500$ MW $\quad \therefore \Delta P_{m1} = \Delta P_{G1} = -500$ MW.

Supplementary control in area 2, $ACE_2 = \Delta P_{21} + B_2\, \Delta f = -\Delta P_{12} + B_2\, \Delta f = 0$

$\Rightarrow -\Delta P_{12} + 5000 * \Delta f = 0 \qquad \Rightarrow \Delta P_{12} = 5000\, \Delta f$ ---------------- (1)

The power balance in area 1 is, $\quad \Delta P_{m1} - \Delta P_{L1} - \Delta P_{12} = D_1 * \Delta f$

$\Rightarrow -500 - 0 - 5000\, \Delta f = 300\, \Delta f$ ($\because$ From (1)) $\qquad \Rightarrow \Delta f = -0.09434$ Hz

PROBLEMS:

(iii) Loss of 1500 MW generation not carrying spinning reserve in area 1:

$\therefore$ Steady state frequency $f_1 = \Delta f + f_0 = -0.09434 + 50 = 49.90566$ Hz

$\therefore$ From (1), Tie-line power flow $\Delta P_{12} = 5000\, \Delta f$

$= 5000 * (-0.09434) = -471.17$ MW

To maintain the power balance in area 2,

$\Delta P_{m2} - \Delta P_{L2} + \Delta P_{12} = D_2 * \Delta f$

$\Rightarrow \Delta P_{G2} - 0 - 471.17 = 600 * (-0.09434) \qquad \Rightarrow \Delta P_{G2} = 415.096$ MW

Change in frequency dependent loads in areas 1 and 2 are,

$\Delta P_{D1} = D_1 * \Delta f = 300 * (-0.09434) = -28.302$ MW

$\Delta P_{D2} = D_2 * \Delta f = 600 * (-0.09434) = -56.604$ MW

$\therefore$ The new generation and load in two areas are as follows.

PROBLEMS:

(iii) Loss of 1500 MW generation not carrying spinning reserve in area 1:

Area 1: New Generation $P_{G1}' = P_{G1} + \Delta P_{G1}$

$= 14000 - 500 = 13500$ MW

New Load $P_{L1}' = P_{L1} + \Delta P_{L1} + \Delta P_{D1} = 15000 + 0 - 28.302$

$= 14971.698$ MW

Area 2: New Generation $P_{G2}' = P_{G2} + \Delta P_{G2}$

$= 31000 + 415.096 = 31415.096$ MW

New Load $P_{L2}' = P_{L2} + \Delta P_{L2} + \Delta P_{D2} = 30000 + 0 - 56.604$

$= 29943.396$ MW

$\therefore$ Power balance in Area 1 = $P_{G1}' - P_{L1}' = 13500 - 14971.698$

$= -1471.698$ MW

Power balance in Area 2 = $P_{G2}' - P_{L2}' = 31415.096 - 29943.396$

$= 1471.7$ MW

PROBLEMS:

(iii) Loss of 1500 MW generation not carrying spinning reserve in area 1:

Hence, the deficit in generation in Area 1 will be met by excess in generation in Area 2 through the tie-line power flow from Area 2 to Area 1.

$\therefore \Delta P_{21} = 1471.7$ MW

(iv) Tripping off tie-line with no change in interchange schedule:

Given, that $P_{L1} = 15000$ MW $\quad P_{L2} = 30000$ MW

$P_{G1} = 14000$ MW $\quad P_{G2} = 31000$ MW

Hence, the power balance in area 1 = $P_{G1} - P_{L1}$

$= 14000 - 15000 = -1000$ MW

and in area 2 = $P_{G2} - P_{L2} = 31000 - 30000 = 1000$ MW

$\therefore$ Tie-line interchange schedule $\Delta P_{21} = -\Delta P_{12} = 1000$ MW

PROBLEMS:

(iv) Tripping off tie-line with no change in interchange schedule:

When the tie-line is tripped, both areas 1 and 2 becomes isolated and can no longer interconnected.

The supplementary control in area 1, $ACE_1 = \Delta P_{12} + B_1 * \Delta f_1 = 0$

(Frequency bias factors considered to be negative for isolated areas)

$\Rightarrow -1000 - 2500 * \Delta f_1 = 0 \qquad \Rightarrow \Delta f_1 = -0.4$ Hz

$\therefore$ Steady state frequency $f_1 = \Delta f + f_0 = -0.4 + 50 = 49.6$ Hz

Frequency dependent load in area 1, $\quad \Delta P_{D1} = D_1 * \Delta f_1$

$\Delta P_{D1} = 300 * (-0.4) = -120$ MW

Similarly, the supplementary control in area 2 is,

$ACE_2 = \Delta P_{21} + B_2 * \Delta f_2 = 0$

$\Rightarrow 1000 - 5000 * \Delta f_2 = 0 \qquad \Rightarrow \Delta f_2 = 0.2$ Hz

PROBLEMS:

(iv) Tripping off tie-line with no change in interchange schedule:

$\therefore$ Steady state frequency $f_2 = \Delta f + f_0 = 0.2 + 50 = 50.2$ Hz

Frequency dependent load in area 2, $\quad \Delta P_{D2} = D_2 * \Delta f_2$

$\Delta P_{D2} = 600 * 0.2 = 120$ MW

The new generations and loads in both areas are as follows.

<u>Area 1:</u> New Load $P_{L1}' = P_{L1} + \Delta P_{L1} + \Delta P_{D1} = 15000 + 0 - 120$

$= 14880$ MW

To match with the load, the new generation $P_{G1}' = P_{L1}' = 14880$ MW

(Generation = 14000 MW and spinning reserve = 880 MW)

<u>Area 2:</u> New Load $P_{L2}' = P_{L2} + \Delta P_{L2} + \Delta P_{D2} = 30000 + 0 + 120$

$= 30120$ MW

To match with the load, the new generation $P_{G2}' = P_{L2}' = 30120$ MW

(Generation will be dropped by 880 MW)

PROBLEMS:

(v) Tripping off tie-line with interchange schedule set to zero:

- With interchange schedule set to zero, the area 1 will pick up generation of 1000 MW from its spinning reserve, to make up for the loss of tie-line power from area 2.

  $P_{G1} = 14000$ MW $\quad SR_1 = 1000$ MW $\quad P_{L1} = 15000$ MW

  Net generation = $P_{G1} + SR_1 = 14000 + 1000 = 15000$ MW

- Similarly, the area 2 will drop a generation of 1000 MW to make up loss of tie-line power to area 1.

  $P_{G2} = 31000$ MW $\quad SR_2 = 1000$ MW $\quad P_{L2} = 30000$ MW

  Required change in generation = -1000 MW

  $\therefore$ Net generation = $31000 - 1000 = 30000$ MW

- The generation in each area will be equal to the load and frequencies in each area will be 50 Hz.

PROBLEMS:

5) The data of a two-area system will be as follows.

Area 1: $P_{G1} = P_{L1} = 1000$ MW, $R_1 = 0.015$ Hz/MW, $D_1 = 0$

Area 2: $P_{G2} = P_{L2} = 1000$ MW, $R_2 = 0.0015$ Hz/MW, $D_2 = 0$

An increase of load of 10 MW takes place in area 1. Determine the change in frequency, ACE and appropriate control action.

Sol.: Since, both areas are interconnected, $\Delta\omega_1 = \Delta\omega_2 = \Delta\omega$

Given, $\Delta P_{L1} = 10$ MW $\therefore$ Frequency deviation $\Delta\omega = \frac{-\Delta P_{L1}}{(\beta_1+\beta_2)}$

For area 1, $\beta_1 = (1/R_1) + D_1 = (1/0.015) + 0 = 66.6667$ MW/Hz

For area 2, $\beta_2 = (1/R_2) + D_2 = (1/0.0015) + 0 = 666.6667$ MW/Hz

$$\therefore \Delta\omega = \frac{-\Delta P_{L1}}{(\beta_1+\beta_2)} = \frac{-10}{(66.6667+666.6667)} = -0.01364\ Hz$$

Change in power generations in both areas are as follows.

PROBLEMS:

For area 1: $\Delta P_{G1} = \frac{-\Delta f}{R_1} = \frac{0.01364}{0.015} = 0.9093\ MW$

For area 2: $\Delta P_{G2} = \frac{-\Delta f}{R_2} = \frac{0.01364}{0.0015} = 9.093\ MW$

$\therefore$ Tie-line power flow deviation $\Delta P_{12} = \frac{-\Delta P_{L1} * \beta_2}{(\beta_1+\beta_2)}$

$$\Delta P_{12} = \frac{-10 * 666.6667}{(66.6667+666.6667)} = -9.0909\ MW$$

The supplementary control signals are,

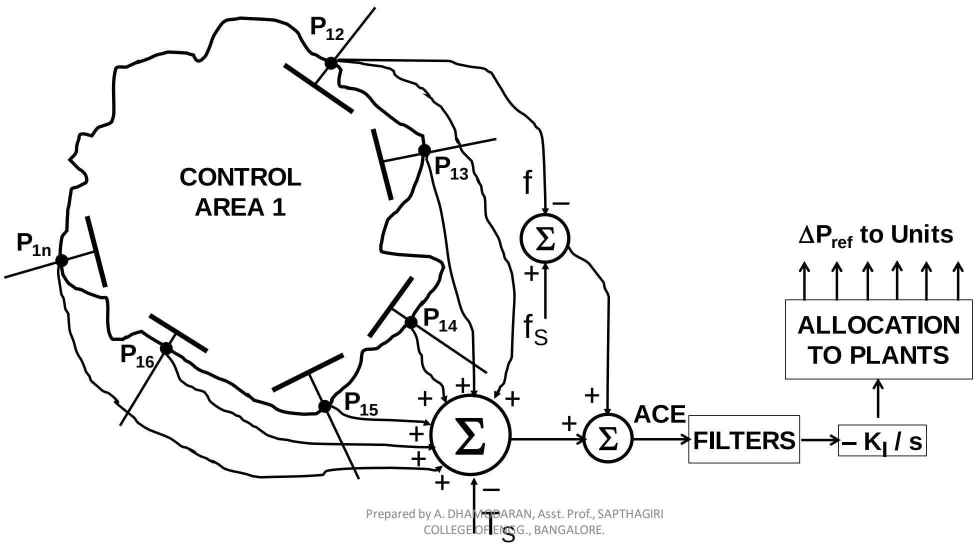
$ACE_1 = \Delta P_{12} + \beta_1 \Delta\omega = -9.0909 + 66.6667 * (-0.01364) = -10$ MW

$ACE_2 = \Delta P_{21} + \beta_2 \Delta\omega = 9.0909 + 666.6667 * (-0.01364) = 0$ MW

Hence, the load reference power set point of area 1 should be – (–10) = 10 MW and increase the generation by 10 MW in area 1 to meet the increased load demand.

No control action to be taken in control area 2 as $ACE_2 = 0$.

IMPLEMENTATION OF AGC:



IMPLEMENTATION OF AGC:

- The implementation of AGC can be achieved as shown in block diagram.
- The frequency of the system is constantly monitored along with the net interchange.
- The ACE signal is filtered and used to determine the reference power setting ΔP_{ref} for all units on AGC.
- If the ACE signal is < 0, then the generation in that area is to be increased.
- If the ACE signal is > 0, then the generation in that area is to be decreased.

THANK YOU