

21EE72: POWER SYSTEM OPERATION & CONTROL

MODULE –3: Automatic Generation Control in Interconnected Power system:



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CONTENTS

- **Module-3: Automatic Generation Control in Interconnected Power system:**

TOPIC OF DISCUSSION:MODULE- 3

Automatic Generation Control in Interconnected Power system:

- Introduction
- Tie – Line Control with Primary speed Control
- Frequency Bias Tie - Line Control
- State-Space Models

INTRODUCTION

- **Basic Generator Control Loops:**
 - AVR → Excitation Control &
 - ALFC → Speed Control
- **AGC → Frequency Deviation (Δf)**
- **Interconnected Systems:**
- **AGC has to take into account tie line flows**

OBJECTIVE: LOAD FREQUENCY CONTROL OF INTERCONNECTED SYSTEMS

INTRODUCTION

- **ISOLATED SYSTEM:**

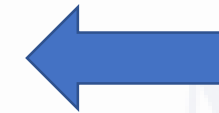
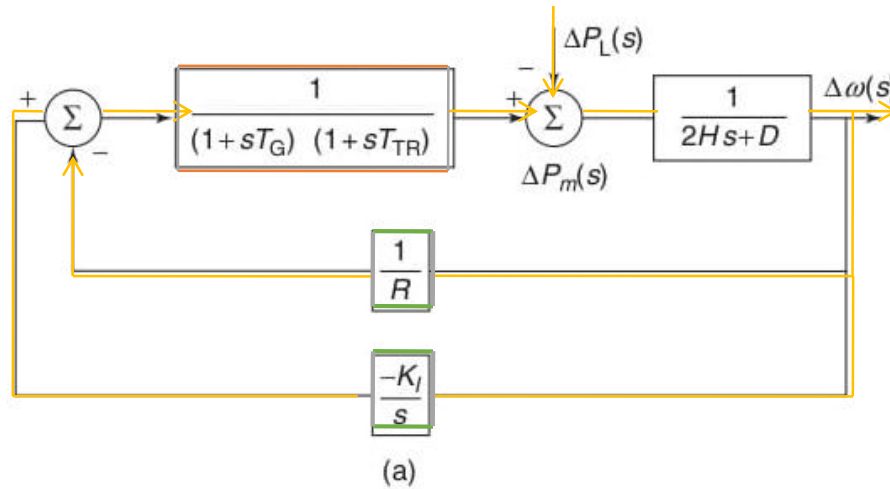
With Primary Speed Control, any change in system load will lead to frequency deviation depending on the

1. **Droop of the governor droop characteristics**
2. **Frequency dependence of the load**

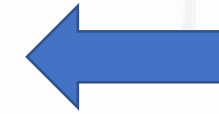
INTRODUCTION

- To restore the frequency to the nominal value, we need **supplementary control** which changes the load reference set point.

PROPORTIONAL INTEGRAL CONTROLLER

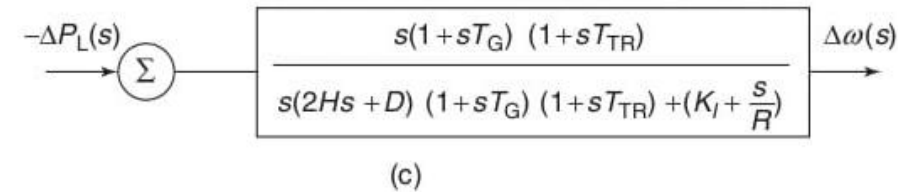
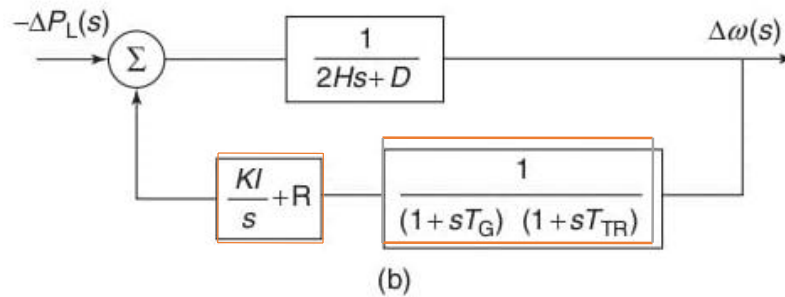


Primary Control



Supplementary Control

we can see that $\lim_{s \rightarrow 0} (s\Delta\omega(s)) = 0$.

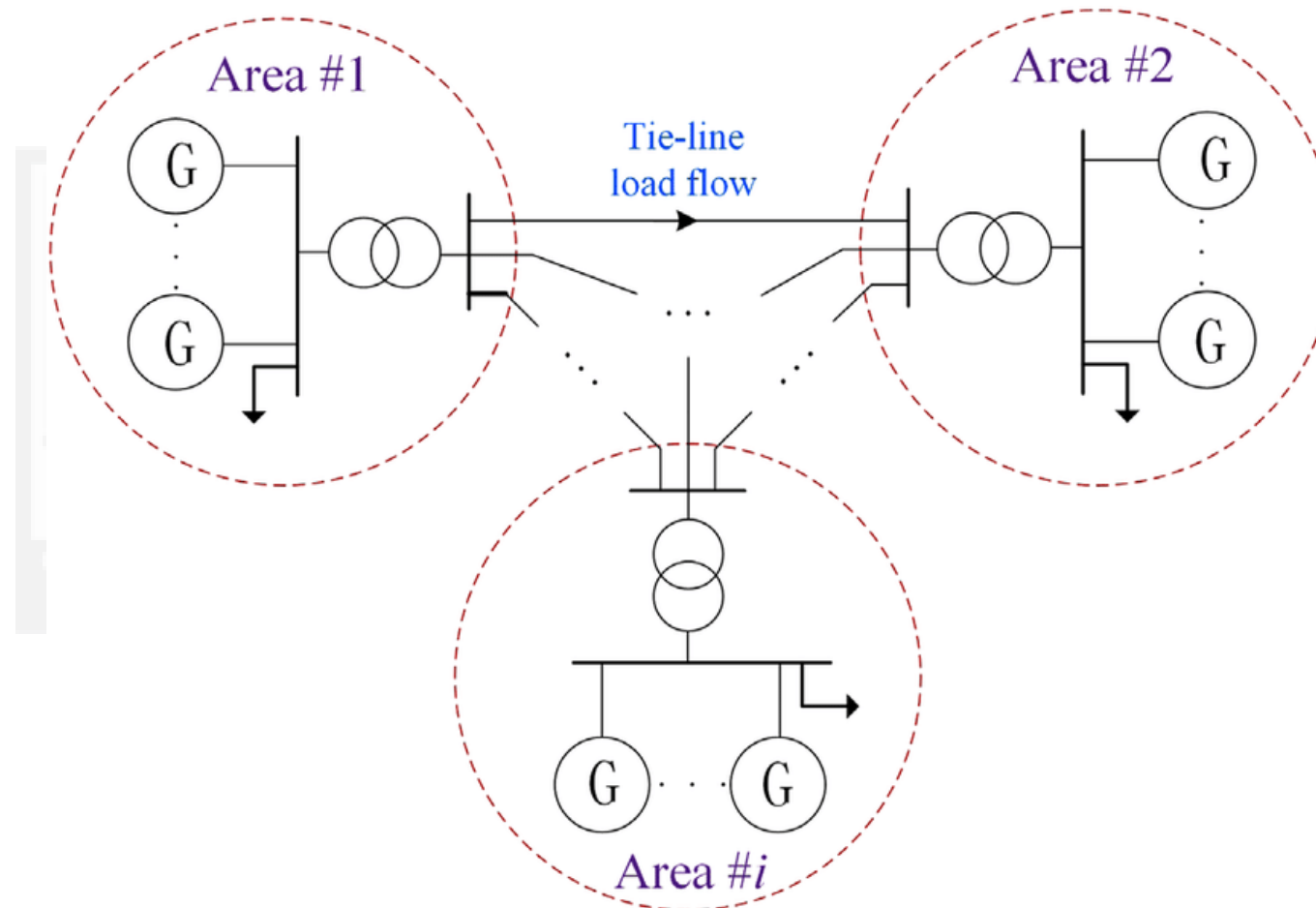


$$\Delta\omega(s) = \frac{-\Delta P_L(s)}{T(s)} \text{ for a step change in load.}$$

- **With different control areas connected, Role of AGC:**

1. Hold the system frequency to the nominal value of 50Hz
2. Maintain correct value of power interchange between the control areas
3. Maintain generation of each unit at an economical value

MULTI AREA SYSTEM: TIE LINE CONTROL



MULTI AREA SYSTEM: TIE LINE CONTROL

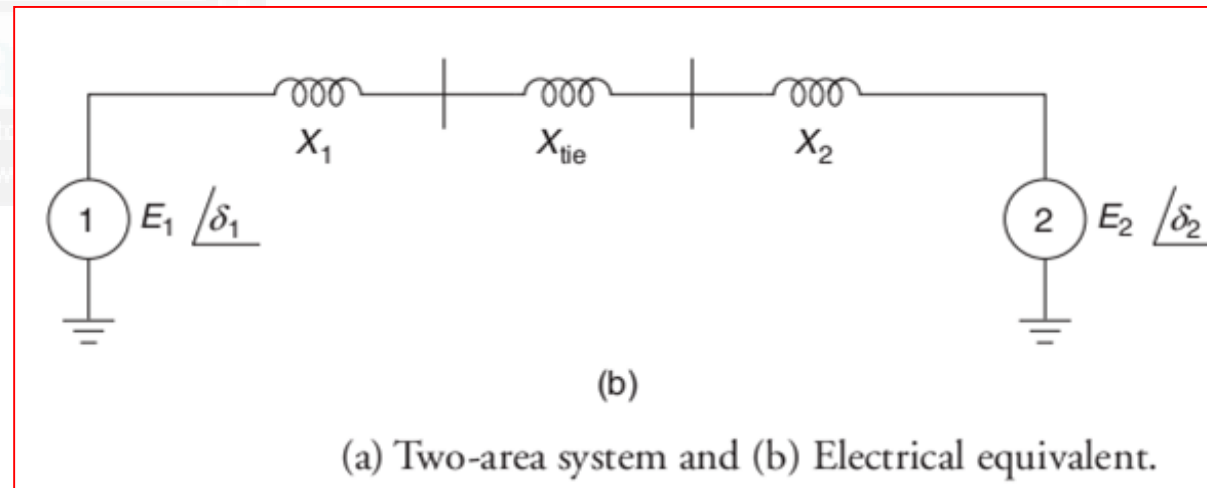
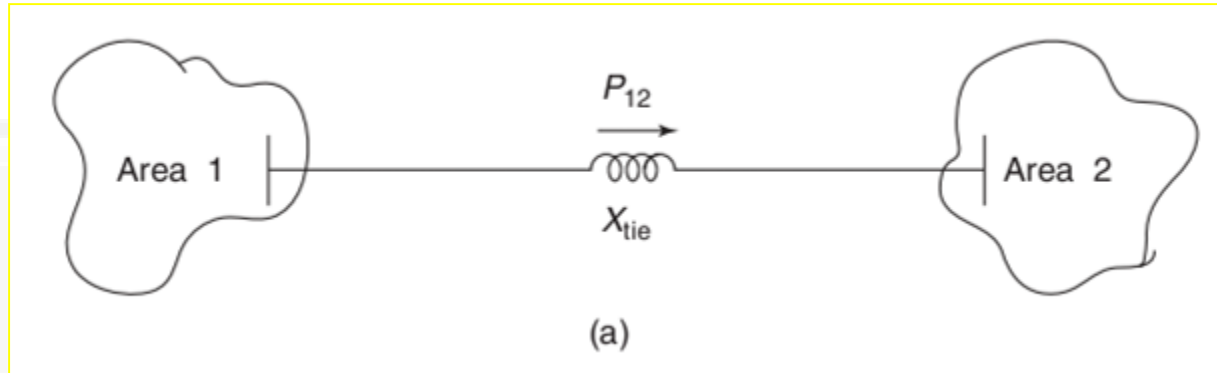
TIE-LINE With Primary Speed Control

Consider Two area system:

1. Let Positive Power Flow from Area 1 to Area 2 be P_{12}
2. Power Flow from Area 1 to Area 2 is:

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

TIE-LINE With Primary Speed Control



TIE-LINE With Primary Speed Control

Power Flow from Area 1 to Area 2 is:

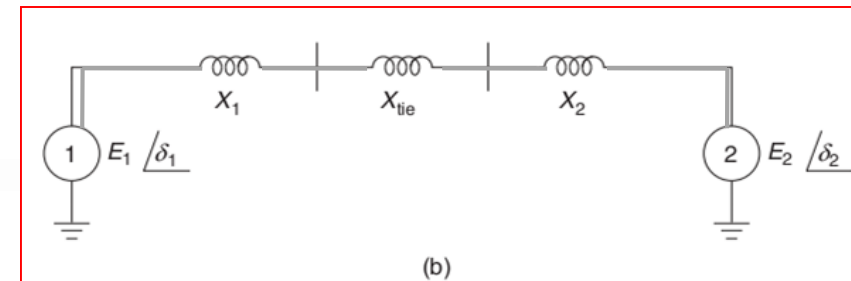
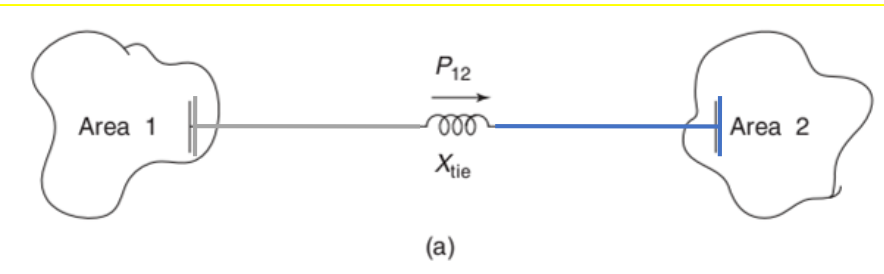
$$P_{12} = \frac{E_1 E_2}{X_{12}} \sin(\delta_1 - \delta_2)$$

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

initial operating point $\delta_1 = \delta_{10}$ and $\delta_2 = \delta_{20}$ as

$$\Delta P_{12} = \frac{E_1 E_2}{X_{12}} \cos(\delta_{10} - \delta_{20}) \Delta \delta_{12}$$

$$\Delta \delta_{12} = \Delta \delta_1 - \Delta \delta_2$$

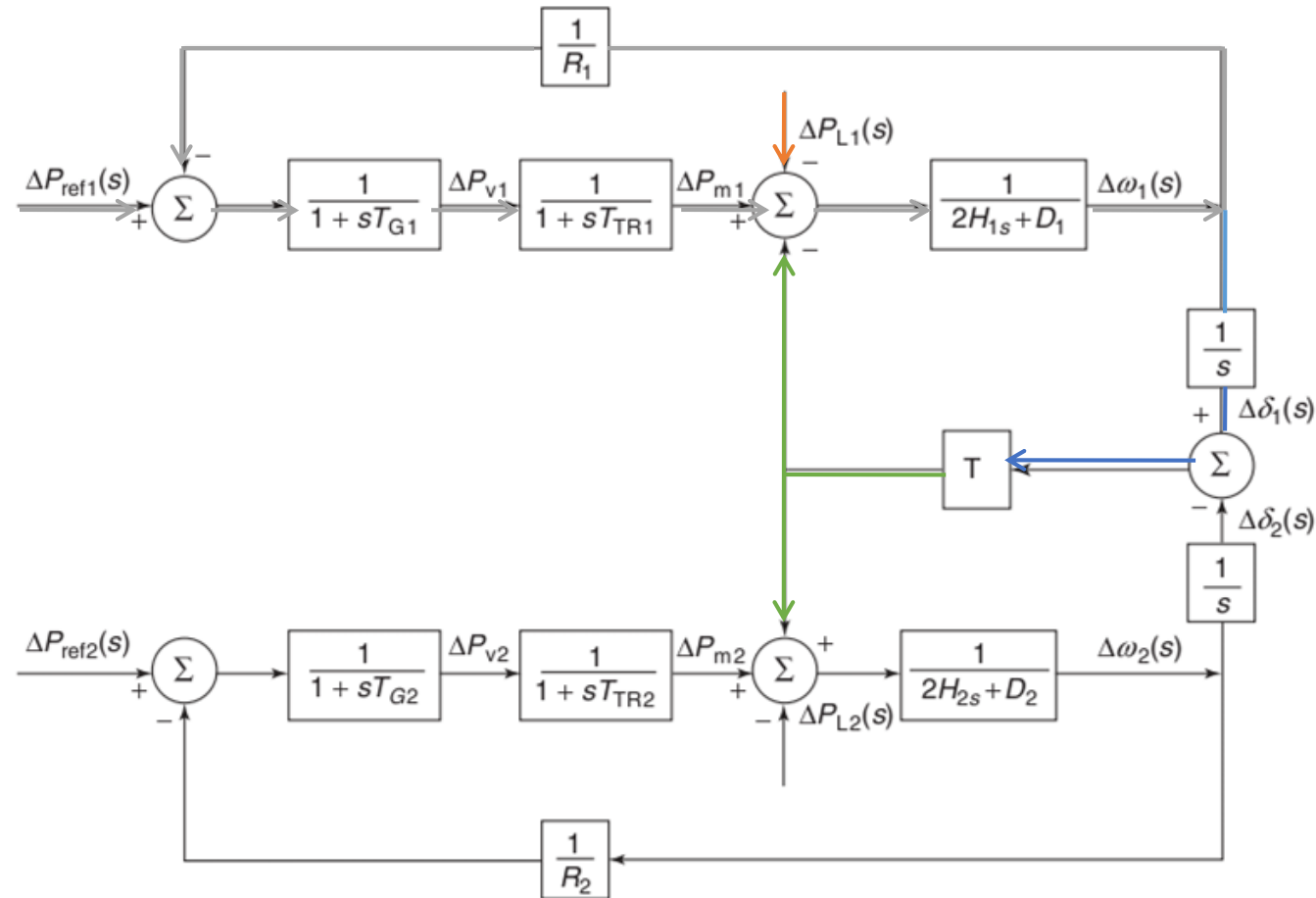


(a) Two-area system and (b) Electrical equivalent.

T is called Synchronizing torque coefficient

$$\text{Let } T = \frac{E_1 E_2}{X_{12}} \cos(\delta_{10} - \delta_{20}) = P_{\text{max}} \cos(\delta_{10} - \delta_{20})$$

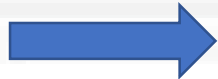
TIE-LINE With Primary Speed Control



Two-area system with primary loop.

Change of Load in Area 1

Consider a load change of ΔP_{L1} in area 1. When the system has reached a steady state, both areas will have same steady-state frequency deviations. Therefore,



$$\Delta\omega = \Delta\omega_1 = \Delta\omega_2$$

(or $\Delta f = \Delta f_1 = \Delta f_2$. Remember that *in pu both Δf and $\Delta\omega$ are the same*)

For area 1, we can write

Assume Mechanical Powers (ΔP_{ref}) Constant

$$\Delta P_{m1} - \Delta P_{12} - \Delta P_{L1} = \Delta\omega D_1$$

For area 2, we have

$$\Delta P_{m2} + \Delta P_{12} = \Delta\omega D_2$$

$$\Delta P_{m1} = \frac{-\Delta\omega}{R_1}$$

$$\Delta P_{m2} = \frac{-\Delta\omega}{R_2}$$

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

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

Change of Load in Area 1

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

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

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

$$\rightarrow \Delta \omega = \frac{-\Delta P_{L1}}{\left(\frac{1}{R_1} + D_1 \right) + \left(\frac{1}{R_2} + D_2 \right)} = \frac{-\Delta P_{L1}}{\beta_1 + \beta_2}$$

β_1 and β_2 are the *composite frequency response characteristics* of area 1 and area 2,

$$\Delta P_{12} = \frac{-\Delta P_{L1} \left(\frac{1}{R_2} + D_2 \right)}{\left(\frac{1}{R_1} + D_1 \right) + \left(\frac{1}{R_2} + D_2 \right)} = \frac{-\Delta P_{L1} \beta_2}{\beta_1 + \beta_2}$$

TOPIC OF DISCUSSION:MODULE- 3

Automatic Generation Control in Interconnected Power system:

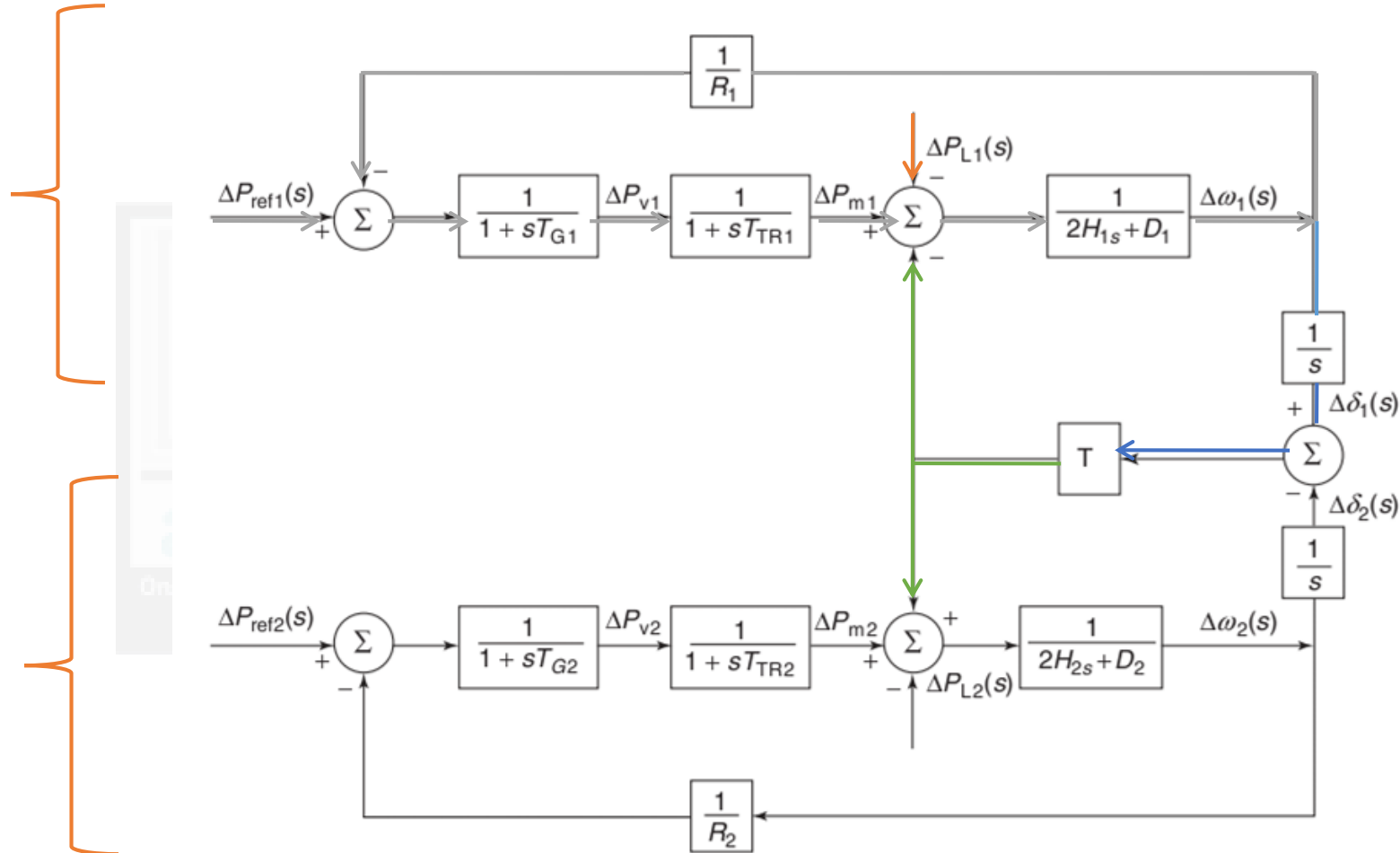
- Introduction
- Tie – Line Control with Primary Speed Control
- Frequency Bias Tie - Line Control
- State-Space Models

SUMMARY

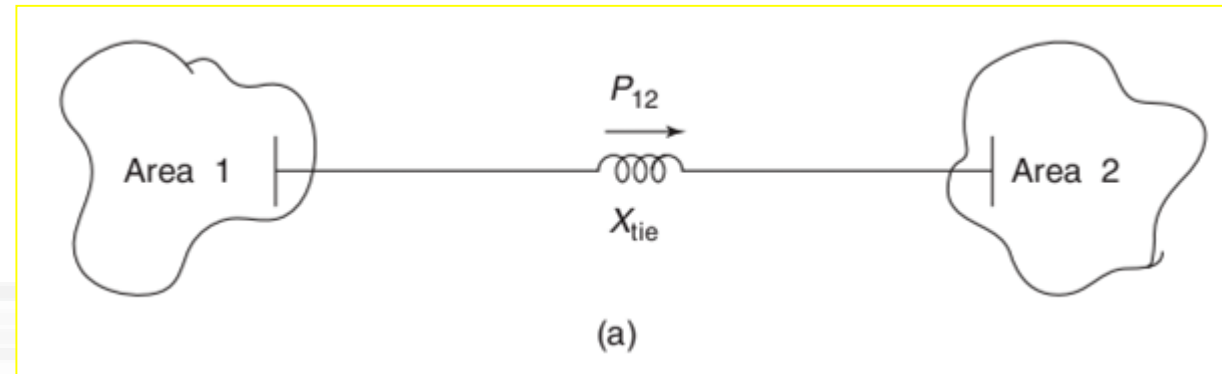
• MULTI AREA SYSTEM:

1. Tie – Line Control with Primary Speed Control
2. Change of Load in Area 1
3. Change of Load in Area 2
4. Change of Load in both the Areas.

TIE-LINE With Primary Speed Control



Two-area system with primary loop.



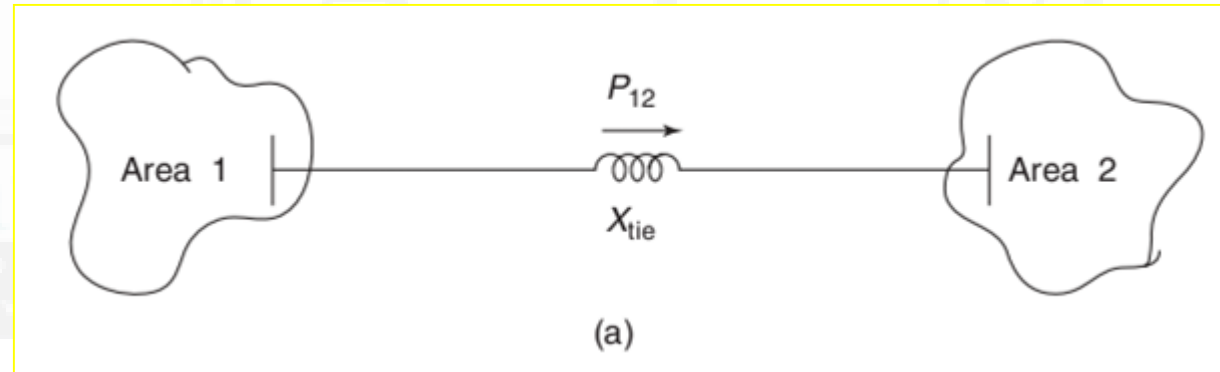
$$\Delta P_{12} = \frac{-\Delta P_{L1} \left(\frac{1}{R_2} + D_2 \right)}{\left(\frac{1}{R_1} + D_1 \right) + \left(\frac{1}{R_2} + D_2 \right)} = \frac{-\Delta P_{L1} \beta_2}{\beta_1 + \beta_2}$$

Change of Load in
Area 1

β_1 and β_2 are the *composite frequency response characteristics* of area 1 and area 2,

CHANGE OF LOAD IN AREA 2

- Consider a Load Change of ΔP_{12} in Area 2



CHANGE OF LOAD IN AREA 2

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

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

$$\Delta P_{m1} = \frac{-\Delta \omega}{R_1} \text{-----(3)}$$

$$\Delta P_{m2} = \frac{-\Delta \omega}{R_2} \text{-----(4)}$$

From (1) and (3)

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

From (2) and (4)

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

CHANGE OF LOAD IN AREA 2

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

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

$$\Delta \omega = \frac{-\Delta P_{L2}}{\beta_1 + \beta_2}$$

$$\Delta P_{12} = \frac{\Delta P_{L2} \beta_1}{\beta_1 + \beta_2} = -\Delta P_{21}$$

CHANGE OF LOAD IN BOTH AREAS

- If we have simultaneous change of Load in both the areas:

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

- Adding (1) $\Delta P_{m2} + \Delta P_{12} - \Delta P_{L2} = \Delta \omega D_2 \quad \text{-----(2)}$

$$-\Delta P_{L1} - \Delta P_{L2} = (\Delta \omega D_1 - \Delta P_{m1}) + (\Delta \omega D_2 - \Delta P_{m2})$$

$$\begin{aligned} &= \Delta \omega \left(D_1 + \frac{1}{R_1} \right) + \Delta \omega \left(D_2 + \frac{1}{R_2} \right) \\ &= \Delta \omega (\beta_1 + \beta_2) \end{aligned}$$

CHANGE OF LOAD IN BOTH AREAS

$$\therefore \Delta\omega = \frac{-(\Delta P_{L1} + \Delta P_{L2})}{\beta_1 + \beta_2}$$

$$\Delta P_{12} = \frac{-\Delta P_{L1} \beta_2}{\beta_1 + \beta_2} + \frac{\Delta P_{L2} \beta_1}{\beta_1 + \beta_2}$$

$$= \frac{1}{\beta_1 + \beta_2} [-\Delta P_{L1} \beta_2 + \Delta P_{L2} \beta_1]$$

We can observe from the above: With only primary governor control, load change in both areas will lead to a steady state deviation in frequency of both areas.

FORMULAS

- **CHANGE OF LOAD
IN AREA 1**

$$\Delta P_{12} = \frac{-\Delta P_{L1} \left(\frac{1}{R_2} + D_2 \right)}{\left(\frac{1}{R_1} + D_1 \right) + \left(\frac{1}{R_2} + D_2 \right)} = \frac{-\Delta P_{L1} \beta_2}{\beta_1 + \beta_2}$$

- **CHANGE OF LOAD
IN AREA 2**

$$\Delta P_{12} = \frac{\Delta P_{L2} \beta_1}{\beta_1 + \beta_2} = -\Delta P_{21}$$

- **CHANGE OF LOAD
IN BOTH AREAS**

$$= \frac{1}{\beta_1 + \beta_2} [-\Delta P_{L1} \beta_2 + \Delta P_{L2} \beta_1]$$

NUMERICALS

Example 7.1

Two control areas are connected via 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 flow if the nominal frequency is 50 Hz? Repeat if the load change occurs in area 2.

Solution

When load change occurs in area 1:

$$\Delta\omega = \frac{-\Delta P_{L2}}{\beta_1 + \beta_2}$$



$$\Delta P_{12} = \frac{-\Delta P_{L1} \beta_2}{\beta_1 + \beta_2}$$

$$\Delta P_{L1} = \frac{100}{500} = \underline{0.2 \text{ pu.}}$$

$$\beta_1 = \frac{1}{R_1} + D_1 = \frac{1}{0.01} + 0.8 = \underline{100.8}$$

$$\beta_2 = \frac{1}{R_2} + D_2 = \frac{1}{0.02} + 1.0 = \underline{51}$$

$$\Delta \omega = \frac{-0.2}{100.8 + 51} = \underline{-1.3175 \times 10^{-3} \text{ pu}}$$

$$\Delta f = -1.3175 \times 10^{-3} \times 50 = \underline{-0.065875 \text{ Hz}}$$

$$\begin{aligned} \text{New frequency} &= 50 - 0.065875 = 49.934125 \text{ Hz} \\ &= \underline{49.93 \text{ Hz}} \end{aligned}$$

$$\Delta P_{12} = \frac{-\Delta P_{L1} \beta_2}{\beta_1 + \beta_2} = \frac{-0.2 \times 51}{100.8 + 51} = -0.0671936 \text{ pu} = \underline{-33.597 \text{ MW}}$$

(There is a drop in tie-line flow)

We balance the changes as follows:

(i) Change in generation of area 1, $\Delta P_{m1} = \frac{-\Delta\omega}{R_1}$



$$= \frac{-(-1.3175 \times 10^{-3})}{0.01} = 0.13175 \text{ pu}$$

$$= \underline{65.875 \text{ MW}} \text{ (Increase in generation since it is a positive value)}$$

(ii) Change in generation of area 2, $\Delta P_{m2} = \frac{-\Delta\omega}{R_2}$



$$= \frac{-(-1.3175 \times 10^{-3})}{0.02} = 0.065875 \text{ pu}$$

$$= \underline{32.9375 \text{ MW}}$$

(iii) Increase in load in area 1 = 100 MW.

(iv) Change in load in area 1 due to drop in frequency = $\Delta\omega D_1 = -1.054 \times 10^{-3}$
 $= \underline{-0.527 \text{ MW}}$.

(v) Change in load in area 2 due to drop in frequency = $\Delta\omega D_2 = -1.3175 \times 10^{-3}$
 $= \underline{-0.65875 \text{ MW}}$

➡ Change in generation = (i) + (ii) = 98.8125 MW

➡ Change in load = (iii) + (iv) + (v) = 98.81 MW

➡ Change in generation = change in load.

ΔP_{12} being negative means there is a flow of 33.597 MW from area 2 to area 1. Out of this, 32.9375 MW comes from increased generation in area 2 and 0.65875 MW from drop in load in area 2.

When load change occurs in area 2:

$$\Delta\omega = \frac{-\Delta P_{L2}}{\beta_1 + \beta_2} = \frac{-0.2}{100.8 + 51} = -1.3175 \times 10^{-3} \text{ pu}$$

$$\Delta f = -0.06875 \text{ Hz}$$

$$f = \underline{49.93 \text{ Hz (same as before)}}$$

$$\Delta P_{12} = \frac{\Delta P_{L2} \beta_1}{\beta_1 + \beta_2} = \frac{0.2 \times 100.8}{100.8 + 51} = 0.1328 \text{ pu} = \underline{66.4 \text{ MW}}$$

(There is an increase in tie-line from area 1 to 2, to meet the increased load in area 2). The increase in tie-line is met by increase in generation in area 1 by 65.875 MW and decrease in load of area 1 by 0.527 MW.

TOPIC OF DISCUSSION:MODULE- 3

Automatic Generation Control in Interconnected Power system:

- Introduction
- Tie – Line Control with Primary Speed Control
- Frequency Bias Tie - Line Control
- State-Space Models

FORMULAS

- **CHANGE OF LOAD
IN AREA 1**

$$\Delta P_{12} = \frac{-\Delta P_{L1} \left(\frac{1}{R_2} + D_2 \right)}{\left(\frac{1}{R_1} + D_1 \right) + \left(\frac{1}{R_2} + D_2 \right)} = \frac{-\Delta P_{L1} \beta_2}{\beta_1 + \beta_2}$$

- **CHANGE OF LOAD
IN AREA 2**

$$\Delta P_{12} = \frac{\Delta P_{L2} \beta_1}{\beta_1 + \beta_2} = -\Delta P_{21}$$

- **CHANGE OF LOAD
IN BOTH AREAS**

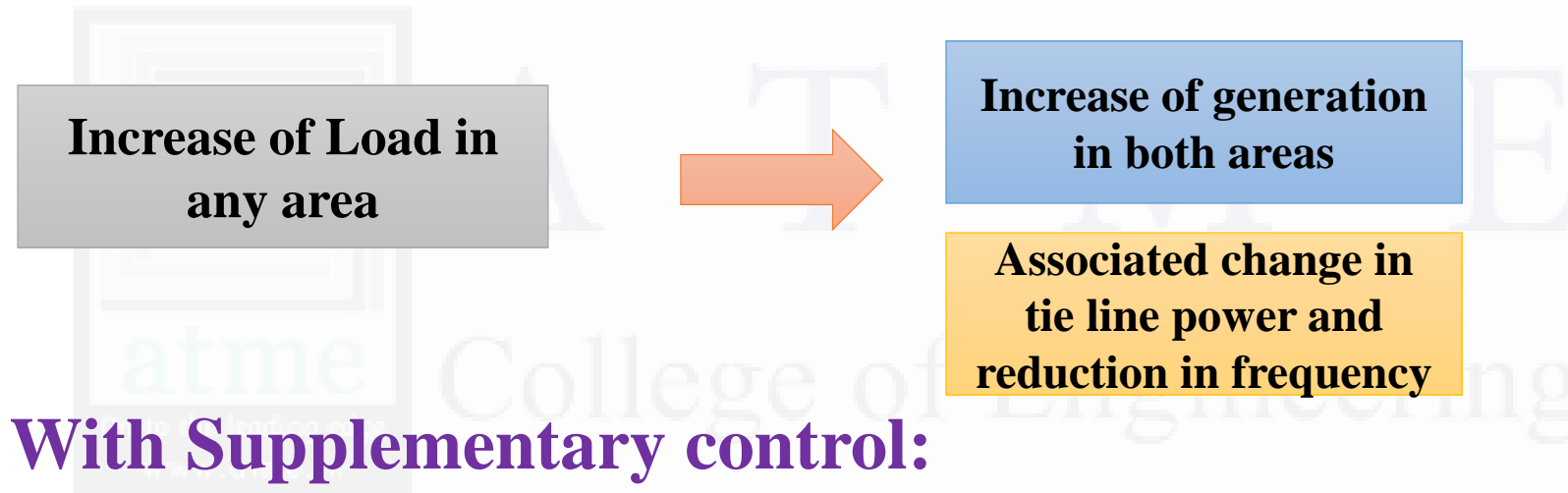
$$\Delta P_{12} = \frac{-\Delta P_{L1} \beta_2}{\beta_1 + \beta_2} + \frac{\Delta P_{L2} \beta_1}{\beta_1 + \beta_2}$$

- **CHANGE IN GENERATION**

$$\Delta P_{m1} = \frac{-\Delta \omega}{R_1}$$

TIE LINE BIAS CONTROL(FREQUENCY BIAS TIE LINE CONTROL)

From previous topic of discussion we observed with only a primary loop control :



With Supplementary control:

Restores balance
between generation
and load

Restores frequency to a
nominal value

TIE LINE BIAS CONTROL(FREQUENCY BIAS TIE LINE CONTROL)

Three Modes in which interconnected operation works:

1. Flat frequency where control is to obtain a constant frequency:

In an interconnected systems, when one of the system responds to frequency change only: It cannot have control over the power flow in the interconnected lines

TIE LINE BIAS CONTROL(FREQUENCY BIAS TIE LINE CONTROL)

Three Modes in which interconnected operation works:

2. **When a system responds to Tie-Line changes and changes its generation to maintain the scheduled tie line interchanges: It cannot respond to frequency changes. This is called FLAT TIE LINE MODE**

TIE LINE BIAS CONTROL(FREQUENCY BIAS TIE LINE CONTROL)

Three Modes in which interconnected operation works:

3. Both the methods specified has disadvantages.

Hence a combined control called Frequency Bias Control is used.

TIE LINE BIAS CONTROL(FREQUENCY BIAS TIE LINE CONTROL)

EXAMPLE: Let us consider identical areas, with area 1 supplying 150MW, over the tie line to area 2.

If there is an increase in load by 50MW in area 2

Primary Control



Each area increases its generation by 25MW and tie line power increases to 175MW

If area 1 had an agreement to sell only 150MW to area 2



Production cost of extra 25MW would be unbilled

TIE LINE BIAS CONTROL(FREQUENCY BIAS TIE LINE CONTROL)

Inference :

Supplementary control in a given area should change the generation only for change in load in same area

TIE LINE BIAS CONTROL(FREQUENCY BIAS TIE LINE CONTROL)

$$\Delta P_{12} = P_{12} - P_{12, \text{sch}}$$

where P_{12} = actual power flow from area 1 to 2

$P_{12, \text{sch}}$ = scheduled interchange power from area 1 to area 2

Tie-line control actions for two-area system

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

TIE LINE BIAS CONTROL(FREQUENCY BIAS TIE LINE CONTROL)

- Control Signal : **Area Control Error**

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

$$ACE_2 = \Delta P_{21} + B_2 \Delta \omega$$

B_1, B_2 are the bias factors and determine the amount of interaction during a disturbance in the other area

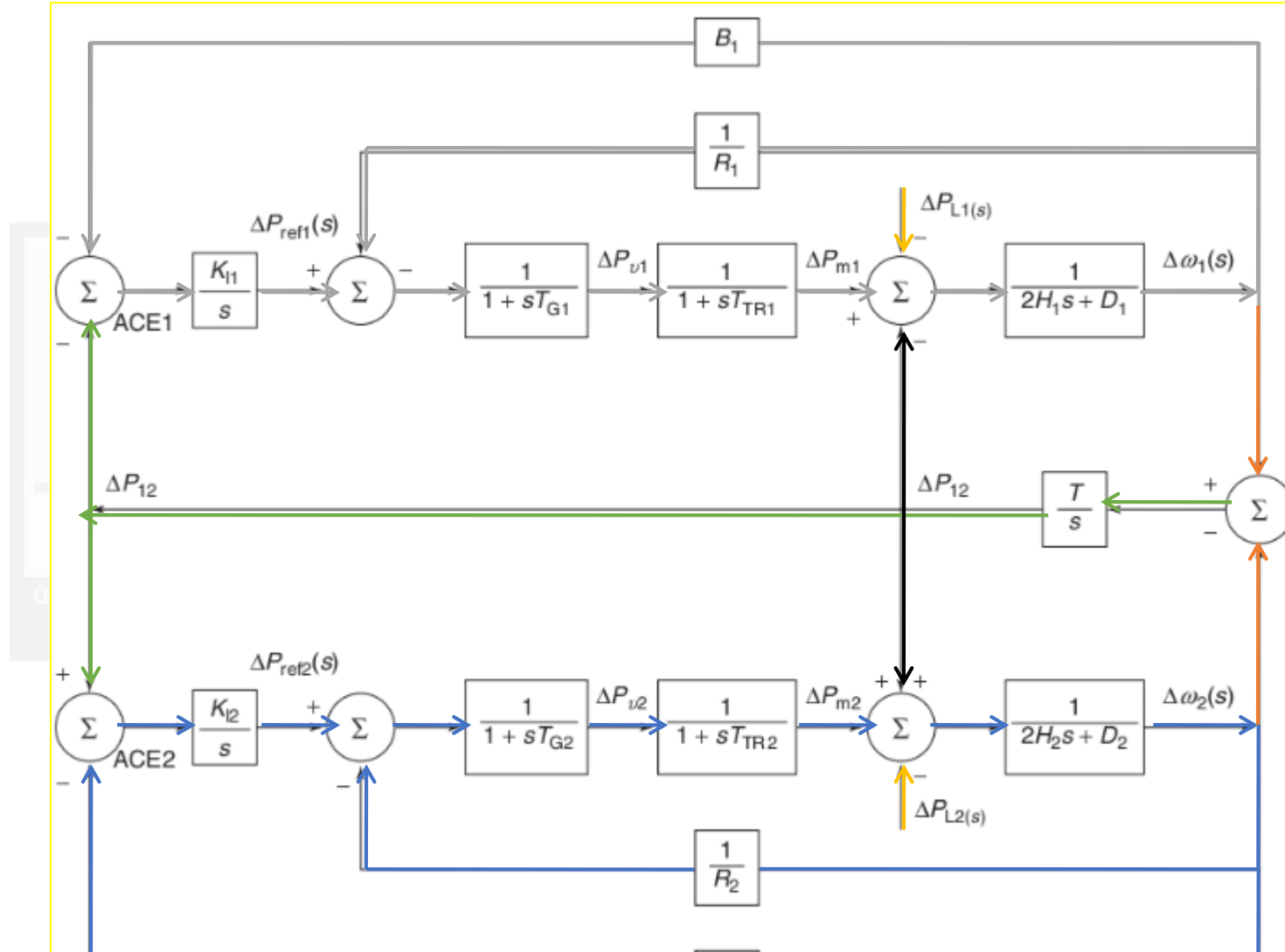
most suitable bias factor for an area is its frequency response characteristic β

$$ACE_1 = \Delta P_{12} + \beta_1 \Delta \omega$$

$$ACE_2 = \Delta P_{21} + \beta_2 \Delta \omega$$

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

Block Diagram of AGC for a Two Area System



ACE Expression

ACE Signal in General Form:

$$ACE_1 = K_1 \Delta P_{12} + B_1 \Delta \omega = 0$$

$$ACE_2 = K_2 \Delta P_{21} + B_2 \Delta \omega = 0$$

$$\Delta \omega = \frac{-\Delta P_{L1}}{\beta_1 + \beta_2}$$

$$\Delta P_{12} = \frac{-\Delta P_{L1} \beta_2}{\beta_1 + \beta_2}$$

$K_1 = K_2 = 1$, $B_1 = \beta_1$ and $B_2 = \beta_2$, we get

ACE Expression

$$\begin{aligned} \text{ACE}_1 &= -\Delta P_{L1} \left[\frac{\beta_1 + \beta_2}{\beta_1 + \beta_2} \right] = -\Delta P_{L1} \\ \text{ACE}_2 &= -\Delta P_{L1} \left[\frac{-\beta_2 + \beta_2}{\beta_1 + \beta_2} \right] = 0 \end{aligned}$$

Thus, only the supplementary control in area 1 will change the load reference point to meet load change in area 1. *The supplementary control of area 2 will not be affected.*

An alternative expression commonly used for ACE is

$$\text{ACE}_i = (T_i - T_{si}) - 10B_i (F_i - F_{si})$$

T_i is net actual tie-line interchange from area i .

T_{si} is the scheduled tie-line interchange of area i .

F_i is actual frequency of area i in Hz.

F_{si} is scheduled frequency of area i in Hz.

B_i is the area frequency bias in MW/0.1 Hz. Multiplying by 10 gives it in MW/Hz.

NUMERICALS:ACE

Example 7.5

The data of a two-area system are as follows:

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

Area 2: $P_{G2} = P_{L2} = 10000 \text{ MW}$, $R_2 = 0.0015$, $D_2 = 0$

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

Solution



$$\Delta P_{m1} = D_1 \Delta \omega_1 + \Delta P_{L1} + \Delta P_{12} = \Delta P_{L1} + \Delta P_{12}$$

$$\Delta P_{m2} = D_2 \Delta \omega_2 + \Delta P_{L2} + \Delta P_{21} = \Delta P_{21} = \Delta P_{12}$$

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NUMERICALS:ACE

$$\Delta\omega = \Delta\omega_1 = \Delta\omega_2$$

$$\Delta P_{m1} = -\frac{1}{R_1} \Delta\omega_1 \text{ and } \Delta P_{m2} = -\frac{1}{R_2} \Delta\omega_2$$

$$\Delta\omega = \frac{-\Delta P_{L1}}{\left(\frac{1}{R_1} + \frac{1}{R_2}\right)} = \frac{-10}{\left(\frac{1}{0.015} + \frac{1}{0.0015}\right)} = \underline{-0.0136 \text{ rad/s}}$$

or

$$\Delta P_{m1} = \frac{-(-0.0136)}{0.015} = \underline{0.9091 \text{ MW}}$$

$$\Delta P_{12} = \Delta P_{m1} - \Delta P_{L1} = 0.9091 - 10 = \underline{-9.091 \text{ MW}}$$

$$\Delta P_{21} = -\Delta P_{12} = \underline{9.091 \text{ MW}}$$

$$ACE_1 = \Delta P_{12} + \frac{1}{R_1} \Delta\omega = -9.091 + \frac{1}{0.015} (-0.0136) = \underline{-10 \text{ MW}}$$

$$ACE_2 = \Delta P_{21} + \frac{1}{R_2} \Delta\omega = 9.091 + \frac{1}{0.0015} (-0.0136) = \underline{0 \text{ MW}}$$

NUMERICALS:ACE

The ACEs indicate the action to be taken in each area. $ACE_2 = 0$ means that area 2 need not take any action.

$ACE_1 = -10$ means that area 1 should increase its load power reference point to $-(-10) = 10$ MW and increase generation to meet the increased load.

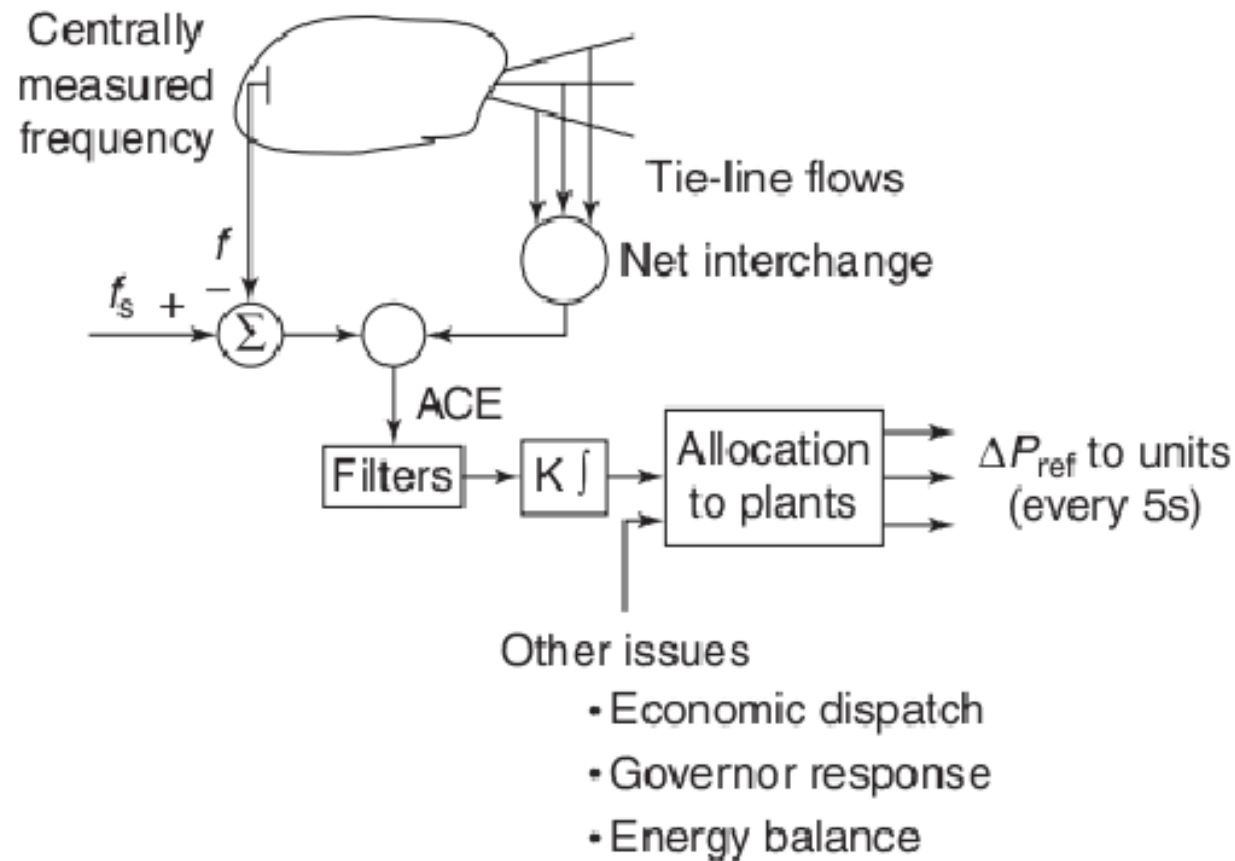
STATE SPACE MODELS

A **state** variable is one of the set of variables that are used to describe the mathematical "**state**" of a dynamical **system**.

Intuitively, the **state of a system** describes enough about the **system** to determine its future behaviour in the absence of any external forces affecting the **system**.

STATE SPACE MODELS

Implementation of AGC



STATE SPACE MODELS: ISOLATED SYSTEM

The s-domain equations are as follows:

$$\left[\frac{1}{2Hs + D} \right] (\Delta P_m(s) - \Delta P_L(s)) = \Delta \omega(s)$$

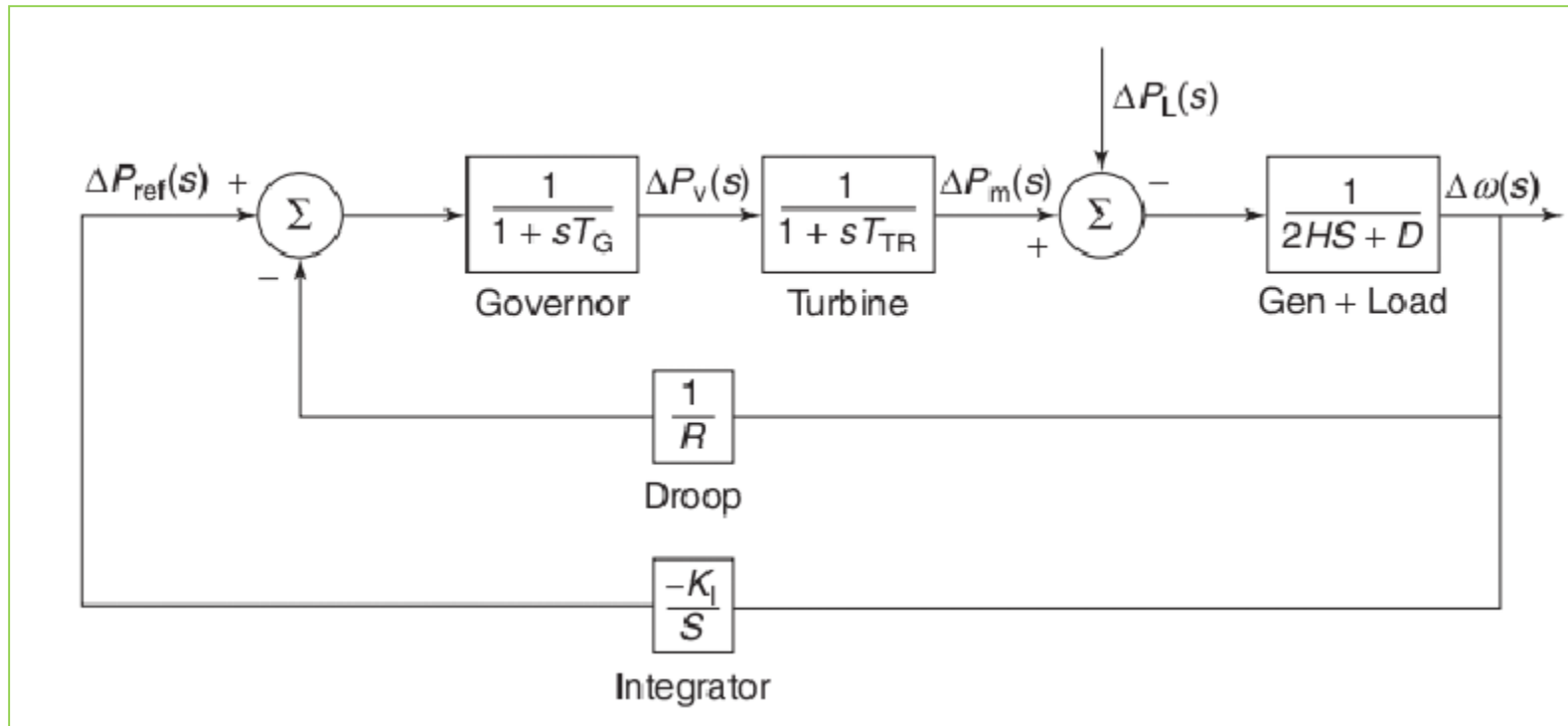


$$\Delta \omega(s) (2Hs + D) = \Delta P_m(s) - \Delta P_L(s)$$

For the turbine we have:

$$\Delta P_v(s) \left[\frac{1}{1 + sT_{TR}} \right] = \Delta P_m(s)$$

ISOLATED SYSTEM WITH AGC



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$$\Delta P_v(s) \left[\frac{1}{1 + sT_{TR}} \right] = \Delta P_m(s)$$



$$(1 + sT_{TR}) \Delta P_m(s) = \Delta P_v(s)$$

$$s\Delta P_m(s) = \frac{-1}{T_{TR}} \Delta P_m(s) + \frac{1}{T_{TR}} \Delta P_v(s)$$

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For the Governors we have



$$\left[\Delta P_{ref}(s) - \frac{1}{R} \Delta \omega(s) \right] \left[\frac{1}{1 + sT_G} \right] = \Delta P_v(s)$$

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

$$s\Delta P_v(s) = \frac{-1}{T_G} \Delta P_v(s) + \frac{1}{T_G} \Delta P_{ref}(s) - \frac{1}{RT_G} \Delta \omega(s)$$

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For the Integrator we have

$$\Delta P_{\text{ref}}(s) = \frac{-K_I}{s} \Delta \omega(s)$$
$$s \Delta P_{\text{ref}}(s) = -K_I \Delta \omega(s)$$

The following are called State Equations

$$\Delta P_v(s) \left[\frac{1}{1 + s T_{\text{TR}}} \right] = \Delta P_m(s)$$

$$s \Delta P_v(s) = \frac{-1}{T_G} \Delta P_v(s) + \frac{1}{T_G} \Delta P_{\text{ref}}(s) - \frac{1}{R T_G} \Delta \omega(s)$$

$$s \Delta P_{\text{ref}}(s) = -K_I \Delta \omega(s)$$

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State Vector in Time domain

$$X = [\Delta\omega \ \Delta P_m \ \Delta P_v \ \Delta P_{ref}]^T$$

State Equations can be transformed into time domain and written in matrix form as:



$$\begin{bmatrix} \dot{\Delta\omega} \\ \dot{\Delta P_m} \\ \dot{\Delta P_v} \\ \dot{\Delta P_{ref}} \end{bmatrix} = \begin{bmatrix} \frac{-D}{2H} & \frac{1}{2H} & 0 & 0 \\ 0 & \frac{-1}{T_{TR}} & \frac{1}{T_{TR}} & 0 \\ -\frac{1}{RT_G} & 0 & \frac{-1}{T_G} & \frac{1}{T_G} \\ -K_I & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \Delta\omega \\ \Delta P_m \\ \Delta P_v \\ \Delta P_{ref} \end{bmatrix} + \begin{bmatrix} -\frac{1}{2H} \\ 0 \\ 0 \\ 0 \end{bmatrix} \Delta P_L$$

ISOLATED SYSTEM WITH AGC

Standard Form of State Space Model



$$\begin{aligned}\dot{X}(t) &= AX(t) + Bu(t) \\ y(t) &= CX(t) + Du(t)\end{aligned}$$

where

$X(t)$ – state vector
 $u(t)$ – input vector
 $y(t)$ – output vector

$$A = \begin{bmatrix} \frac{-D}{2H} & \frac{1}{2H} & 0 & 0 \\ 0 & \frac{-1}{T_{TR}} & \frac{1}{T_{TR}} & 0 \\ \frac{-1}{RT_G} & 0 & \frac{-1}{T_G} & \frac{1}{T_G} \\ -K_1 & 0 & 0 & 0 \end{bmatrix}$$
$$B = \begin{bmatrix} -\frac{1}{2H} \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad C = [1 \ 0 \ 0 \ 0] \quad D = 0$$

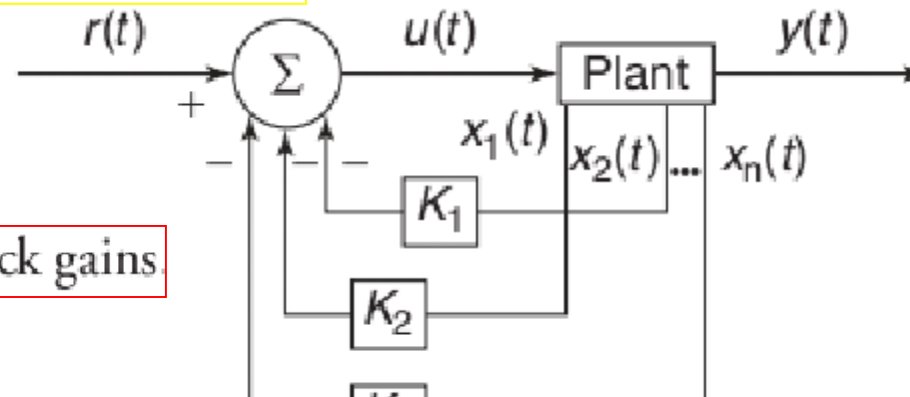
Pole Placement Design

- The Co-efficient matrix **A** determines the stability of the system
- For the system to be stable co-efficients of the **Eigen Matrix** should be on the LHS of the s-plane.

The state feedback control used is given by

$$u(t) = -KX(t)$$

where K is a $1 \times n$ vector of feedback gains



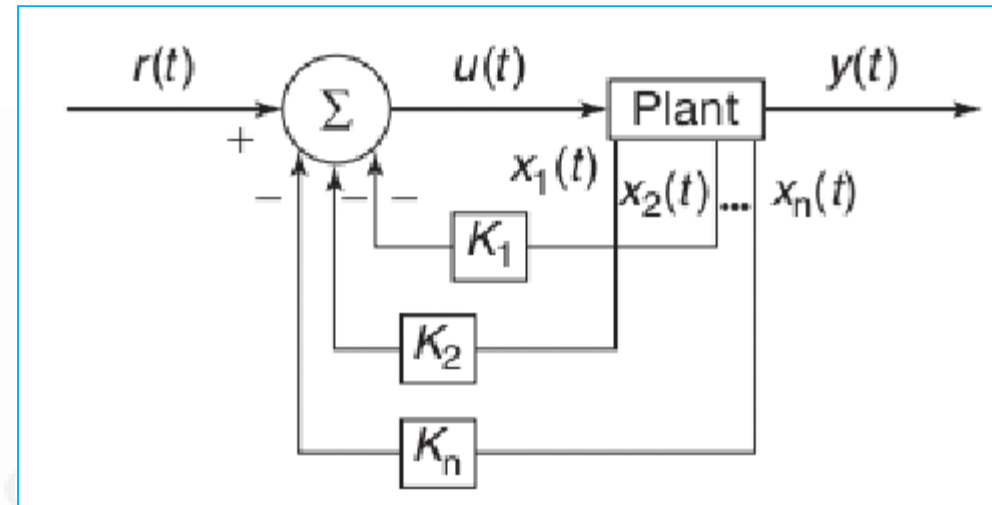
Pole Placement Design

The state feedback control used is given by

$$u(t) = -KX(t)$$

We can now substitute
in the state equation to get

$$\begin{aligned}\dot{X}(t) &= AX(t) + B(-KX(t)) \\ &= (A - BK)X(t) = A_{fb} X(t)\end{aligned}$$



where A_{fb} is the coefficient matrix with feedback

The characteristic equation for the above state model

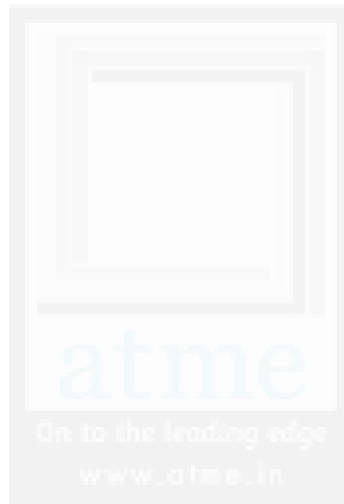
$$|sI - A_{fb}| = |sI - A + BK| = 0$$



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Thank You



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