Load Frequency Control

Prof. M VENKATESWARA RAO

Dept. of EEE,

JNTUA College of Engineering, Kalikiri

Chittoor District, A P, India

Outline of Presentation

❖Introduction

❖Mathematical modeling

❖LFC of a single area system

❖LFC of a two area interconnected power system

❖ Previous years GATE Questions

Introduction

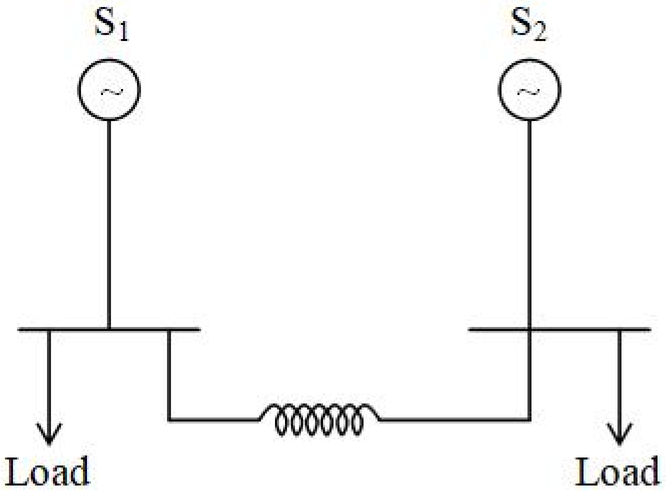
❖The difference between generated power and instant load demand causes changing of nominal system frequency at the normal state. If the amount of generated power is less than the demanded amount, speed and frequency of the generator units begin to decrease, and vice versa.

❖Hence, the amount of production of the synchronous generators is made sense for frequency deviations occurred in the power system in order to maintain that balance.

❖The frequency normally vary by about 5% between light load and full load conditions.

Introduction (contd…)

❖If a change in load is taken of by two machines running in parallel as shown below :



❖If the change in load is either at S_1 (or) S_2 and if the generation of S_1 alone is regulated to adjust this change so as to have constant frequency, the method of regulation is known as flat frequency regulation.

Introduction (contd...)

❖The other way of sharing the change in load is that both S_1 and S_2 would regulate their generations to maintain the frequency constant. This is known as parallel frequency regulation.

❖The change in a particular area is taken care of by the generator in that area thereby the tie-line loading remains constant. This method of regulating the generation for keeping constant frequency is known as flat-tie line loading control.

❖All the generators in such an area constitute a coherent group so that all the generators speed up and slow down together maintaining their relative power angles. Such an area is defined as a **control area**. The boundaries of a control area will generally coincide with that of an individual electricity board company.

Effects of change in frequency

- ❖Most AC motors run at speeds that are directly related to frequency. The speed and induced electro motive force (E.M.F) may vary because of the change of frequency of the power circuit.
- ❖When operating at frequencies below 49.5 Hz; some types of steam turbines, certain rotor states undergo excessive vibration.
- ❖The change in frequency can cause mal operation of power converters by producing harmonics.
- ❖For power stations running in parallel it is necessary that frequency of the network must remain constant for synchronization of generators.
- ❖Many devices connected to the grid will only work properly when the input frequency is within a certain range.

Effects of change in frequency(contd...)

❖It is globally economically optimum to keep the grid frequency within a small range than it is to make all devices tolerate a greater frequency range.

❖The inductance of the inductive elements (e.g. Transformer) are chosen based on the switching frequency. Changes in the frequency will cause disturbances in the output and may even cause the supply's control system to become unstable.

Mathematical modelling of an isolated system

Mathematical modelling of an isolated power system constitutes :

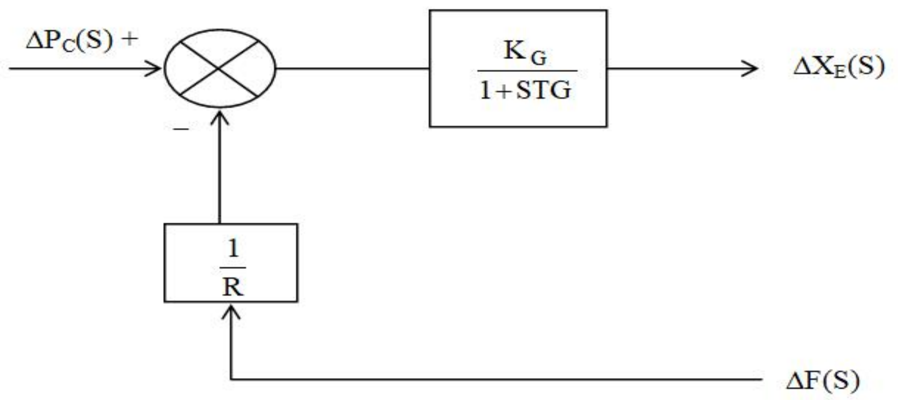
❖Speed governor model

❖Turbine model

❖Generator model

Speed governor model :

Speed governor model can be developed by considering various steady state conditions. The resulting speed governor model is :



From the above block diagram we can get the following expression :

$$\Delta X_E(S) = \frac{K_G}{1+ST_G}\left[\Delta P_C(S) - \frac{1}{R}\Delta F(S)\right] \quad ....[1]$$

Where R = Speed regulation of the governor

K_G = Gain of speed governor

T_G = time constant of speed governor

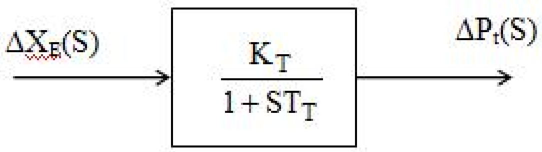
Turbine model :

The turbine model requires a relation between changes in power output of the steam turbine to changes in its steam valve opening ΔX_E.

$$G_T(S) = \frac{\Delta P_t(S)}{\Delta X_E(S)} = \frac{KT}{1+ST_T}$$

Mathematical modelling of an isolated system(contd..)

A non-reheat turbine with a single gain factor K_T and a single time constant T_T and thus the model representation of the turbine the transfer function is given as



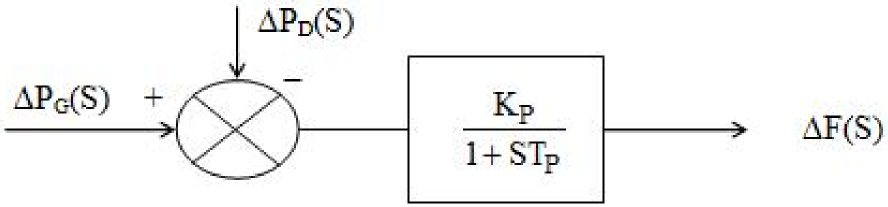
The time constant T_T lies in the range 0.2 to 2.0 sec.

Generator – load model:

The model gives relation between the change in frequency as a result of change in generation when the load changes by a small amount.

Mathematical modelling of an isolated system(contd..)

The block diagram representation of the generator-load model is



From the above block diagram we have

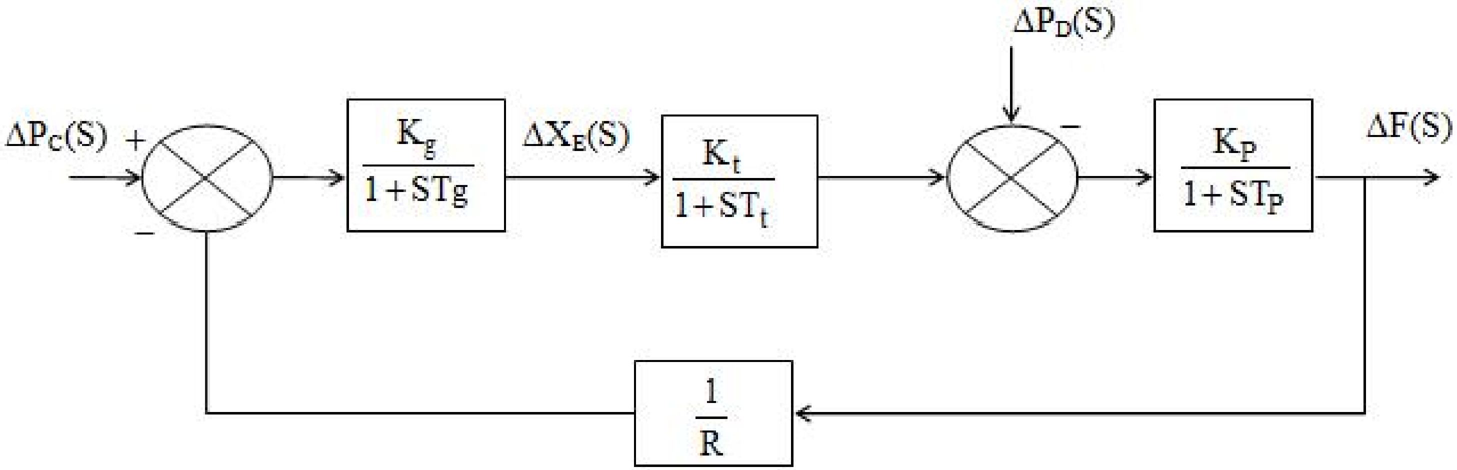
$$F(S) = [\Delta P_G(S) - \Delta P_D(S)] \frac{kp}{1+ST_P} \quad ....[2]$$

where $T_P = \dfrac{2H}{Df^0}$ = power system time constant .

k_p =1/D= power system gain.

LFC of a single area system

Development of the single area power system includes the combined structure of speed governor, turbine and generator-load models.



LFC of a single area system(contd...)

Steady state analysis:

This can be done by considering two cases

❖The speed changer has a fixed setting i.e. $\Delta P_C = 0$ and the load demand changes. This is known as **free governor operation**.

$$\Delta f = -\left(\frac{1}{D+\frac{1}{R}}\right)\Delta P_D \qquad \text{Where } k_p = \frac{1}{D} \text{ and } D = \frac{\partial P_D}{\partial f}$$

❖Consider a step change in speed governor setting and the load demand remains constant. i.e. $\Delta P_D(S) = 0$

$$\Delta f = \left(\frac{1}{D+\frac{1}{R}}\right)\Delta P_C$$

LFC of a single area system(contd...)

If the speed changer setting is changed by ΔP_C while the load demand changes by ΔP_D, the steady state frequency change is obtained by superposition theorem.

$$\Delta f = \left(\frac{1}{D + \frac{1}{R}} \right) (\Delta P_C - \Delta P_D) \qquad \text{..........................[3]}$$

Dynamic response:

It gives the variations of frequency with respect to time for a given step change in load demand. By considering the first order approximation and the system is assumed to be under free governor operation, then

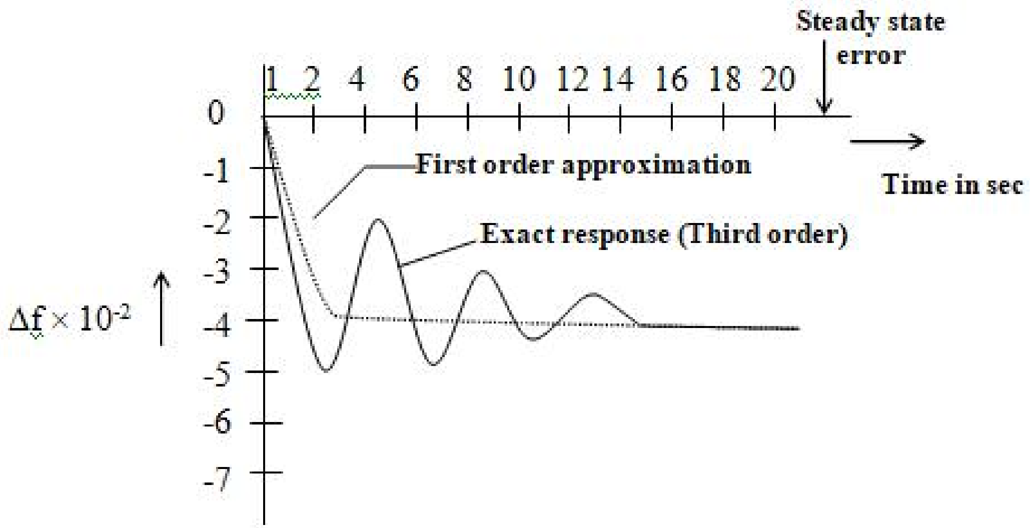
$$\Delta F(S)\Big|_{\Delta P_C(S)=0} = -\frac{k_p \mid T_p}{S\left[S + \frac{R + k_p}{RT_p}\right]} * \Delta P_D \qquad \text{..................[4]}$$

LFC of a single area system(contd...)

$$\Delta f(t) = -\frac{RK_p}{R+K_p}\left\{1-\exp\left(\frac{-t}{T_p\left(\frac{R}{R+K_p}\right)}\right)\right\}\Delta P_D$$

....................[5]

Comparision of the system under dynamic conditions and First order approximation is as shown below



LFC of a single area system(contd…)

Uncontrolled system:

In a single area uncontrolled system whenever a load increase takes place it is taken care of by the system in the following three ways.

❖Borrowed kinetic energy from the rotating machines of the system.

❖Released customer load.

❖Increased generation.

Proportional plus Integral control of single area:

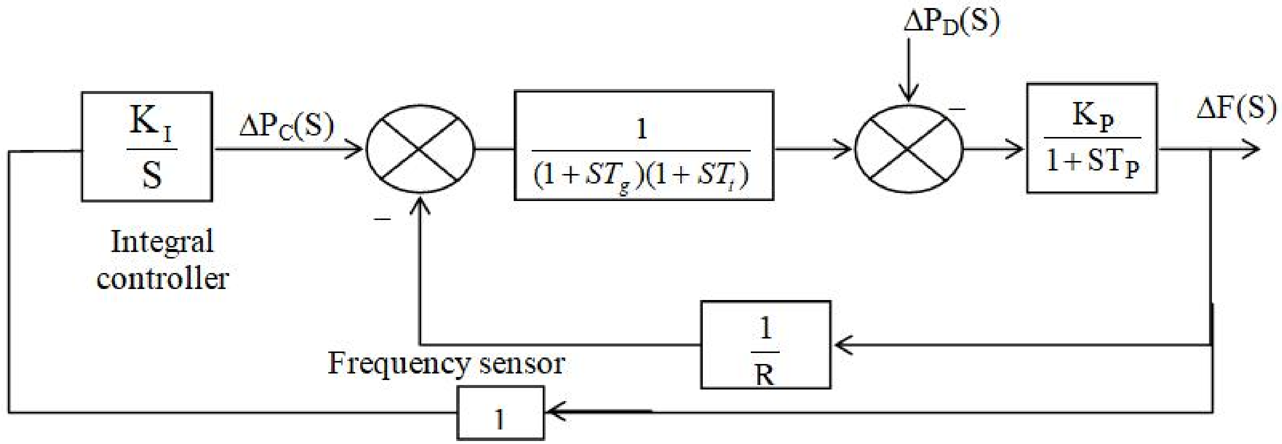
By using the control strategy shown in figure. Let the speed changer be commanded by a signal obtained by first amplifying and then integrating the frequency error.

LFC of a single area system(contd…)

$$\Delta P_C = -K_I \int \Delta f \, dt$$

❖The unit for K_I is per unit megawatt per hertz and second.

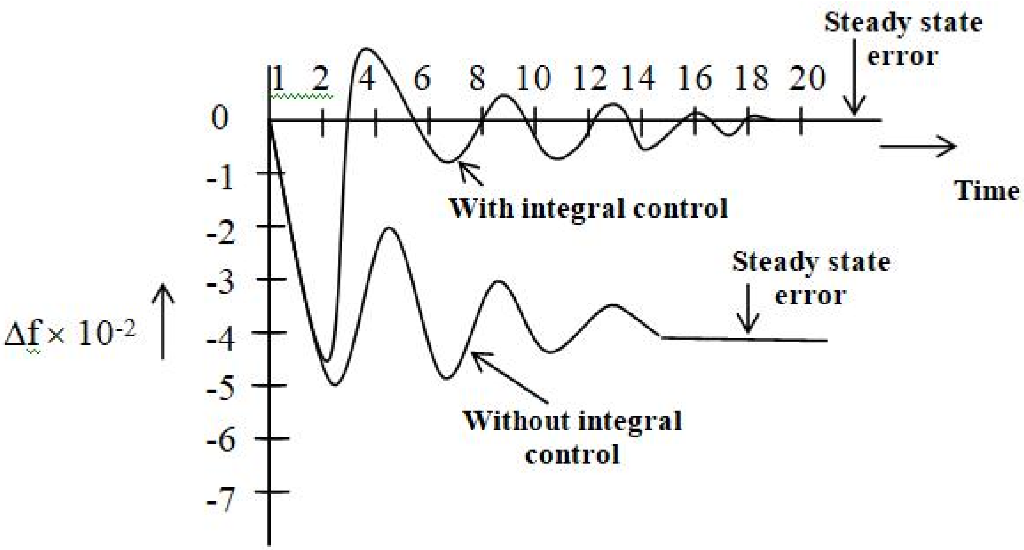
❖Integral control will give rise to zero static frequency error following a step load change. Single area LFC system with PI control is



LFC of a single area system(contd...)

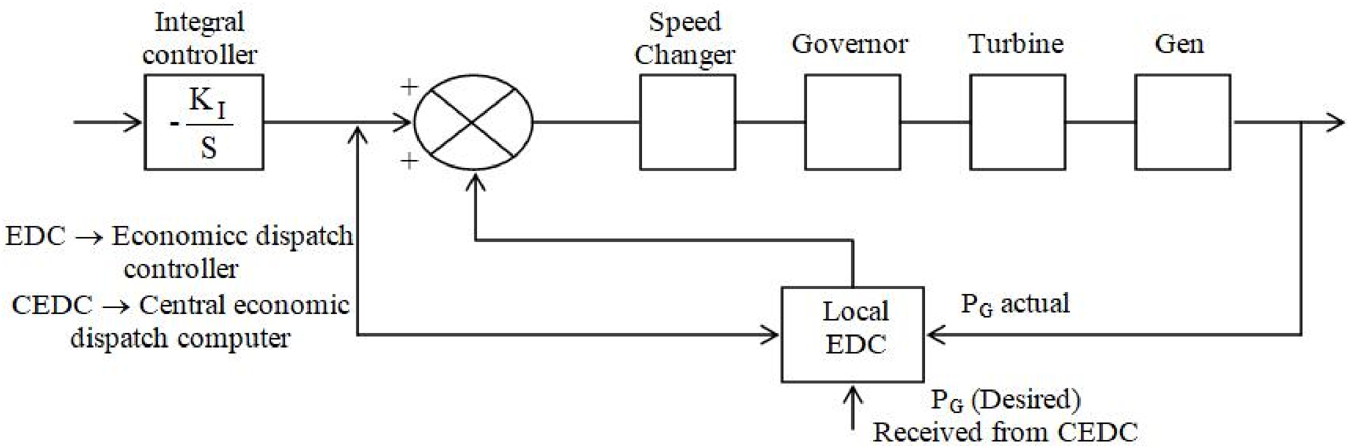
❖The system now modifies to a proportional plus integral controller, gives zero steady state error.

❖The dynamic response of load frequency controller with and without integral control action given below:



LFC of a single area system(contd…)

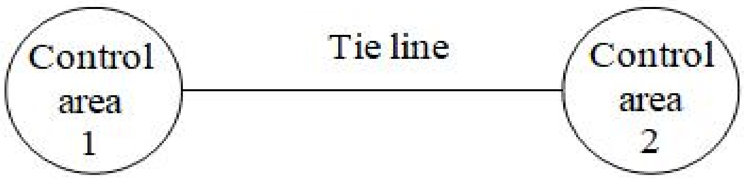
Load frequency control and Economic dispatch control:



The load frequency control change the speed changes setting of the governors of all the generator units of the area, so that the frequency return to the scheduled frequency. The signal P_G(desired) is computed by the central economic despatch computer (CEDC) and is transmitted to the local economic despatch controller (EDC) installed at each station.

LFC of a two area interconnected system

An extended power system can be divided into a number of load frequency control areas inter connected by means of tie lines. Consider a two area case connected by a single tie line as illustrated as below :



Power transmitted from the area 1 is given by

$$P_{tie,\,1} = \frac{|V_1||V_2|}{X_{12}} \sin(\delta_1^0 - \delta_2^0). \qquad \text{.....................[6]}$$

i.e.

$$\Delta P_{tie,1}\ (pu) = T_{12}\ (\Delta\delta_1 - \Delta\delta_2) \qquad \text{.....................[7]}$$

$$\text{Where } T_{12} = \frac{|V_1||V_2|}{Pr_1\ X_{12}} \cos(\delta_1^0 - \delta_2^0) = \text{Synchronizing coefficient} \qquad \text{..[8]}$$

LFC of a two area interconnected system(contd...)

Change in angle can be expressed as the integral of change in frequency

$$\Delta P_{tie,\,2} = 2\pi T_{21} \left[\int \Delta f_2 dt - \Delta f_1 dt \right]$$

$$\text{Where } T_{21} = \frac{|V_2||V_1|}{Pr_2 X_{21}} \cos(\delta_2^0 - \delta_1^0)$$

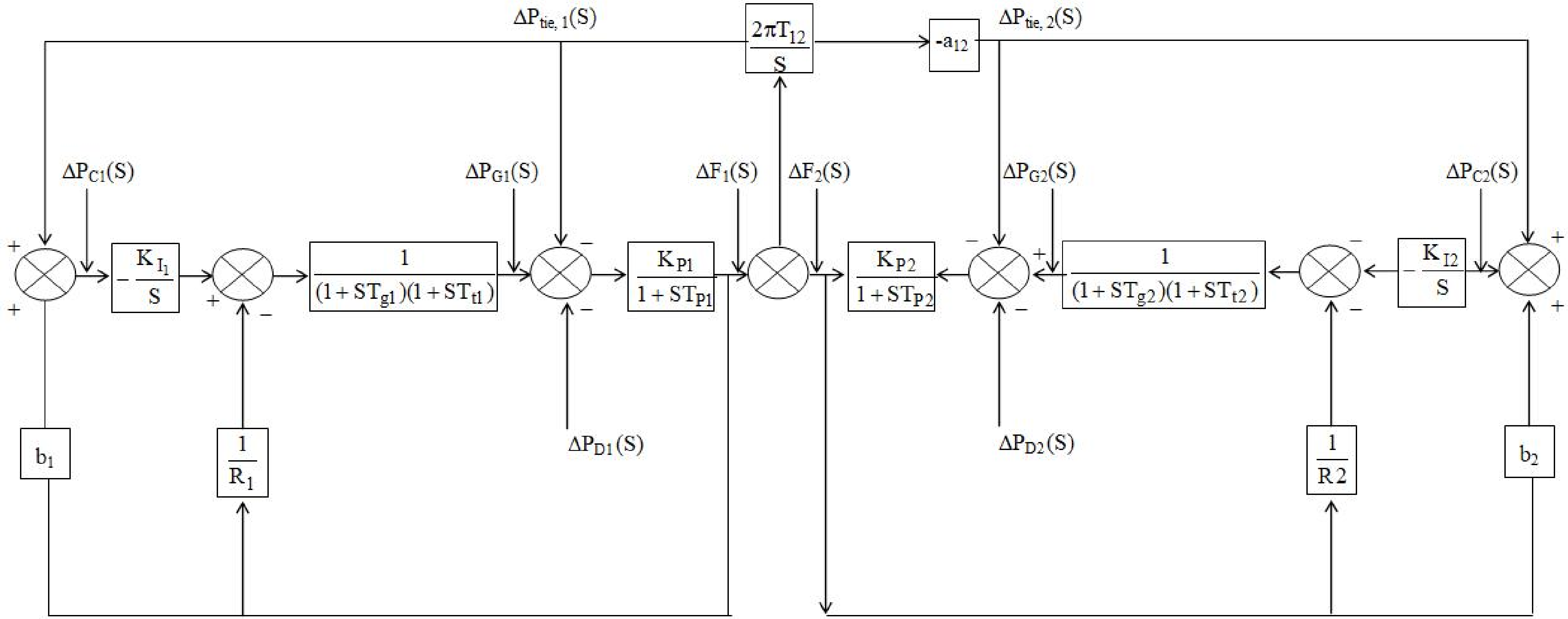
$$T_{21} = \left(\frac{Pr_1}{Pr_2}\right) T_{12} = a_{12} T_{12}$$

In general load model $\rightarrow$ the incremental power balance equation of area1 can be written as

$$\Delta P_{G1} - \Delta P_{D1} = \frac{2H_1}{f_1^0} \frac{d}{dt} (\Delta f_1) + B_1 \Delta f_1 + \Delta P_{tie,\,1}$$

LFC of a two area interconnected system(contd...)

Block diagram model of a two area interconnected system is obtained as



LFC of a two area interconnected system(contd...)

Static response of two-area system: (Uncontrolled case)

❖In uncontrolled case, the response of the two-area system with fixed speed changer positions. i.e. $\Delta P_{C1} = \Delta P_{C2} = 0$

❖Assumed that the loads in each area suddenly increased by the constant incremental steps $\Delta P_{D1} = M_1$ And $\Delta P_{D2} = M_2$

❖The steady state frequency is given by

$$\Delta f = -\frac{M_1 + M_2}{\beta_1 + \beta_2} \text{ Hz} \qquad \text{................[9]}$$

Where $\beta_1 = D_1 + 1/R_1$; $\beta_2 = D_2 + 1/R_2$

❖Tie line power deviation is given by

$$P_{12(tie)} = -\Delta P_{21(tie)} = \frac{\beta_1 M_2 - \beta_2 M_2}{\beta_1 + \beta_2} \text{ pu MW} \qquad \text{.............[10]}$$

LFC of a two area interconnected system(contd...)

Dynamic response of two – area system: (Uncontrolled case)

The dynamic response of the two area, system is based on the following assumptions.

❖ Consider the case of two equal areas.

❖ Consider the turbine controller fast relative to the inertia part of the system. $G_H = G_T = 1$

❖Neglect the system damping

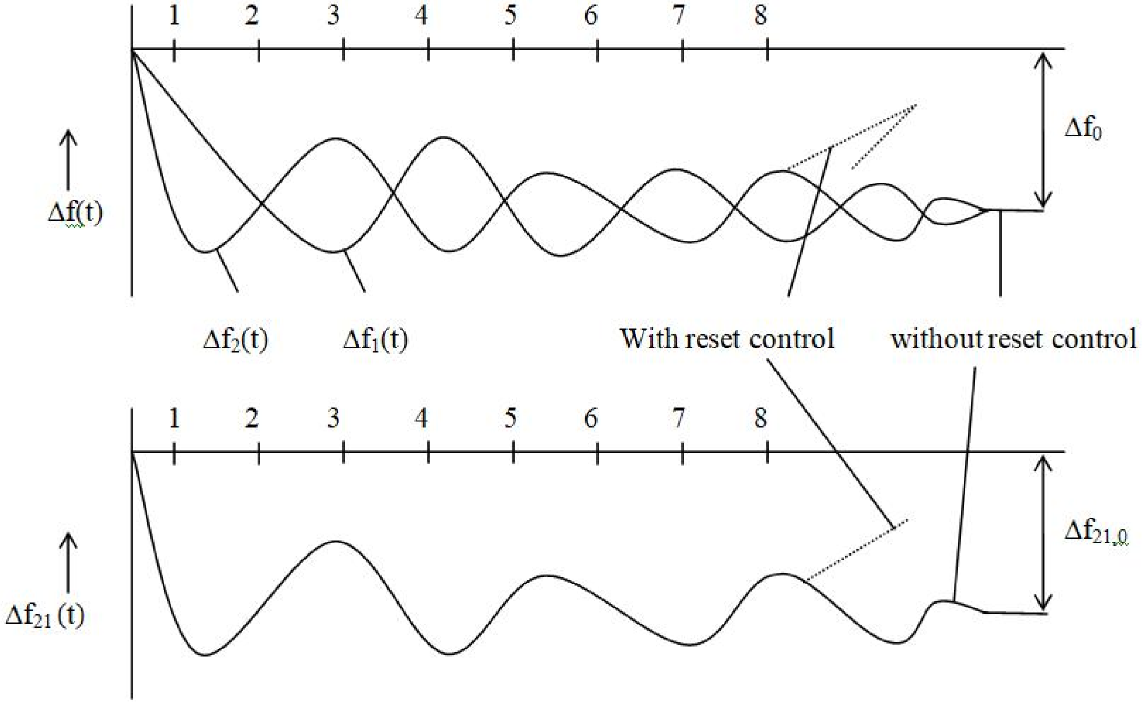
i.e. Assume the load not to vary with frequency $D_1 = D_2 = 0$.

❖Derive the following expression for the tie-line from the block diagram

$$\Delta P_{tie,\,1}(S) = \frac{\pi f^0 T_{12}}{H} \cdot \frac{\Delta P_{D_2}(S) - \Delta P_{D_1}(S)}{S^2 + \left(\frac{f^0}{2RH}\right)S + \frac{2\pi f^0 T^0}{H}} \qquad ....[11]$$

LFC of a two area interconnected system(contd...)

Above observations, conclude that the system damping is strongly dependent on the α-parameter. For low value of D, the value of α is increased and thus high damping is obtained. Therefore, D parameter fills an important damping function in interconnected systems.



LFC of a two area interconnected system(contd…)

Controlled case:

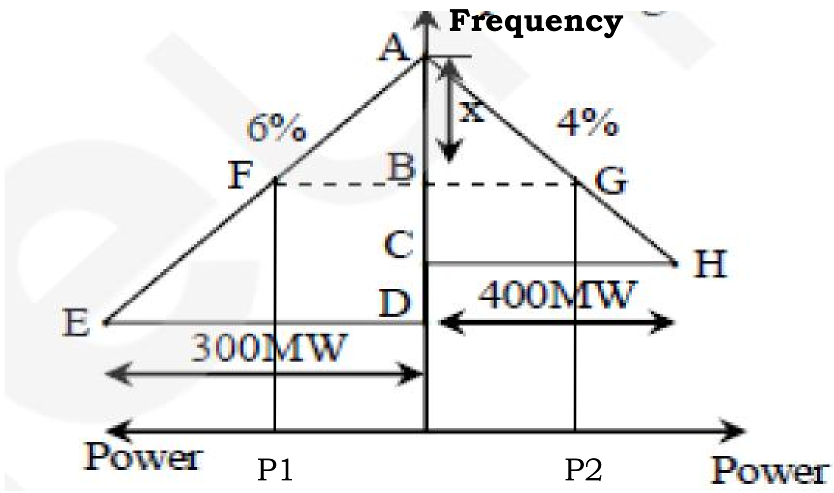
❖If frequency of two areas is to be controlled, the static frequency drop is just one half of that of the isolated operation of two systems If there is change in load in any area, half of it will be shared by the other area.

❖It is found that if a load changes in an area, the frequency and interchange errors in that area have the same sign while these opposite signs for the other area. Thus the relative signs of the frequency and interchange deviations help to identify the area where the load has changed.

Previous years GATE Questions

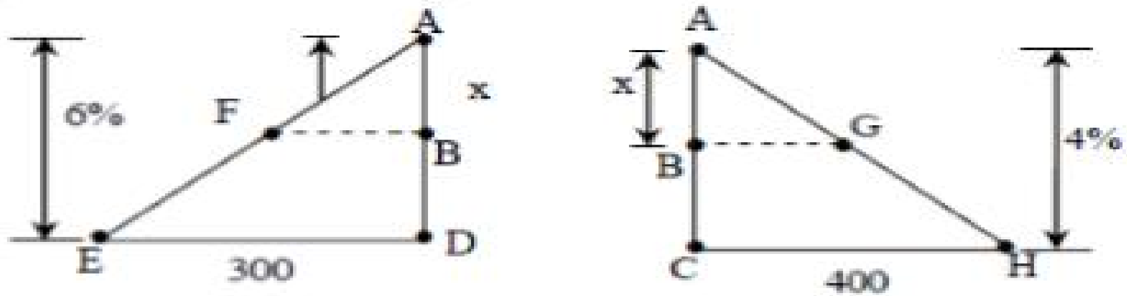
Q. Two generating units rated 300 MW and 400 MW have governor speed regulation of 6% and 4% respectively from no load to full load. Both the generating units are operating in parallel to share a load of 600 MW. Assuming free governor action, the load shared by the larger unit is _______ MW. (gate 2017, set-2)

Sol : let x be the frequency at which 600w load is met.



Previous years GATE Questions(contd...)

From similar triangles method



$$\frac{FB}{ED} = \frac{FB}{ED} \qquad \frac{BG}{CH} = \frac{AB}{AC}$$

$$P_1 = 300 \times \frac{x}{6} \qquad P_2 = 400 \times \frac{x}{4}$$

$$P_1 = 50x \qquad P_2 = 100x$$

Given that $P_1 + P_2 = 600MW$

150x=600

x=4

∴ The load supplied by largest machine is P2=100×4=400MW

Prof. M Venkateswara Rao, Dept. of EEE, JNTUA College of Engineering, Kalikiri, Chittoor District, A P, India