CMR INSTITUTE OF TECHNOLOGY	USN											

Internal Assesment Test 2 – April-2024							
Sub:	Power System operation & Control					Code:	18EE81
Date:	13/04/2024	Duration:	90 mins	Max Marks:	50	Sem: 8	Section: A & B

Note: Answer any **FIVE FULL** Questions

Sketch neat figures wherever necessary. Answer to the point. **Good luck!**

		Marks	OBE CO	OBE RBT
1.	Derive the transfer function and the block diagram of complete ALFC loop	[10]	CO3	L2
2.	Draw the block diagram of two area system with necessary equations	[10]	CO4	L2
3.	Obtain the mathematical model of the ALFC components -speed governor & turbine	[10]	CO2	L3
4.	Write the transfer function & draw the block diagram of ALFC loop with proportional integral controller	[10]	CO3	L2
5	A 1000 MVA generator operates on full load at the rated frequency of 50 Hz. The load is reduced to 800 MW. The steam valve has an operating time lag of 0.6s.If H=5s, determine the change in frequency.	[10]	CO3	L4
6	Consider an isolated generator of 500 MVA , M=8 pu MW/pu Hertz on the machine base. The unit is supplying a load of 400 MVA. The load changes by 1.5 % for a 1% change in frequency. Draw the block diagram for the equivalent generator -load system .For an increase of 10 MVA in the load, determine the steady state frequency deviation and the response.	[10]	CO4	L4

Solutions

1)

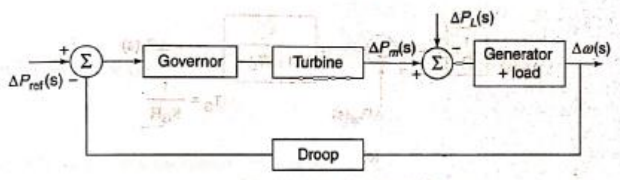


Figure 6.16 Functional block diagram of ALFC.

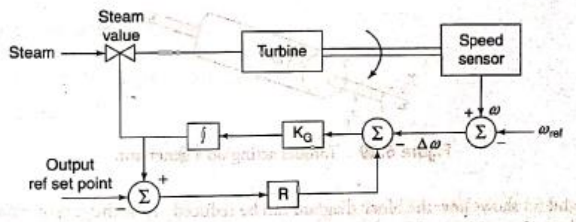


Figure 6.17 Block diagram of governor with droop.

We will now build the mathematical model for each one of the blocks.

6.6.1 Governor Model

The block diagram of the governor with speed-droop mechanism is shown in Fig. 6.17.

Here, the output of speed sensor ω is compared with the reference speed ω_{ref} to produce the speed error $\Delta\omega$. We have a reference set point for the output. By adjusting this set point on a unit, its output can be varied while holding the system frequency close to the standard frequency. The error due to difference between actual power output and reference set point is fed back through the speed regulation R. The transfer function equivalent of Fig. 6.17 is shown in Fig. 6.18(a).

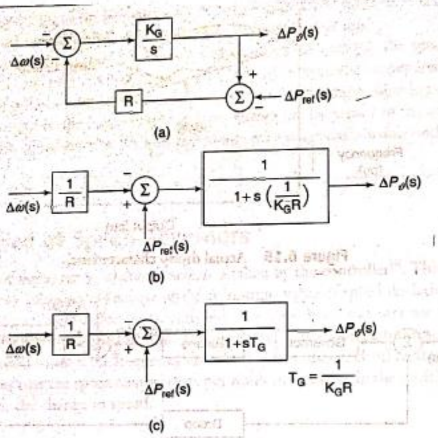


Figure 6.18 Model of governor.

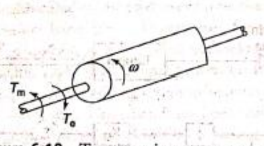


Figure 6.19 Torques acting on a generator.

Figure 6.18(b) and (c) shows how the block diagram can be reduced. T_G is the *governor time constant*. It can be seen that it depends on the speed regulation R and on the gain of the hydraulic amplifier, K_G.

6.6.2 Generator Model

There are two torques acting on a generator: the *shaft torque* (due to the prime mover) and the *electromagnetic torque*, neglecting losses. The shaft torque tends to accelerate the generator in the positive direction of rotation and the electromagnetic torque in the negative direction, as shown in Fig. 6.19.

where I is the moment of inertia,
α is the angular acceleration,
T is the net torque.
Equation (6.7) can be written as

$$I\frac{d^2\theta_m}{dt^2} = T_m - T_e \tag{6.8}$$

where θ_m, the rotor angle, is now converted into an angle, measured with respect to a synchronously rotating reference axis such that

$$\delta_m = \theta_m - \omega_{sm}t \tag{6.9}$$

where ω_{sm} is the synchronous speed in rad/s,
δ_m is the angular displacement in rad.
From Eq. (6.9)

$$\frac{d^2\delta_m}{dt^2} = \frac{d^2\theta_m}{dt^2} \tag{6.10}$$

Substituting into Eq. (6.8), we get

$$I\frac{d^2\delta_m}{dt^2} = T_m - T_e \ N-m \tag{6.11}$$

Multiplying both sides by the angular velocity ω_m, we get

$$\omega_m I\frac{d^2\delta_m}{dt^2} = \omega_m(T_m - T_e) \ N-m \tag{6.12}$$

where
$\omega_m I = M$ = angular momentum or inertia constant
$\omega_m T_m = P_m$ = mechanical power input at the shaft minus rotational losses
$\omega_m T_e = P_e$ = electrical power output minus losses

We can write Eq. (6.12) as

$$M\frac{d^2\delta_m}{dt^2} = P_m - P_e = P_a \ \text{W} \tag{6.13}$$

M depends on the speed ω_m. However, since the deviation in speed is limited, M can be assumed to be a constant. The value of M varies over a wide range depending on the rating and type of the generator. Hence, another constant H is used to specify the energy stored in the machine.

$$\text{H} = \frac{\text{Stored kinetic energy in MJ at synchronous speed}}{\text{Machine rating in MVA}} \ \text{MJ/MVA} \tag{6.14}$$

H is also called *inertia constant*. It lies in a narrow range for different machines.
M and H are related as follows

$$M = \frac{2GH}{\omega_{sm}} \ \text{MJ-s/mech rad} \tag{6.15}$$

where G = MVA rating of machine. In pu, M = 2H.
Now, Eq. (6.13) can be written as

$$\frac{2H}{\omega_{sm}}\frac{d^2\delta_m}{dt^2} = \frac{P_m - P_e}{G} \tag{6.16}$$

We can express both δ_m and ω_{sm} in terms of electrical radians to get

$$\frac{2H}{\omega_s}\frac{d^2\delta_m}{dt^2} = P_m - P_e = P_a \ \text{pu}$$

Here, P_m = per unit mechanical power [P_m in MW/G].
ω_s = synchronous speed in electrical rad/s
$= \frac{P}{2}\omega_{sm}$
P_a = acceleration power

Equation (6.17) is called the *swing equation*. We can linearize Eq. (6.17) to get

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

We express the speed deviation also in pu to get

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

Taking the Laplace transform we get

$$\Delta\omega(s) = \frac{1}{2Hs}(\Delta P_m(s) - \Delta P_e(s))$$

Eq.(6.20) can be written in a block diagram form, as shown in Fig. 6.20.

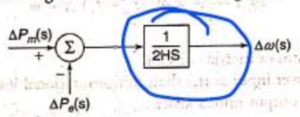


Figure 6.20 Model of generator.

6.6.3 Load Model

We have seen the load models in detail in Chapter 2. Some loads exhibit variation in active power drawn with respect to frequency variations. This relationship is given by

$$\Delta P_{Lfreq} = D\Delta\omega$$

or D = load damping constant

$$D = \frac{\Delta P_{Lfreq}}{\Delta\omega} \tag{6.21}$$

where ΔP_{Lfreq} = frequency-dependent load.

D is expressed as a % change in load divided by % change in frequency. For example, if D = 1.5, it means that the load changes by 1.5% for a 1% change in frequency. The value of D is with respect to that particular load. If the system base is different from the nominal value of load, the value of D must be changed appropriately. Consider a 1,000 MVA load with D = 1.5. This means that the load would change by 1.5% (of 1,000 MVA) for a 1% change in frequency. If now the system base were to be 800 MVA, then D to be considered on this base is

$$D_{New} = D \times \left(\frac{1000}{800}\right) = 1.5 \times \frac{1000}{800} = 1.875$$

Neglecting losses, the change in electrical output of the generator, ΔP_e, is equal to the load. Therefore,

$$\Delta P_e = \Delta P_L + D\Delta\omega \tag{6.22}$$

where ΔP_L = non-frequency sensitive load change

$D\Delta\omega$ = frequency sensitive load change

Or

$$\Delta P_e(s) = \Delta P_L(s) + D\Delta\omega(s) \tag{6.23}$$

Equation (6.22) can be introduced into Fig. 6.20 to obtain Fig. 6.21.

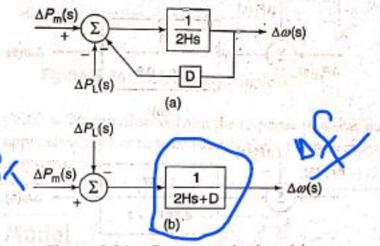


Figure 6.21 Generator + load model.

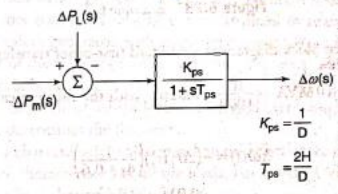
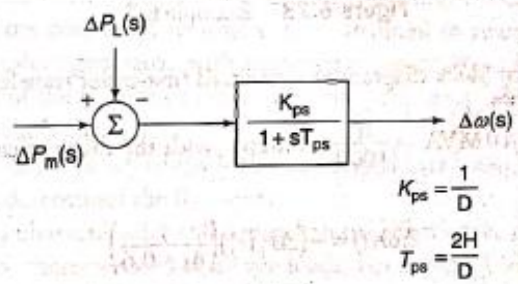


Figure 6.22 Standard first-order model for generator + load.



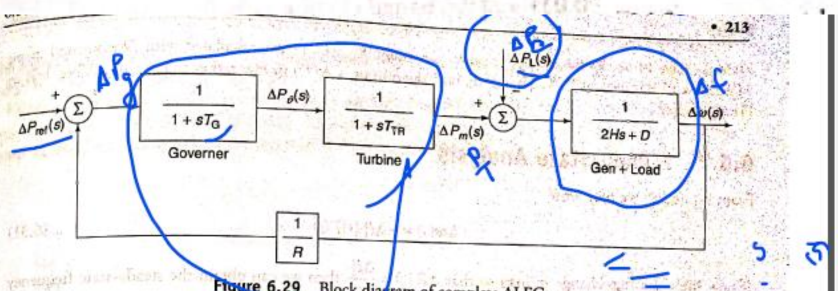


Figure 6.29 Block diagram of complete ALFC.

We are now interested in deriving the effect of change in load on the frequency without change in the reference set point. By changing the reference set point, we can set the system to give specified frequency at any load point as explained in Fig. 6.7(b). This is a secondary control to be discussed later. Here, we assume P_{ref} is kept at a constant value so that $\Delta P_{ref} = 0$. We now find the transfer function $\frac{\Delta\omega(s)}{-\Delta P_L(s)}$. From the block diagram of Fig. 6.29,

$$\Delta\omega(s) = -\Delta P_L(s)\left[\frac{\frac{1}{2Hs+D}}{1+\frac{1}{R}\left(\frac{1}{2Hs+D}\right)\left(\frac{1}{1+sT_G}\right)\left(\frac{1}{1+sT_{TR}}\right)}\right] \tag{6.29a}$$

$$= -\Delta P_L(s)\left[\frac{(1+sT_G)(1+sT_{TR})}{(2Hs+D)(1+sT_G)(1+sT_{TR})+\frac{1}{R}}\right] \tag{6.29b}$$

The transfer function is given by

$$T(s) = \left[\frac{(1+sT_G)(1+sT_{TR})}{(2Hs+D)(1+sT_G)(1+sT_{TR})+\frac{1}{R}}\right]$$

An alternate expression for the transfer function commonly used is

2)

7.2 Tie-Line Control with Primary Speed Control

Let us consider a two-area system as shown in Fig. 7.1.

Let us take the positive power flow to be P_{12}, to be the power flow from area 1 to area 2. The power flow on the tie-line from area 1 to area 2 is

$$P_{12} = \frac{E_1 E_2}{X_{12}} \sin(\delta_1 - \delta_2) \tag{7.1}$$

where

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

Equation (7.1) can be linearized about an initial operating point $\delta_1 = \delta_{10}$ and $\delta_2 = \delta_{20}$ as

$$\Delta P_{12} = \frac{E_1 E_2}{X_{12}} \cos(\delta_{10} - \delta_{20}) \Delta\delta_{12} \tag{7.2}$$

$$\Delta\delta_{12} = \Delta\delta_1 - \Delta\delta_2 \tag{7.3}$$

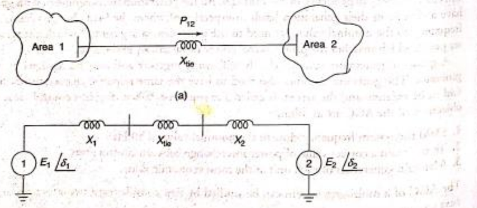
$$\text{Let } T = \frac{E_1 E_2}{X_{12}} \cos(\delta_{10} - \delta_{20}) = P_{max} \cos(\delta_{10} - \delta_{20}) \tag{7.4}$$

where T is called the *synchronizing torque coefficient* (often designated as P_s).

Substituting Eq. (7.4) into Eq. (7.2), we get

$$\Delta P_{12} = T(\Delta\delta_1 - \Delta\delta_2) \tag{7.5}$$

The block diagram representation of the two-area system with only primary control is shown in Fig. 7.2. A positive ΔP_{12} means an increase in power flow from area 1 to 2. This is equivalent to a load increase in area 1 and/or decreasing load in area 2. Therefore, the feedback from ΔP_{12} has a *negative sign* for area 1 and positive sign for area 2. We will now see how the system behaves for a change in the load.



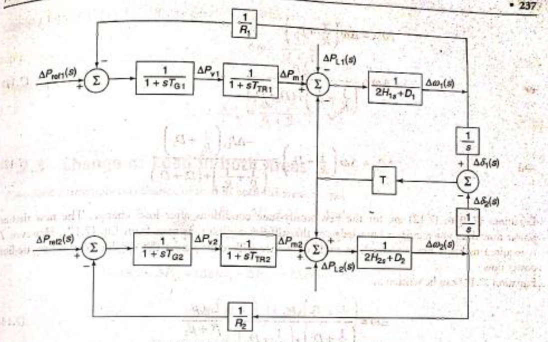


Figure 7.2 Two-area system with primary loop.

7.2.1 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,

$$\Delta\omega = \Delta\omega_1 = \Delta\omega_2 \tag{7.6}$$

(or $\Delta f = \Delta f_1 = \Delta f_2$. Remember that *in pu both Δf and $\Delta\omega$ are the same*). If we assume that the mechanical powers are constant (which means ΔP_{ref} is constant), the tie-line and rotating masses exhibit damped oscillations called *synchronizing oscillations*. For area 1, we can write

$$\Delta P_{m1} - \Delta P_{12} - \Delta P_{L1} = \Delta\omega D_1 \tag{7.7}$$

For area 2, we have

$$\Delta P_{m2} + \Delta P_{12} = \Delta\omega D_2 \tag{7.8}$$

We have further

$$\Delta P_{m1} = \frac{-\Delta\omega}{R_1} \tag{7.9}$$

$$\Delta P_{m2} = \frac{-\Delta\omega}{R_2} \tag{7.10}$$

Substituting Eqs. (7.9) and (7.10) in Eqs. (7.7) and (7.8), respectively, we get

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

or

$$\Delta\omega = \frac{-\Delta P_{L1}}{\left(\frac{1}{R_1} + \frac{1}{R_2}\right) + (D_1 + D_2)} \tag{7.11}$$

and

$$\Delta P_{12} = \Delta\omega\left(\frac{1}{R_2} + D_2\right) = \frac{-\Delta P_{L1}\left(\frac{1}{R_2} + D_2\right)}{\left(\frac{1}{R_1} + \frac{1}{R_2}\right) + (D_1 + D_2)} \tag{7.12}$$

Equations (7.7) to (7.12) are for the new steady-state conditions after load change. The new tie-line power flow does not require a knowledge of the stiffness constant, as seen from Eq. (7.12). However, T is required to know how much phase angle difference will result across the tie due to the new tie-line power flow.

Equation (7.11) can be written as

$$\Delta\omega = \frac{-\Delta P_{L1}}{\left(\frac{1}{R_1} + D_1\right) + \left(\frac{1}{R_2} + D_2\right)} = \frac{-\Delta P_{L1}}{\beta_1 + \beta_2} \tag{7.13}$$

and

$$\Delta P_{12} = \frac{-\Delta P_{L1}\left(\frac{1}{R_2} + D_2\right)}{\left(\frac{1}{R_1} + D_1\right) + \left(\frac{1}{R_2} + D_2\right)} = \frac{-\Delta P_{L1}\beta_2}{\beta_1 + \beta_2} \tag{7.14}$$

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

7.2.2 Change of Load in Area 2

Consider a change of ΔP_{L2} in the load of area 2. We get the following relationships:

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

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

From Eqs. (7.15) and (7.9)

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

From Eqs. (7.16) and (7.10)

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

Adding Eqs. (7.17) and (7.18), we get

$$\Delta\omega = \frac{-\Delta P_{L2}}{\beta_1 + \beta_2} \tag{7.19}$$

From Eq. (7.17)

$$\Delta P_{12} = \frac{\Delta P_{L2}\,\beta_1}{\beta_1 + \beta_2} = -\Delta P_{21} \tag{7.20}$$

7.2.3 Change of Load in both Areas

If we have a simultaneous change of load in both the areas, we get

$$\Delta P_{m1} - \Delta P_{12} - \Delta P_{L1} = \Delta\omega D_1 \tag{7.21}$$

$$\Delta P_{m2} + \Delta P_{12} - \Delta P_{L2} = \Delta\omega D_2 \tag{7.22}$$

Adding Eqs. (7.21) and (7.22) we get

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

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

$$= \Delta\omega(\beta_1 + \beta_2)$$

$$\therefore \Delta\omega = \frac{-(\Delta P_{L1} + \Delta P_{L2})}{\beta_1 + \beta_2} \tag{7.23}$$

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

$$= \frac{1}{\beta_1 + \beta_2}[-\Delta P_{L1}\,\beta_2 + \Delta P_{L2}\,\beta_1] \tag{7.24}$$

We can observe from the above discussion that with only primary governor control, load change in either of the areas will lead to a steady-state deviation in frequency of both areas.

3)

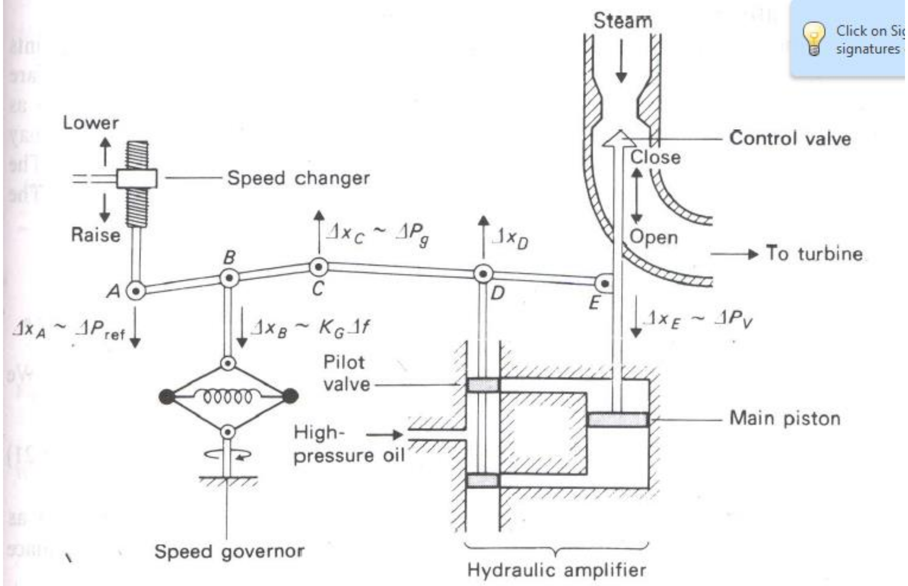


Figure 9-7 Simplified functional diagram of the primary ALFC loop.

megawatt increment ΔP_V. This flow increase translates into a turbine power increment ΔP_T in the turbine (not shown in the figure).

Very large mechanical forces are needed to position the main valve (or gate) against the high steam (or water) pressure, and these forces are obtained via several stages of hydraulic amplifiers. In our simplified version we show only one stage. The input to this amplifier is the position x_D of the *pilot valve*. The output is the position x_E of the *main piston*. Because the high-pressure hydraulic fluid exerts only a slight differential force on the pilot valve, the force amplification is very great.

The position of the pilot valve can be affected via the linkage system in three ways:

1. *Directly*, by the *speed changer*. A small downward movement of the linkage point A corresponds to an increase ΔP_{ref} in the reference power setting.
2. *Indirectly*, via feedback, due to position changes of the main piston.
3. *Indirectly*, via feedback, due to position changes of linkage point B resulting from speed changes.

It should prove a useful exercise for the reader to find, *qualitatively*, the workings of the mechanism. For example, give a "raise" command to the speed changer and prove that this indeed results in an increase in turbine output. Prove also that a speed drop will give the same effect.

Presently we shall give a *quantitative* description of the mechanism.

In the analysis to follow, incremental movements of the five linkage poin $A \cdots E$ in Fig. 9-7 are of particular interest. In reality these movements ar measured in millimeters but in our analysis we shall rather express them a *power increments* expressed in megawatts or per-unit megawatts as the case ma be. The movements are assumed positive in the directions of the arrows. Th governor *output command* ΔP_g is measured by the position change Δx_C. Th governor has two inputs:

1. Changes ΔP_{ref} in the reference power setting
2. Changes Δf in the speed of frequency of the generator, as measured by Δx_B

An *increase* in ΔP_g results from an *increase* in ΔP_{ref} *and* a *decrease* in Δf. W thus can write for *small* increments

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\Delta f \qquad \text{MW} \qquad (9\text{-}21$$

The constant R has dimension hertz per megawatt, and is referred to a *regulation* or *droop*. (For numerical values see Example 9-2 below.) Laplac transformation of Eq. (9-21) yields

$$\Delta P_g(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta f(s) \qquad (9\text{-}22$$

Using well-known block diagram symbols we have represented the governo as shown in Fig. 9-8.

9-3-2 Hydraulic Valve Actuator

The input position Δx_D of the valve actuator increases as a result of an increased command ΔP_g but decreases due to increased valve output, ΔP_V. Equal increases in both ΔP_g and ΔP_V should result in $\Delta x_D = 0$. We can thus write

$$\Delta x_D = \Delta P_g - \Delta P_V \qquad \text{MW} \tag{9-23}$$

For small changes Δx_D the oil flow into the hydraulic motor is proportional to position Δx_D of the pilot valve. Thus we obtain the following relationship for the position of the main piston:

$$\Delta P_V = k_H \int \Delta x_D \, dt \tag{9-24}$$

The positive constant k_H depends upon orifice and cylinder geometries and fluid pressure.

Upon Laplace transformation of the last two equations and upon elimination of Δx_D we obtain the actuator transfer function

$$G_H(s) = \frac{\Delta P_V}{\Delta P_g} = \frac{1}{1 + sT_H} \tag{9-25}$$

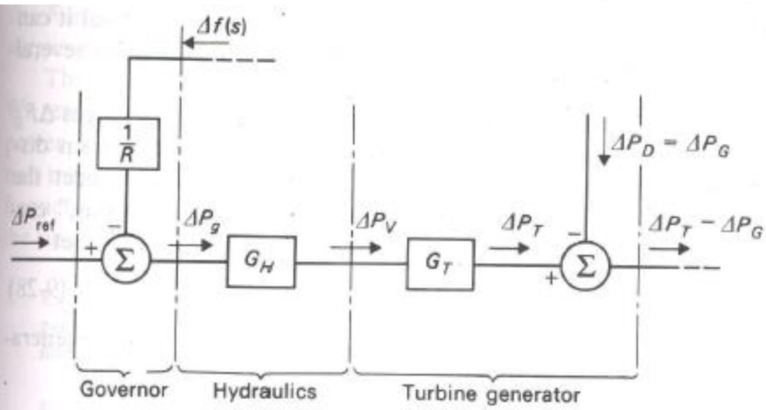


Figure 9-8 Linear model of the primary ALFC loop (minus the power system response).

where the *hydraulic time constant*

$$T_H = \frac{1}{k_H}$$

typically assumes values around 0.1 s.

The hydraulic valve actuator has been represented by the transfer function $G_H(s)$ in Fig. 9-8.

4)

response to the load change, irrespective of the location of the load.

Restoration of the system frequency to the scheduled value requires *supplementary control* to change the load reference set point. This secondary control, called AGC, becomes the basic means of controlling prime mover power to match the variations of the system load. The controller should satisfy the following[6,7]:

- Stable closed loop control operation
- Keep frequency deviation to a minimum
- Limit the integral of the frequency error
- Divide the load economically

In an isolated system as considered here, there is no interchange power to be considered. The function of the AGC is purely to maintain the frequency at the scheduled value. This is achieved by adding a proportional integral controller in the feedback path to change the load reference setting depending on the frequency deviation. From control theory it is known that the steady-state error of a proportional integral controller is zero.

6.8 Proportional Integral Controller

The proportional integral controller is added to the ALFC as shown in Fig. 6.35(a), along with the reduced models in Fig. 6.35(b) and 6.35(c).

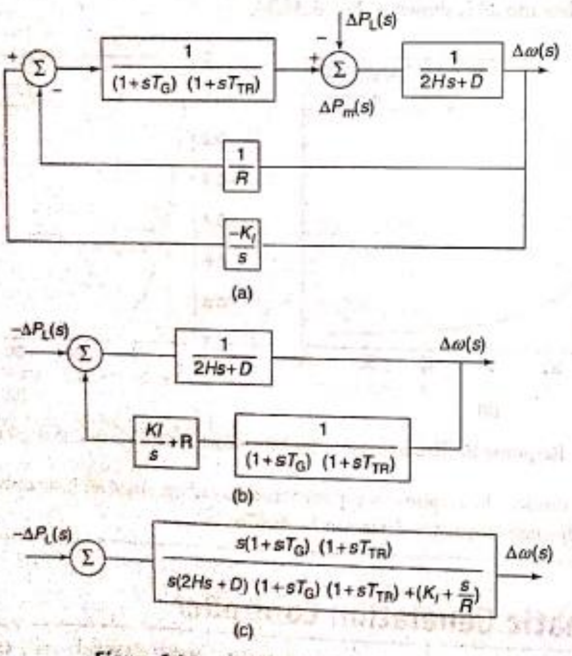


Figure 6.35 AGC with integral controller.

The signal generated by the integral controller must be of opposite sign to $\Delta\omega(s)$ (or $\Delta f(s)$). This means that for a decrease in $\Delta f(s)$ the generation must increase ($\Delta P_{ref}(s)$ must be positive). Hence, the integrator block in Fig. 6.35(a) is shown with a negative sign. K_I itself is positive. It can be seen that $\Delta\omega(s) = \frac{-\Delta P_L(s)}{s} T(s)$ for a step change in load. From Fig. 6.35(c), we can see that $\lim_{s\to 0}(s\Delta\omega(s)) = 0$. Hence, the steady-state frequency deviation is zero. The frequency error is called the area control error (ACE). The additional signal which controls the power setting is the integral of the ACE.

The integral controller can also be represented in terms of the system constants as follows:

$$\frac{\Delta f(s)}{-\Delta P_L(s)} = \frac{sK_{ps}(1+sT_G)(1+sT_{TR})}{s(1+sT_{ps})(1+sT_G)(1+sT_{TR})+K_{ps}\left(K_I+\frac{s}{R}\right)} \tag{6.35}$$

The command signal is given by $\Delta P_{ref} = -K_I \int \text{ACE}\, dt$, where K_I is the integral gain constant which controls the rate of integration. The steady-state deviation is driven to zero, irrespective of the choice of the integral gain and R. We thus now have two parameters, K_I and R, to control the dynamic response of the system. *The integrator output is zero only when the speed deviation is zero.* Under this condition, $\Delta P_{ref} = 0$.

This supplementary control is much *slower* than the primary speed control action. It comes into effect only after the primary control has stabilized the system frequency. The primary control acts on all units with speed regulation, whereas AGC adjusts the load reference setting in only a few selected units. The outputs of these units override the effect of the composite frequency regulation characteristics of the system and in the process force the generation of all other units not on AGC to scheduled values.

5)

Solution

Let the kinetic energy stored initially at nominal frequency be KE_0. Let the kinetic energy after the change in load be KE, at a frequency equal to $f_0 + \Delta f$. The kinetic energy is proportional to (frequency)^2 or ω^2. Therefore,

$$\frac{KE}{KE_0} = \left(\frac{f_0 + \Delta f}{f_0}\right)^2$$

$$f = f_0 + \Delta f = f_0 \sqrt{\frac{KE}{KE_0}}$$

The kinetic energy stored in the rotor initially is GH.

$$GH = 1000 \times 10^3 \times 5 = 5 \times 10^6 \text{ kW-s}$$

When the load drops suddenly, the mechanical power output remains at 1000 MW. The excess power (1000 − 800) of 200 MW is converted to kinetic energy. The amount of kinetic energy input to the rotating masses in 0.6s is given by

$$KE = 200 \times 10^3 \times 0.6 = 1.2 \times 10^5 \text{ kW-s}$$

The total kinetic energy after change in load is sum of the two. Using the expression for f, derived above, the frequency at the end of 0.6s is

$$= 50 \times \sqrt{\left(\frac{5 \times 10^6 + 1.2 \times 10^5}{5 \times 10^6}\right)} = 50.596 \text{ Hz}$$

6)

Solution

(Refer example 6.5 where it is solved graphically)

Choose a base of 200 MW. $D = 0$

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

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

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

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

Frequency at new load = 1.01538 pu
= 50.769 Hz

$$\Delta P_1 = \frac{-\Delta f}{R_1} = \frac{-0.01538}{0.04} = -0.3845\,\text{pu}$$
$$= -0.3845 \times 200$$
$$= -76.9\,\text{MW}$$
$$P_1 = 200 - 76.9 = 123.1\,\text{MW}$$
$$\Delta P_2 = \frac{-\Delta f}{R_2} = \frac{-0.01538}{0.025} = -0.6152\,\text{pu}$$
$$= -123.04\,\text{MW}$$
$$P_2 = 400 - 123.04 = 276.96\,\text{MW}$$
$$P_1 + P_2 = P_L = 400\,\text{MW}$$

Now $D = 1.5$

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

Frequency at new load = 1.01504 pu
= 50.752 Hz

$$\Delta P_1 = \frac{-0.01504}{0.04} \times 200 = -75.2\,\text{MW}$$
$$P_1 = 200 - 75.2 = 124.8\,\text{MW}$$
$$\Delta P_2 = \frac{-0.01504}{0.025} \times 200 = -120.32\,\text{MW}$$
$$P_2 = 279.68\,\text{MW}$$

$D\Delta\omega$ = increase in load due to frequency change = 1.5×0.01504
= 0.02256 pu
= 0.02256×200
= 4.512 MW

$$P_1 + P_2 = 404.5\,\text{MW}$$
$$= P_L + D\Delta\omega$$