Module 3 : Frequency Control in a Power System

Lecture 15 : Speed Governor

Objectives

In this lecture you will learn the following

- What are the transient processes before system frequency settles down to steady state ?

We have seen the effect of speed droop settings on sharing of excess load between generators in steady state.

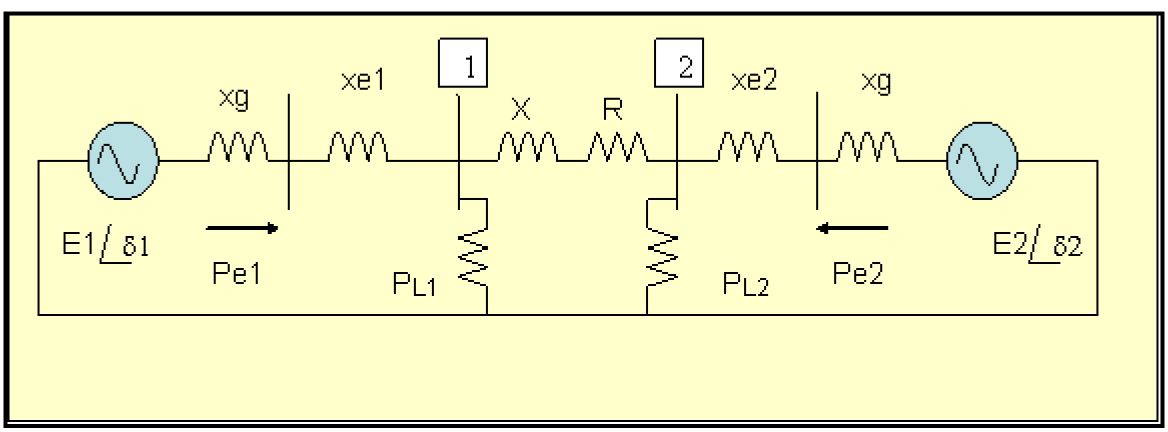
Although we have considered only the steady state conditions, it is to be noted that governors, turbines and generators (and practically all constituents of a power system) are governed by dynamic equations. This means that steady state is not reached instantaneously. Indeed, if the transient processes are not stable, the system will not settle down to the steady state. Thus it is important to consider the dynamical equations which govern the physical structures, especially the prime mover system. While dynamical modelling of components is beyond the scope of this course, we will briefly discuss the working of a steam governor.

A speed governor is a device which senses speed deviation from its reference value and appropriately changes control valve position in a steam turbine or gate position in a hydraulic turbine. This is achieved in older units using mechanical and hydraulic arrangements (mechanical hydraulic governors), while in modern units, the sensing and computing functions are done electrically (electrohydraulic governors). A speed governor should allow us to change the governor gain (or equivalently the droop) and also change the speed and/or load reference. A governor may also have additional parameters which tailor its dynamic response so that instability does not take place.

A student is referred to the book "Power System Stability and Control" by P. Kundur, McGraw Hill, New York, 1994, for further reading on this subject.

We study the frequency *transients* for a simplified two generator system with speed governing, by an **example**.

onsider 2 identical generators supplying 2 loads as shown in the figure below.



Consider the 2 generator, 2 load system shown in the figure below.

The generator field voltage is controlled to maintain its terminal voltage. A simplified model of a generator is used (a voltage source behind an equivalent reactance -xg). The loads are voltage dependent but not frequency dependent, and are of unity power factor.

Load 1 : $P_{L1} = 0.5 * \left(\frac{V_1}{V_o}\right)^2$

Load 2 : $P_{L2} = 0.5 * \left(\frac{V_2}{V_o}\right)^2$

$V_o = 1.0$

A simplified composite transfer function of governor and turbine for both generators is assumed to be as follows:

$$\Delta P_{mi} = C_{Gi}\left(\frac{0.2s+1}{0.7s+1}\right)\left(\frac{\omega_{REFi}-\omega_i}{\omega_o}\right)$$

$$P_{mi} = P_{m0i} + \Delta P_{mi}$$

All values are on a common base.

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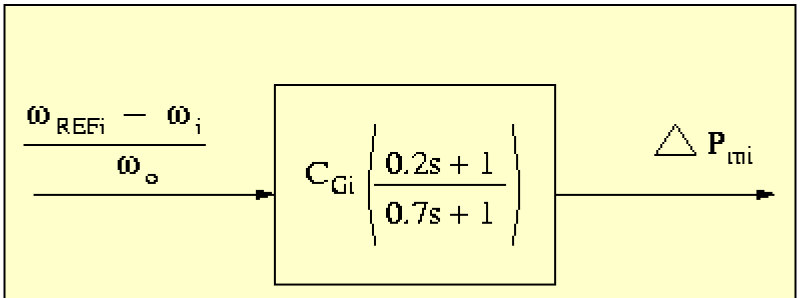

Governor & Turbine simplified model

Assume that for both generators, $P_{m0i} = 0.5$ and $C_{Gi} = 20$; $\omega_{REFi} = \omega_o = 2 * \pi * 50$

Here, C_{Gi} represents the gain of a ***proportional speed controller***. Note that in steady state :

$$\Delta P_{mi} = C_{Gi}\left(\frac{\omega_{REFi} - \omega_i}{\omega_o}\right)$$

Thus C_{Gi} is related to the droop of the generator characteristic.

Plot the variation in generator speeds if Load 1 is increased by 10 %, i.e.,

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Assume inertia constant of each generator $H = 3$ MJ/MVA

$x_g = 0.5, x_e = 0.2, R = 0.02, X = 0.2$

Initially, the voltage at the load buses 1 and 2 are 1.0 pu.

The generator mechanical ("swing") equations have already been discussed before. The natural transients associated with the electrical network/loads are assumed to be fast compared to the electro-mechanical transients; therefore the network and loads are represented by their sinusoidal steady state equations.

The solution of the problem is given in the following slides.

Solution:

The variation in generator speeds can be obtained by numerically integrating the swing equations and the dynamical equations corresponding to the speed governors and turbines. They are :

$$\frac{d(\omega_i - \omega_o)}{dt} = \frac{d\omega_i}{dt} = \frac{\omega_B}{2H_i}(P_{mi} - P_{ei}) = \frac{\omega_B}{2H_i}(P_{m0i} + \Delta P_{mi} - P_{ei})$$

$$\frac{d\delta_i}{dt} = (\omega_i - \omega_o)$$

The dynamical equations of the turbine -governor for each generator can be written as follows:

$$\frac{d\Delta P_{si}}{dt} = \frac{1}{0.7}\left(-\Delta P_{si} + C_{Gi}\left(\frac{\omega_{REFi} - \omega_i}{\omega_o}\right)\right)$$

$$\Delta P_{mi} = C_{Gi}\left(\frac{\omega_{REFi} - \omega_i}{\omega_o}\right) * \frac{0.2}{0.7} + \Delta P_{si} * \left(1 - \frac{0.2}{0.7}\right)$$

where ΔPsi is a state of the system.

Verify that these yield the transfer function

$$\Delta P_{mi} = C_{Gi}\left(\frac{0.2s + 1}{0.7s + 1}\right)\left(\frac{\omega_{REFi} - \omega_i}{\omega_o}\right)$$

Solution (Con td..):

Also,

$$P_{ei} = \mathbf{Re}(\bar{V}_{Gi}\bar{I}^*_{Gi})$$

where $\bar{V}_{Gi}$ and $\bar{I}_{Gi}$ are the generator terminal voltages and current respectively. These may be obtained by solving the network (in terms of δ_1 and δ_2).

The initial conditions of the various state are as follows:

Initial Conditions:

$$\Delta P_{si} = \Delta P_{mi} = \frac{\omega_{REFi} - \omega_i}{\omega_o} = 0,$$

$$P_{m01} = P_{m02} = 0.5$$

There is no power flow initially on the line connecting bus1 and 2. Thus $\theta_1 = \theta_2$ initially. If the initial phase angle at load bus 1 is taken to be zero, then $\theta_1 = \theta_2 = 0.0$.

$$\delta_1 = 19.29; \quad \delta_2 = 19.29 \text{ deg}$$

Verify that $E_1 = E_2 = 1.0595$, so that the load bus voltages are 1.0 pu.

The results of the numerical integration (Runge-Kutta 4th order method with time step of 0.01) are shown below. **A MATLAB/SIMULINK simulation model files to do the same can be downloaded from here (init.m, governor.mdl)**. First run the file init.m by typing init at the MATLAB prompt. After that, run the SIMULINK file.

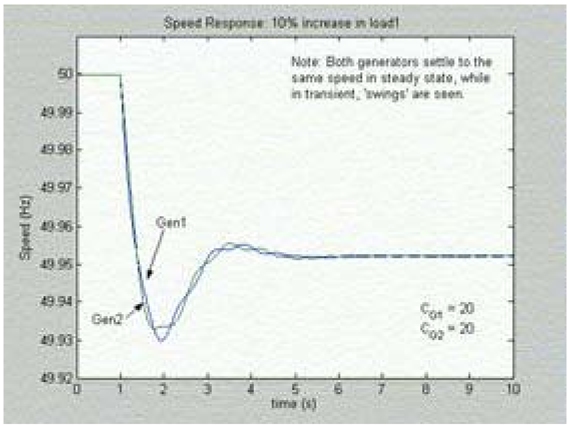
For the step increase in load 1 by 10% (i.e., the load resistance at bus1 reduces by 10%), note the following:

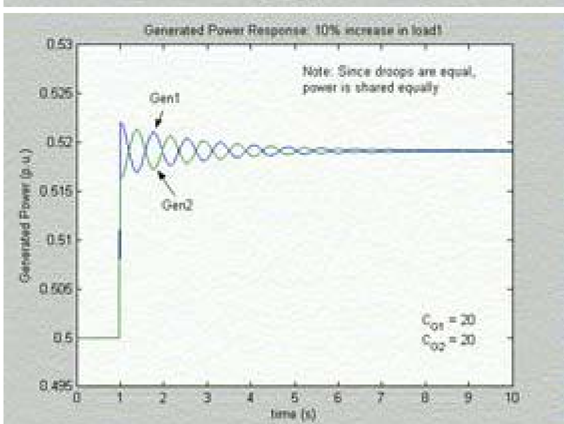
a) Changes in generator speeds. Notice the aggregate movement as well as the relative motion (swings).

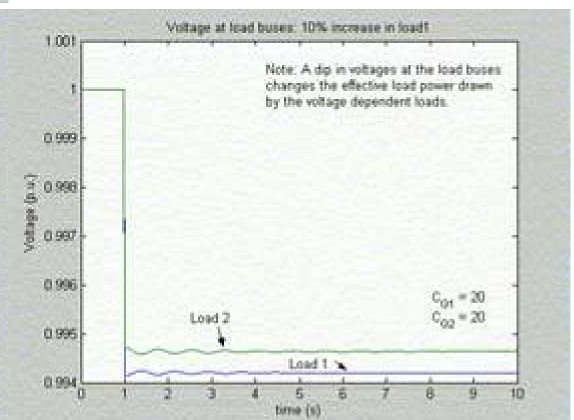
b) Power output of both machines

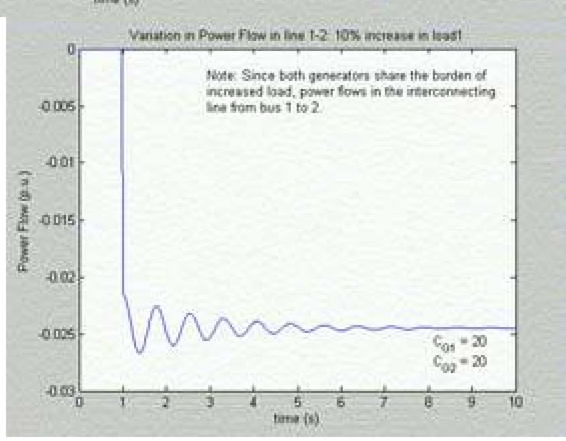
c) Voltages at both load buses

d) Power Flow through the tie line between buses 1 and 2 (it changes : why?)









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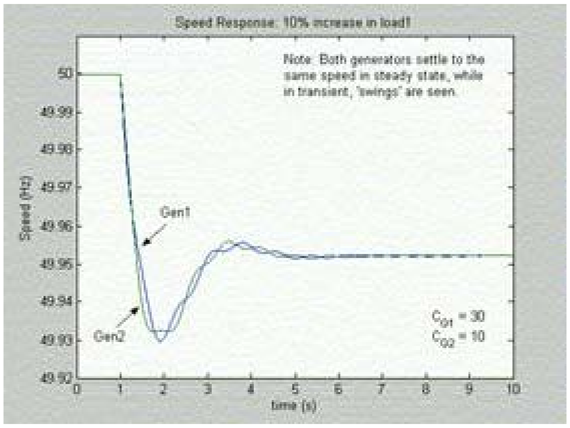
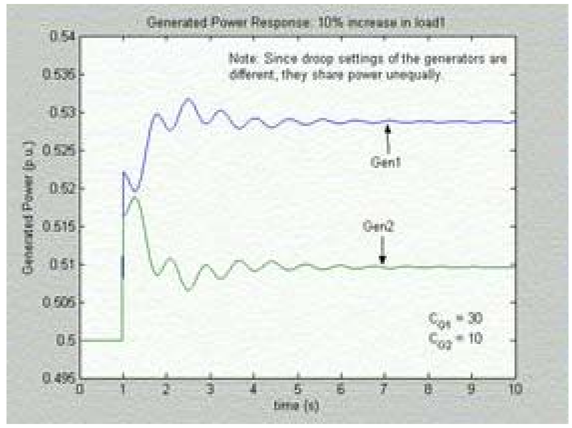
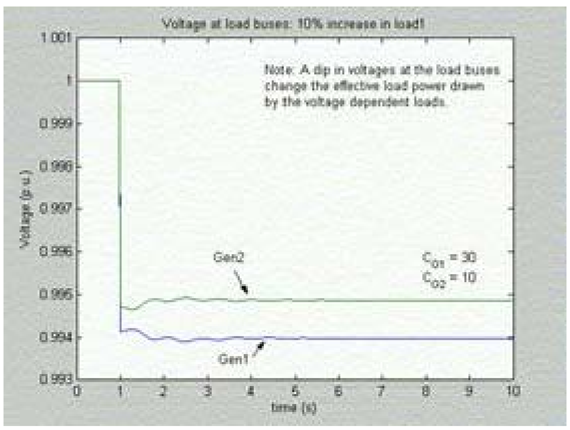
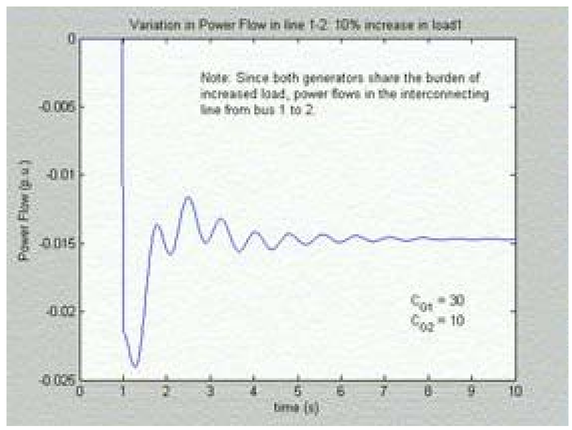
Let $C_{G1} = 30$ and $C_{G1} = 10$ and let us repeat the exercise.
The change in the generation share is obvious. The generator with a larger C_G takes on more load. The values of C_{Gi} not only determine the load sharing, but also the speed of response.









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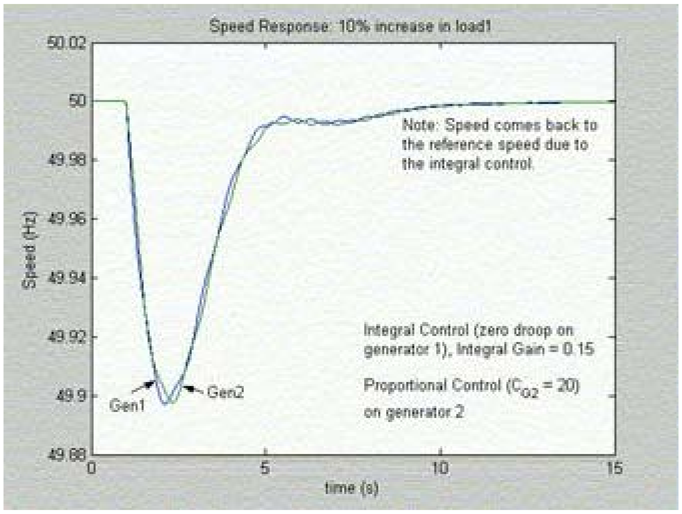
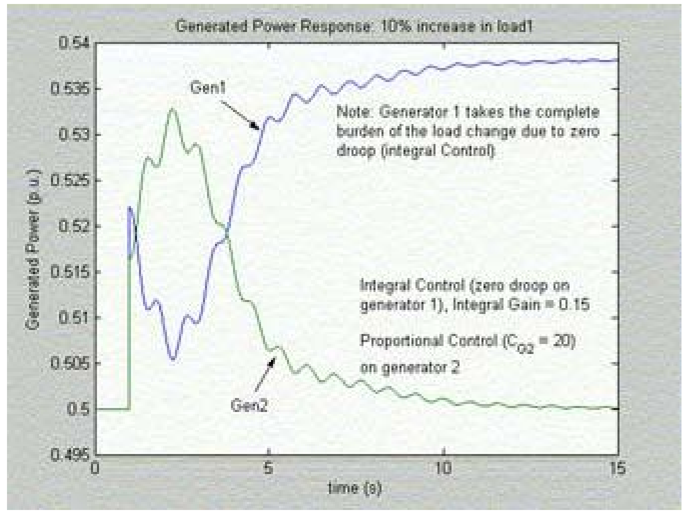
Since $C_{Gi}\frac{\mathbf{1}}{s}$ is infinite in steady state, $\omega_{REFi} - \omega_i$ has to be equal to zero for ΔP_{mi} to be finite.

In other words, the droop of this speed governor characteristic is zero.
We have discussed in detail the consequences of having one or more than one generator having droop zero.
If generator 1 has the integral speed governor, then it takes on ***all*** the load change as shown in the figures below.





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However we emphasize the point that it is not feasible to have integral type speed governors (or equivalently zero droop characteristics) on *more than one* generator in the system; non-zero droops on all machines is preferable for load sharing among generators.

Recap

In this lecture you have learnt the following

- The transient processes before a system settles to equilibrium have been discussed.
- This is illustrated using an example wherein numerical integration of system equations is done.
- It is clear that droop decides the load sharing; Zero droop on *one* generator causes that generator to take on the complete burden of excess load.

Congratulations, you have finished Lecture 15. To view the next lecture select it from the left hand side menu of the page.