Module 3 : Frequency Control in a Power System

Lecture 11 : Definition of Frequency

What determines grid frequency?s

While it has been stressed that frequency is the same in steady state throughout a synchronous grid, two very interesting questions need to be answered:

- What is the precise value of frequency to which a system will settle?
- How does the "system frequency" vary during transients? How does one obtain a useful definition of frequency when individual generators speeds can be different during transients?

To understand this we need to look at the basic governing equations of synchronous machines in a system.

We know that for the **ith** generator,

$$\frac{d(\omega_i - \omega_o)}{dt} = \frac{d\omega_i}{dt} = \frac{\omega_B}{2H_i}(T_{mi} - T_{ei})$$

where ω_i is the rotor speed and ω_o is the nominal (or rated) speed.

T_{mi}, T_{ei} are the mechanical and electrical torques respectively expressed in per-unit.

ω_B is the base frequency and H is the inertia constant in MJ/MVA.

By summing up these equations we obtain,

$$\sum \frac{2H_i}{\omega_B}\frac{d\omega_i}{dt} = \sum(T_{mi} - T_{ei})$$

If frequency deviations are assumed to be small, then in per-unit $(T_{mi} - T_{ei}) \approx (P_{mi} - P_{ei})$

Therefore,

$$\sum \frac{2H_i}{\omega_B}\frac{d\omega_i}{dt} = \sum(P_{mi} - P_{ei})$$

If natural transients in the transmission network are neglected, $\sum P_{ei} = \sum P_{Lk} + losses$

where, $\sum P_{Lk}$ is the total load on the system.

$$\sum \frac{2H_i}{\omega_B}\frac{d\omega_i}{dt} = \sum P_{mi} - \sum P_{Lk} - losses$$

Note : P_{mi} and P_{ei} denote the per unit mechanical and electrical powers respectively.

Since in general, P_{Lk}, P_{mi} and even losses are functions of the frequency:

$$\sum \frac{2H_i}{\omega_B}\frac{d\omega_i}{dt} = \sum P_{mi}(\omega_i) - \sum P_{Lk}(\omega_{bk}) - losses(\omega_1, \omega_2 \dots)$$

ω_{bk} is the bus frequency at the k^{th} load.

Note that frequency all over the system is equal in steady state.

Therefore, in steady state

$$\sum P_{mi}(\omega_e) - \sum P_{Lk}(\omega_e) - losses(\omega_e) = 0$$

The solution of the above equation gives the value of steady state frequency ω_e.

It was seen that steady state frequency is determined by the load-generation-loss balance equation. For analysis under transient conditions, consider the analytical development and illustrative analogy given below.

There are two types of motion to be considered when generator rotors are subject to transients :

a) **Relative motion between generators:** Rotor speeds may not be equal during transients. Exchange of power between generators during transients causes relative rotor movement ("swings"). This phenomenon was considered in the previous module. Relative motion dies down if the system is *angular stable*. Relative motion needs to be stable so that eventually all rotors move together at a common speed.

b) **Motion of the center of inertia** or the "**common motion**": If we sum up the swing equations of individual generators, we obtain:

$$\sum \frac{2H_i}{\omega_B}\frac{d\omega_i}{dt} = \frac{2(\sum H_i)}{\omega_B}\frac{d\left(\frac{\sum H_i\omega_i}{\sum H_i}\right)}{dt} = \frac{2H_{coi}}{\omega_B}\frac{d\omega_{coi}}{dt} = \sum P_{mi} - \sum P_{Lk} - losses$$

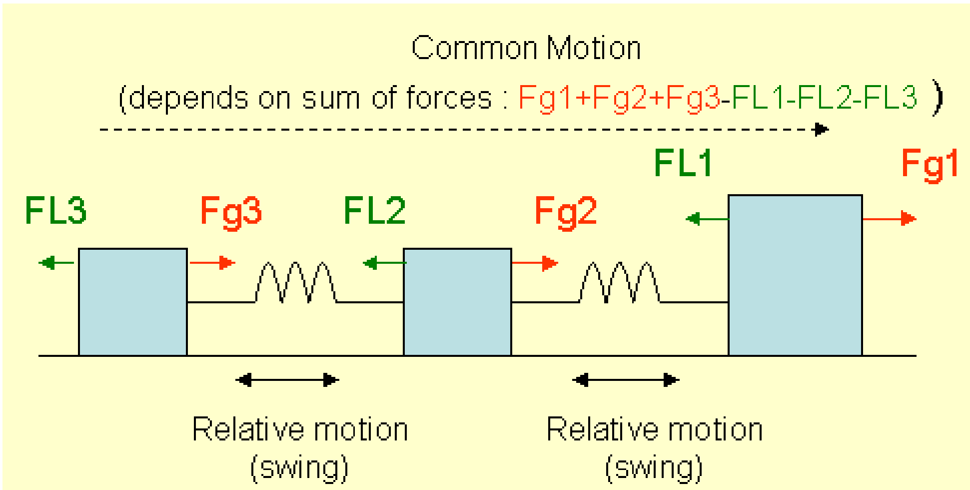
Note $\omega_{coi} = \left(\frac{\sum H_i\omega_i}{\sum H_i}\right)$ represents the centre of inertia speed of the system.

Interestingly**, center of Inertia** movement is determined **ONLY** by the load-generation-loss balance. Motion of center of inertia may exist even if there is no *relative* movement between rotors. Conversely it is possible to have relative motion between generator rotors without center of inertia movement.

Center of inertia frequency can be considered as a definition of "system frequency" under transient conditions. You can verify that under equilibrium conditions, i.e., when all machines settle to a common speed we, center of inertia frequency also equals we.

In this module, we will concentrate on center of inertia movement and not on relative motion between rotors. We shall assume that relative motion is stable (machines stay in synchronism).

We illustrate the concept of "system frequency" as a quantity affected by the aggregate of forces acting on the system by the familiar mass - spring analogy.



Recap

In this lecture you have learnt the following

- A system settles to a frequency at which generation is equal to the load plus losses.

- It is important to distinguish between relative motion between generator rotors and center of inertia (common) movement. Center of inertia movement is dependent **only** on the load-generation balance and is a useful definition of frequency under transient conditions.

- Congratulations, you have finished Lecture 11. To view the next lecture select it from the left hand side menu of the page.