Power Systems Operation and Control
Lecture 10
Load frequency controlling(LFC)

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Lecture learning outcomes:

At the end of this lecture, you will be able to:

i. Understand the importance of frequency control

ii. Knows the single area modeling of frequency control

iii. Differentiate the free governor and reference control mechanisms

iv. Develop the composite system modeling

Content

1. Introduction

- A single-area control system is designed to maintain the balance between generation and load within a specific area.
- A single area control system (SAC) typically refers to a system used in power grid management to contr ol and optimize the operation of a specific area within a larger power system
- The primary goal is to ensure that the system operates at its desired frequency and power output.
- To analyze a single-area control system in a power system, we need to consider both steady-state and dynamic responses, as well as the effects of control mechanisms.
- It focuses on maintaining the balance between electricity supply and demand, ensuring reliability, and m anaging resources effectively.

Introduction Cont.…

Components of the Control System

- Generation Control: Regulating output from power plants to meet demand.
- Load Forecasting: Predicting electricity demand based on historical data and trends.
- Frequency Control: Maintaining the system frequency within acceptable limits.
- Data Monitoring: Continuous monitoring of system parameters to detect issues.

Introduction Cont.…

- Communication Systems: Facilitating real-time data exchange among control centers.
- Provides Improved Reliability: Minimizes outages and enhances service quality.
- Better for Operational Efficiency: Optimizes resource use, reducing costs.
- Adapts to changes in demand and supply conditions.
- Used by utilities to manage localized power systems, such as cities or regions and Integrates r enewable energy sources to enhance sustainability.

2. Single Control Area(SCA)

- A models for speed governor, turbine-generator and load (frequency dependant and non-frequency dependant loads are very important and used as an input for frequency control[1].
- However, in practice, a single generator feeds a large area rarely exist and the model developed could be extended into large system.
- Thus, several generators are connected in parallel, which are located in different places and remote area will supply the power needs of overall area.
- Normally, these generators have to be synchronized and have to have the same response characteristics in load demand.

SCA Cont….

- This kind of coherent operational is called a single control area(SCA).
- In control area , the frequency is assumed to be the same throughout in static as well as dynamic conditions.
- In such a case, it is possible to define a control area, grouping all the generators in the area together and treating them as *a single equivalent* generator,
- Thus, for the purpose of developing a suitable control strategy, a control area can be reduced to a single speed governor, turbo-generator and load system.
- Putting together, the carious models derived so far is considered as a single control area can be conceived in Fig.1.

SCA Cont….

- The block diagram of single area system, where the gain and time constant in each block are as described in the individual section before, is as shown below[2].

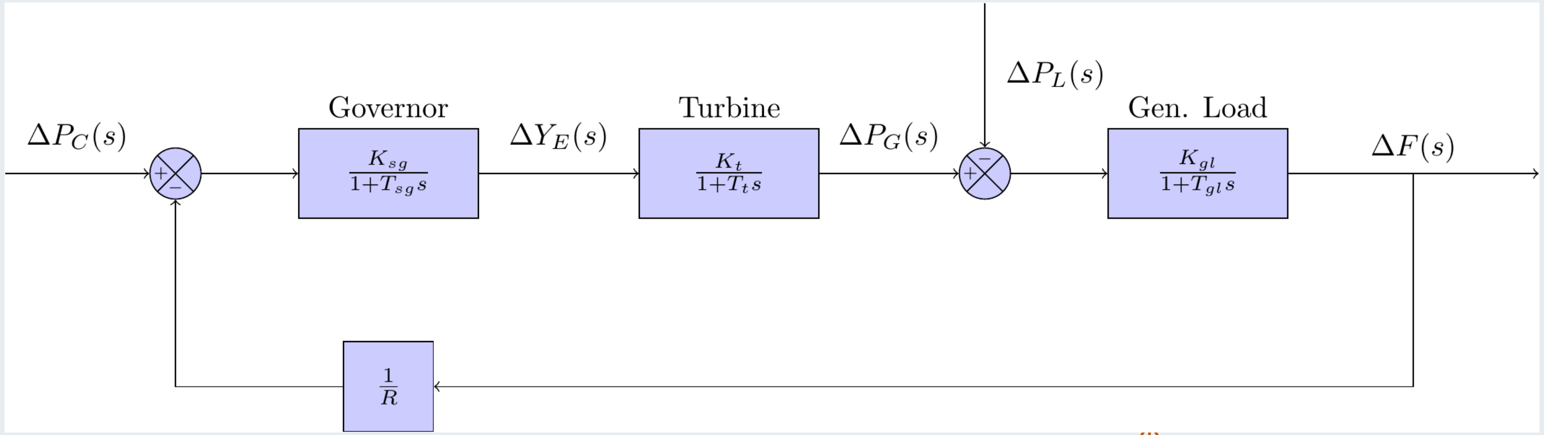

Figure 1. Single area control system. Url:https://skreynolds.github.io/assets/single_area_p_control_model.png

$$\Delta F(s) = \left[\left[\Delta P_{ref} - \frac{\Delta F(s)}{R}\right]\left(\frac{K_s}{1+sT_s}\right)\left(\frac{K_{TG}}{1+sT_{TG}}\right) - \Delta P_L\right]\frac{K_p}{1+sT_p} \qquad \text{eqn.(1)}$$

SCA Cont.…

In a SCA, the basic recruitments for fruitful operation of the network are :

- The generation must be adequate enough to meet all the load demand and losses.
- The system frequency must be maintained with narrow and acceptable limits.
- The system voltage profile must be maintained within reasonable and acceptable limits
- In case of interconnected operation, the tie-line power flows must be maintained at the spe cified values.

SCA Cont.…

- If the generation is not adequate enough to balance the load demand & loss, it is imperative that one of the following alternatives will be considered for keeping the system in operating condition:

a. Starting fast peaking units

b. Load shedding for unimportant loads, and

c. Generation rescheduling

d. Scheduled maintenances and repairing the units

e. Demand side management

3. Single Area Control System Analysis

- The model in Fig.1 shows that there are two important incremental inputs to the load frequency control system[3]:

- Which are the ΔP_{ref}, the change in speed changer setting, and $\Delta \mathbf{P}_L$, **the change in load demand**.

- Assume a simple situation in which the speed changer has a fixed setting ($\Delta P_{ref,} = 0$.) and the load demand changes.

- This is known as free governor operation.

- In the given condition, the block diagram will be simplified and presented in Fig.2

Single Area Control System Analysis Cont.,…

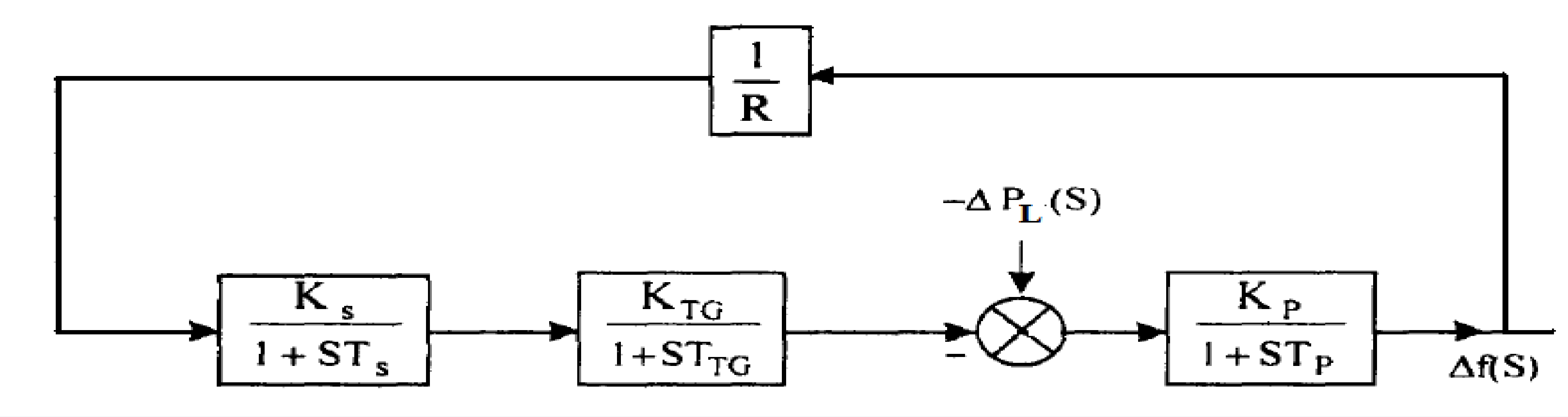

Figure 2. Free governor operation

Free governor operation or Load change only:

- Considering $T_s < T_G << T_P$ and $K_S K_{TG} \cong 1$, the dynamic response which is giving the change in fre quency as a function of the time for a step change in load
- Then, the block diagram is further reduced and presented in Fig.3.

Single Area Control System Analysis Cont.,…

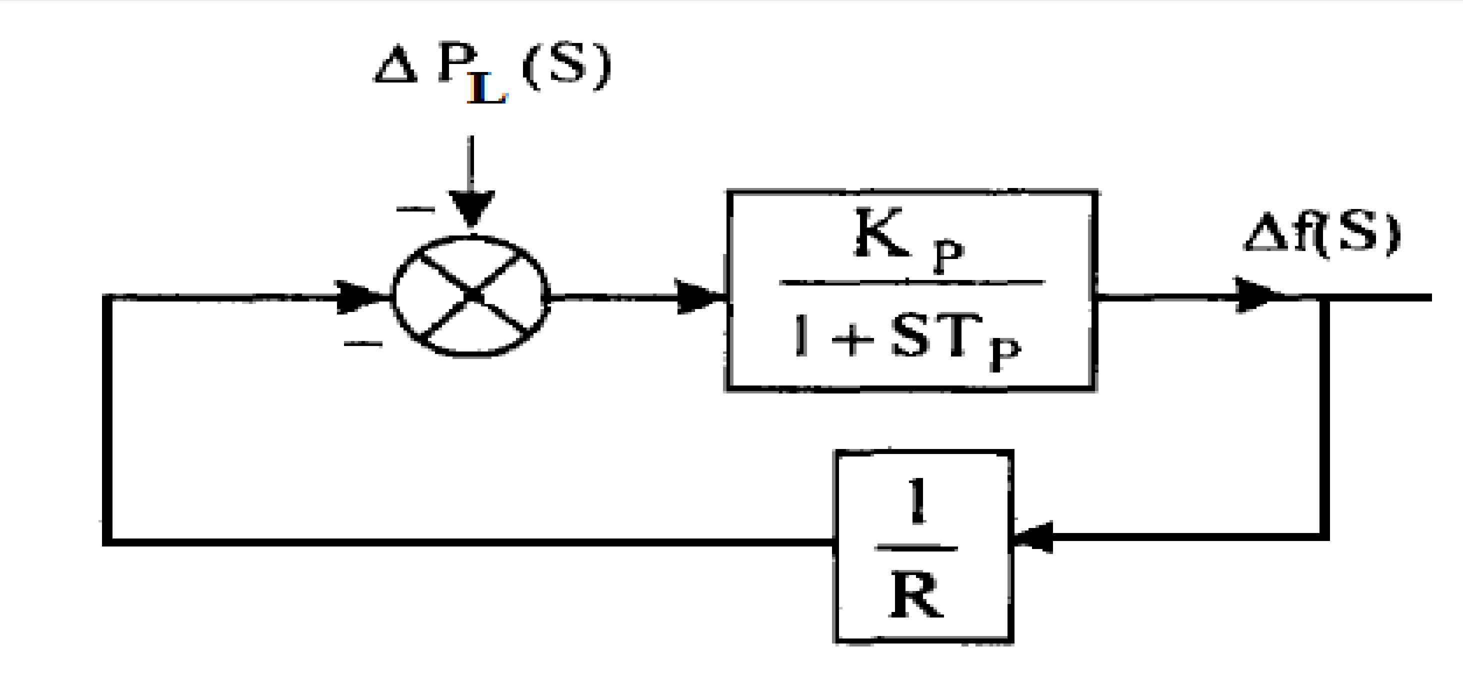

Figure 3. Simplified Free governor block diagram

- Considering the transfer function presented in eqn.2, the overall system frequency for free gover nor or load change only is presented in eqn.3.

Single Area Control System Analysis Cont.,…

For, $$G(s) = \frac{K_P}{(1 + sT_P)} \text{ and } H(s) = \frac{1}{R}. \qquad \text{eqn.(2)}$$

- Then the output frequency is given as:

$$\Delta F(s) = T(s)\Delta P_L$$

$$T(s) = \frac{G(s)}{1 + G(s)H(s)} \qquad \text{eqn.(3)}$$

$$\Leftrightarrow \Delta F(s) = \frac{G(s)}{1 + G(s)H(s)} \Delta P_L$$

- By substitution the output input relation is presented in eqn.(4).

eqn.(4)

$$\underbrace{\Delta F(s)}_{\text{Output}} = -\left[\frac{\dfrac{K_p}{1 + sT_p}}{1 + \left(\dfrac{K_p}{1 + sT_p} \right)\left(\dfrac{1}{R} \right)} \right] \underbrace{\frac{\Delta P_L}{s}}_{\text{Step input}} \Longrightarrow \Delta F(s) = -\left[\frac{K_p}{\left(1 + \dfrac{K_p}{R} \right) + sT_p} \right] \frac{\Delta P_L}{s}$$

Single Area Control System Analysis Cont.,…

- The partial fractions for the expression can be simplified using:

$$\frac{1}{s}\frac{1}{A+Bs}=\frac{C}{s}+\frac{D}{A+BS}\Rightarrow L^{-1}=\left[\frac{C}{s}+\frac{(D/A)}{1+(B/A)s}\right]^{-1}$$
$$\Leftrightarrow C+(D/A)\exp(-B/A)t$$

eqn.(5)

- Accordingly, the expression in eqn.4 can be simplified

$$\Delta F(s)=-\Delta P_L\,\frac{K_p}{T_p}\left[\frac{1}{s+\left(\dfrac{R+K_p}{RT_p}\right)}\right]\frac{1}{s}$$

eqn.(6)

Single Area Control System Analysis Cont.,…

- The Laplace transform of eqn.6 given as:

$$\Delta f(t) = -\frac{RK_p}{R+K_p}\left\{1-\exp\left[-\frac{t}{T_p}\left(\frac{R}{R+K_p}\right)\right]\right\}\Delta P_L \qquad \text{eqn.(7)}$$

$$\Rightarrow \Delta f(t) = -\beta\Delta P_L\left\{1-\exp\left[-\frac{t}{T_p}\kappa\right]\right\}$$

- Where,

$$\beta = \frac{1}{(D+1/R)} \qquad k = \frac{1}{(1+1/RD)} = \beta D$$

Single Area Control System Analysis Cont.,…

- The plot of change in frequency versus time for first order approximation given above is as shown below.

steady state result (at t = ∞)

dynamic response

$$\Delta f(t) = -\beta \Delta P_L \qquad \text{eqn.(8)}$$

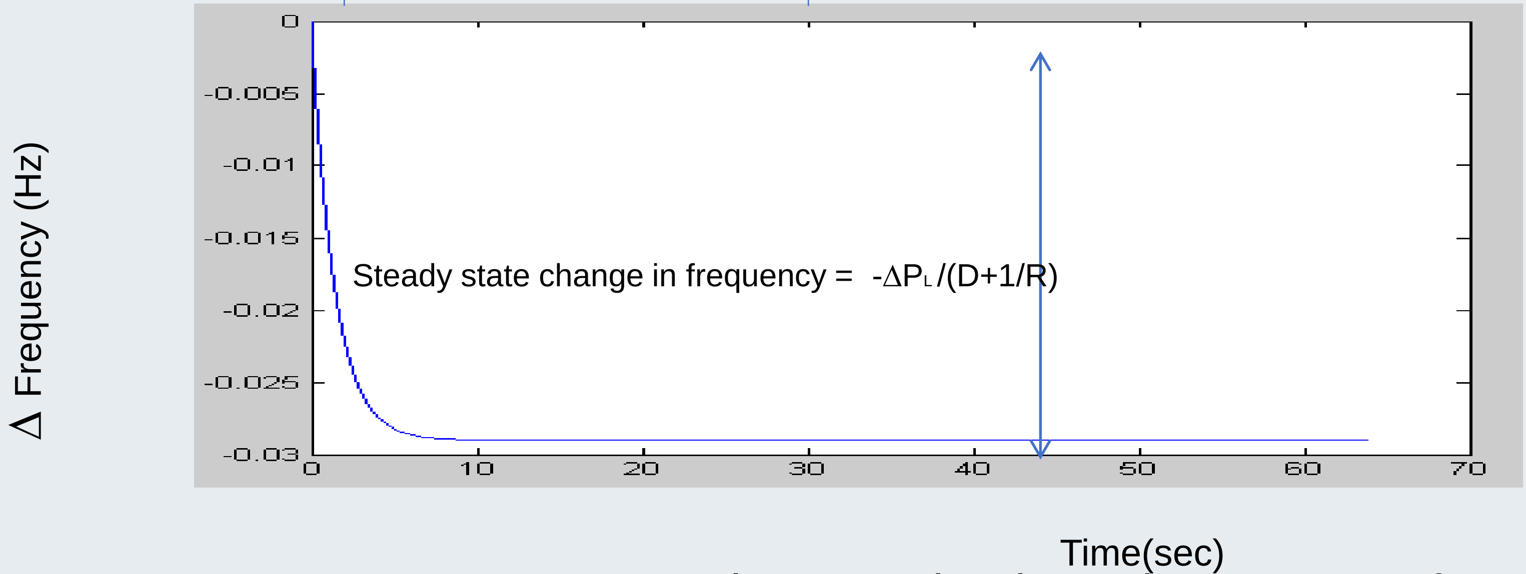

Figure 4. The dynamic response of eqn.7

- Therefore, we can say that the LFC system posses inherently steady state error for a step input of load change provided that the reference setting remains unchanged.

Single Area Control System Analysis Cont.,…

B. Reference Power setting control only while load is constant:

- Consider now the steady effect of changing speed changer setting with load demand remaining fixed. Similar to the previous condition, letting $T_S < T_{TG} << T_P$ and $K_S K_{TG} \cong 1$, the simplified block diagram and transfer function is presented in Fig.5.

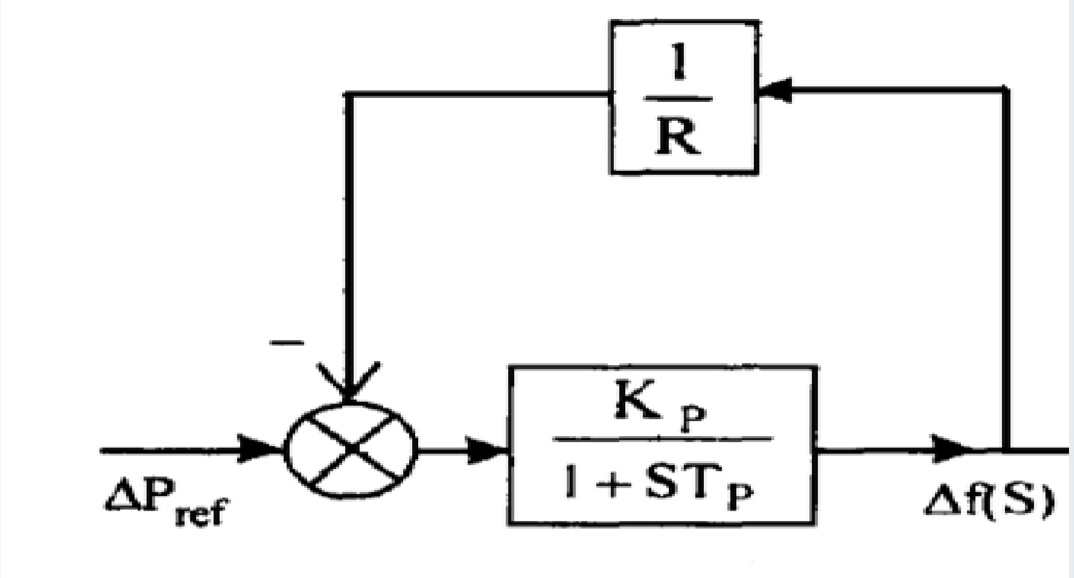

Figure 5. Reference power setting only

Single Area Control System Analysis Cont.,…

$$\text{Where } G(s) = \frac{K_P}{(1+sT_P)} \text{ and } H(s) = 1/R$$

eqn.(9)

$$\Delta F(s) = T(s)\Delta P_L$$

$$T(s) = \frac{G(s)}{1+G(s)H(s)}$$

Single Area Control System Analysis Cont.,…

$$\underbrace{\Delta F(s)}_{\text{Output}} = \left[\frac{\dfrac{K_p}{1+sT_p}}{1+\left(\dfrac{K_p}{1+sT_p}\right)\left(\dfrac{1}{R}\right)} \right] \frac{\Delta P_{ref}}{\underbrace{s}_{\text{Step input}}} \qquad \text{Eqn.(10)}$$

- Which, means that:

$$\Delta F(s) = -\left[\frac{K_p}{\left(1+\dfrac{K_p}{R}\right)+sT_p} \right] \frac{\Delta P_{ref}}{s} \qquad \text{Eqn.(11)}$$

Single Area Control System Analysis Cont.,…

- Following the same procedure as case A, the steady state change in frequency due to change in ref erence setting will have similar expression:

$$\Delta f(t) = \beta \Delta P_{ref} \qquad \text{eqn.(12)}$$

- If the speed change setting is changed by ΔP_{ref} while the load demand changes by ΔP_L, the steady s tate frequency change is obtained by superposition, i.e.

$$\Delta f = \beta\left(\Delta P_{ref} - \Delta P_L\right) \qquad \text{eqn.(13)}$$

- According to the above equation, the frequency change caused by load demand can be compensate d by changing the setting of the speed changer, i.e. for $\Delta f = 0$.

$$\Delta P_{ref} = \Delta P_L \qquad \text{eqn.(14)}$$

Single Area Control System Analysis Cont.,…

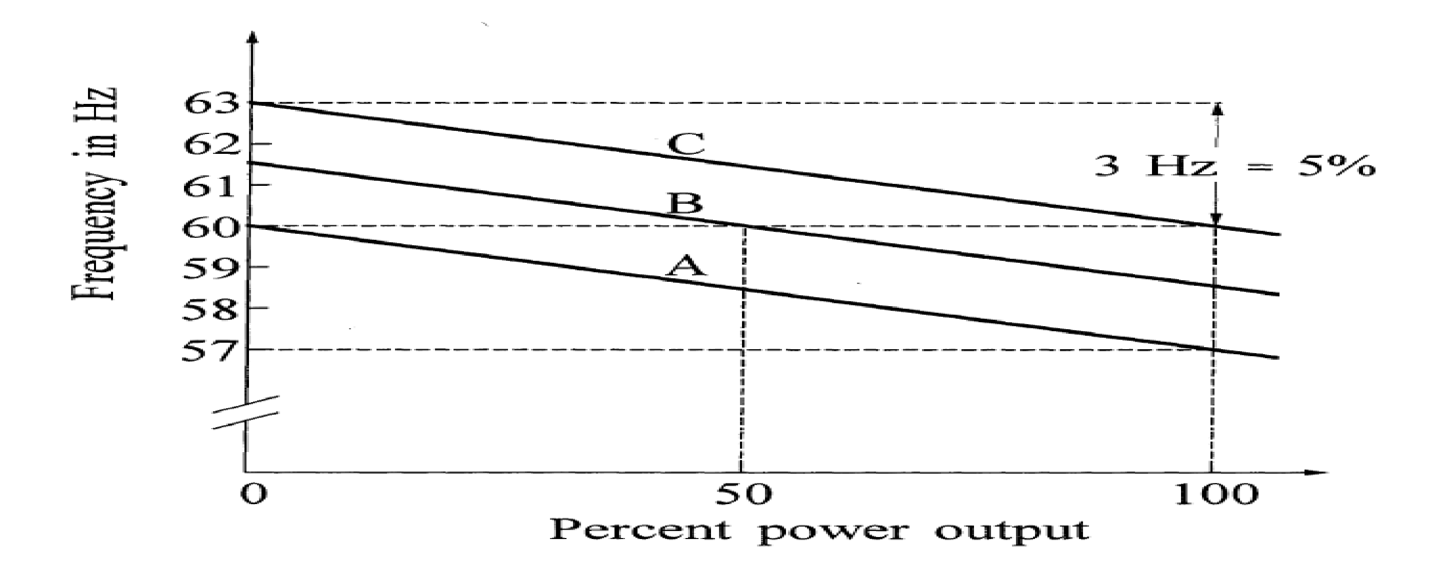

Figure*: Effect of speed changer setting on the frequency stability of the system.*

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- Therefore, for this purpose, a signal from Δf is fed through an integrator to the speed changer resulti ng in the block diagram configuration shown below.

Single Area Control System Analysis Cont.,…

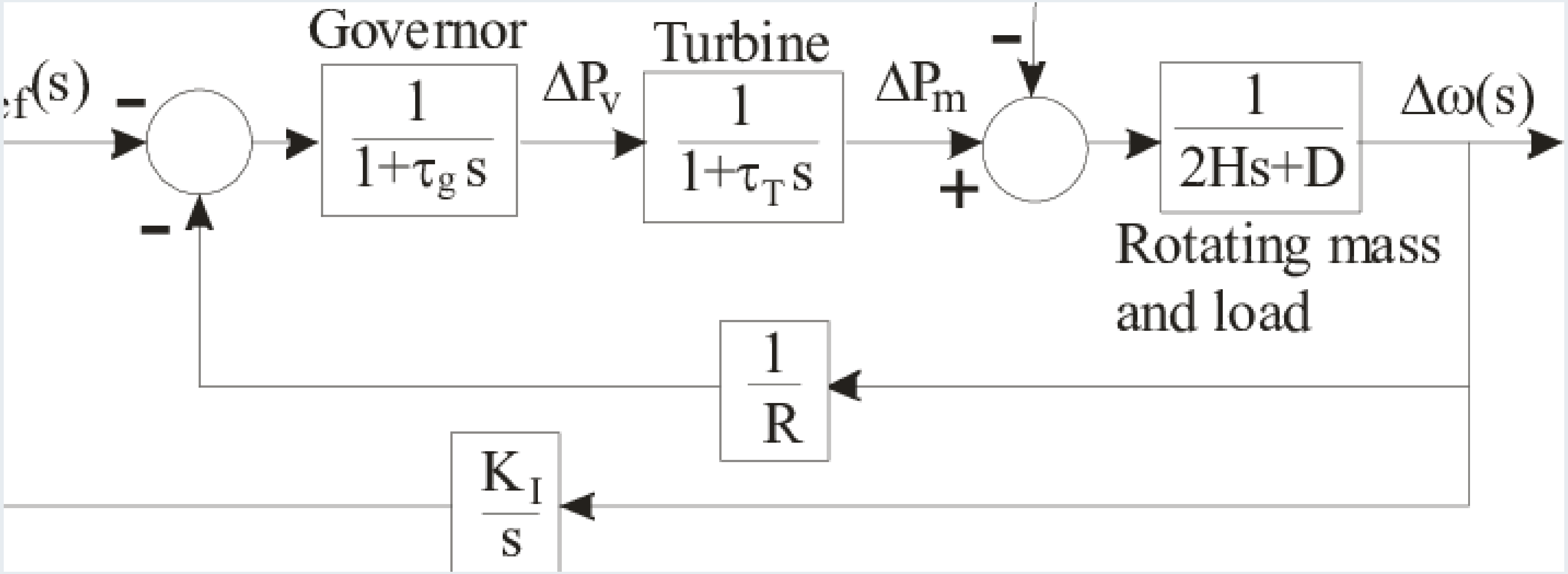


Figure 6. Integral control of single area frequency control.

https://www.researchgate.net/publication/224651818/figure/fig1/AS:669033770790917@1536521489876/Block-diagram-of-a-single-area-load-frequency-control.png

Single Area Control System Analysis Cont.,…

- Now, the analysis on input-output relation results

$$\Delta F(s)=\left[\left[-\frac{\Delta F(s)K}{s}-\frac{\Delta F(s)}{R}\right]\left(\frac{K_s}{1+sT_s}\right)\left(\frac{K_{TG}}{1+sT_{TG}}\right)-\Delta P_L\right]\frac{K_p}{1+sT_p} \qquad \text{eqn.(15)}$$

- Neglecting T_S and T_{TG}, both have << T_p and $K_S K_{TG} \cong 1$, eqn.(15), is rewritten as;

$$\Delta F(s)=\left[\left[-\frac{\Delta F(s)K}{s}-\frac{\Delta F(s)}{R}\right]-\Delta P_L\right]\frac{K_p}{1+sT_p} \qquad \text{eqn.(16)}$$

Single Area Control System Analysis Cont.,…

- Rearranging,

$$\Delta F(s) = -\frac{K_p}{\left((1+T_p s) + \left(\frac{K}{s} + \frac{1}{R} \right) K_p \right)} \times \frac{\Delta P_L}{s}$$

eqn.(17)

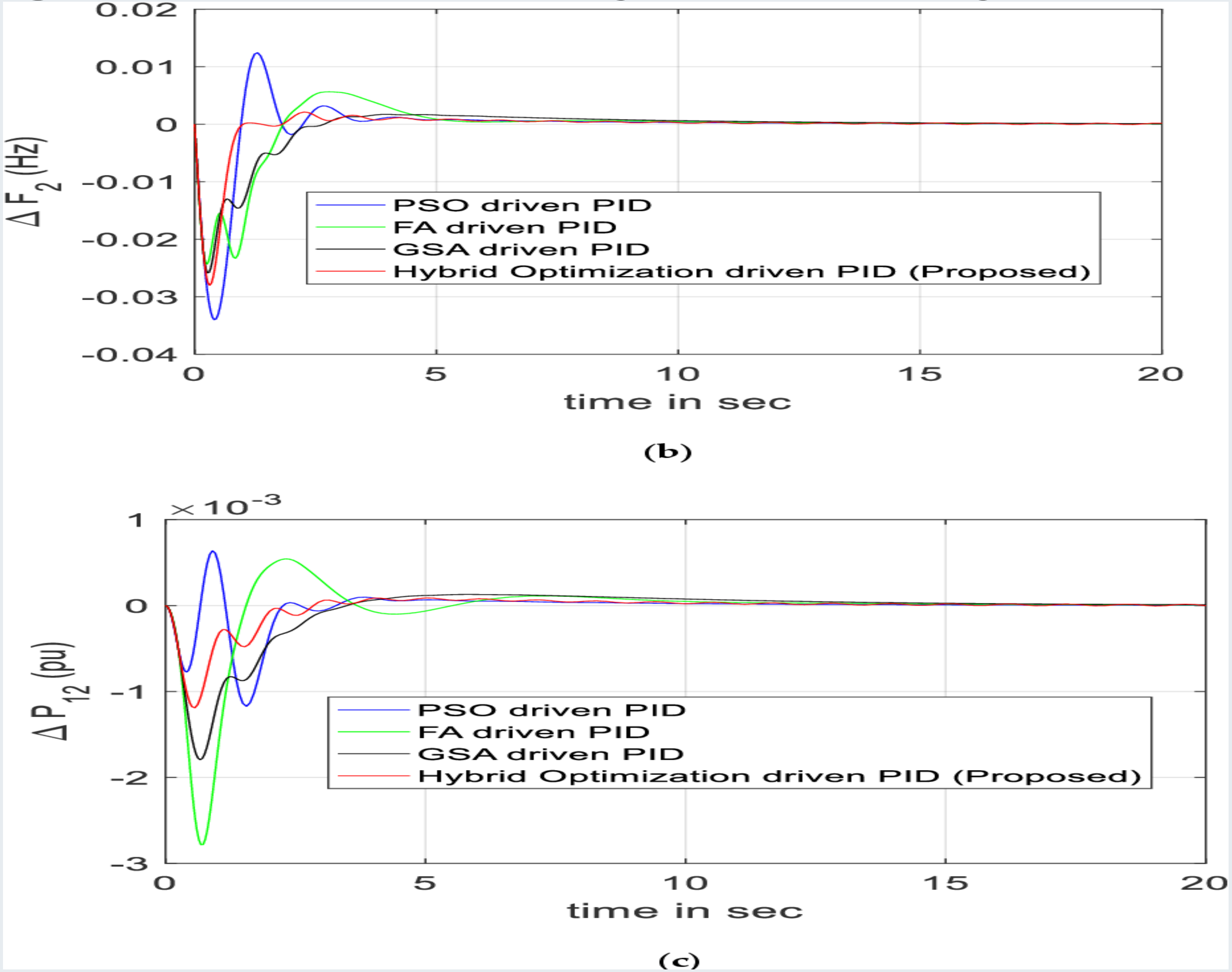
- Then, the change in steady state frequency is :

$$\Delta f_{steadystate} = \lim_{s \to 0} s\Delta F(s)$$

eqn.(18)

$$= \lim_{s \to 0} s \times \left(-\frac{sRK_p}{\left(sR(1+T_p s) + (KR+s)K_p \right)} \times \frac{\Delta P_L}{s} \right) = 0$$

Single Area Control System Analysis Cont.,…



[Figure 7: The PID control results with different optimization.](https://ai2-s2-public.s3.amazonaws.com/figures/2017-08-08/d1cc751540adf680dca379c82503d9e522ae587b/12-Figure3-1.png)

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Single Area Control System Analysis Cont.,…

- Here we find that the steady state change in frequency has been reduced to zero by the addition of the i ntegral controller.
- In central load frequency control of a given control area, the change (error) in frequency is known as Ar ea Control Error (ACE).
- The additional signal fed back in the modified control scheme presented above is the integral of ACE.
- Which, reduces the error to zero and advisable to apply the integral over derivative

Single Area Control System Analysis Cont.,…

- From the above analysis, it is clear that proportional integral and derivative control strategy can be applied for load frequency control.
- While proportional control is inherent in the feedback through the governor mechanism itself, derivative control when introduced improves transient performance and ensures better margin of stability for the system.
- The selection of the gain controller in the secondary LFC should be such that:
- **i.** control loop must be stable
- **ii**. Frequency error should return to zero

4. COMPOSITE SYSTEM IN SINGLE CONTROL AREA:

- In a composite system for frequency control within a single area, you typically focus on managing the generation and consumption of electrical power to maintain a stable frequency across the network.

Generation Sources:

- Conventional Power Plants: These include fossil fuel, nuclear, and hydroelectric plants that can be con trolled to adjust output based on demand.
- Renewable Energy Sources: Wind, solar, and other renewables contribute to the mix but are less pred ictable. Integration with storage or backup systems is essential.
- Energy Storage Systems: Batteries or pumped hydro storage can quickly inject or absorb power to sta bilize frequency.

composite system Cont.….

Load Management:

- Demand Response: Programs that adjust consumer demand based on real-time frequency or grid conditi ons.
- Smart Grids: Advanced metering infrastructure allows for real-time data collection and analysis, enabling more responsive load management.

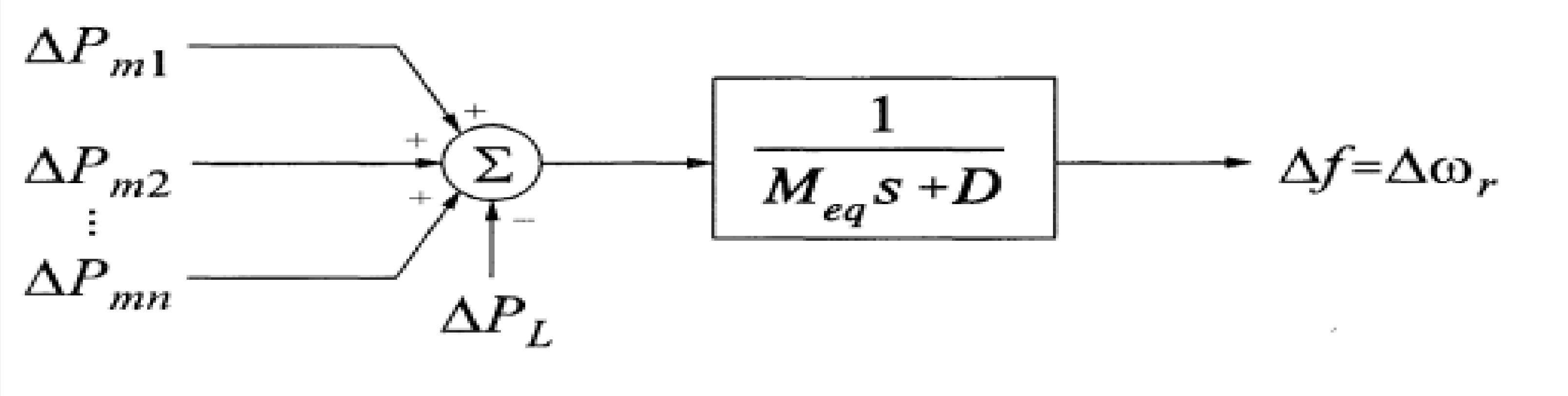
Control Systems:

- Automatic Generation Control (AGC): This system balances the output of multiple power plants and adju sts them in real-time to match the load and maintain frequency.
- Frequency Regulation: Techniques that involve adjusting the output of generation sources based on real-time frequency measurements. The composite system is given in Fig.8

composite system Cont…..

- The composite power/frequency characteristics of a power system thus depends on the combined effect of the droops of all generator speed governors.

- It also depends on the frequency characteristics of all the loads in the system as given in Fig.



where M_{eq} /equivalent generator/

$= \Sigma M$

Figure 8. composite system.

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- For a system with N generators and a composite load-damping constant of D, the steady-state frequency deviation following a load change ΔP_L is given by

$$\Delta f_{ss} = \frac{-\Delta P_L}{(1/R_1 + 1/R_2 + 1/R_3 \ldots 1/R_n) + D}$$

Summary

- The brief overview of single area control is discussed in this lecture.
- It is noted that there is no single generator, governor , turbine and load exists in reality, but the number of generators and other systems are considered as a single system for SAC.
- The two basic approaches used are: changing the load only or free governor mechanism and reference setting changing are adopted in this lecture to come up with the real-time control.
- In addition, the advantage of integral control while minimizing the error is discussed in this lecture
- Finally, the composite system modeling considering N-Generation units is also discussed well.

References

[1]. S., Pahadasingh; C., Jena and C., Panigrahi. "SCA Based Load Frequency Control Incorporating Electric Vehicle Using Cascaded Controller’’. International Conference on Power Electronics and Energy (ICPEE), Bhubaneswar, India, 2021, pp. 1-5, doi: 10.1109/ICPEE50452.2021.9358648.

[2]. D., Serhat and Y., Nuran. ‘’Load Frequency Control of A Single Area Power System using Gravitational Search Algorithm.’’ confrenace , 2012. pp.1-6. DOI: 10.1109/INISTA.2012.6246992.

[3]. K., Dillip; K., Bikash; P., Swagatika and etl. ‘’Load Frequency Control of a Single Area Power System using Firefly Algorithm’’. International Journal of Engineering Research & Technology (IJERT). V.9(5), 2020.

Thank you !