第61回自動制御連合講演会

南山大学 2018/11/17

# 蓄電池ステーションによる電力網の負荷周波数の階層分散制御

# Hierarchically Decentralized Control of Load Frequency for Power Networks with Battery Stations

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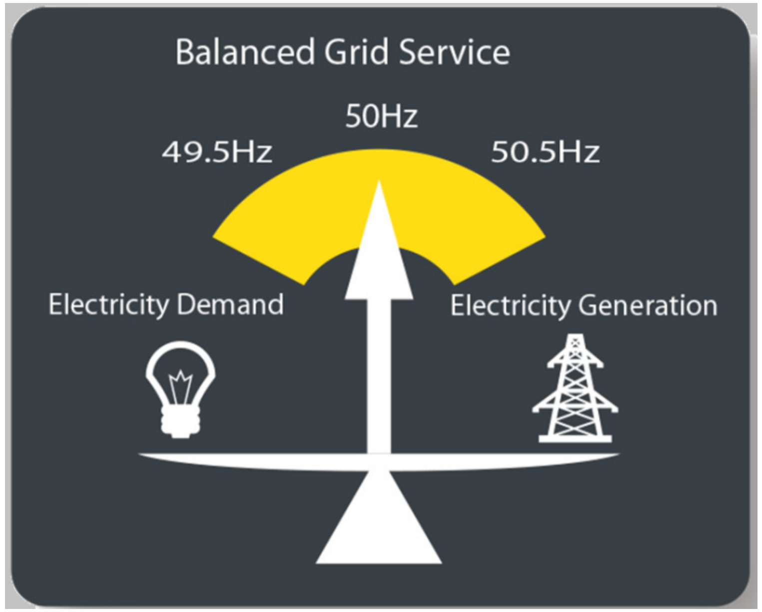
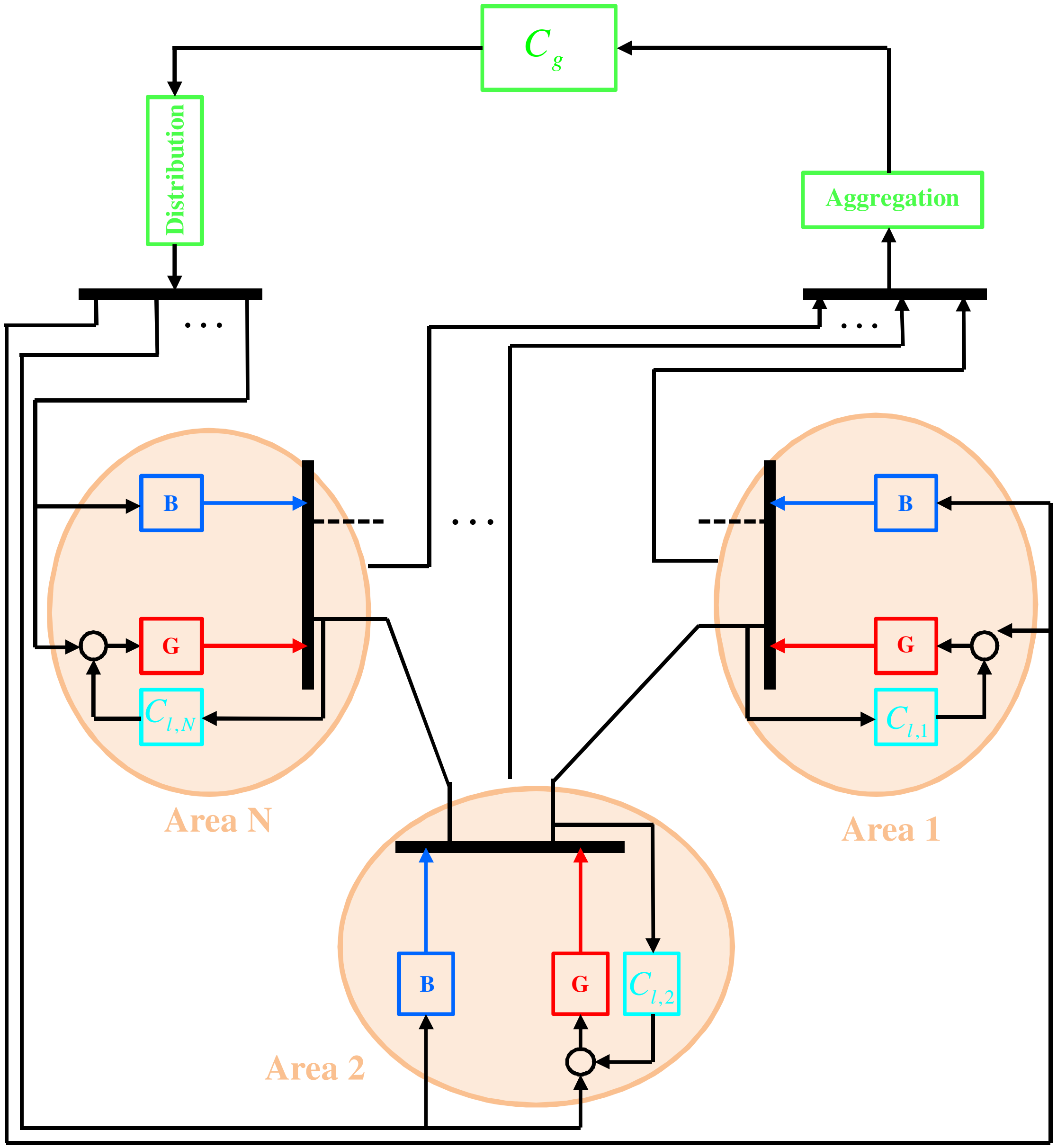


# Challenge of load frequency control (LFC)





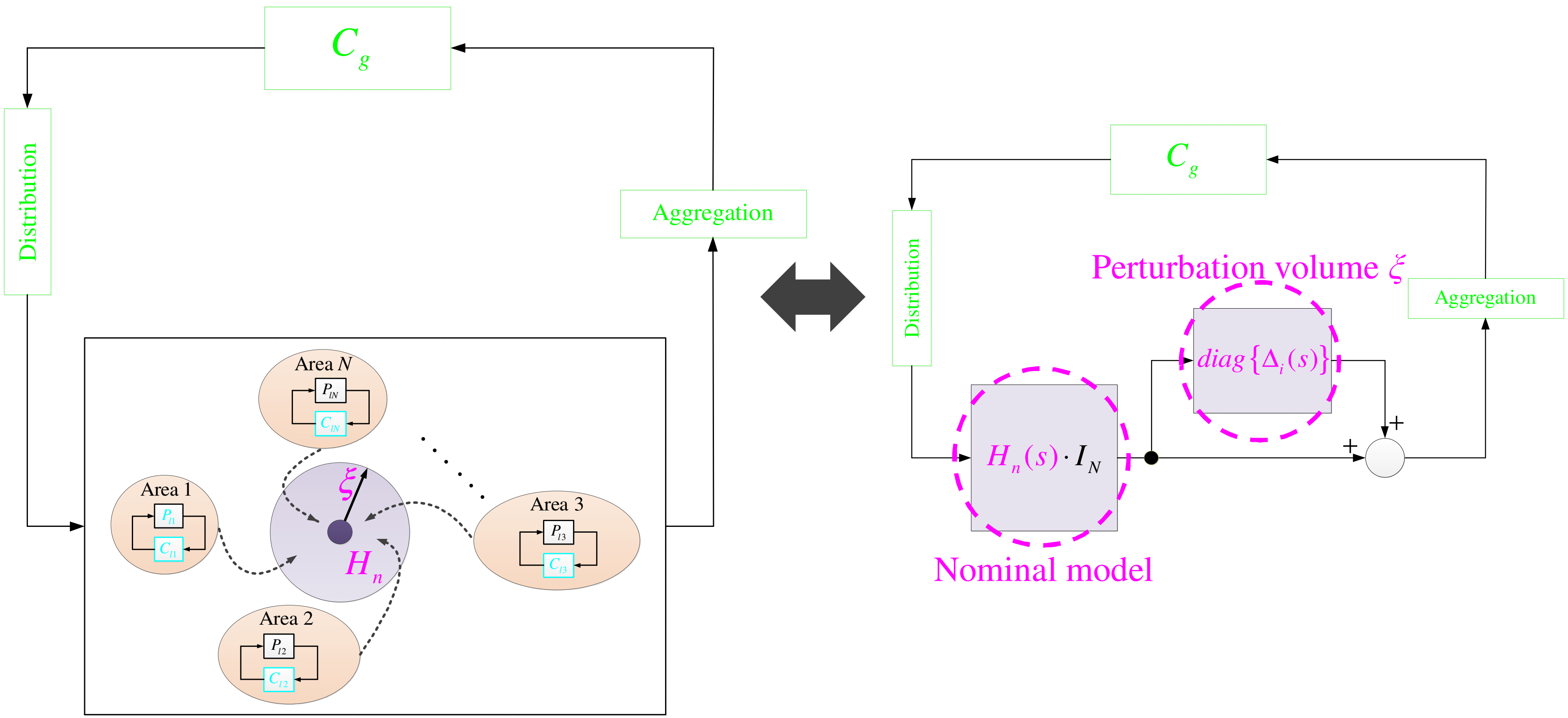

- ❑ **Merit of Battery Station:** Improve both control performance and economy of LFC.
  (J. Tomic, J. Power Sources, 2007)

- ❑ **Challenges**
  - How to assure the stability of the LFC system?

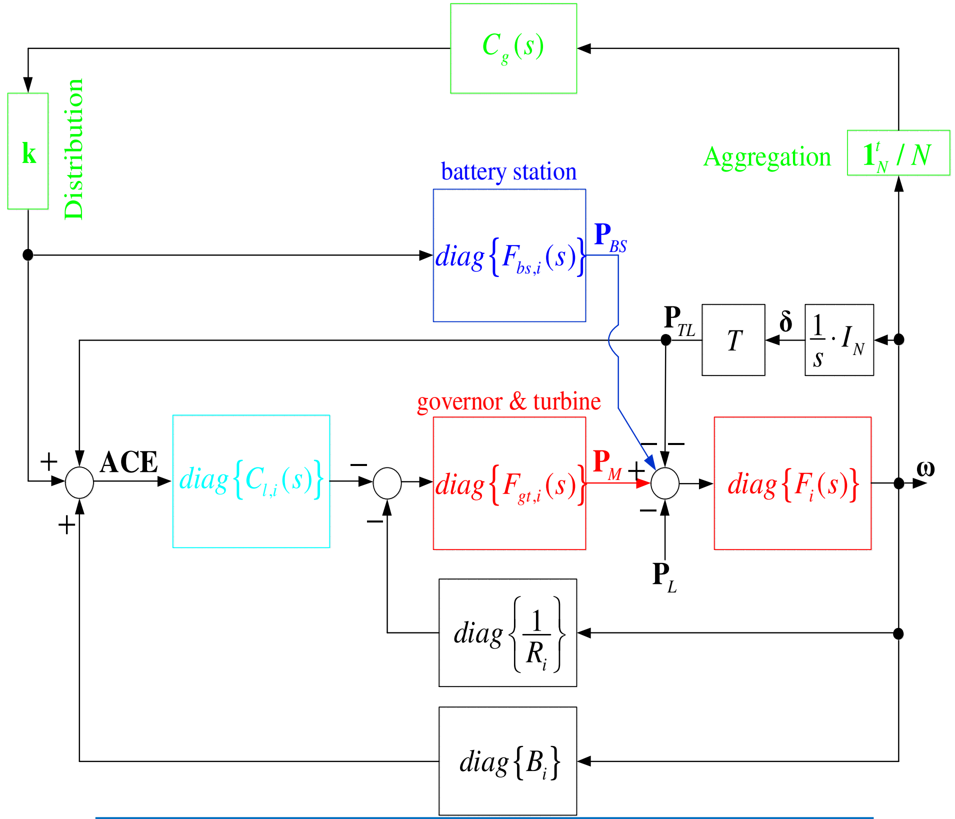
**System description:**

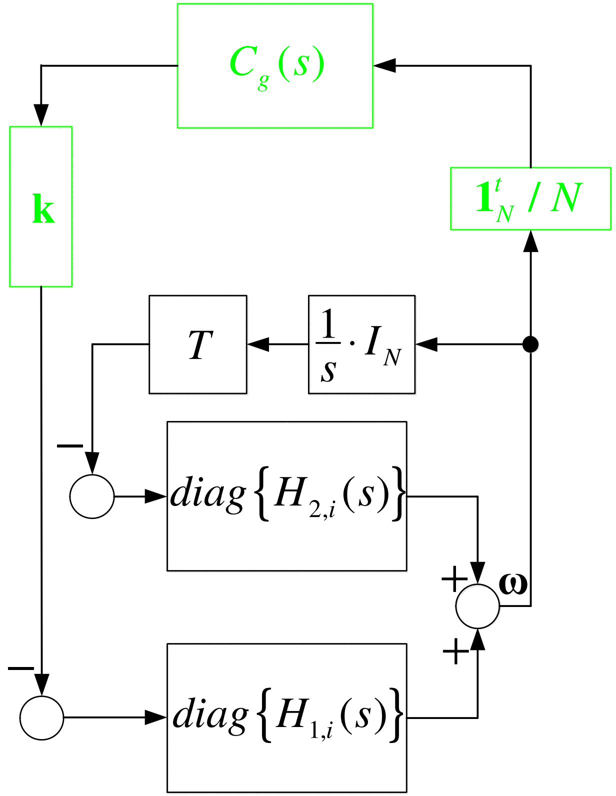
- G: traditional source
- B: battery station
- Global controller: $C_g$
- Local controller: $C_{l,i}$

# General idea of shared model sets



# LFC control system with BS



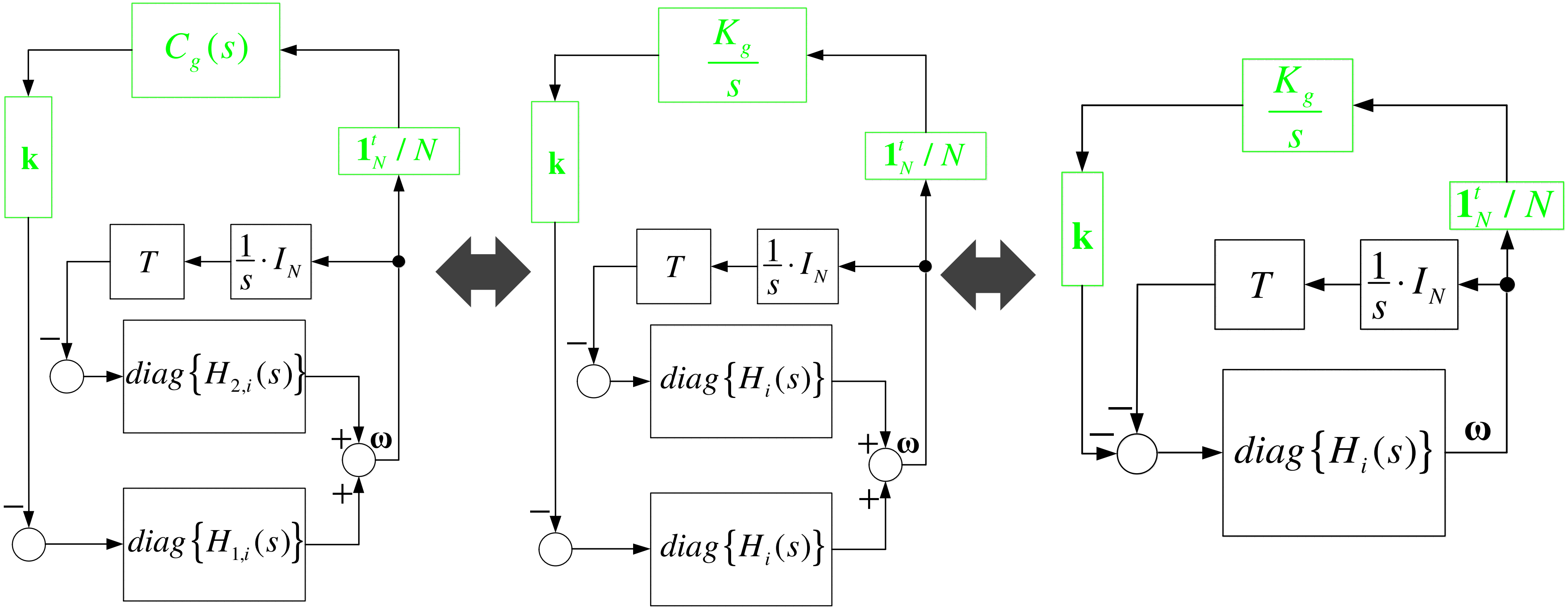




**Assumption:** In future, the cost of battery system is considerably reduced, so we have enough battery power to support the LFC.

$$H_{1,i}(s) = \frac{\left(F_{bs,i}(s) + C_{l,i}(s) F_{gt,i}(s)\right) F_i(s)}{1 + \left(B_i C_{l,i}(s) + 1/R_i\right) F_{gt,i}(s) F_i(s)}$$

$$H_{2,i}(s) = \frac{\left(1 + C_{l,i}(s) F_{gt,i}(s)\right) F_i(s)}{1 + \left(B_i C_{l,i}(s) + 1/R_i\right) F_{gt,i}(s) F_i(s)}$$

# Problem setting for this presentation

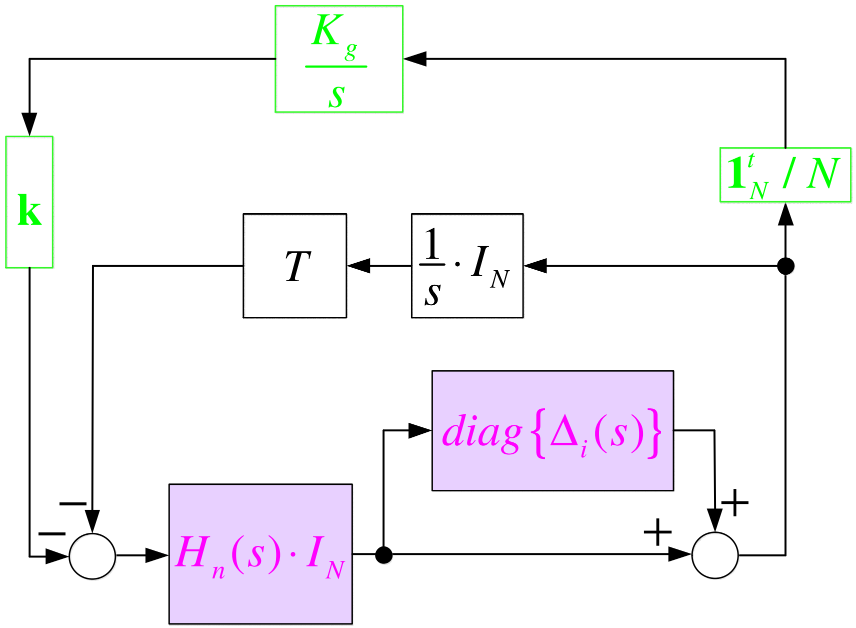


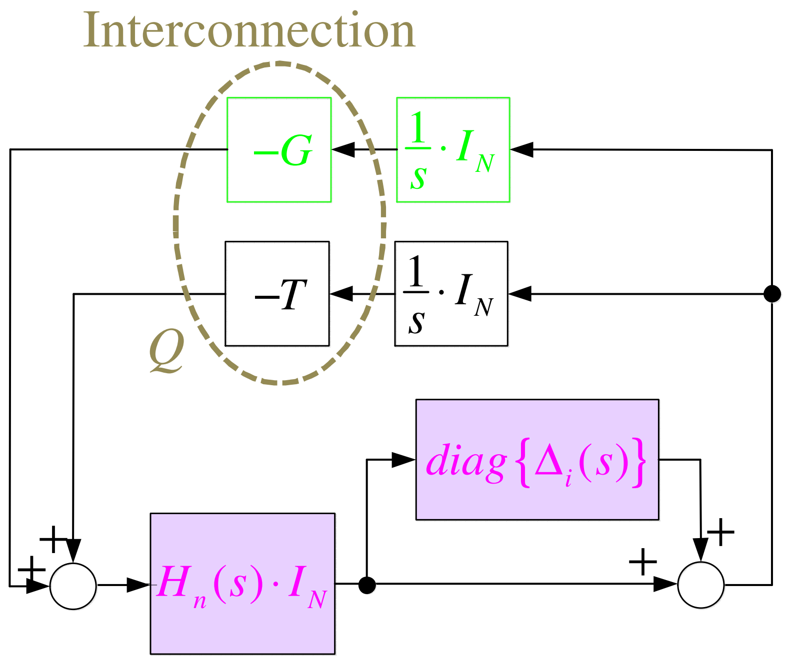

Problem setting:

- $C_g(s) = K_g/s$
- $F_{bs,i}(s) \approx 1$

$$H_i(s) = \frac{\left(1 + C_{l,i}(s) F_{gt,i}(s)\right) F_i(s)}{1 + \left(B_i C_{l,i}(s) + 1/R_i\right) F_{gt,i}(s) F_i(s)}$$

# Representation of LFC system by nominal model




- $H_n(s)$: nominal model for $\{H_i(s)\}$.
- Perturbation: $\Delta_i(s) = \dfrac{H_i(s) - H_n(s)}{H_n(s)}$

- Interconnection matrix

$$G = \frac{K_g}{N}\mathbf{k} \cdot \mathbf{1}_N^t$$

$$Q = -G - T$$

# Stability of the overall LFC system

**Proposition 1:** The LFC system is stable if

(i) The nominal interconnected system $\sum\left(\tilde{H}_n(s), Q\right)$ is stable

where $\tilde{H}_n(s) = H_n(s)/s$

(ii) Model matching condition is s.t.: $\|\Delta_i(s)\|_\infty \leq \xi \;\; \forall i$ from 1 to $N$

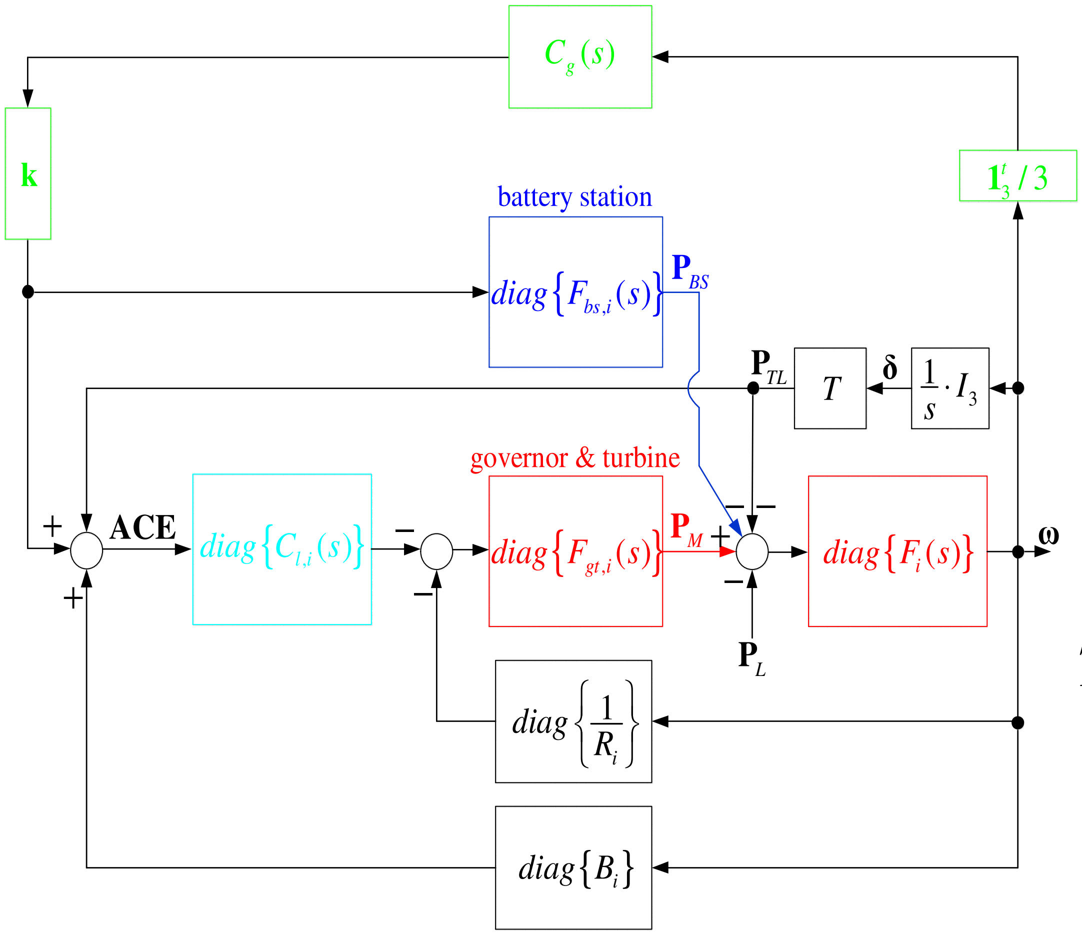
(iii) Robust stability condition of nominal system is s.t.:

$$\left\| \frac{\lambda_{Q,i}\tilde{H}_n(s)}{1-\lambda_{Q,i}\tilde{H}_n(s)} \right\|_\infty \leq \frac{1}{\xi} \;\; \forall \lambda_{Q,i} \in \sigma(Q)$$

**Remark 1:** (i) is satisfied if all the eigenvalues of matrix $Q$ are located in the stable domain given by the nominal GFV $\tilde{\phi}_n(s) = 1/\tilde{H}_n(s)$ (Hara *et al*, IEEE TAC 2014).

# Three-area-power-network




$$F_{gt,i}(s) = \frac{1}{(T_{g,i}s+1)(T_{t,i}s+1)}$$

$$F_i(s) = \frac{L_{p,i}}{T_{p,i}s+1}$$

$$C_{l,i}(s) = \frac{K_{l,i}}{s}$$

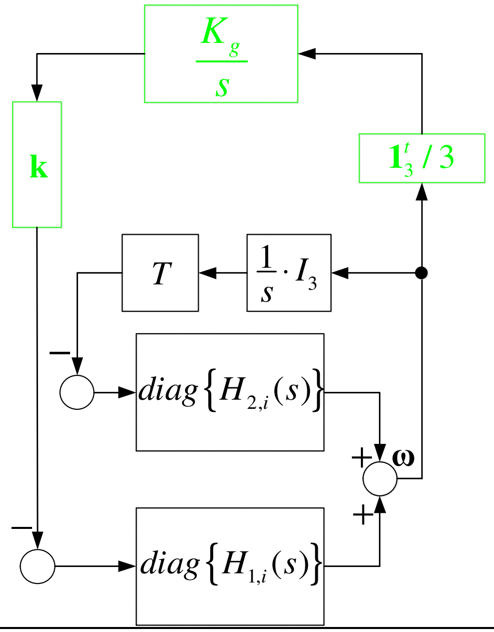
$$T = \begin{bmatrix} t_{12}+t_{13} & -t_{12} & -t_{13} \\ -t_{21} & t_{21}+t_{23} & -t_{23} \\ -t_{31} & -t_{32} & t_{31}+t_{32} \end{bmatrix}$$

where $t_{ij} = 1/3 \ \forall i \neq j$

- **Other parameters:**
  Tan *et al*, Electrical Power and Energy System, 2012.

# Two test cases

## Test A: Without Battery Station

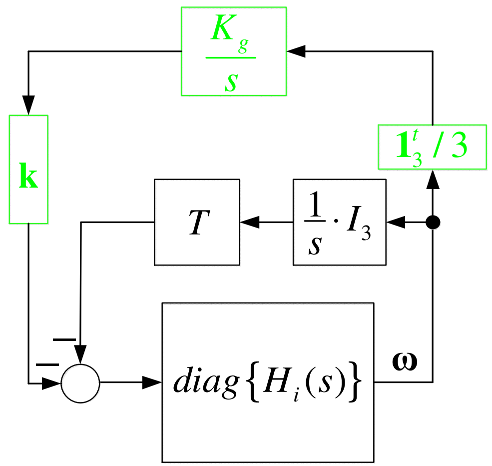



$$\begin{cases} H_{1,i}(s) = \dfrac{C_{l,i}(s)F_{gt,i}(s)F_i(s)}{1+\left(B_iC_{l,i}(s)+1/R_i\right)F_{gt,i}(s)F_i(s)} \\ H_{2,i}(s) = \dfrac{\left(1+C_{l,i}(s)F_{gt,i}(s)\right)F_i(s)}{1+\left(B_iC_{l,i}(s)+1/R_i\right)F_{gt,i}(s)F_i(s)} \end{cases}$$

2 nominal models:

$$\begin{cases} H_{1n}(s) = \dfrac{C_{ln}(s)F_{gtn}(s)F_n(s)}{1+\left(B_nC_{ln}(s)+1/R_n\right)F_{gtn}(s)F_n(s)} \\ H_{2n}(s) = \dfrac{\left(1+C_{ln}(s)F_{gtn}(s)\right)F_n(s)}{1+\left(B_nC_{ln}(s)+1/R_n\right)F_{gtn}(s)F_n(s)} \end{cases}$$

## Test B: With Battery Station



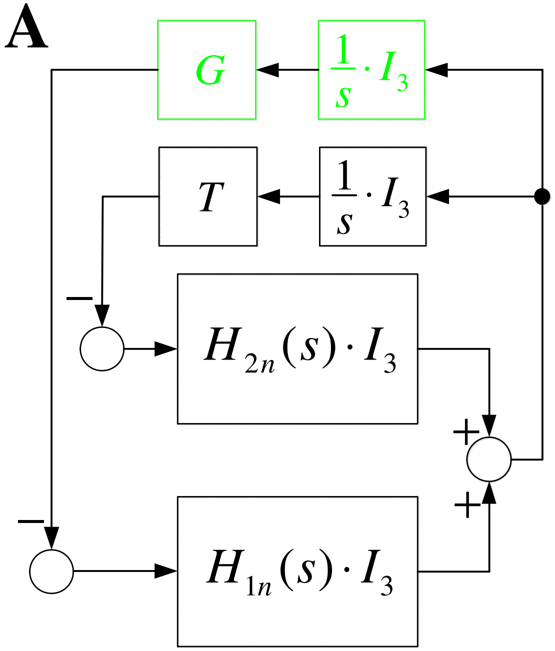

$$H_i(s) = \frac{\left(1+C_{l,i}(s)F_{gt,i}(s)\right)F_i(s)}{1+\left(B_iC_{l,i}(s)+1/R_i\right)F_{gt,i}(s)F_i(s)}$$

1 nominal models:

$$H_n(s) = \frac{\left(1+C_{ln}(s)F_{gtn}(s)\right)F_n(s)}{1+\left(B_nC_{ln}(s)+1/R_n\right)F_{gtn}(s)F_n(s)}$$

# Stability of two nominal systems

## Test A




$$\tilde{\phi}_{1(2)n}(s) = \frac{1}{\tilde{H}_{1(2)n}(s)} = \frac{s}{H_{1(2)n}(s)}$$

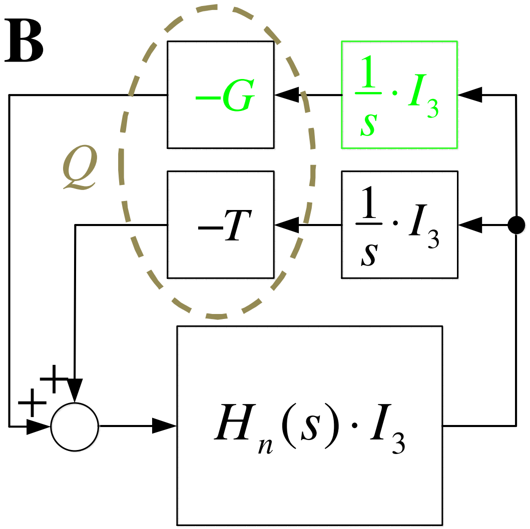
The nominal system of Test A is stable if

$$\forall\, \lambda_{T,i} \in \sigma(T):\ \ \tilde{\phi}_{2n}(s) + \lambda_{T,i} \neq 0 \text{ for all } s \in \mathbb{C}_+$$

$$\forall\, \lambda_{G,i} \in \sigma(G):\ \tilde{\phi}_{1n}(s) + \lambda_{G,i} \neq 0 \text{ for all } s \in \mathbb{C}_+$$

$$G = \frac{K_g}{3}\mathbf{k}\cdot\mathbf{1}_3^t \Rightarrow \sigma(G) = \{K_g/3;\ 0;\ 0\}$$

## Test B




$$\tilde{\phi}_{n}(s) = \frac{1}{\tilde{H}_{n}(s)} = \frac{s}{H_{n}(s)}$$

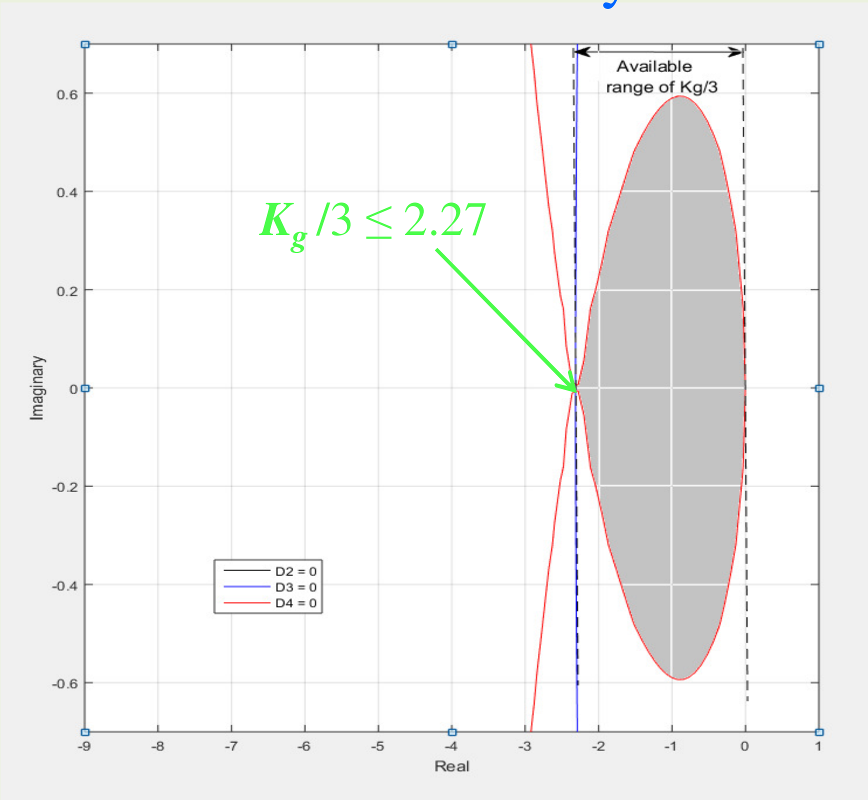
The nominal system of Test B is stable if

$$\forall\, \lambda_{Q,i} \in \sigma(Q):\ \ \tilde{\phi}_{n}(s) - \lambda_{Q,i} \neq 0 \text{ for all } s \in \mathbb{C}_+$$

$$Q = -T - G \Rightarrow \sigma(Q) = \{-K_g/3; -1; -1\}$$

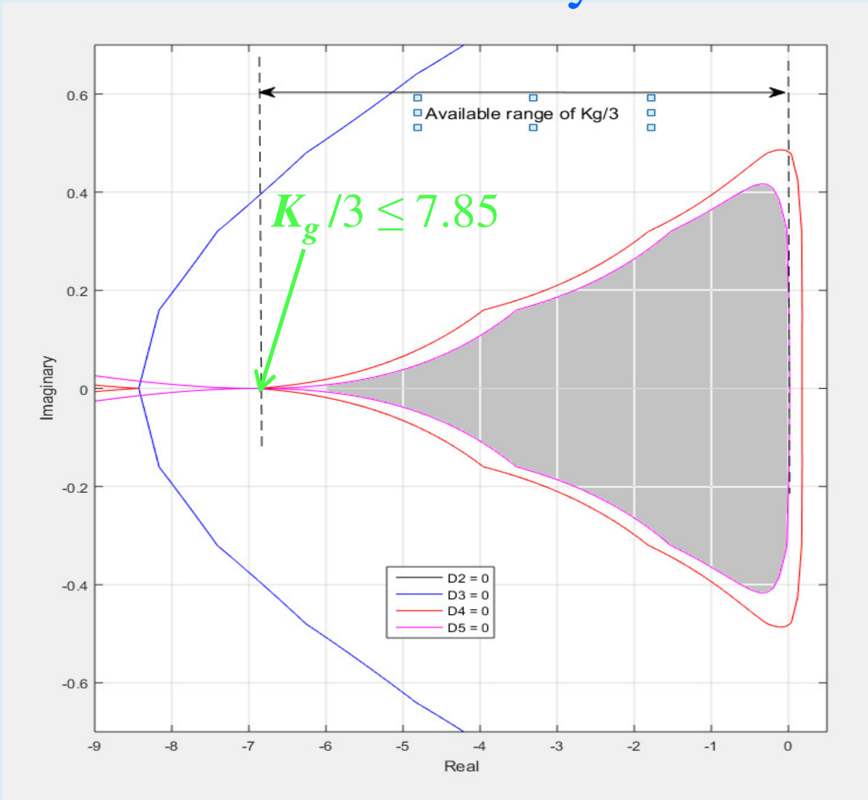
# Available range of $K_g$ given by nominal models

**Test A**: Without Battery Station




Stable domain given by the nominal GFV $\tilde{\phi}_{1n}(s) = 1/\tilde{H}_{1n}(s)$

**Test B**: With Battery Station

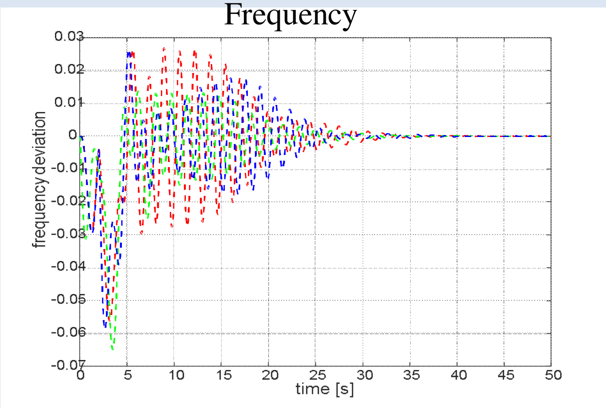


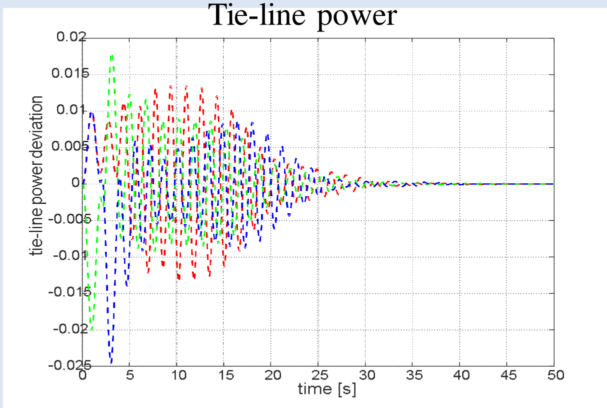

Stable domain given by the nominal GFV $\tilde{\phi}_{n}(s) = 1/\tilde{H}_{n}(s)$

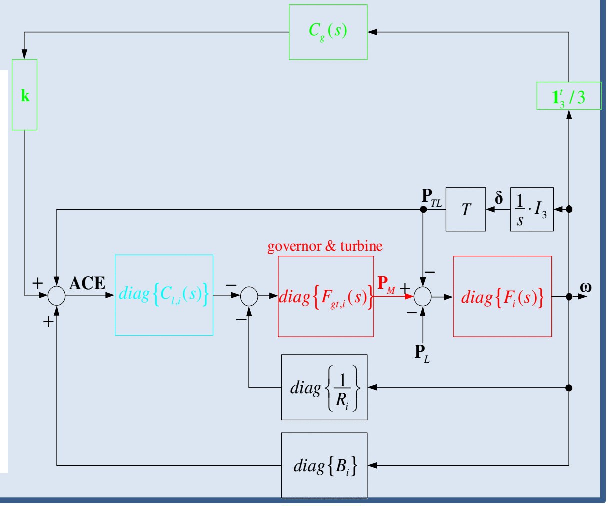
→ With Battery station, we might have more freedom to adjust the global control gain.

# Simulation results

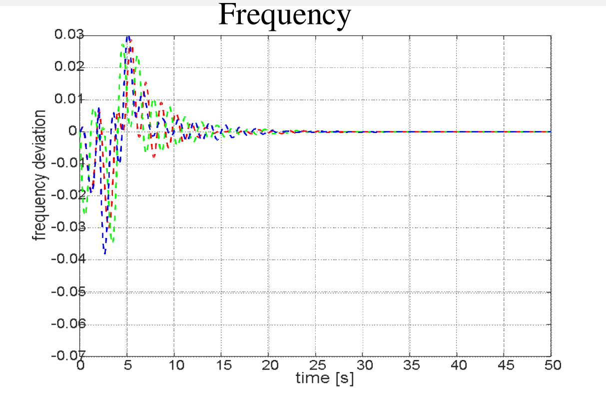
## Test A: Without battery stations

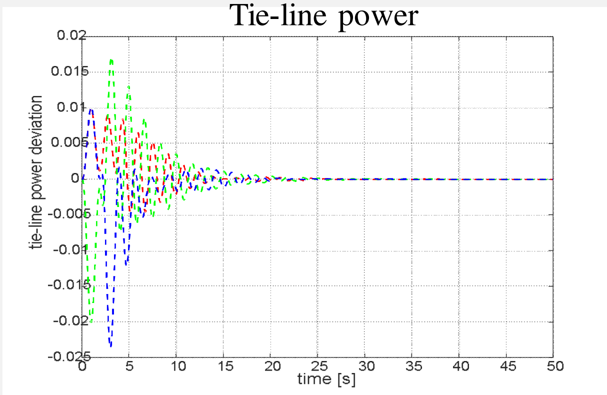


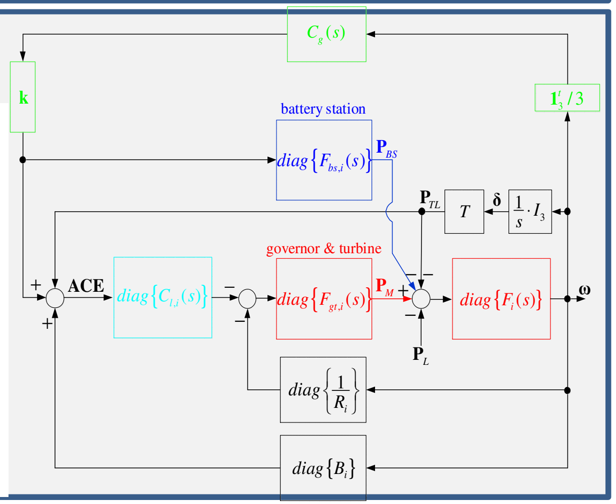




## Test B: With Battery stations




- Simulation conducted with the volume of model set $\xi = 0.32$
- With Battery stations, the deviation of frequency and tie-line power are quickly suppressed.

# Conclusions

❑ **Advantages of shared model set:**

- Any local area can be designed without understanding the others.
- The global controller can be designed simply, without understanding of the local subsystems and the details of the network structure.

❑ **Achieved result:**

- Apply the idea of shared model set to LFC with battery station.

❑ **Future works:**

- System design considering the general problem setting.