Optimal Control Design for Multi-Terminal HVDC

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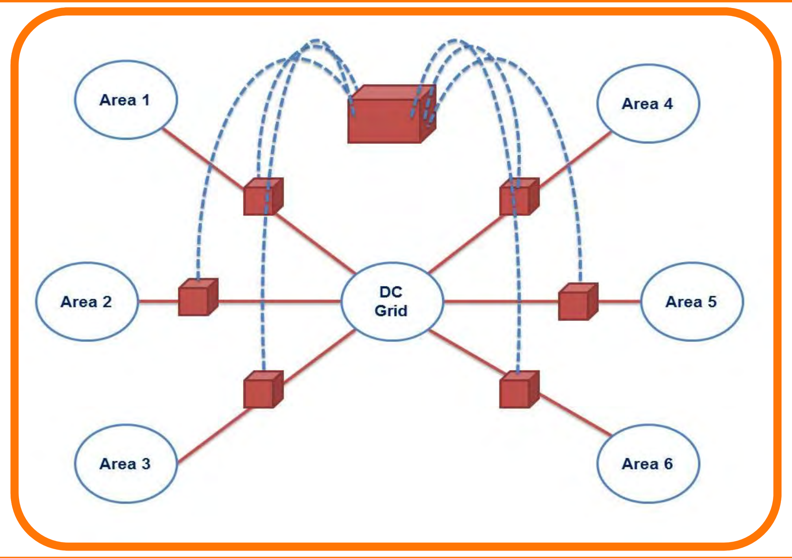
Frequency Control & MTDC

In a Multi-Terminal HVDC configuration, the majority of the control methods developed in the literature consider:

- Proportional-Integral (PI) strategies.
- Each sub-system is isolated from the frequency point of view.



- It allows connections between non-synchronous sub-systems.
- Its helps to prevent a possible cascade of outages within the DC grid.
- However, it prevents each sub-system from sharing their primary reserves within the DC grid. This sharing is decisive for reducing the operational transmission cost.

How can we find an optimal control structure which allows primary reserve sharing between non-synchronous system ?

State Feedback Control

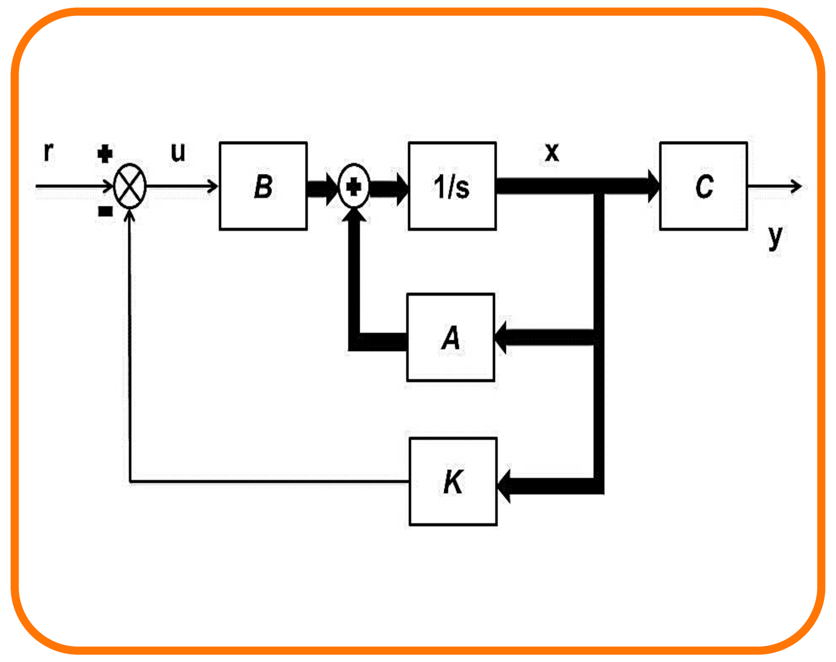
The dynamics of the system are synthesized with the state-space system:

$$\dot{\mathrm{x}} = A\mathrm{x} + B u$$

$$\mathrm{y} = C\mathrm{x}$$

with $\mathrm{u} = -K\mathrm{x}$

K is defined has a PID: $\Delta P_i^{\mathrm{dc}} = K_i \int \Delta f_i + K_p \Delta f_i + K_d \Delta P_{\mathrm{mech}i}$



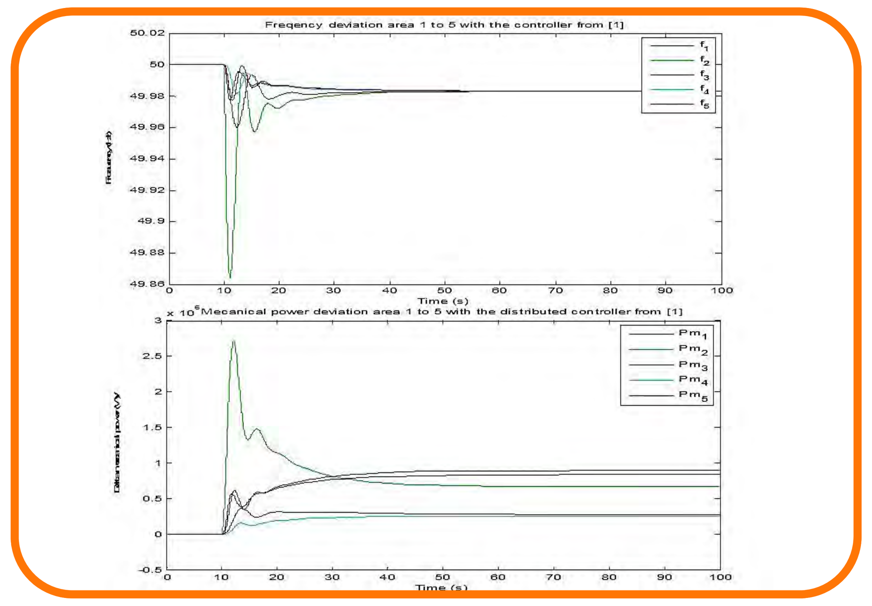
- The aim of the state feedback regulator is simple : Re-placing the eigenvalues of the system.
- The placement of the eigenvalues determines the stability of the system.
- With a good configuration of the system, state space feedback allows a simple calibration and interpretations of the results.

"Rendez-Vous" Method [1]

This method is based on a consensus protocol between a number of agents x_i called consensus average or nearest neighbor rules: $\dot{x}_i = -\sum_{j \in N_i} (x_i - x_j) \quad i \in \{1, ..., N\}$

Under the condition that the graph stays connected:

$$\lim_{t \to \infty} x_i(t) = \frac{1}{N} \sum_{j=1}^{N} x_{ij}(0) \quad i \in \{1, ..., N\}$$



Based on this method a PI control is designated in [1] as :

$$\frac{\mathrm{d}P_i^{\mathrm{dc}}}{\mathrm{d}t} = \lambda_1 \sum_{j=1}^{N} b_{ij}(\Delta f_i - \Delta f_j) + \lambda_2 \sum_{j=1}^{N} b_{ij}\left(\frac{\mathrm{d}f_i}{\mathrm{d}t} - \frac{\mathrm{d}f_j}{\mathrm{d}t}\right)$$

with λ_1, λ_2 respectively the integral and proportional gain of the controller.

[1] J. Dai, Y. Phulpin, A. Sarlette, and D. Ernst, \Coordinated primary frequency control among non-synchronous systems connected by a multi-terminal high-voltage direct current grid," IET Generation Transmission and Distribution, vol. 6, no. 2, pp. 99-108, 2012.

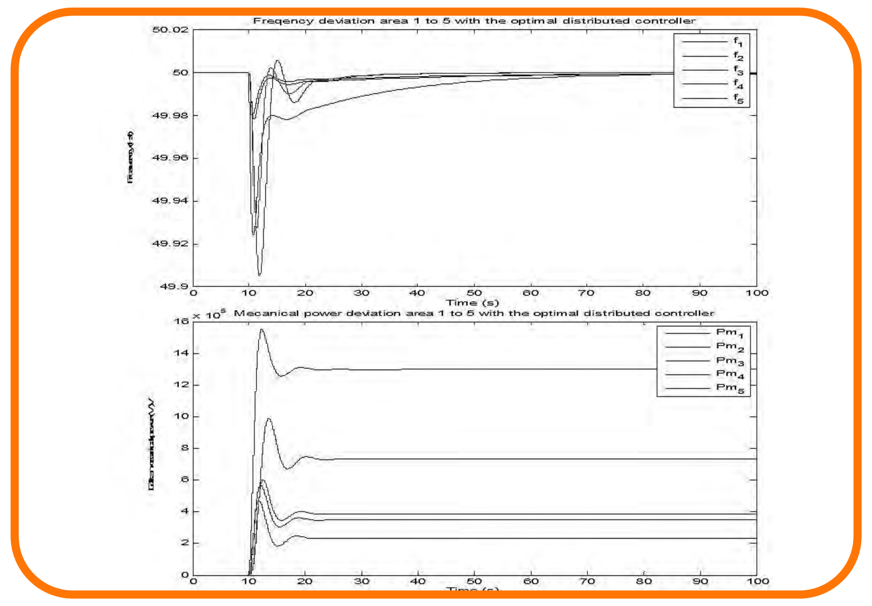
Optimal State Feedback Control

Using state feedback design optimal control theory can be easily implemented to find the optimal K. The cost function J is defined as:

$$J = \frac{1}{2} \int_0^{\infty} [\mathrm{x}^{\mathrm{T}}(t) Q \mathrm{x}(t) + \mathrm{u}^{\mathrm{T}}(t) R \mathrm{u}(t)] \, dt$$

Under optimal state feedback control K is defined as: $K = R^{-1} B^{\mathrm{T}} S.$

with S the solution of the Riccati equation.



Future Work

- Optimal state feedback requires that each distributed controller has a knowledge of each state of the system.
- An optimal communication topology, stabilizing the system, would allow for decreased communication cost.
- Using Linear Matrix Inequality (LMI) the optimal topology search can be integrated within the control process.