Distributed Control Schemes For Damping Inter-area Oscillations

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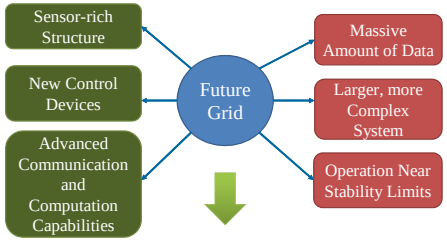
Introduction

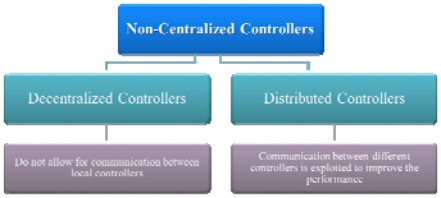
- Integration of technologies capable of monitoring, communicating, and controlling the electric power system, renders the grid one of the most complex cyber physical systems.



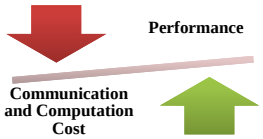
While future control designs can benefit from a real-time broader view of the system, being rationally localized to avoid intensive communication and computation is a key.

One Approach → **Distributed Control**

Distributed Control



While local controllers are blind to the widespread effects of disturbances and centralized controllers are challenging to implement, distributed controllers can achieve a trade-off between performance and associated cost.



Conventional Control	Distributed Control
• Conventional controller design problem assumes that all the controllers in the system have access to the same information. • Given a plant P of the form $x(k+1) = Ax(k) + Bu(k) + w(k)$ design a controller that generates control inputs u(k) as a function of the measurements $y(k) = Cx(k) + v(k)$ and minimizes a quadratic cost function of the form below. $J = E\sum_{k=0}^{K}[x(k)^T Qx(k) + u(k)^T Ru(k)]$	• In the corresponding distributed control problem, multiple plants of the form $x_i(k+1) = A_i x_i(k) + \sum_{j \in N_i} A_{ij} x_j(k) + B_i u_i(k) + w_i(k)$ are present. • Each plant i has access to observations about the states of a set of other agents (N_i). The aim is to design the control laws of the individual agents to minimize the same quadratic cost function. • **The additional constraint is that each control input $u_i(k)$ can only depend on the states of agents in the set N_i.**

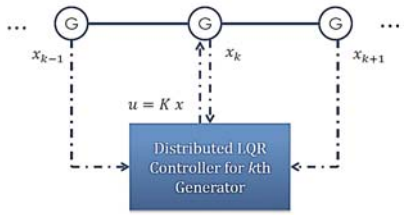
Distributed Control Design Challenges

➢ Theoretical Challenges:

Since in a distributed control problem, different controllers have access to different information sets, the problem is inherently difficult!

Two main approaches that have been proposed:

1. Identifying sub-optimal solutions.
2. Identifying special conditions or information patterns under which the problem can be solved.



➢ Implementation Challenges:

Some of the implementation challenges in power system are:

1. Implementation of a robust communication network
2. IEEE Standards Privacy in data sharing agreements
3. Associated cost for building new control infrastructure
4. Real-time computation and data management
5. Cyber security concerns

Power System Model

- Generators are modeled using fourth-order model with AVR and Excitation System. It is assumed that non of the generators have power system stabilizers (PSS) installed on them.

Distributed LQR Excitation Control

Fourth Order Model

$$\frac{d}{dt}\omega(t) = \frac{\pi f_s}{H}(P_m - P_e - P_D)$$

$$\frac{d}{dt}\delta(t) = \omega(t) - \omega_s(t)$$

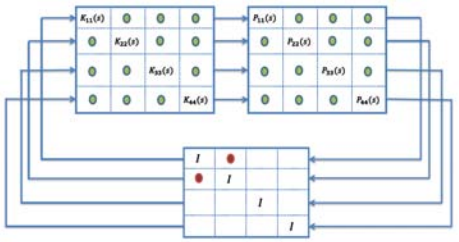
$$\frac{d}{dt}E'_{iq} = \frac{1}{T_{d0}}\left[E_{fd}(t) - E'_{iq}(t) - (X_d - X_d')I_d(t)\right]$$

$$\frac{d}{dt}E_{fd}(t) = \frac{1}{T_A}\left[-E_{fd} + K_A(V_{ref} - E_t(t) + V_{DLQR}(t))\right]$$

Designed by Proposed Distributed Controller

Mathematical Framework

Distributed LQR Control Design: Known and Limited Communication



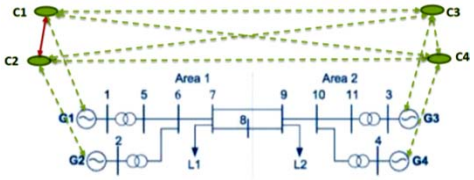
: Interdependency Element

: Communication Link

- Assumed communication network has been designed or known before designing the distributed control.
- The controllers are designed using centralized LQR formulation, but the feedback gain matrix will be reduced based on the communication laplacian matrix to include only the corresponding ***generator states*** and ***communicated measurements*** .

Implementation on Two-Area Test System

Two- Area Test System and all possible communication links

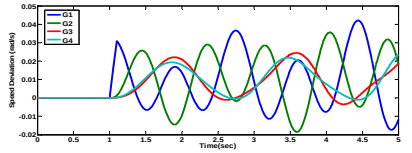


Improvements in damping of inter-area mode for different controllers

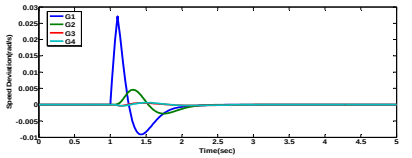
Type of Control	Inter-area Mode	Damping Ratio
No Control	0.06811 ± j3.8214	-0.01782
Decentralized Control	**-1.9377 ± j3.2428**	**0.5129**
Distributed Control	-4.0276 ± j3.5630	0.74899
Centralized Control	**-4.1272 ± j3.1181**	**0.7978**

Simulation Results

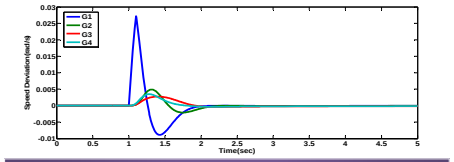
No Control



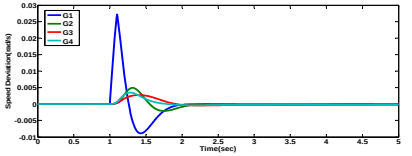
Centralized Control



Distributed Control



Decentralized Control



Conclusion and Future Work

- For the smart grid to be resilient to disturbances, wide-area monitoring and control is a necessity.
- Simulations show that proposed distributed control can improve damping for inter-area oscillations and result in performances almost similar to centralized control.
- **Future Work**: to design the controller for each study area, while maintaining critical tie-lines, external areas will be modeled using measurement based model identification techniques. Then the controller can be designed and updated in real-time using conventional well-known control methods.