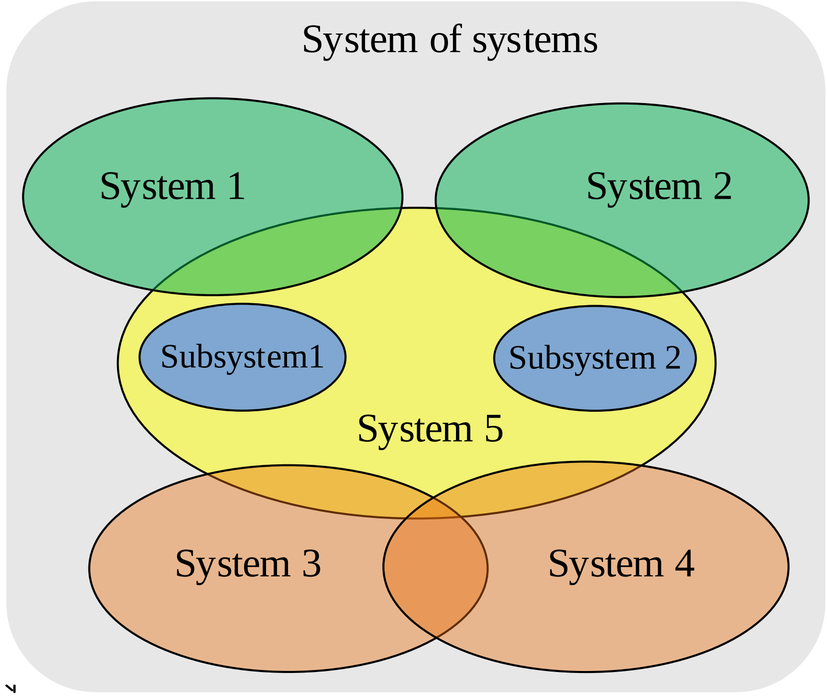
i-PCGRID Workshop 2014

Innovations in Protection & Control for Greater Reliability Infrastructure Development

Smart Power Scheduling: A System of Systems Framework



Yong Fu, Ph.D.
Assistant Professor
Electrical and Computer Engineering
Mississippi State University

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San Francisco

JAMES WORTH BAGLEY COLLEGE OF ENGINEERING MISSISSIPPI STATE UNIVERSITY

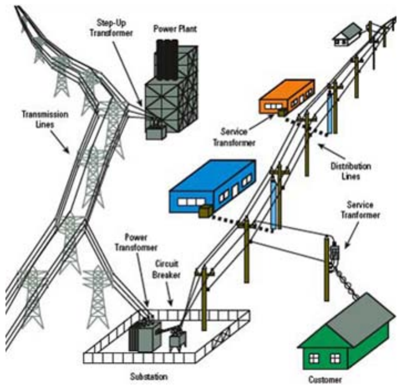
Power System Scheduling

- **<u>Motivation</u>**
  - Provide a more accurate and detailed understanding of power grid, which is "making the grid as good as possible"
  - Provide a secure and economic power system operation

- **<u>Benefits</u>**
  - To reduce the overall cost of delivering power to end users
  - To get more out of the existing infrastructure and thus defer investments in new facilities
  - To improve reliable delivery of power to end users – never fails to customers
  - To reduce emissions

- **<u>Outcomes</u>**
  - Operation of generation, transmission and distribution systems
  - Incorporation of distributed energy resources and energy storages
  - Load side management considering demand response
  - Cooperation of multiple energy infrastructures
  - More …

Challenges & Opportunities



❑ Conventional Power Systems

- Monopolistic systems - Vertically Integrated Utility
- Lack of competition and collaboration
- Scheduling of central power generators
- Passive distribution grids, and unidirectional power flow
- The operator has all data and information
- Centralized decision

❑ Modern Power Systems

- Many individual entities – Restructuring Power System
- Each entity might have its own operating policies and rules.
- Competition and collaboration to maximize the benefit
- Active distribution grid, and bidirectional power flow
- Scheduling among perhaps millions of distributed generators
- Operational confidence at high levels of renewable energy resources
- Data and information of the entities are usually commercially sensitive
- Decentralized/Distributed decision

A System of Systems Framework

- **System of Systems (SoS):** The entities are independent systems that can function independently with their own operation and control regulations, the competition and collaboration relationship among them can be represented by the concept of system of systems.

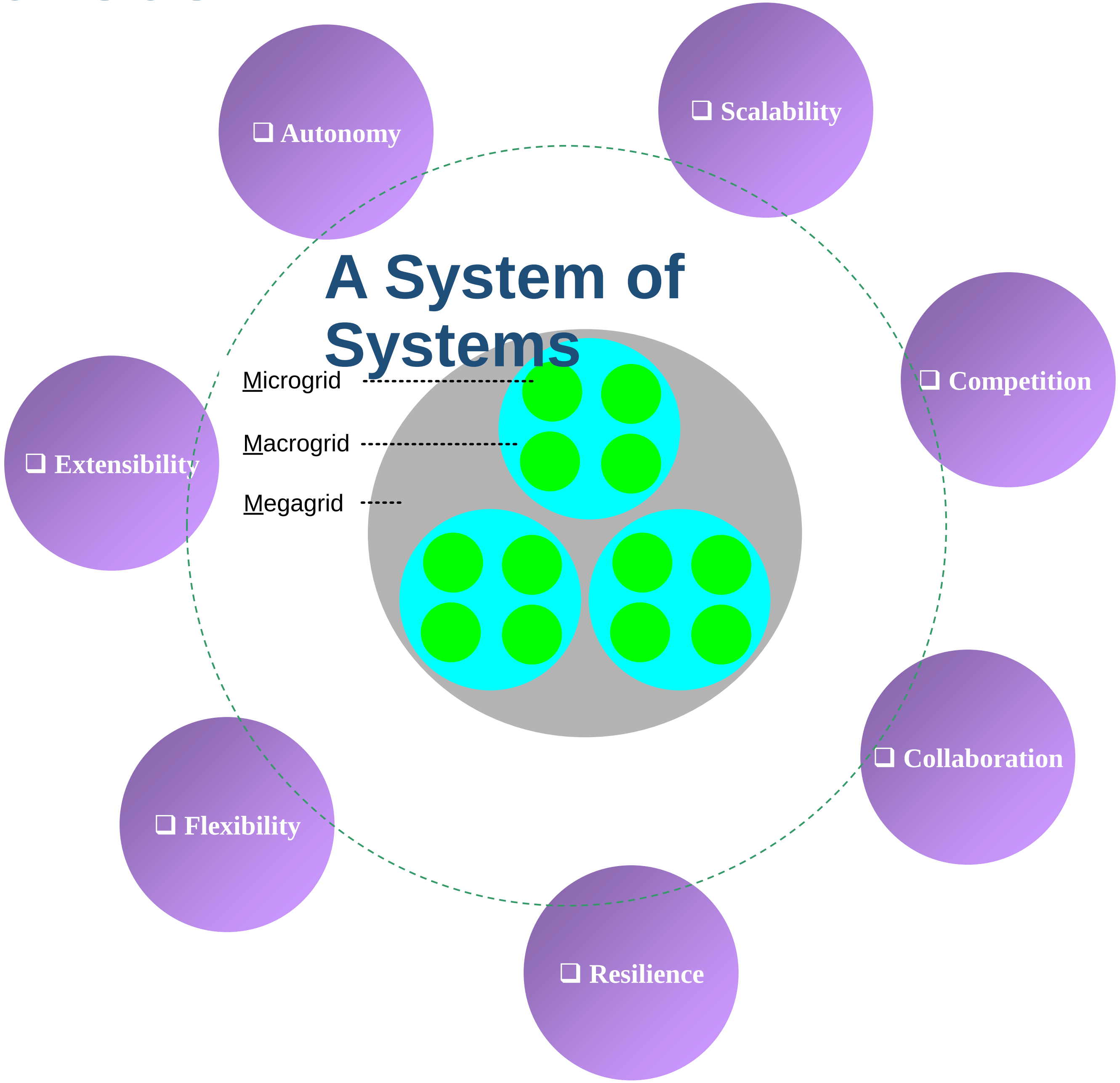
- Systems could be different sizes at different levels, have different functions, and even follows different physical laws

- Each system, as a distributed and independent decision-making entity, implements dual functionalities:

  - System's internal management: effectively manages heterogeneous electric power components in its individual area

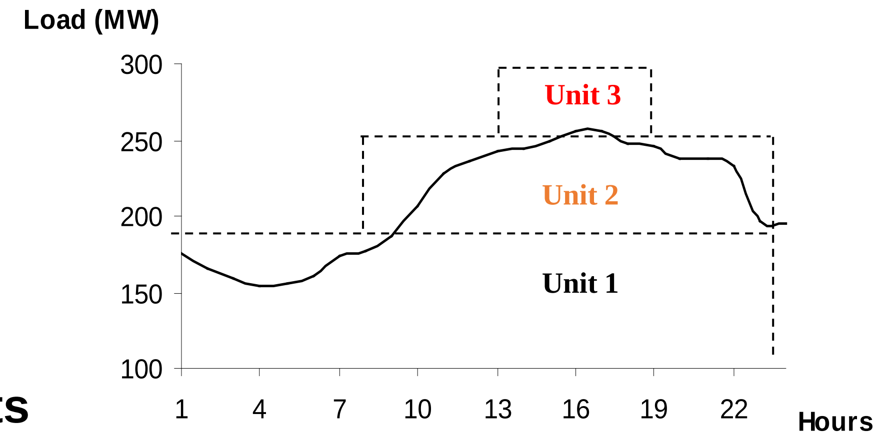
  - System's external interaction: successfully interacts with inner and/or outer systems.

Attributes of SoS



A Typical Power System Scheduling Problem
– Security Constrained Unit Commitment

- **Objective Function – Minimize**
  - Generation and startup/shutdown costs
- **Generating Unit Constraints**
  - Generation capacity
  - Minimum ON/OFF time limits
  - Ramping UP/DOWN limits
  - Must-on and area protection constraints
  - Forbidden operating region of generating units



- **System Operation Constraints**
  - Power balance
  - System reserve requirements
  - Power flow equations
  - Transmission flow and bus voltage limits
  - Limits on control variables
  - Limits on corrective controls for contingencies

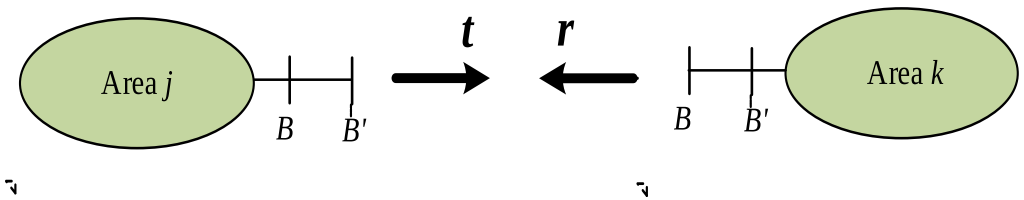
Large Scale, Non-Convex, Mixed Integer Nonlinear Problem

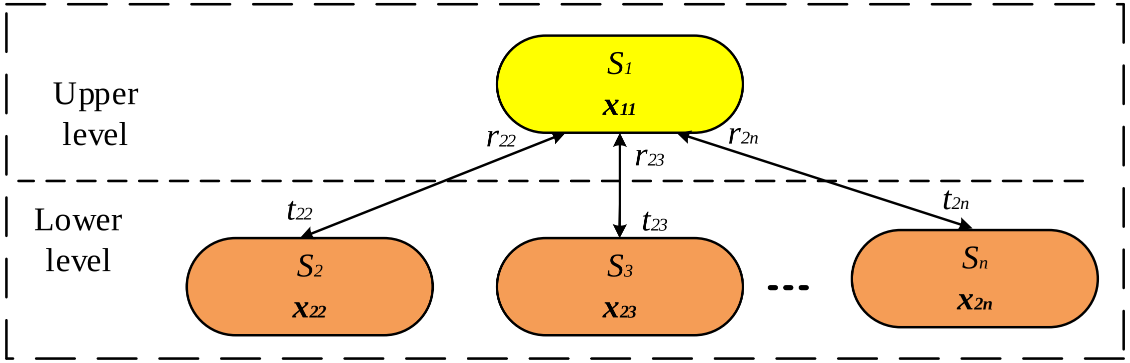
A Distributed Solution to Power System Scheduling

- Large Size: Physically and Mathematically
- Distributed Structure: Geographically and Managerially
- Decision Quality: Fast and Accurate
- Information Privacy: Restricted and Shared

Multiple-Area and Multiple-Levels Scheduling

- Target variables (t): sending from Area/System j toward Area/System k
- Response variables (r): sending from Area/System k toward Area/System j





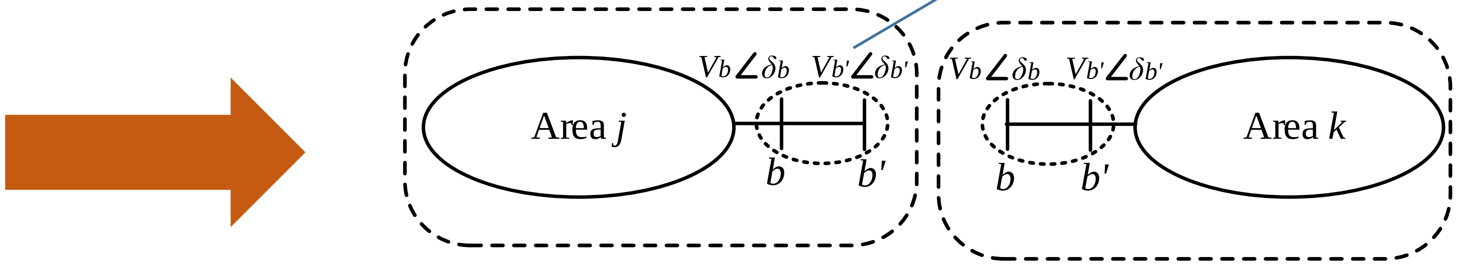
$$\begin{aligned} Min \quad & f_j(\mathbf{x}, \boldsymbol{t}, \boldsymbol{r^*}) + \pi(\boldsymbol{t}, \boldsymbol{r^*}) \\ s.t. \quad & \boldsymbol{g}_j(\mathbf{x}, \boldsymbol{t}, \boldsymbol{r^*}) \le 0 \\ & \boldsymbol{h}_j(\mathbf{x}, \boldsymbol{t}, \boldsymbol{r^*}) = 0 \end{aligned}$$

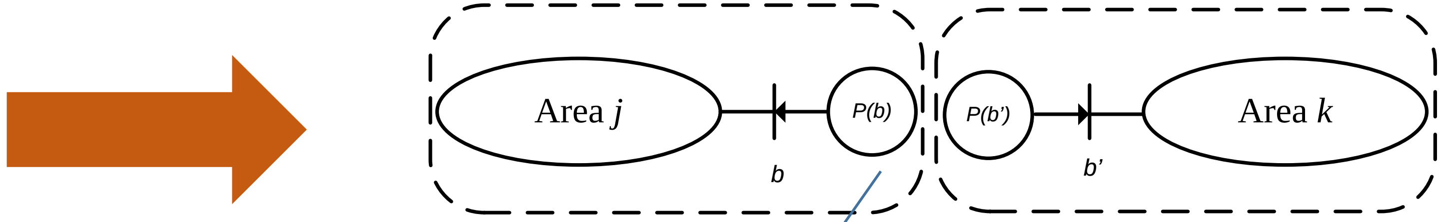
$$\begin{aligned} Min \quad & f_k(\mathbf{y}, \boldsymbol{t^*}, \boldsymbol{r}) + \pi(\boldsymbol{t^*}, \boldsymbol{r}) \\ s.t. \quad & \boldsymbol{g}_k(\mathbf{y}, \boldsymbol{t^*}, \boldsymbol{r}) \le 0 \\ & \boldsymbol{h}_k(\mathbf{y}, \boldsymbol{t^*}, \boldsymbol{r}) = 0 \end{aligned}$$

$$\boldsymbol{t} = \boldsymbol{r}\ ?$$

Modeling Shared Variables

Boundary variables are duplicated in both local systems

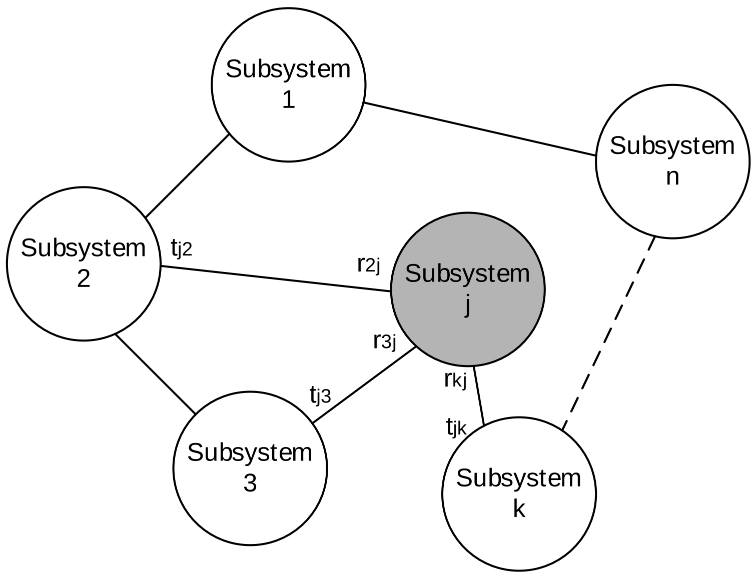




$$P(b) = -\frac{\delta_b - \delta_{b'}}{X_{bb'}}$$

Pseudo power injections follow KVL

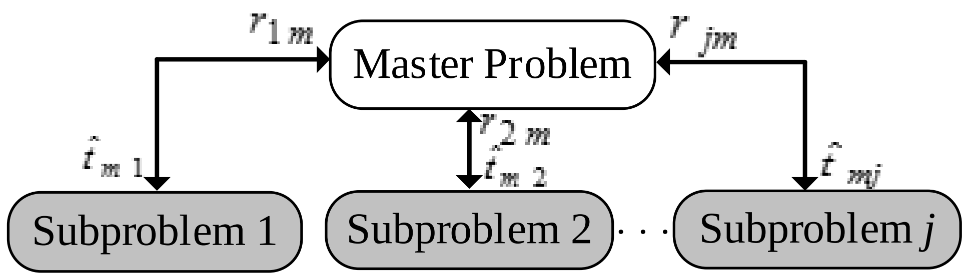
Solutions: Sequential and Parallel



Sequential

For each subsystem:

$$Min\ f_j(\tilde{\mathbf{x}}_j) + \sum_{k\in \text{neighbor}} (\boldsymbol{\alpha}_{jk}(\mathbf{t}_{jk}-\mathbf{r}_{kj}) + \left\|\boldsymbol{\beta}_{jk}\circ(\mathbf{t}_{jk}-\mathbf{r}_{kj})\right\|_2^2)$$



Parallel

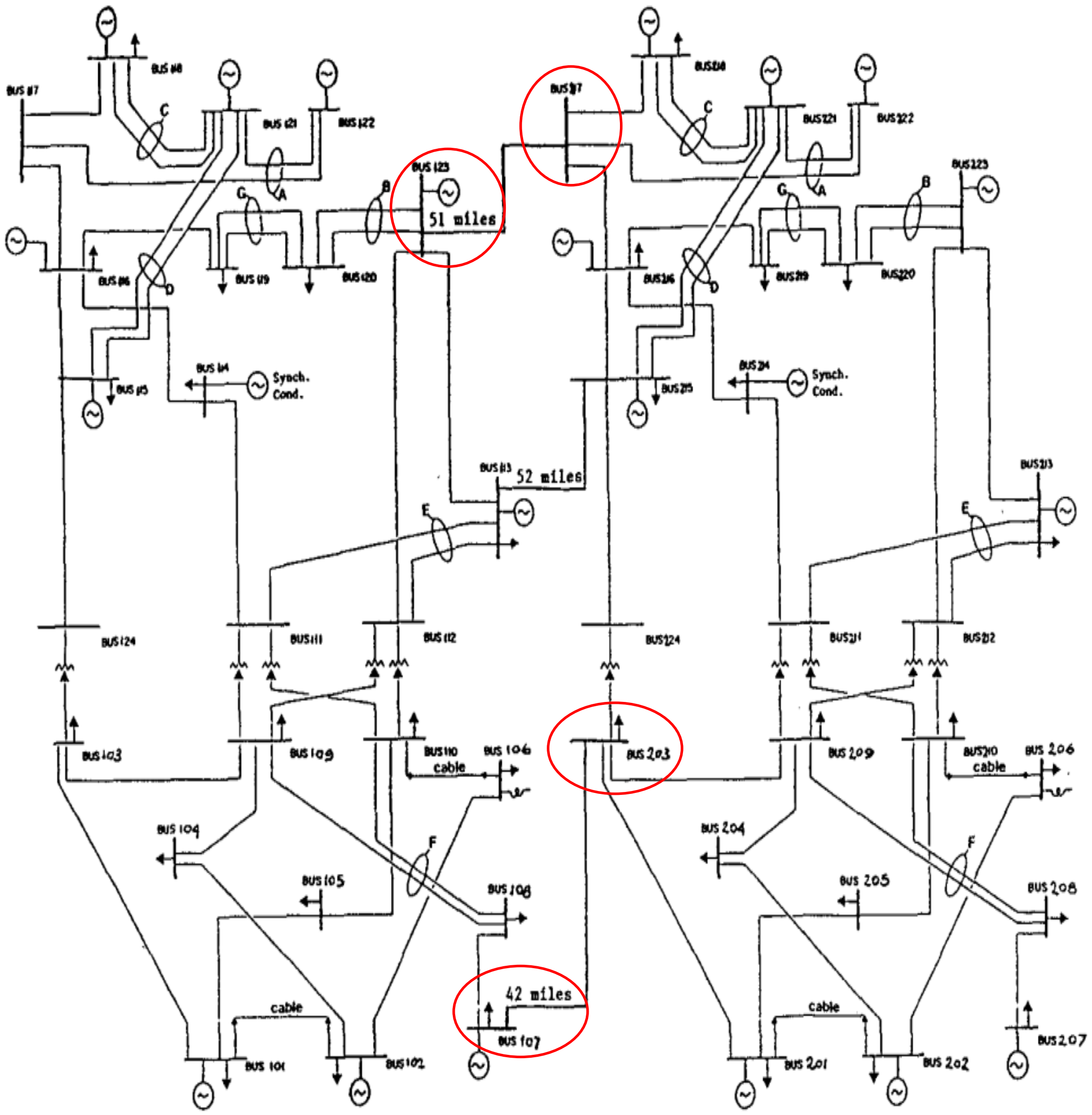
For master problem: Minimize Interaction Errors

$$Min \sum_j \left\{\alpha_{jm}(\hat{t}_{mj}-r^*_{jm}) + \left\|\beta_{jm}\circ(\hat{t}_{mj}-r^*_{jm})\right\|_2^2\right\}$$

For each subsystem:

$$Min\ f_j(\tilde{\mathbf{x}}_j)+\alpha_{jm}(\hat{t}^*_{mj}-r_{jm})+\left\|\beta_{jm}\circ(\hat{t}^*_{mj}-r_{jm})\right\|_2^2$$

IEEE 48-bus System



System Information:

48 buses

71 branches

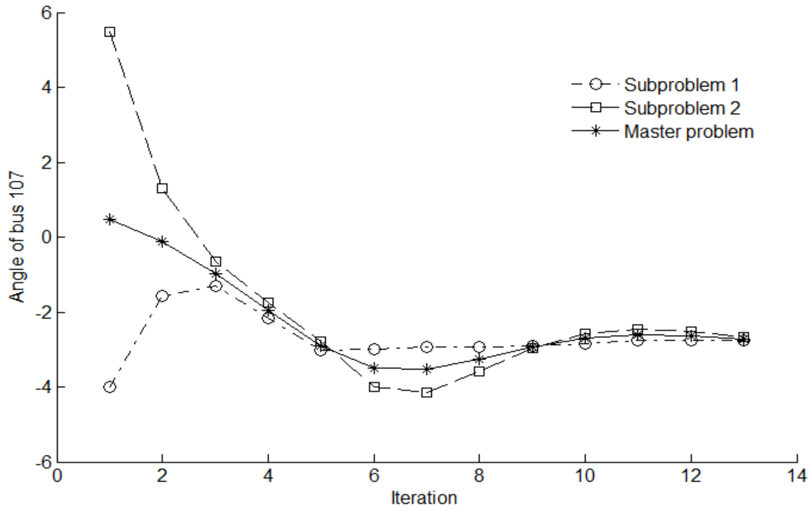
34 loads

20 thermal units

Items	C-SCUC	D-SCUC
Total operating cost ($)	$766,400	$766,490

Units	Hours (1-24)																						
1-3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4-6	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10-13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14-16	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
19	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

IEEE 48-bus System



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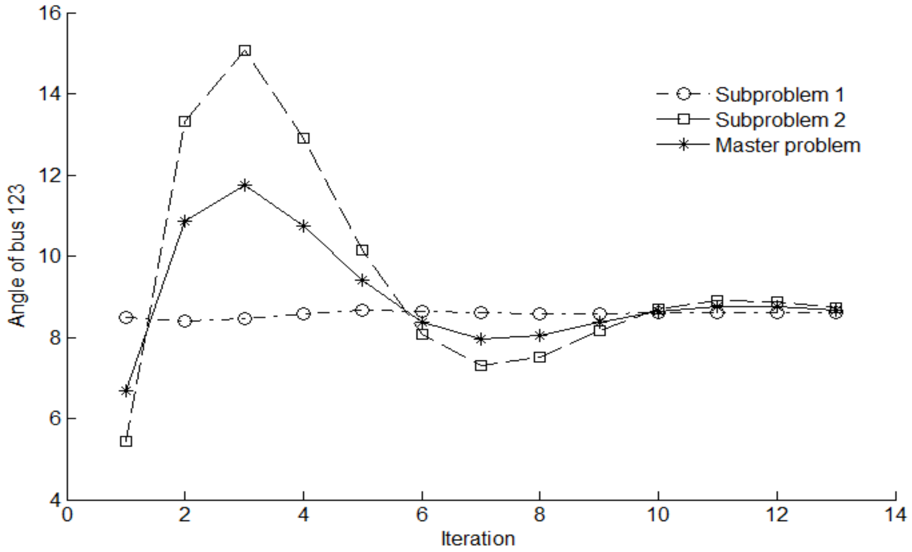
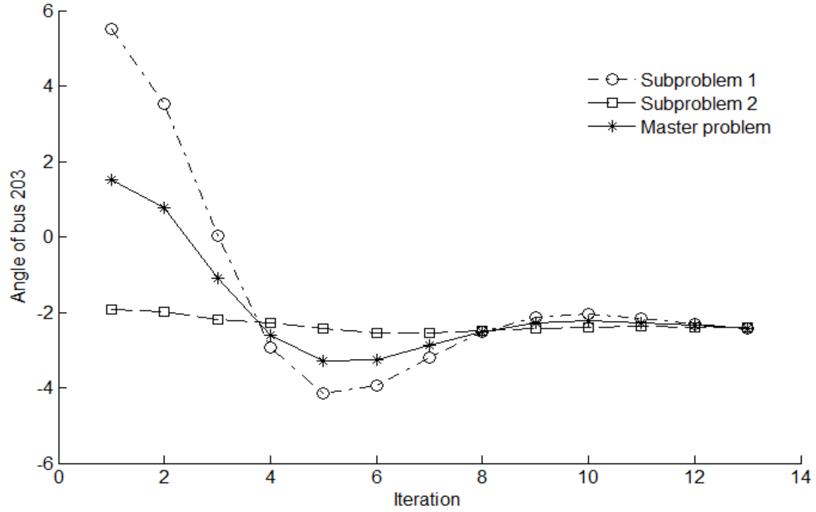
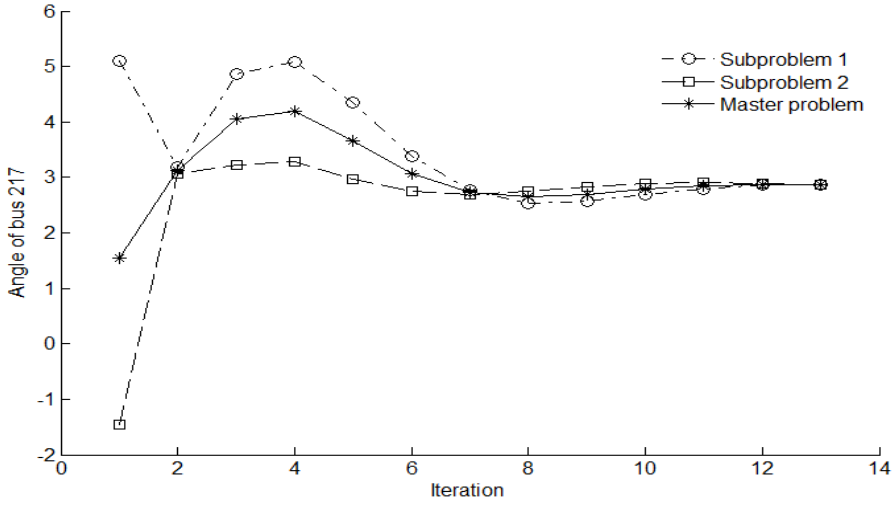
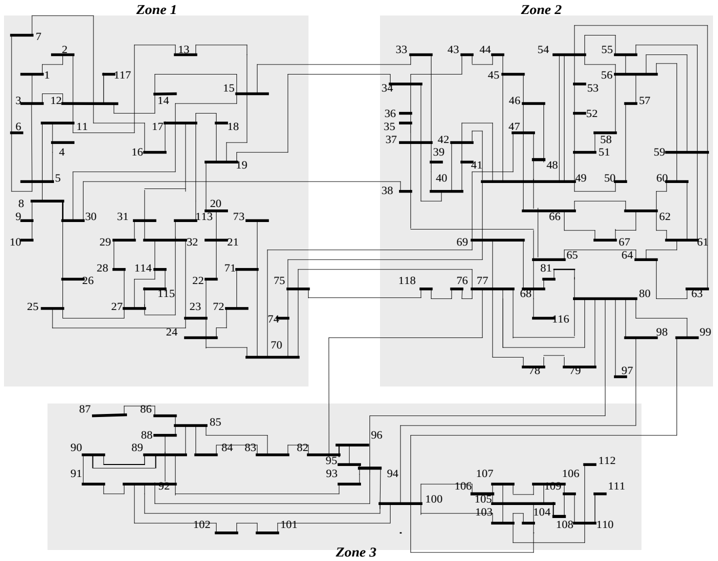
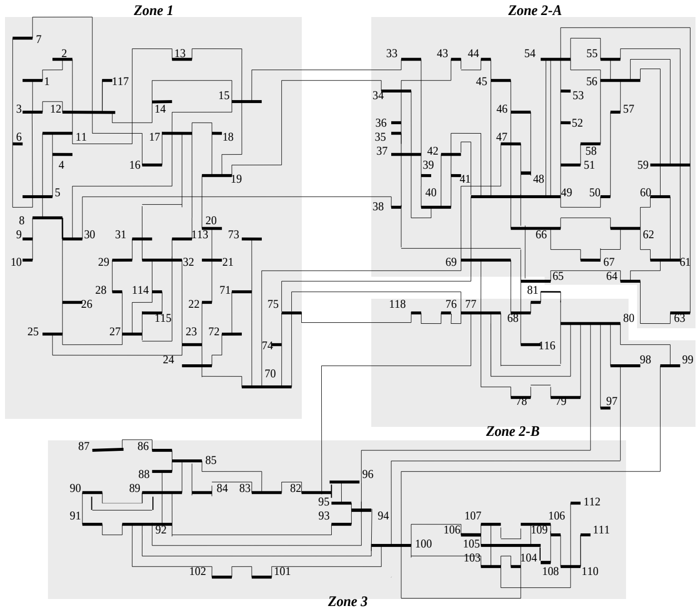






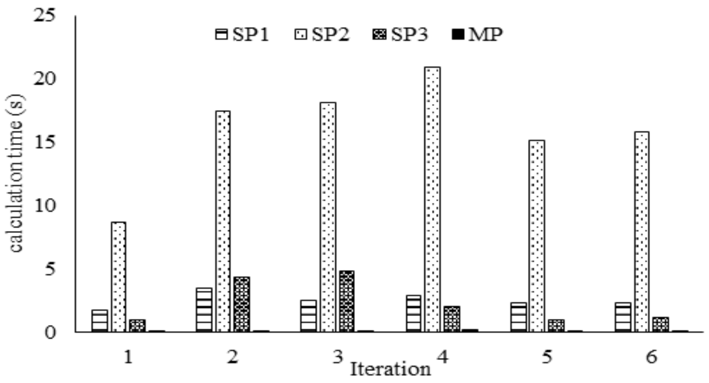
IEEE118-bus System

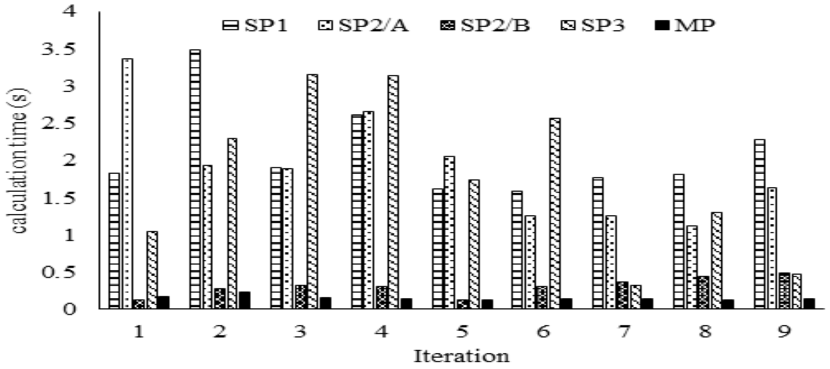




System Information:

- 118 buses
- 186 branches
- 91 loads
- 54 thermal units

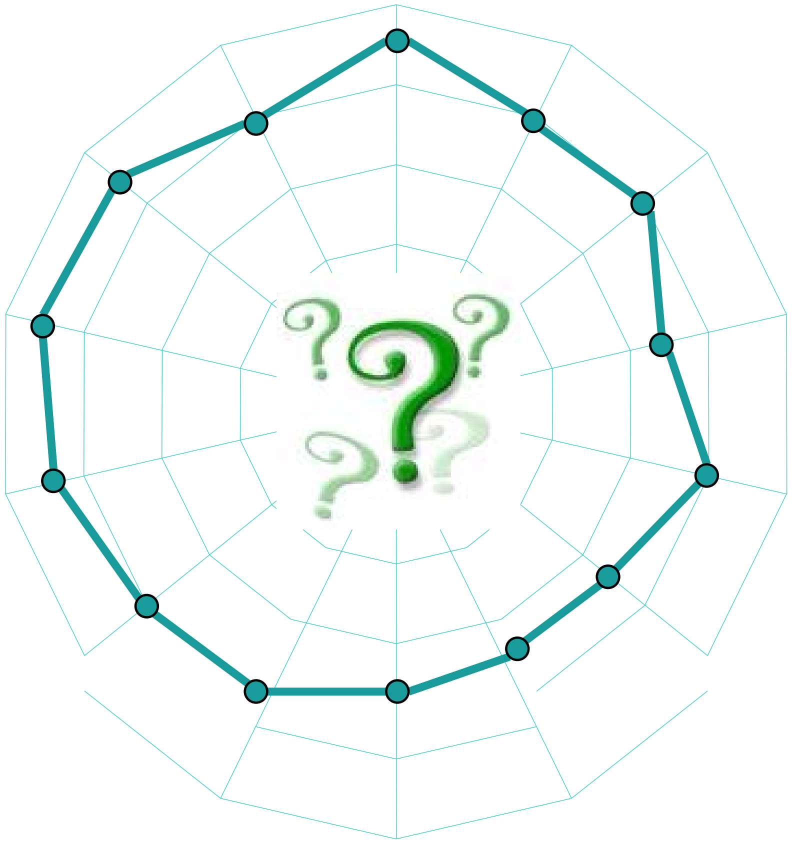




C-SCUC	D-SCUC	
	Case 1	Case 2
$1,339,000	$1,342,900	$1,344,000
69 sec.	98 sec.	22 sec.

Conclusions

- A System of Systems concept can meet the operational architecture of modern power systems.
- A distributed decision-making tool is effective for a collaborative and cooperative operation of multiple systems.
- Notice that there is no general rule to partition subproblems for specific power systems. Thus, **TWO** generic guidelines are suggested below for the application of the proposed distributed solution:
    - Each subproblem in the distributed solution should be scalable and tractable.
    - The calculation efforts among subproblems should be balanced.
- The ideas can be applied to various power system applications, such as Planning, Operation, Control, Protection, and even Infrastructure Interdependency.



Thanks !

fu@ece.msstate.edu