Dynamic Decomposition for Monitoring and Decision Making in Electric Power Systems

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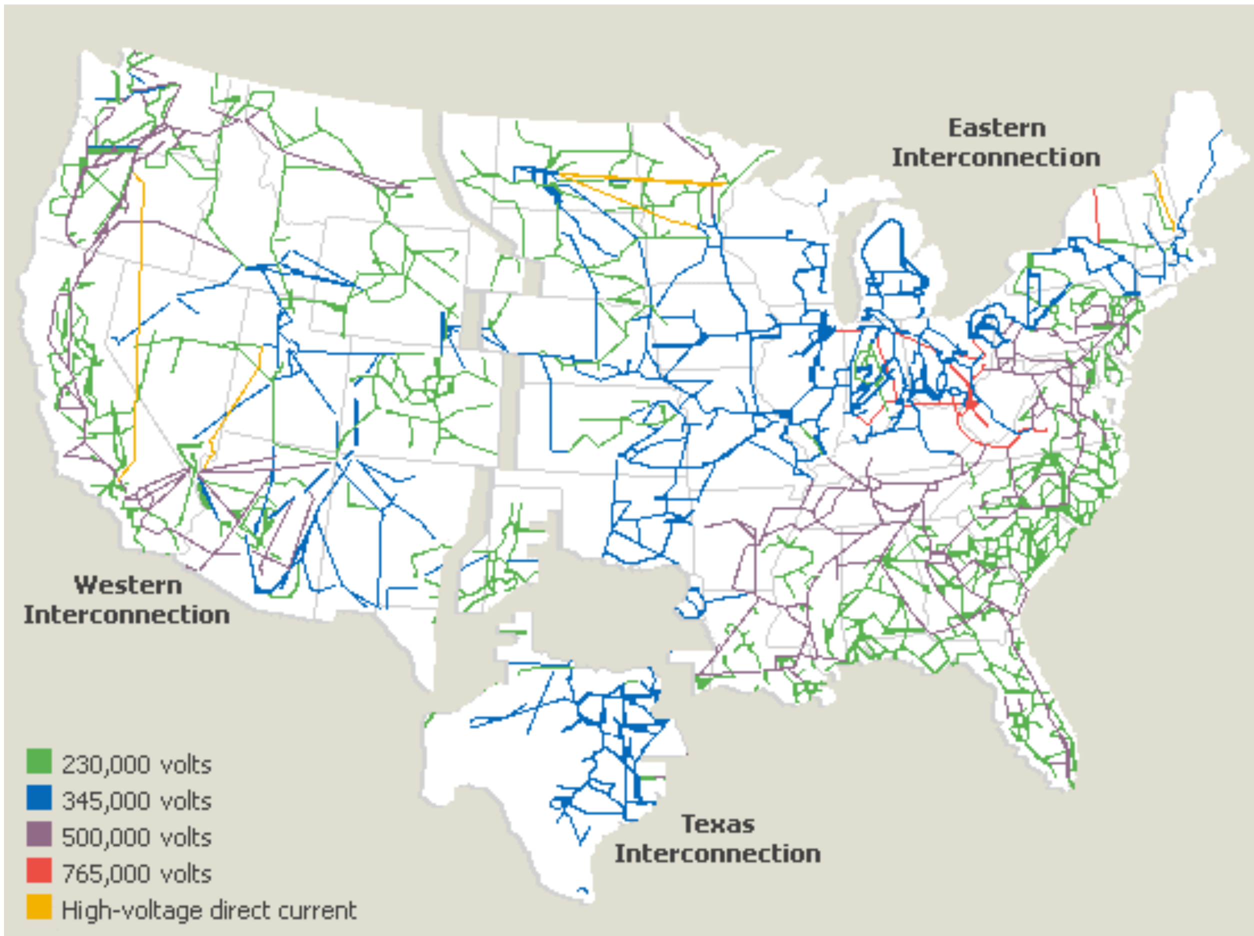
Outline

- Motivation
- Problem Statement
- Proposed Methodologies
  - Performance index (PI)
  - Decomposition method
- Example
- Conclusions

U.S National Power Grid

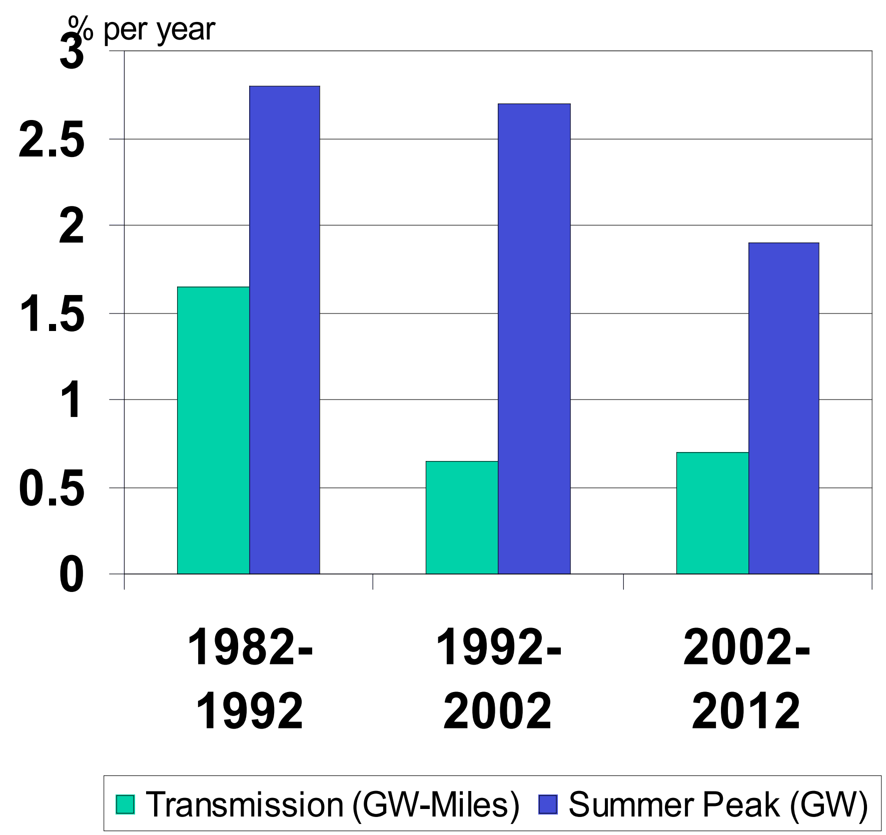


Data Source: FERC

Motivation

- Power system is operated over a much broader range than it was originally designed for.
- More and more stressed conditions are encountered in real-time operations.

Annual average growth rates in U.S. transmission capacity and peak demand for three decades (projected for 2002-2012)



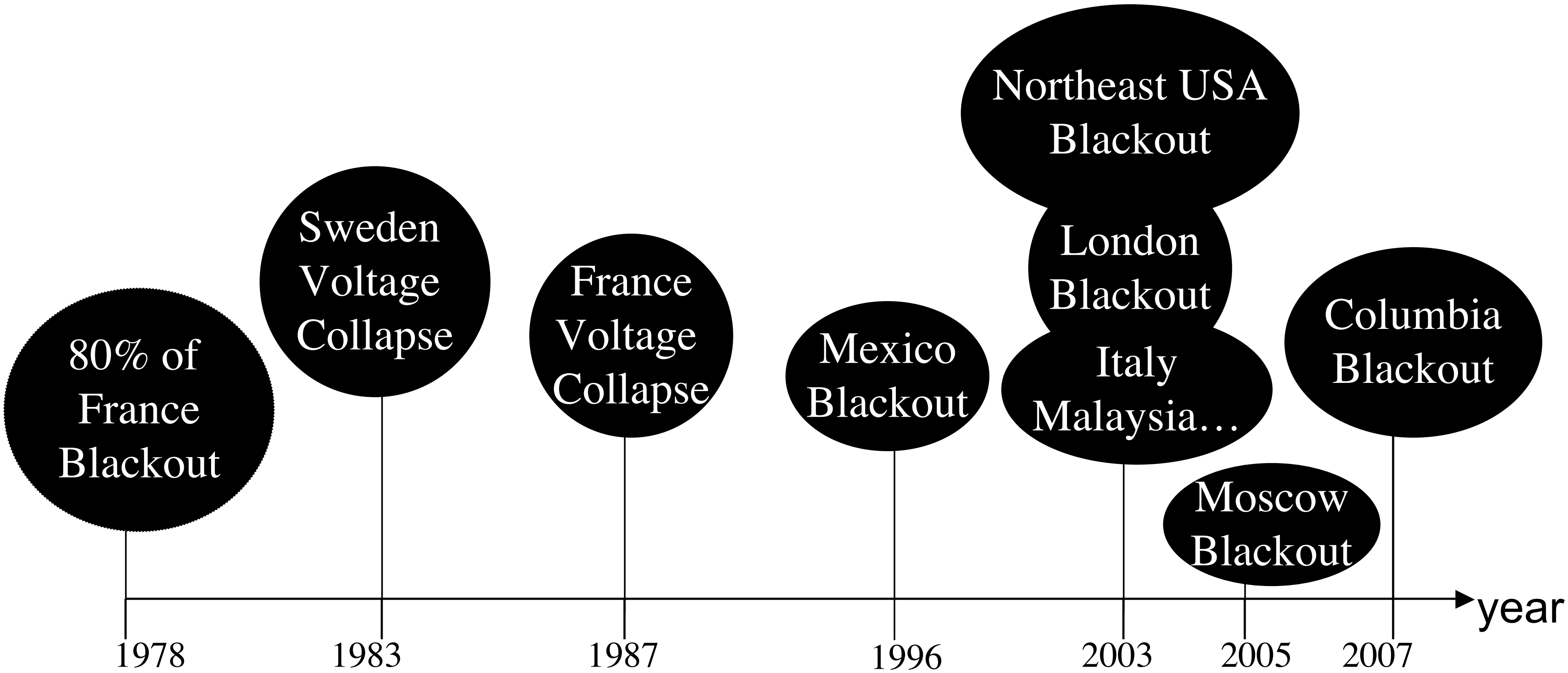
Data Source: FERC

Challenges for Power System Operation

- Goal: meet the continually changing load demand for both active and reactive power while the desired system frequency and voltage profile are maintained.
- Traditional power system operation is designed as a hierarchical structure. However, the assumptions underlying this hierarchical control design are not always satisfied when system experience large deviation from normal conditions.

P. Kundur, "Power System Stability and Control," pp. 27, McGraw-Hill, 1994

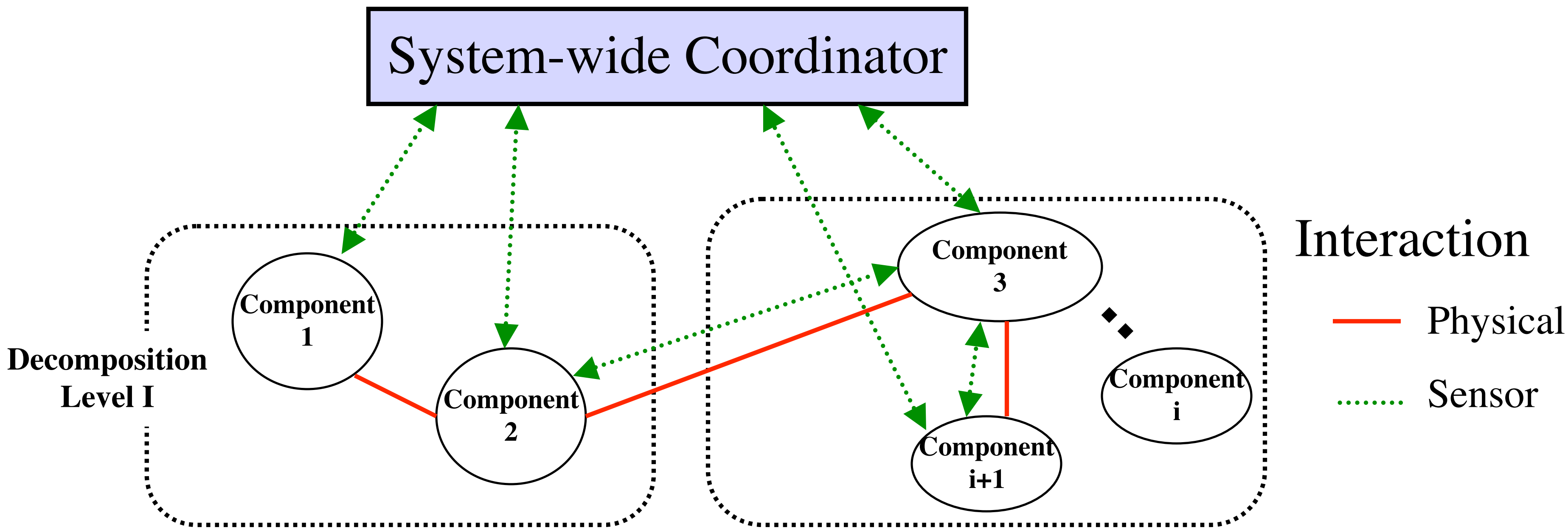
Major Blackouts in the Past 30 Years



Lessons from History

- Control devices are tuned and most effective under normal load conditions.
- Control devices may not function as designed when load level becomes severe and/or hierarchical assumptions are violated.
- Need for intelligent online monitoring and decision making tools.

As more sensors are placed for the power system

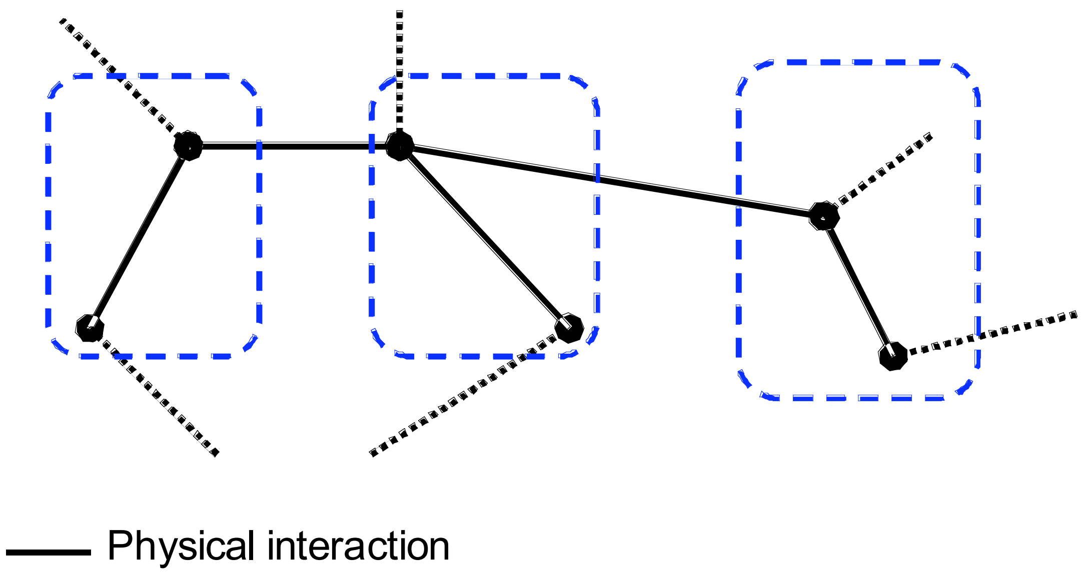


- Two basic questions
  - Who talks to whom and for what purpose?
  - Sensors communicate what data/information?

Goal of Research

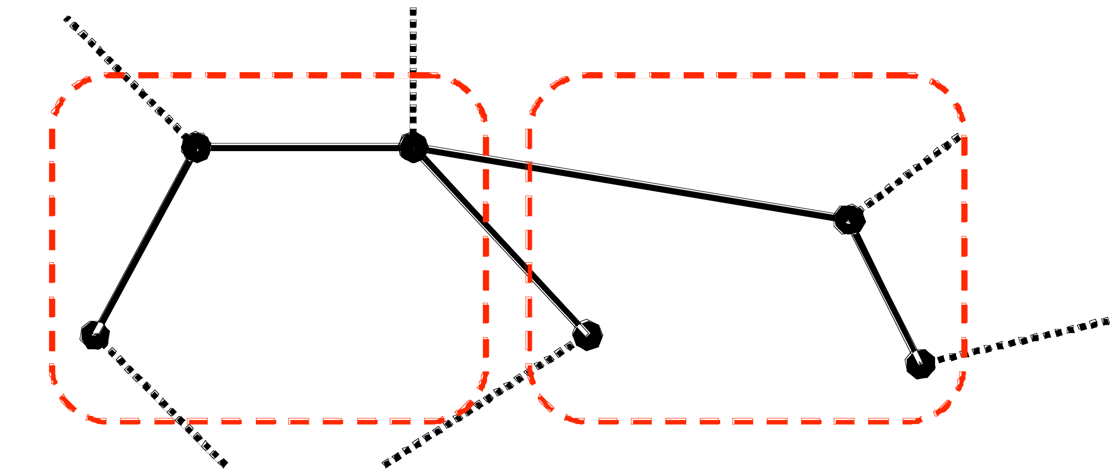
Dynamic re-grouping over time, space and organizational boundaries as the power system conditions vary

Goal of Research



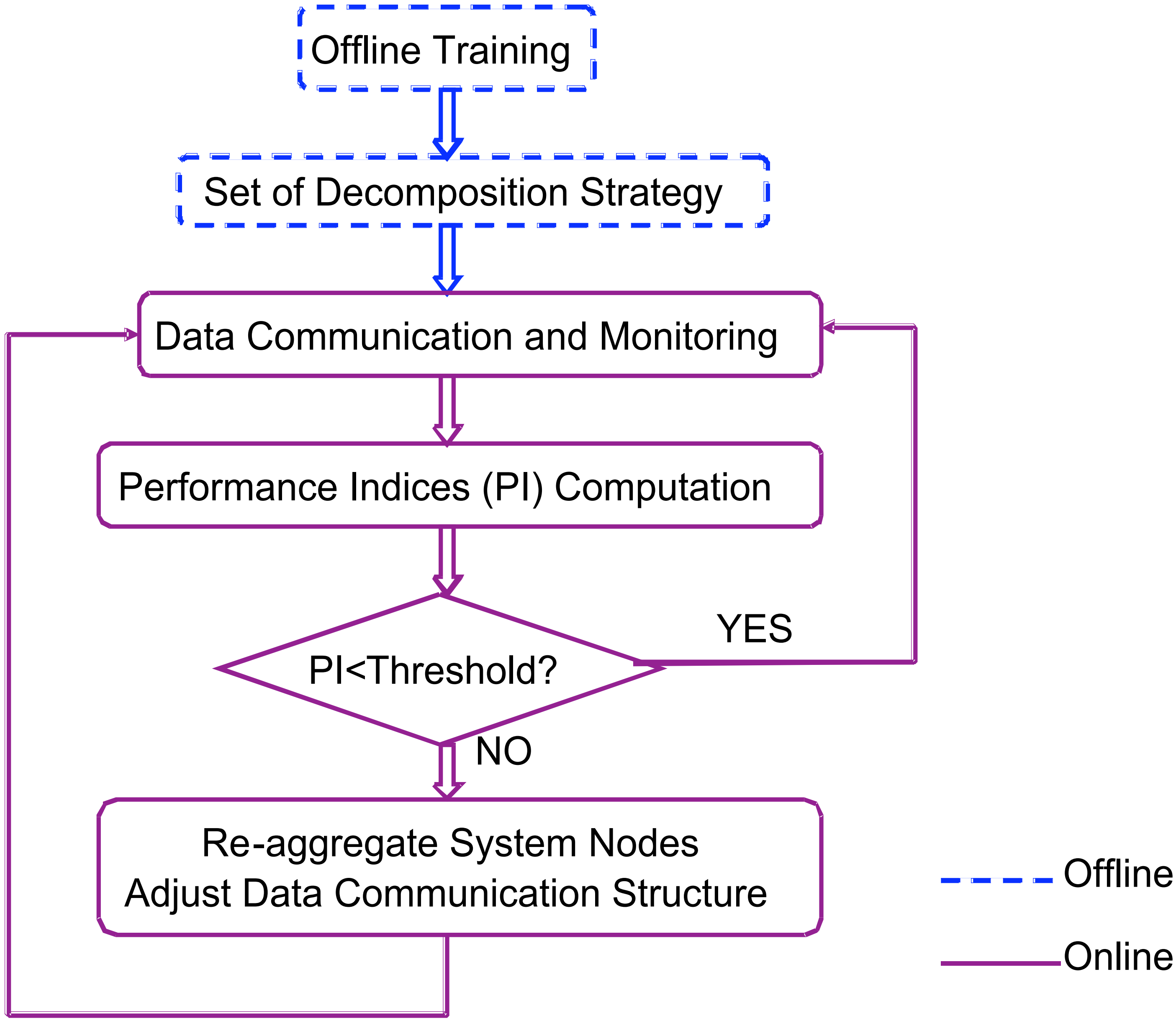
Normal Operating Conditions

Goal of Research



Physical interaction

Abnormal Operating Conditions


Offline Training
Set of Decomposition Strategy
Data Communication and Monitoring
Performance Indices (PI) Computation
PI<Threshold?
YES
NO
Re-aggregate System Nodes
Adjust Data Communication Structure
Offline
Online

Example: Monitoring of Static Voltage Stability

$$\dot{x} = f(x, y, p) \qquad x(t_0) = x_0$$

$$0 = g(x, y, p)$$

- x- state variables, define system dynamics (such as rotor angles of generators)
- y- algebraic coupling variables (such as the voltage magnitude and phase angle of all the buses)
- p- system parameters (such as network topology, load consumption)

M. Ilic and J. Zaborszky, “Dynamics and Control of Large Electric Power Systems”, 2001

Proposed Performance Index

- The singularity of linearized system load flow equations (Jacobian matrix) indicates the static voltage instability.
- Sensitivity of minimum singular value of load flow Jacobian with respect to the the load level
  - Define Load Level as the algebraic sum of |apparent power consumption| at all nodes in a system

$$S = \sum_i |S_i| = \sum_i \sqrt{P_i^2 + Q_i^2}$$

  - Define PI for a system (subsystem)

$$PI = \left| \frac{\Delta \min(SV(J_{QV}))}{\Delta S} \right|$$

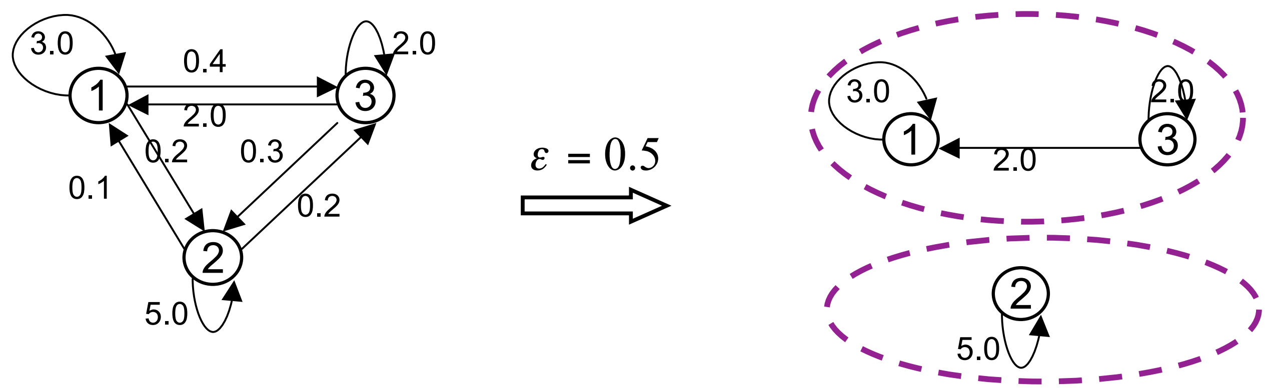
← Min singular value

← Load level

Epsilon Decomposition

- Clustering algorithm that decomposes weakly coupled sub-groups

$$\begin{bmatrix} 3.0 & 0.2 & 0.4 \\ 0.1 & 5.0 & 0.2 \\ 2.0 & 0.3 & 2.0 \end{bmatrix} \xrightarrow{\varepsilon = 0.5} \left[\begin{array}{cc:c} 3.0 & 0 & 0 \\ 2.0 & 2.0 & 0 \\ \hdashline 0 & 0 & 5.0 \end{array}\right]$$



D. D. Siljak, *Decentralized Control of Complex Systems.* Academic Press, 1991

Epsilon Decomposition: cont.

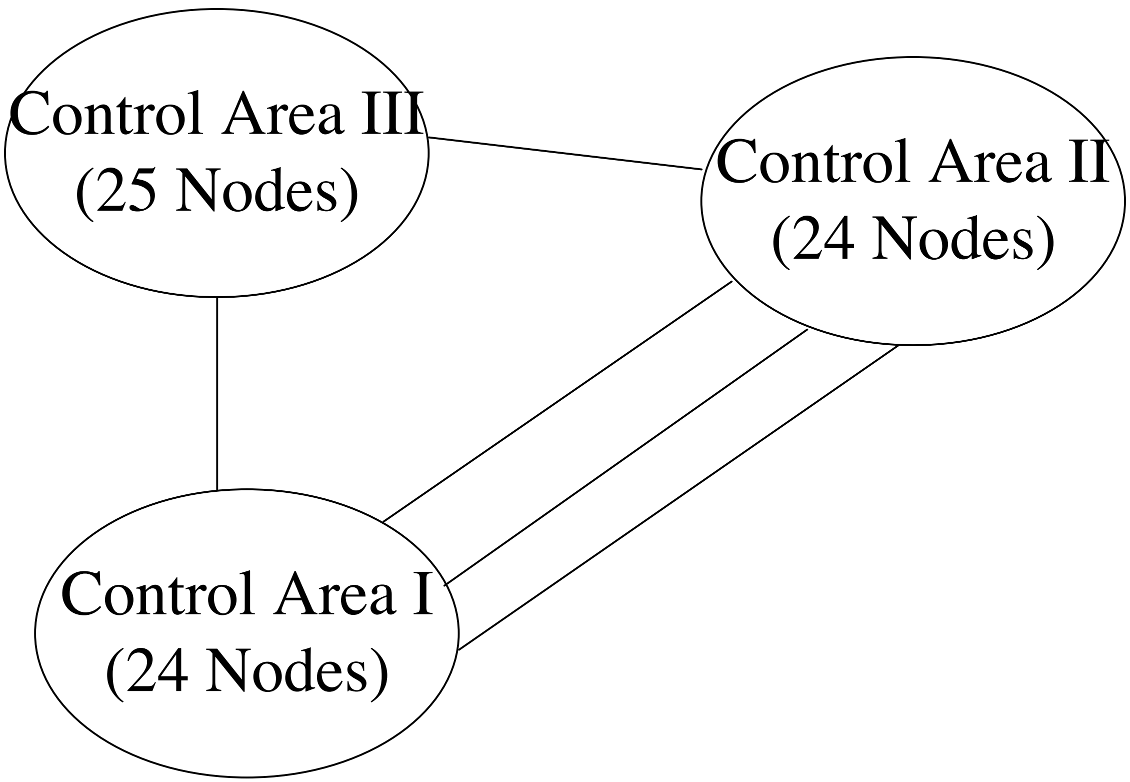
- Row and column permutation to J_{QV} s.t.

$$P' J_{QV} P = \begin{bmatrix} \frac{\partial Q_a}{\partial V_a} & \frac{\partial Q_a}{\partial V_b} \\ \frac{\partial Q_b}{\partial V_a} & \frac{\partial Q_b}{\partial V_b} \end{bmatrix}$$

In which $\left| \frac{\partial Q_a}{\partial V_b}(i,j) \right| < \varepsilon$ and $\left| \frac{\partial Q_b}{\partial V_a}(i,j) \right| < \varepsilon$

$$\begin{bmatrix} \frac{\partial Q_a}{\partial V_a} & 0 \\ 0 & \frac{\partial Q_b}{\partial V_b} \end{bmatrix} \begin{bmatrix} \Delta V_a \\ \Delta V_b \end{bmatrix} = \begin{bmatrix} \Delta Q_a \\ \Delta Q_b \end{bmatrix}$$

IEEE Reliability Test System (RTS)



- 3 control areas
- 5 tie line buses
- Keep constant power factor increasing of the load at bus #308 (in area III) until static voltage instability limit is reached

Grigg, et. al, "The IEEE Reliability Test System-1996 ", IEEE Tran. Power Systems, 1996

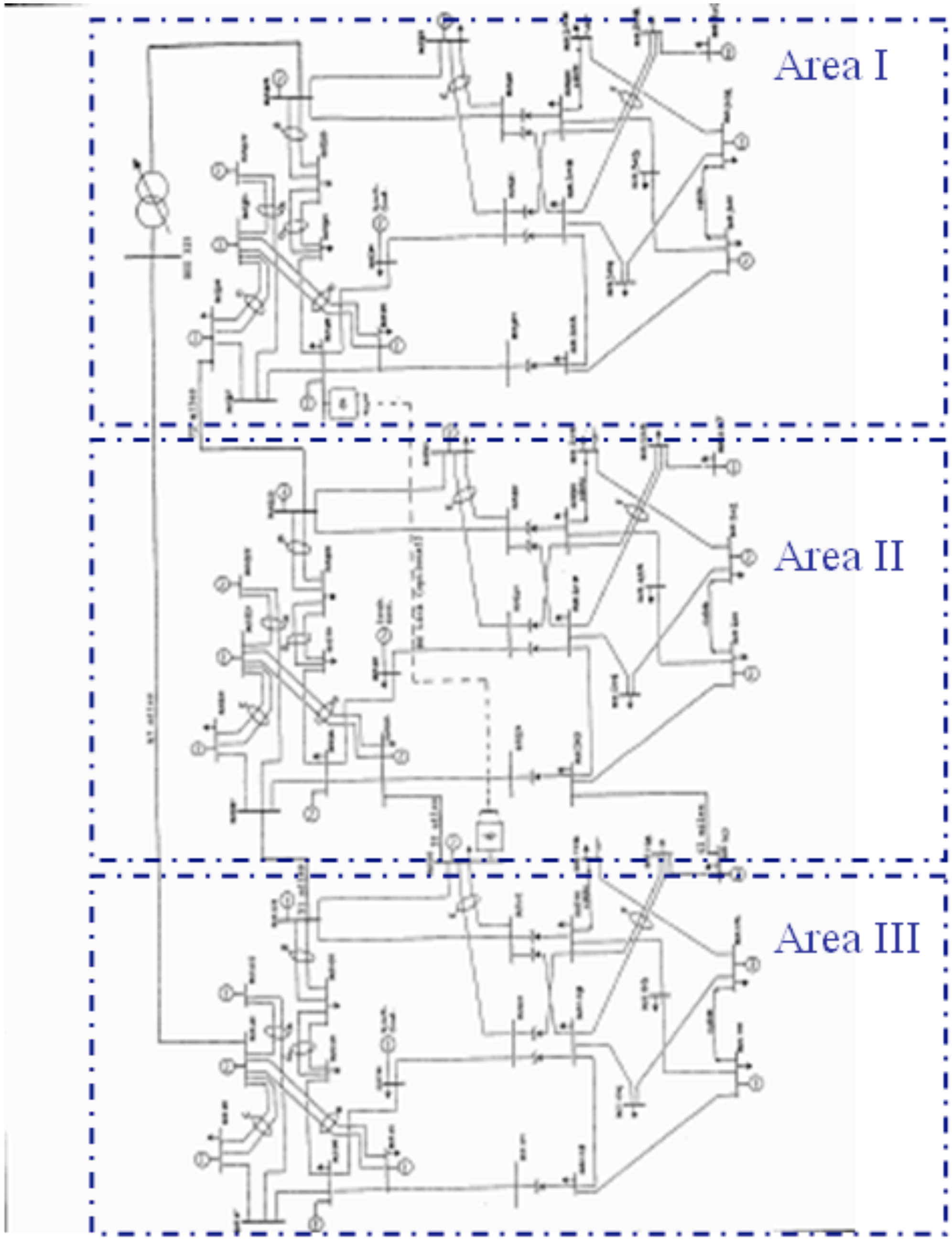
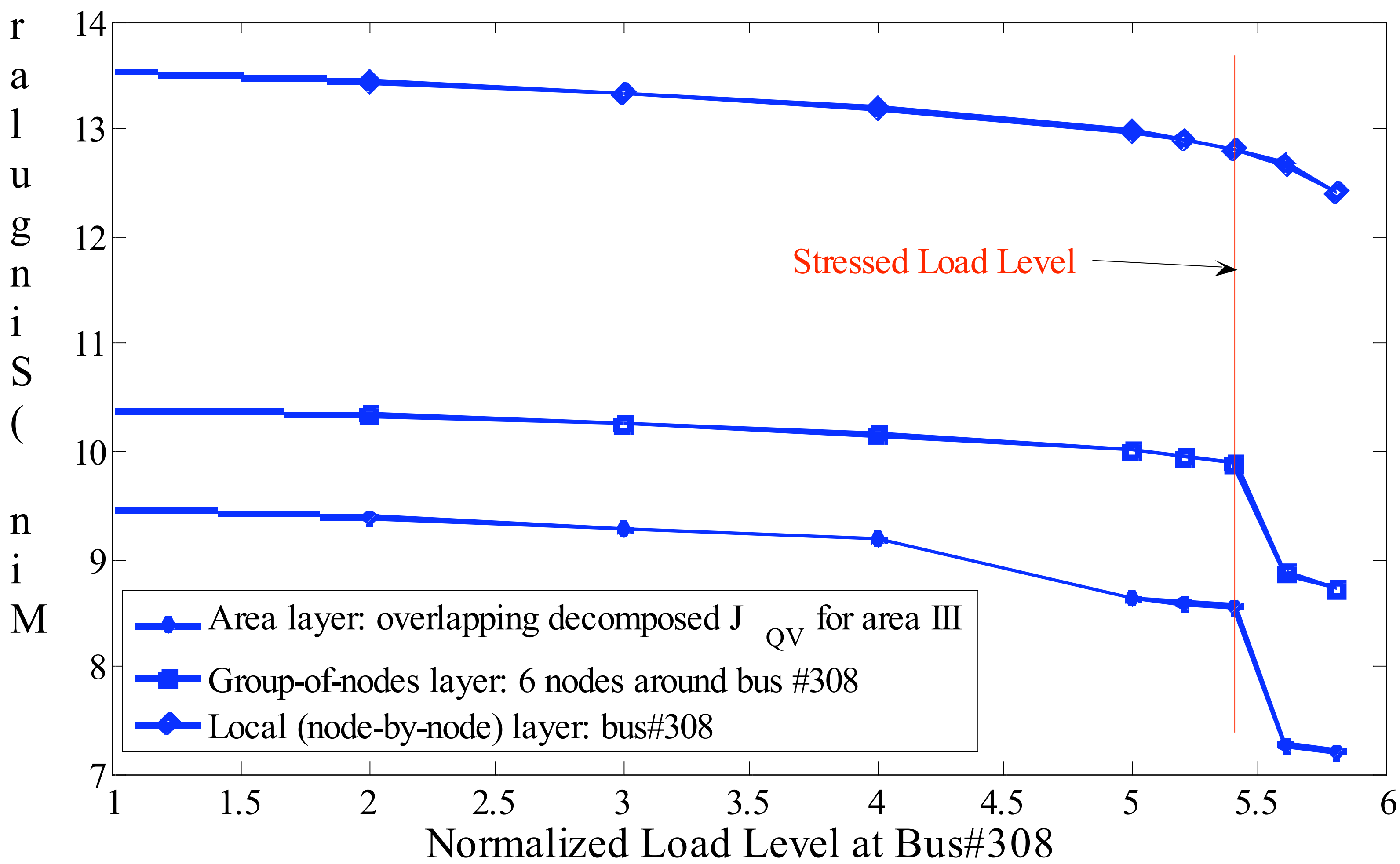
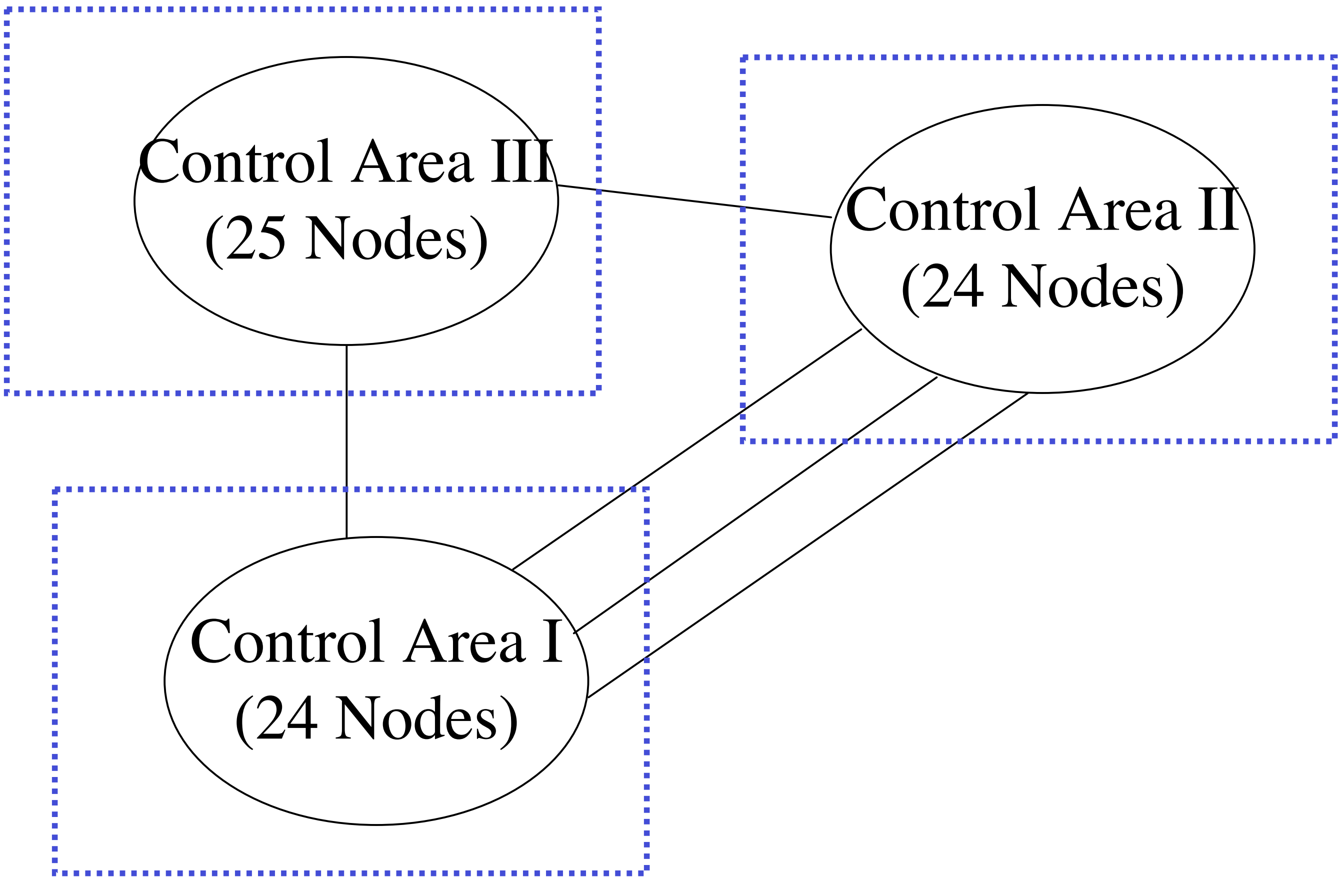


Fig. 7 IEEE RTS-1996 three-area system

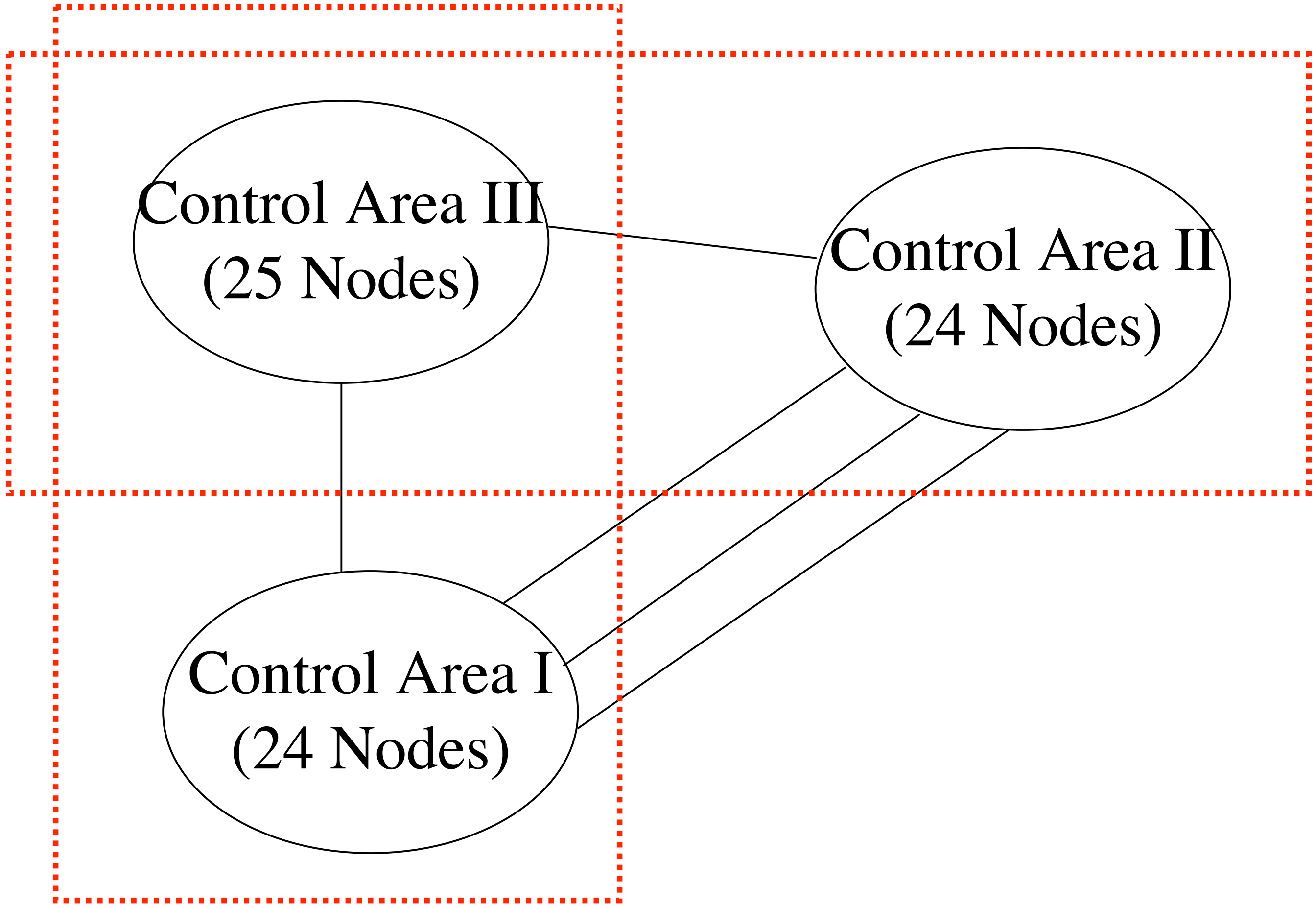
Epsilon Decomposition Result



Normal Conditions



Abnormal (Stressed) Conditions



Conclusions

- A dynamic decomposition method, which is based on coupling strength among sub-groups, is proposed to monitor and control the power system over a broad range of operating conditions.
- A performance index is proposed as an example to monitor the static voltage problem in a dynamical decentralized approach.
- Dynamic decomposition could potentially form the framework for adaptive real-time power system operation.

References

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Thank you!