Management of Precursors to Catastrophe:
Identifying & Measuring Precursors

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Lead, Mathematics & Information Sciences

Roundtable on Management of Precursors to Catastrophe

National Academy of Engineering

February 21, 2002, Washington, D.C.

EPRI

Vulnerabilities: Power Grid Examples

- November 1965 blackout in the Northeast U.S., which cascaded system collapse in ten states.
- 1967 Pennsylvania-New Jersey-Maryland.
- July 13, 1977 blackout in New York City.
- December 19, 1978 blackout due to voltage collapse in France.
- July and August 1996 outages in the western U.S.
- December 1998, Bay Area black-out. NY July 7, 1999 blackout.
- December 1998 ice storms in Hydro Quebec
- December 1999 winter storms in France
- Industry-wide Y2K readiness program identified telecommunications failure as the biggest risk of the lights going out on rollover to 2000.
- Past summers' price spikes
- Aftermath of tragic events of 11th September.

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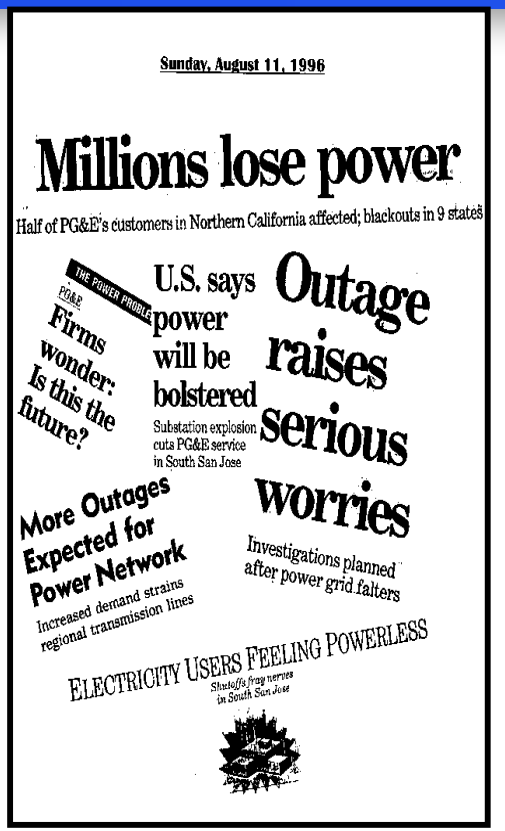
EPRI/DOD Complex Interactive Network/Systems Initiative

The Reason for this Initiative: "Those who do not remember the past are condemned to repeat it."
George Santayana

- Two faults in Oregon (500 kV & 230 kV) led to…
  - …tripping of generators at McNary dam
  - …500 MW oscillations
  - …separation of the Pacific Intertie at the California-Oregon border
  - …blackouts in 13 states/provinces
- Some studies show with proper "intelligent controls," all would have been prevented by shedding 0.4% of load for 30 minutes!
- … everyone wants to operate the power system closer to the edge. It's a good idea. But to do that we should know
  - *where is the edge*, and
  - *how close are we to it*.


Sunday, August 11, 1996

Millions lose power

Half of PG&E's customers in Northern California affected; blackouts in 9 states

THE POWER PROBLE

PG&E Firms wonder: Is this the future?

U.S. says power will be bolstered

Substation explosion cuts PG&E service in South San Jose

Outage raises serious worries

Investigations planned after power grid falters

More Outages Expected for Power Network

Increased demand strains regional transmission lines

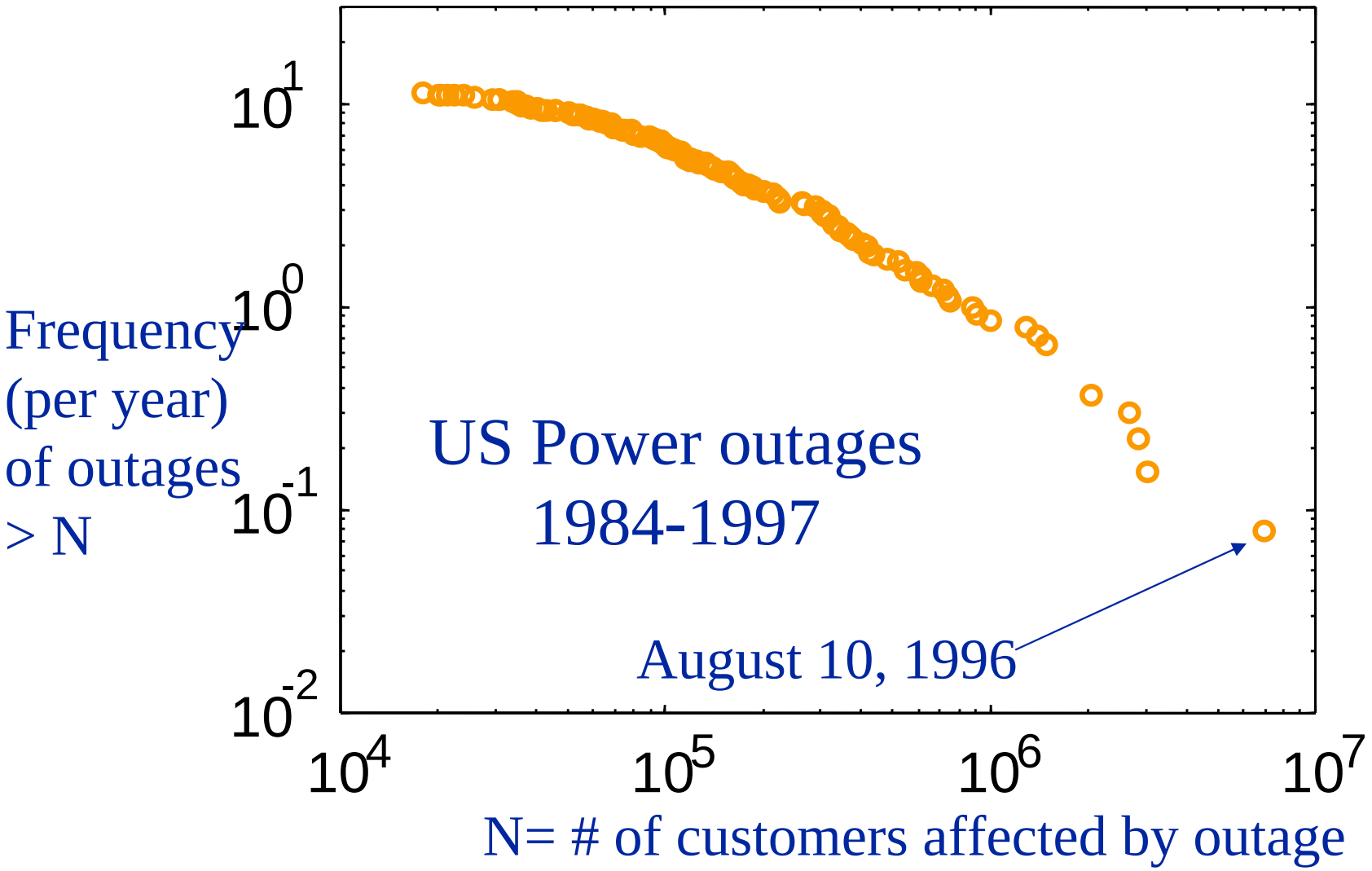
ELECTRICITY USERS FEELING POWERLESS

Shutoffs frag nerves in South San Jose

August 10, 1996

EPRI

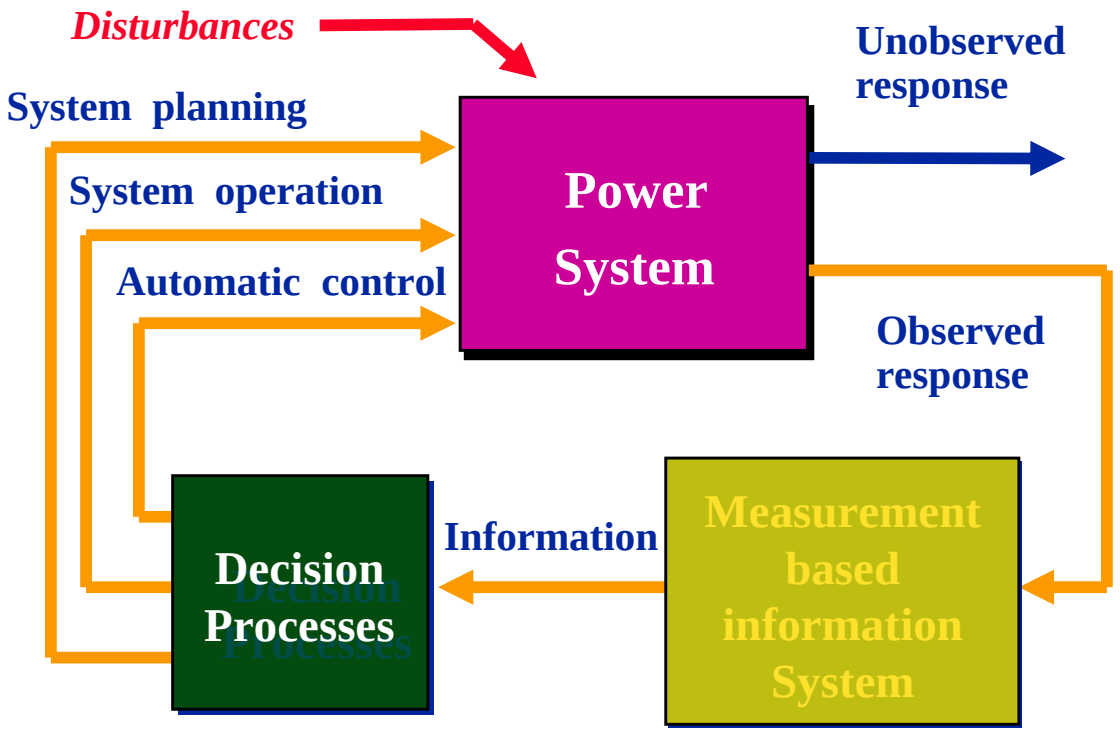
Modeling and Simulation:
An Example- US Power Outages

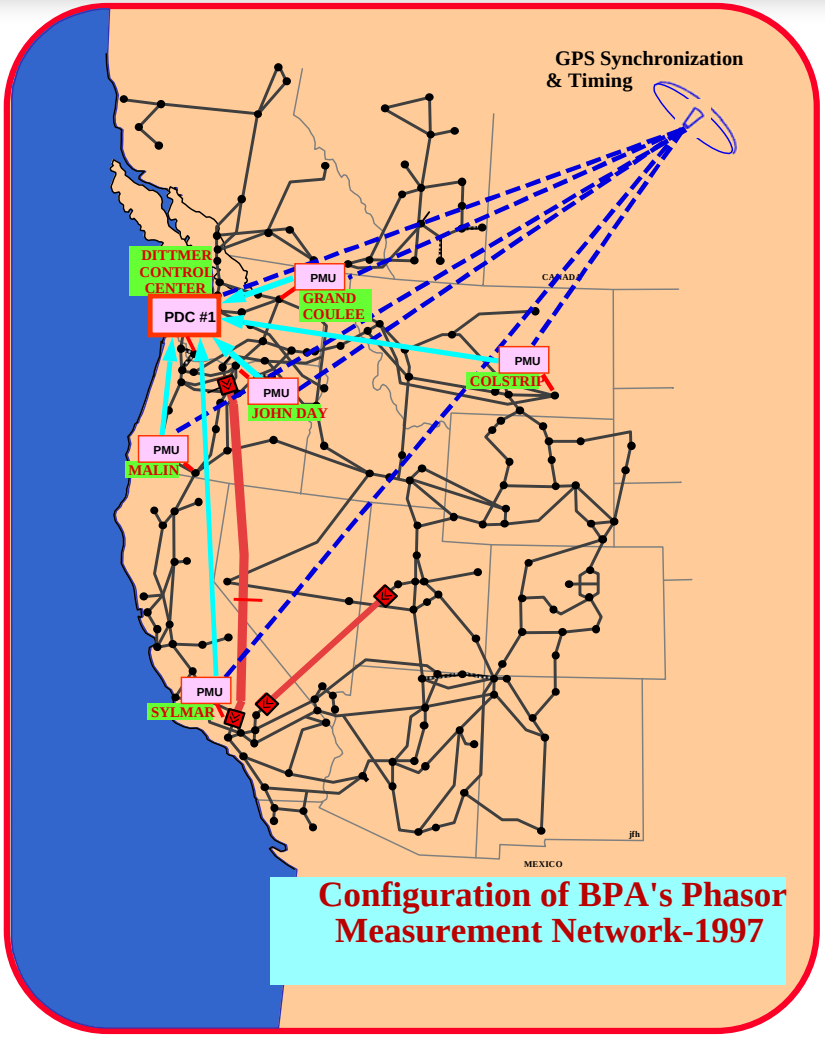


Wide-Area Measurement System (WAMS)

Integrated measurements facilitate system management

"Better information supports better - and faster - decisions."





Source: DOE/EPRI WAMS project-- BPA & PNNL

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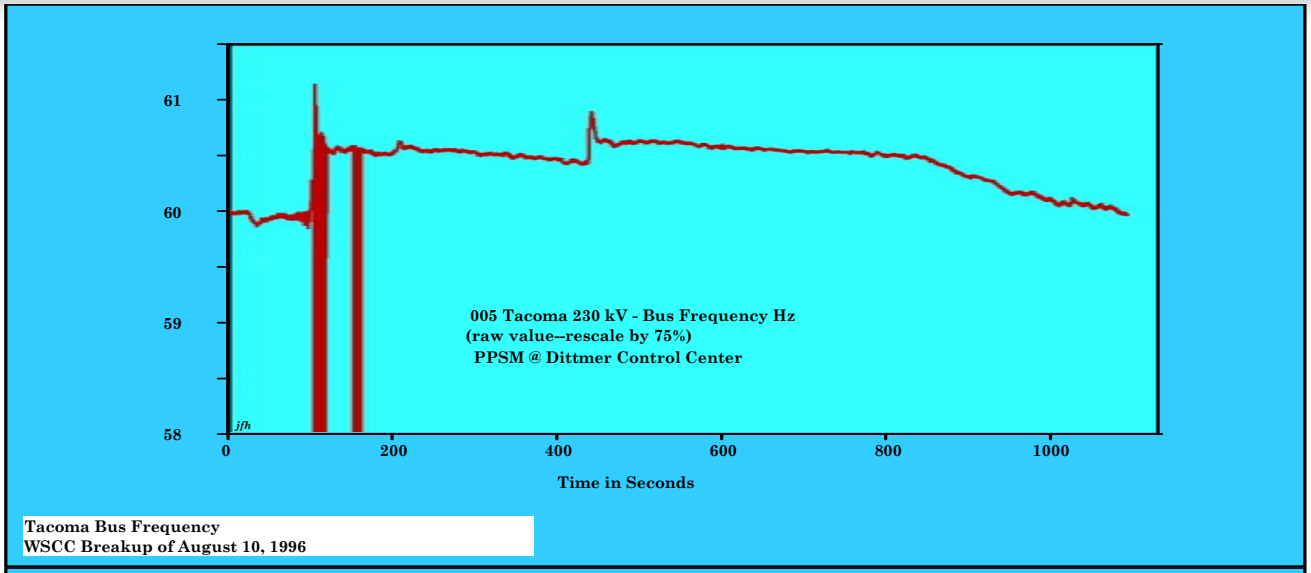
Real-Time System Data

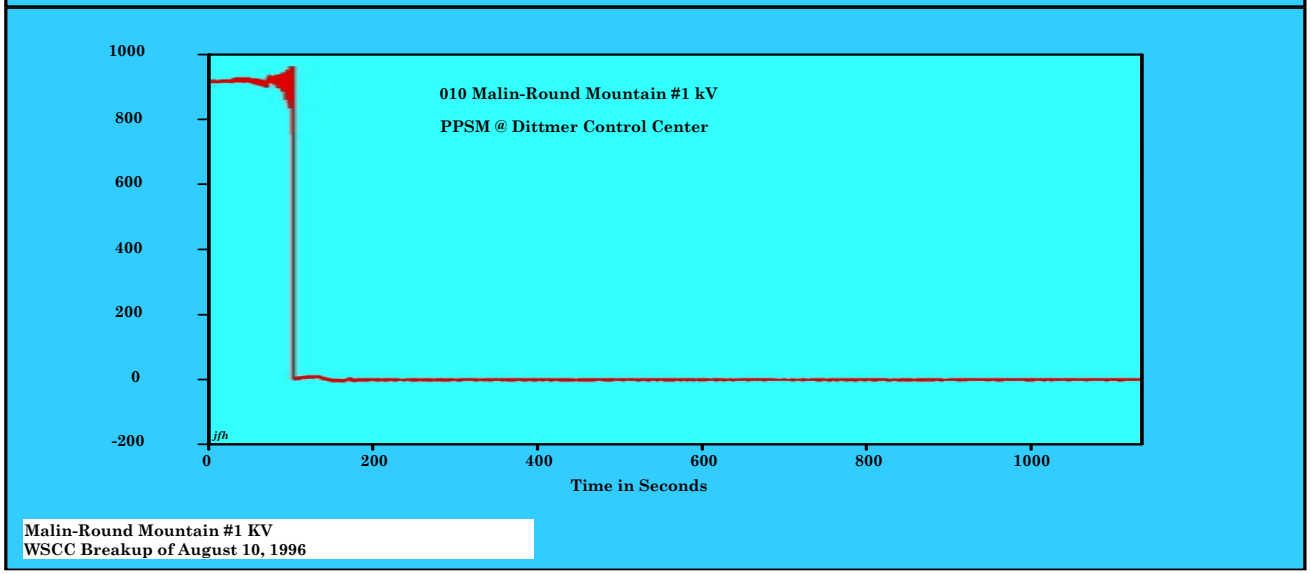
Collected from various monitors throughout the grid

Example: BPA's Phasor Data Concentrator

Disturbance records for WSCC breakup of August 10, 1996



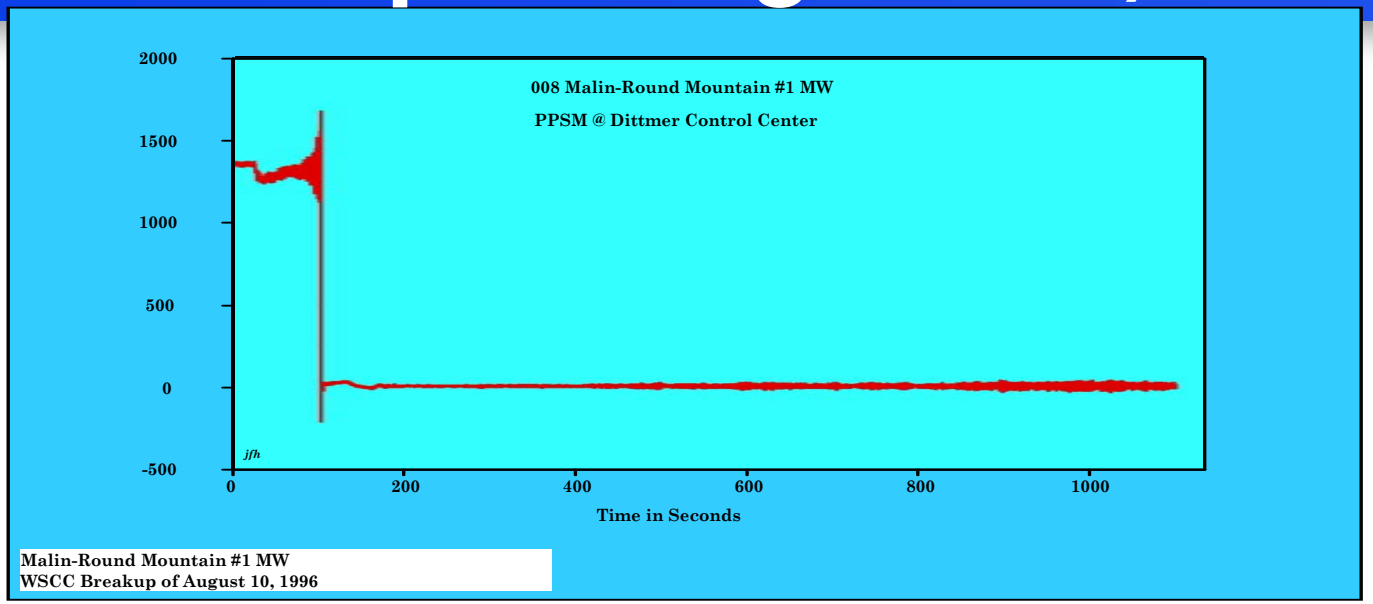
Tacoma Bus Frequency
WSCC Breakup of August 10, 1996



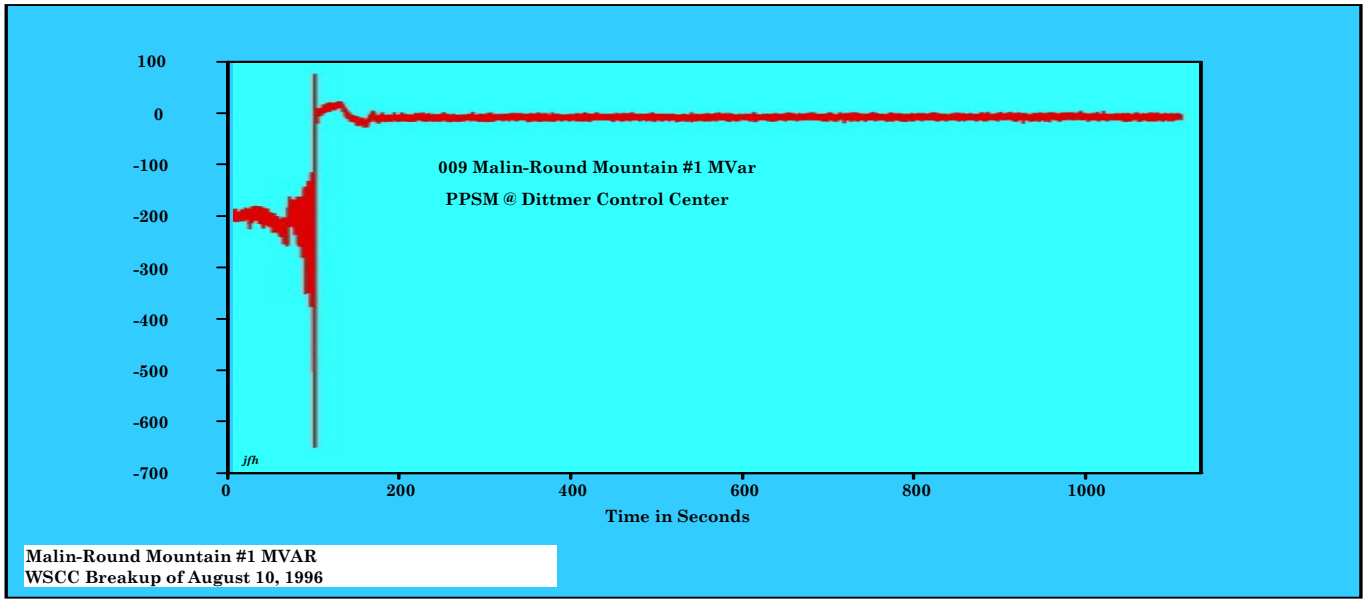
Malin-Round Mountain #1 KV
WSCC Breakup of August 10, 1996

Source: DOE/EPRI WAMS project

Disturbance records for WSCC breakup of August 10, 1996

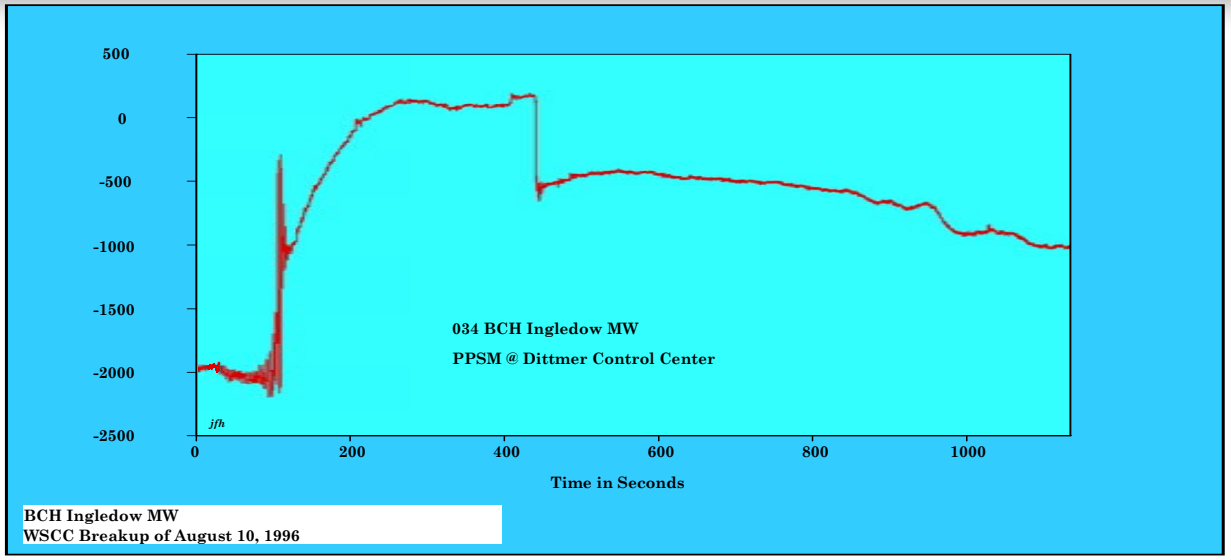


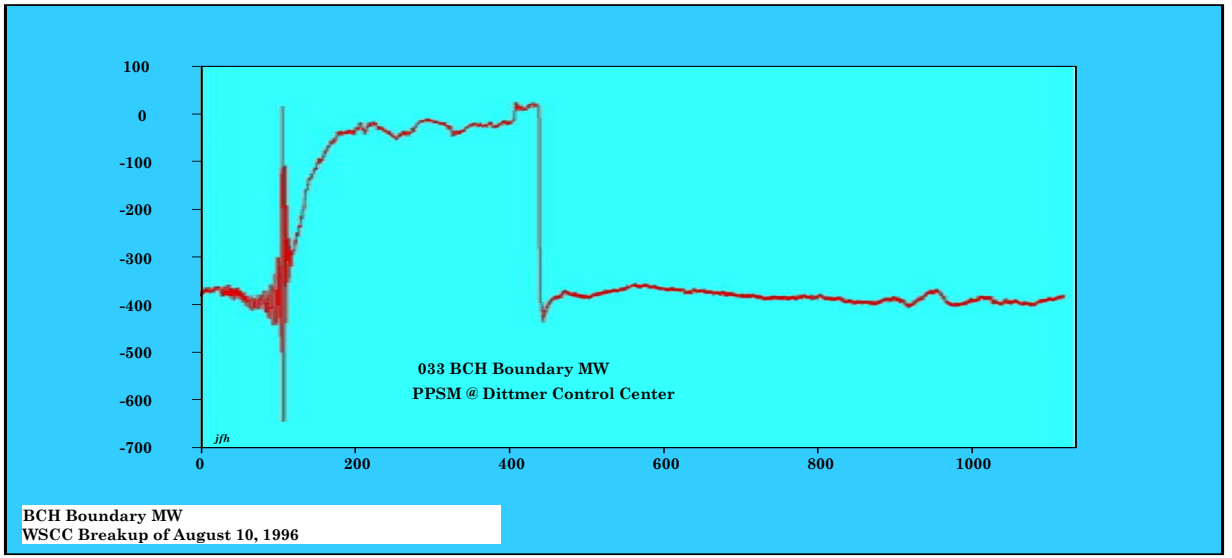
Malin-Round Mountain #1 MW
WSCC Breakup of August 10, 1996



Malin-Round Mountain #1 MVAR
WSCC Breakup of August 10, 1996

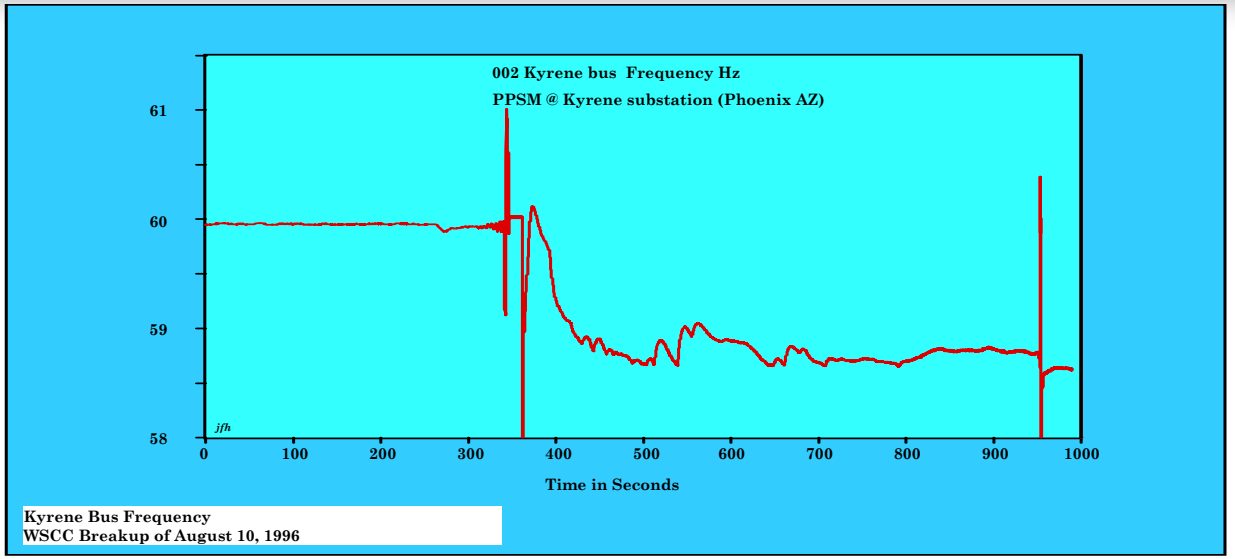
Disturbance records for WSCC breakup of August 10, 1996

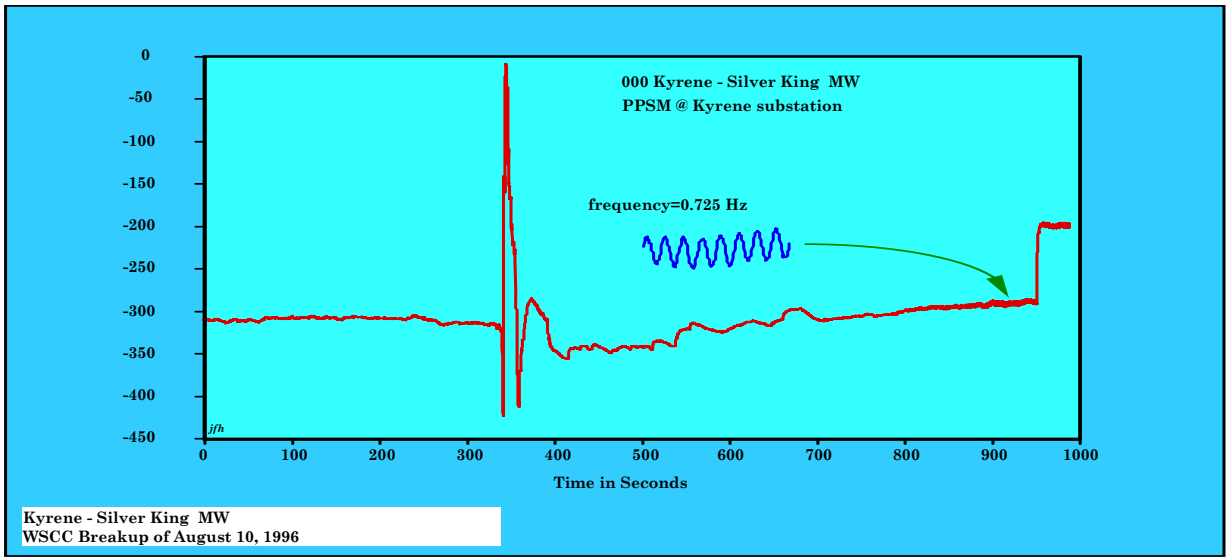




Source: DOE/EPRI WAMS project

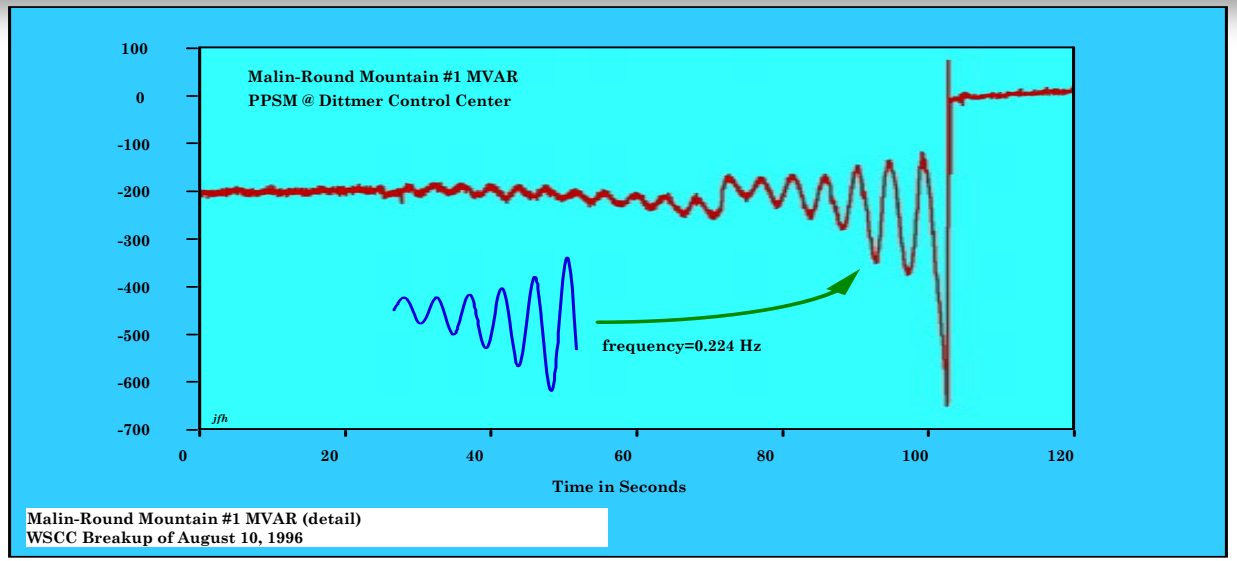
Disturbance records for WSCC breakup of August 10, 1996



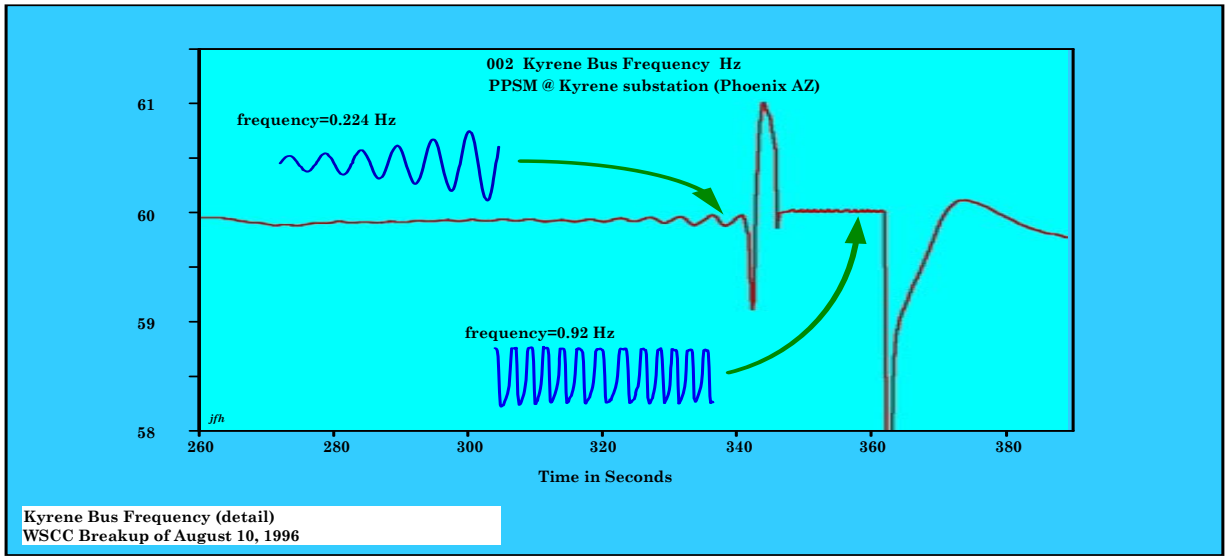


Source: DOE/EPRI WAMS project

Disturbance records for WSCC breakup of August 10, 1996



Malin-Round Mountain #1 MVAR (detail)
WSCC Breakup of August 10, 1996



Kyrene Bus Frequency (detail)
WSCC Breakup of August 10, 1996

EPRI/DoD Complex Interactive Networks
Use DRDs to Enhance Real Time System Operation

Use recorded data to

1. identify the type and location of disturbances
2. determine whether multiple events have occurred
3. assess the impact of disturbances on system
4. monitor whether the system is adequately damped
5. evaluate the needs for immediate control actions or retuning control algorithms

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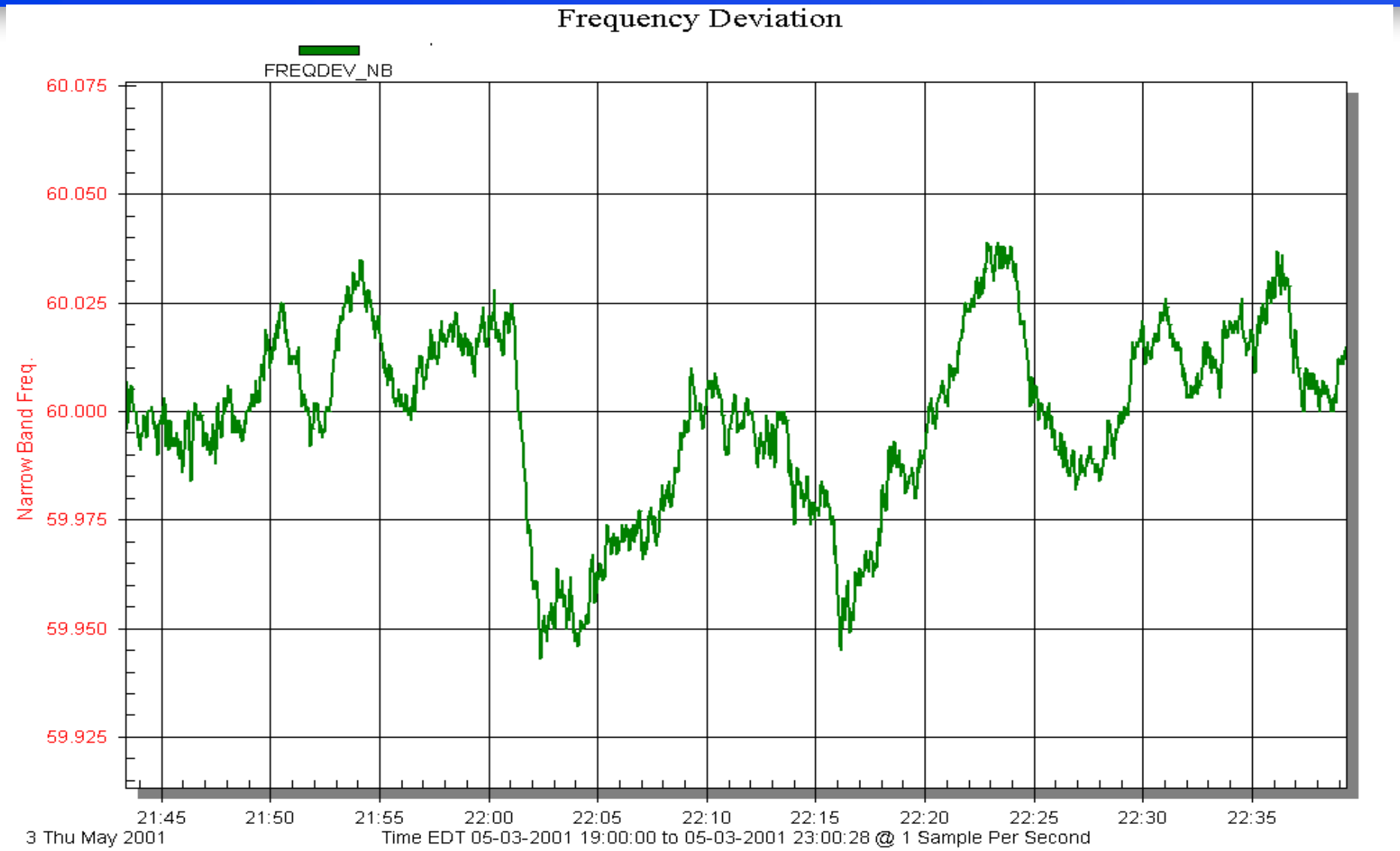
Last Episode of the TV series“Survivor”

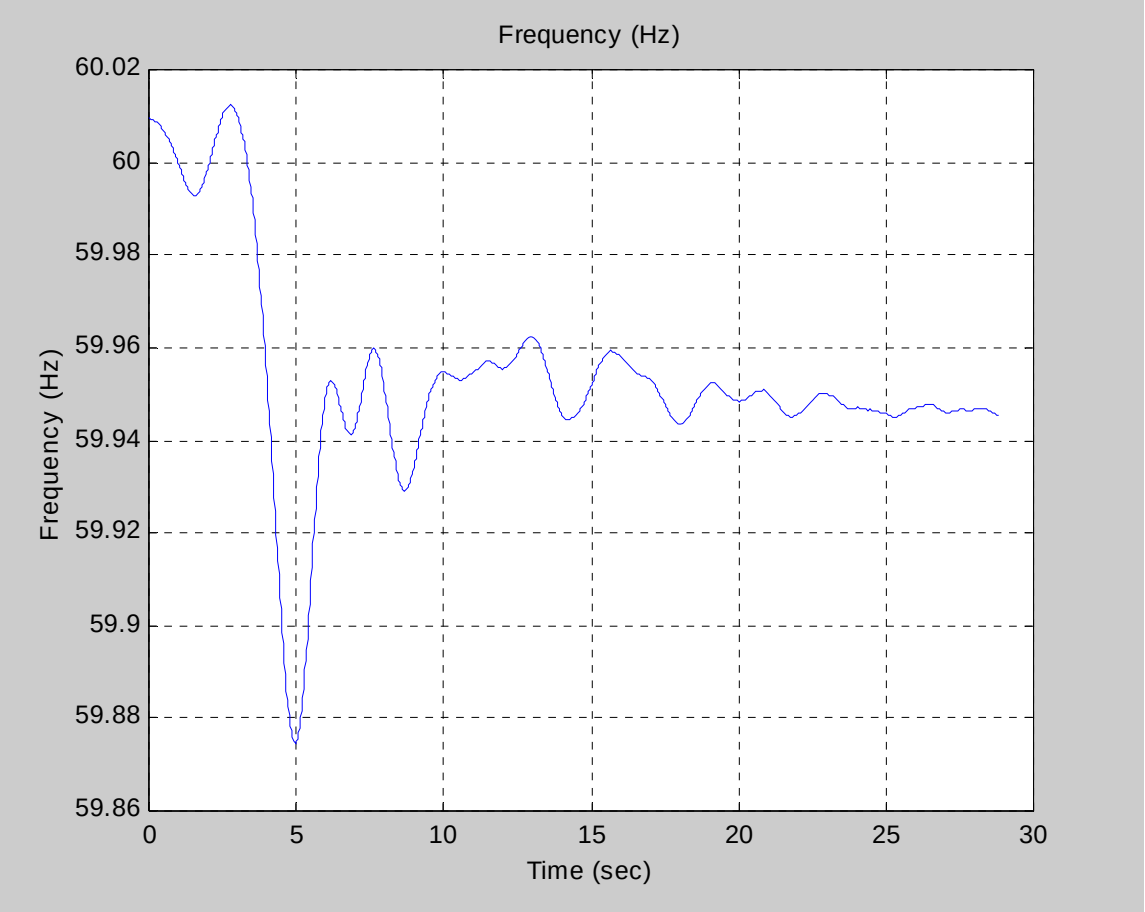


Source:Jim Ingleson of NYISO and Joe Chow (RPI)

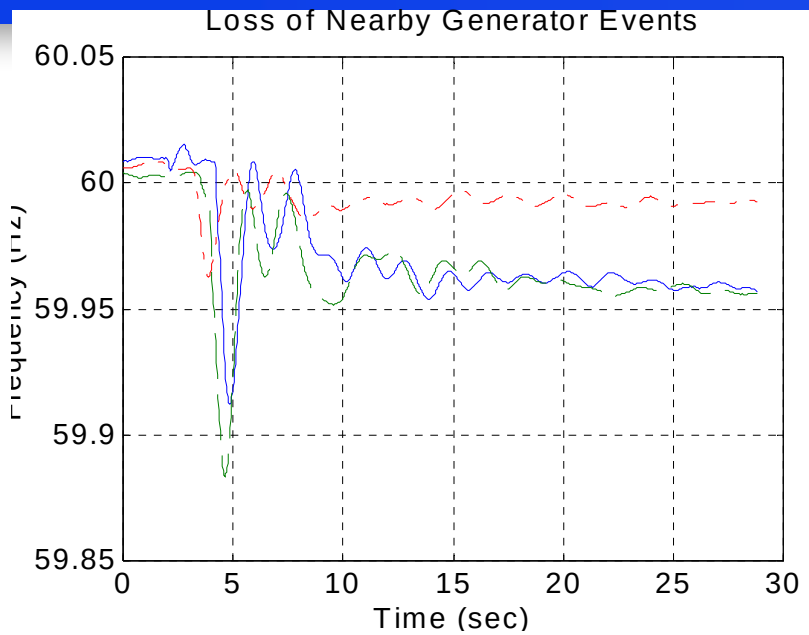
Disturbance Identification using Dynamic Recorded Data

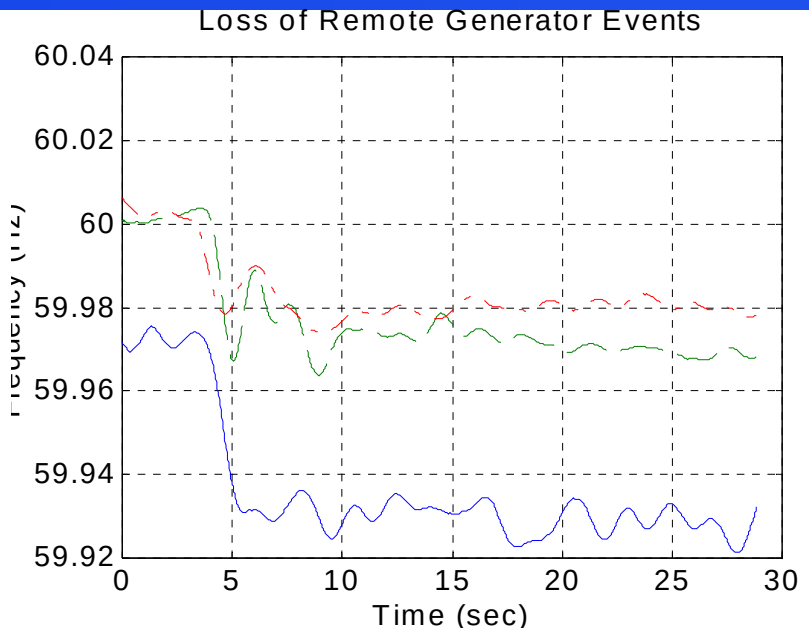
- 47 disturbance (out of several hundreds) events recorded at Northfield Substation in New England Power System were analyzed
- Feature extraction – frequency deviation, frequency derivative, and power flows
- Clustering algorithm based on frequency deviation and frequency derivative features

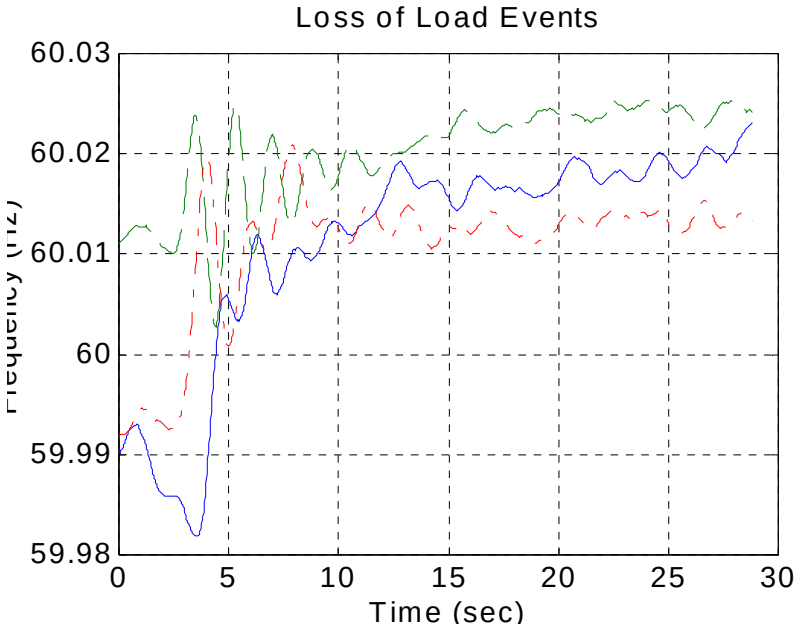
Disturbance

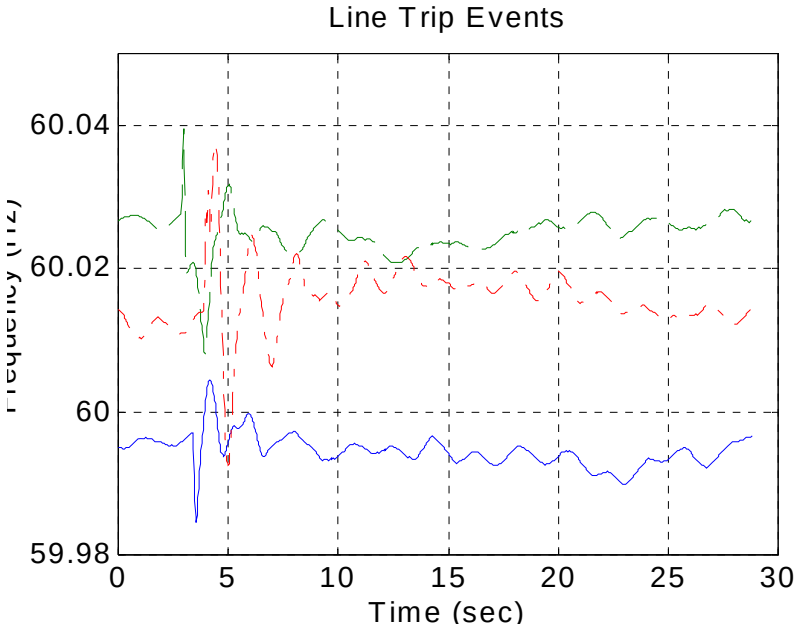


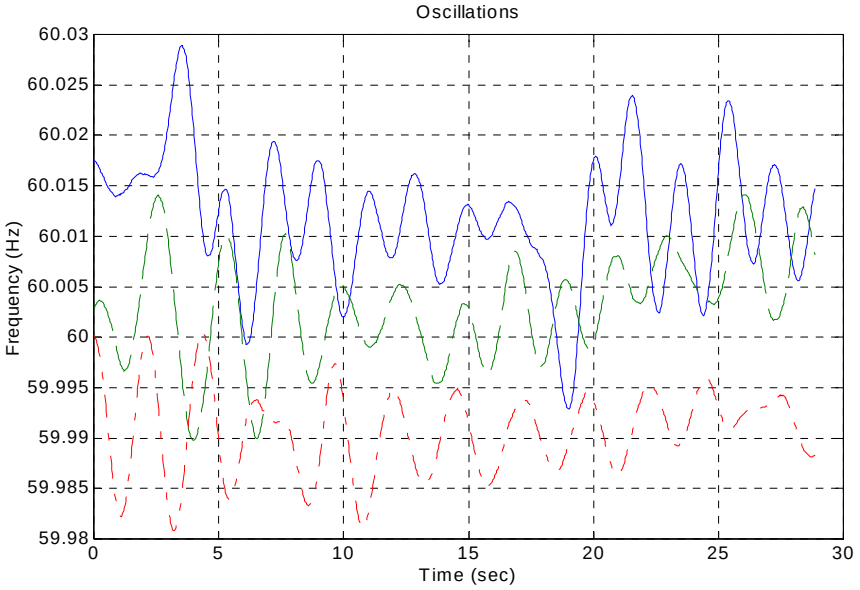
- Loss of close by generation
- Estimate how much generation is lost from tracking system frequency

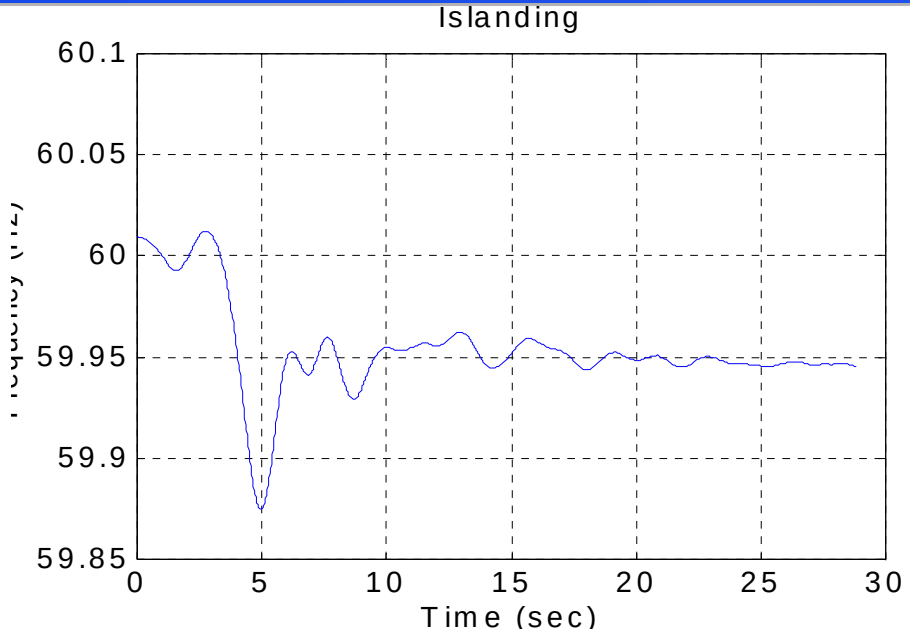

Loss of Nearby Generator Events
60.05
60
59.95
59.9
59.85
0
5
10
15
20
25
30
Time (sec)

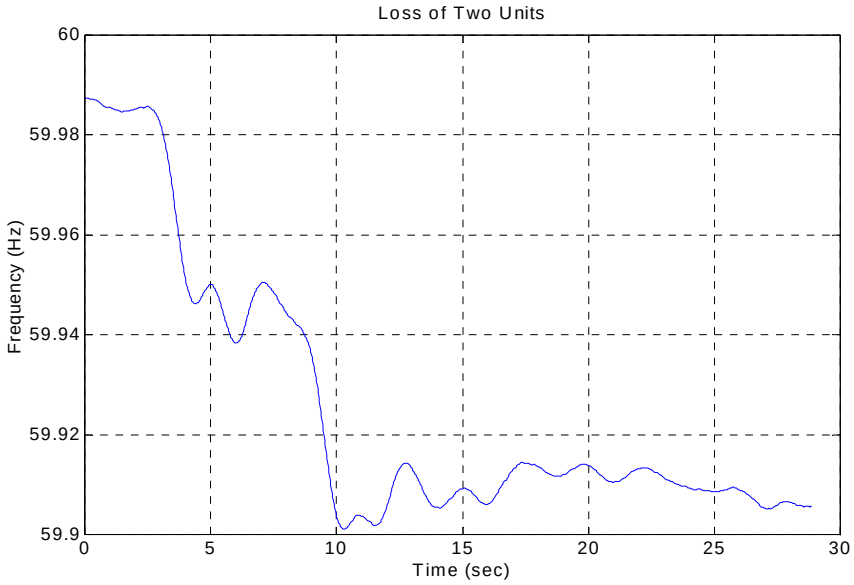

Loss of Remote Generator Events
60.04
60.02
60
59.98
59.96
59.94
59.92
0
5
10
15
20
25
30
Time (sec)


Loss of Load Events
60.03
60.02
60.01
60
59.99
59.98
0
5
10
15
20
25
30
Time (sec)


Line Trip Events
60.04
60.02
60
59.98
0
5
10
15
20
25
30
Time (sec)


Oscillations
Frequency (Hz)
Time (sec)
60.03
60.025
60.02
60.015
60.01
60.005
60
59.995
59.99
59.985
59.98
0
5
10
15
20
25
30

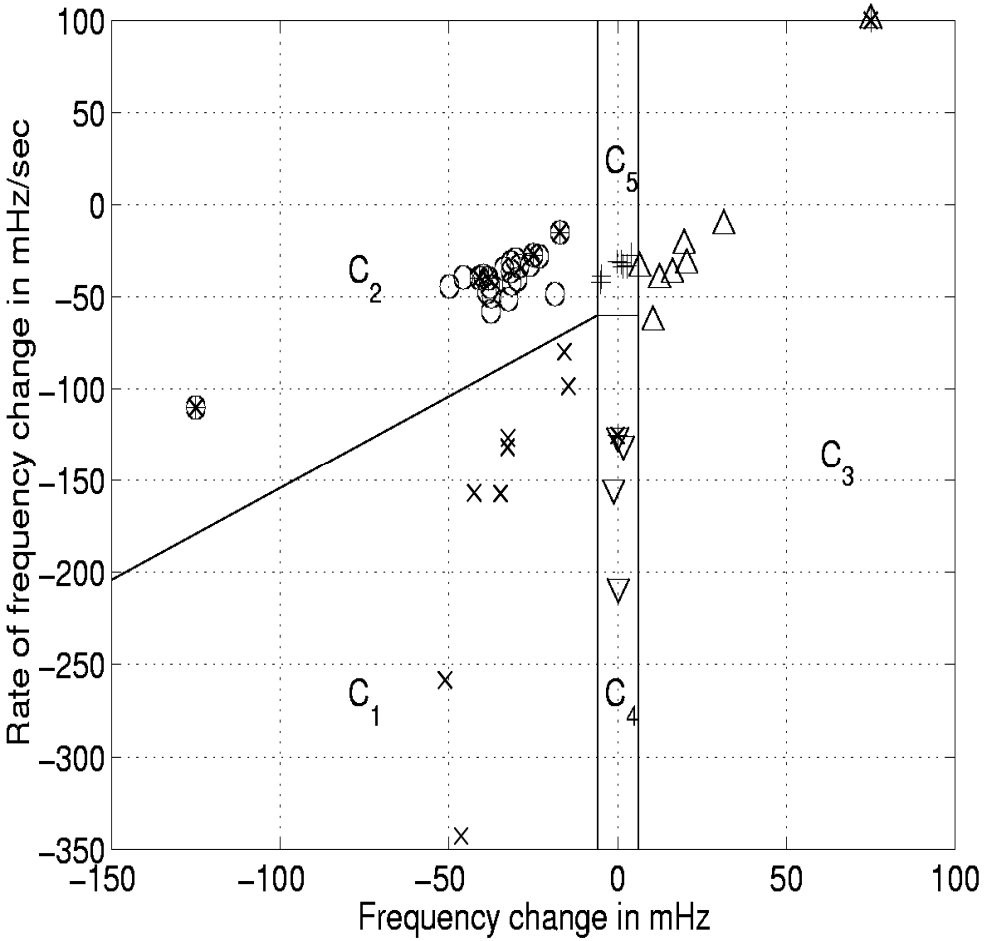

Islanding
60.1
60.05
60
59.95
59.9
59.85
0
5
10
15
20
25
30
Time (sec)


Loss of Two Units
Frequency (Hz)
Time (sec)
60
59.98
59.96
59.94
59.92
59.9
0
5
10
15
20
25
30

Disturbance Feature Extraction

Disturbance	Frequency change	Frequency derivative	Line flow change
Loss of nearby generation	Negative	Steep	Large
Loss of remote generation	Negative	Moderate	Negligible
Loss of load	Positive	Moderate	Detectable
Line trip close to DRD	Negligible	Steep	Large
Oscillations	Negligible	Small	oscillations

Clustering Algorithm – separate disturbance classes by hyperplanes

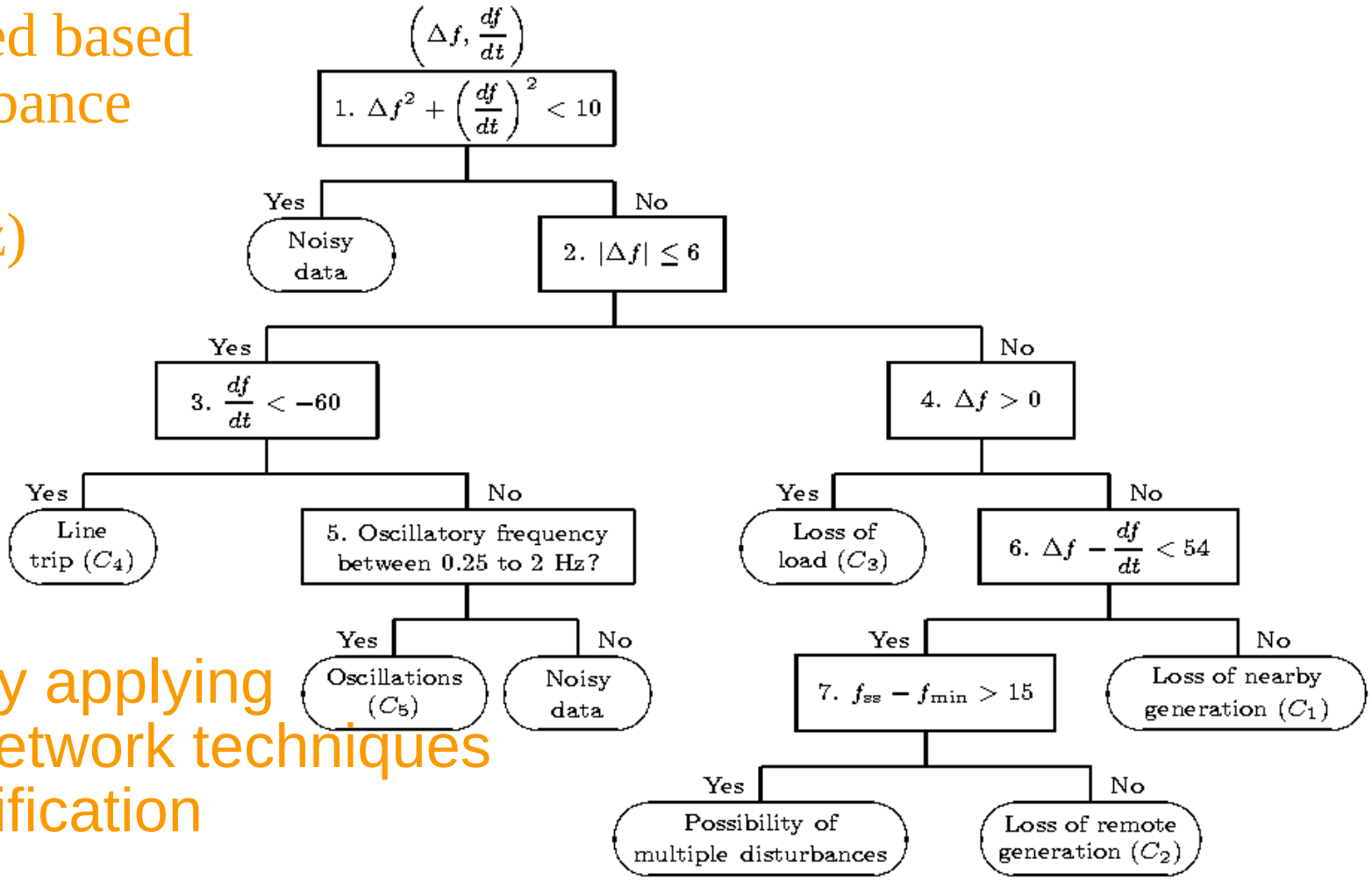


- C_1 – loss of nearby generation
- C_2 – loss of remote generation
- C_3 – loss of load
- C_4 – line trip
- C_5 – oscillations

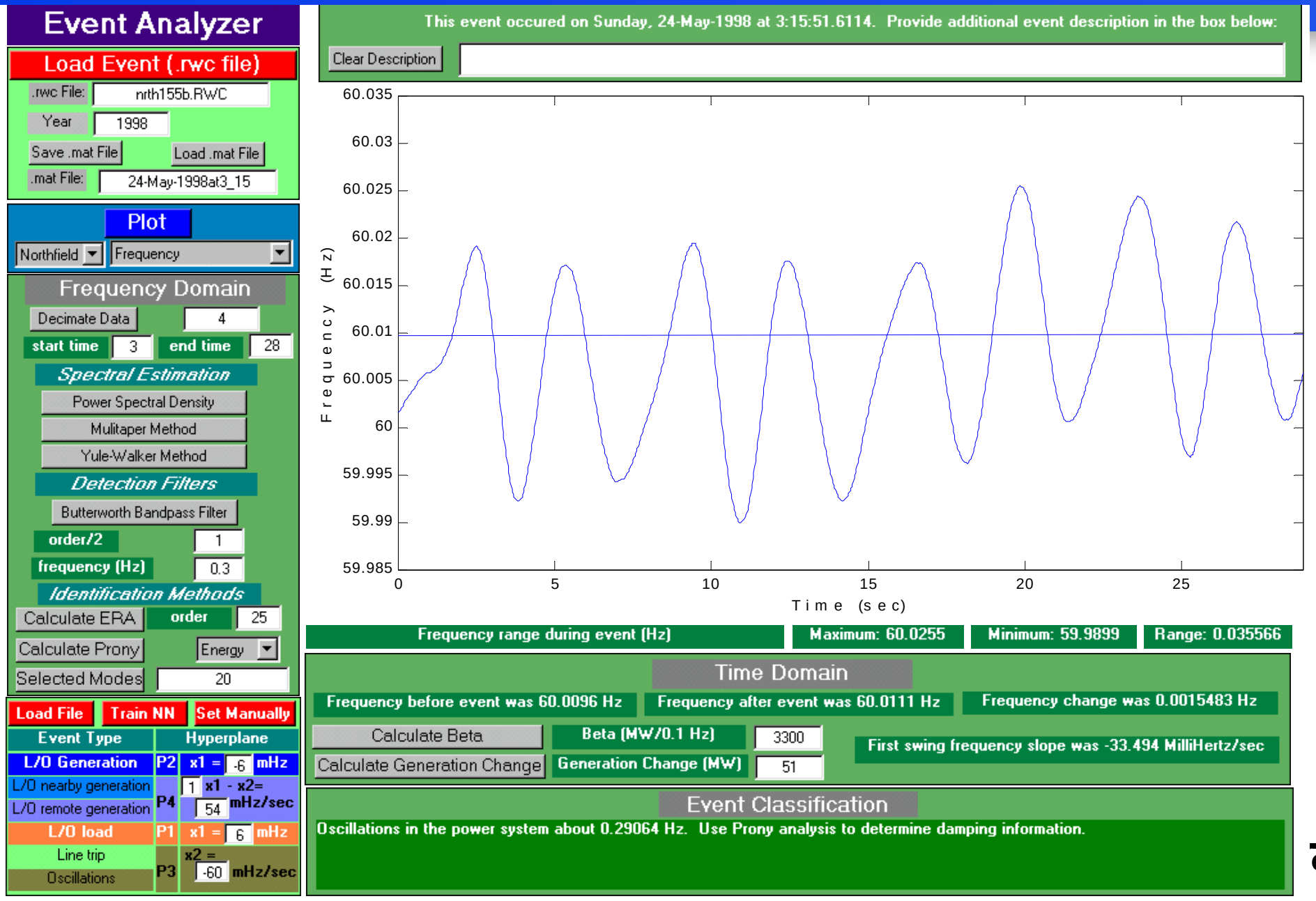
* Markers show recorded data

Decision Tree for Disturbance Identification

- Developed based on disturbance classes (f in mHz)
- Presently applying neural network techniques for identification



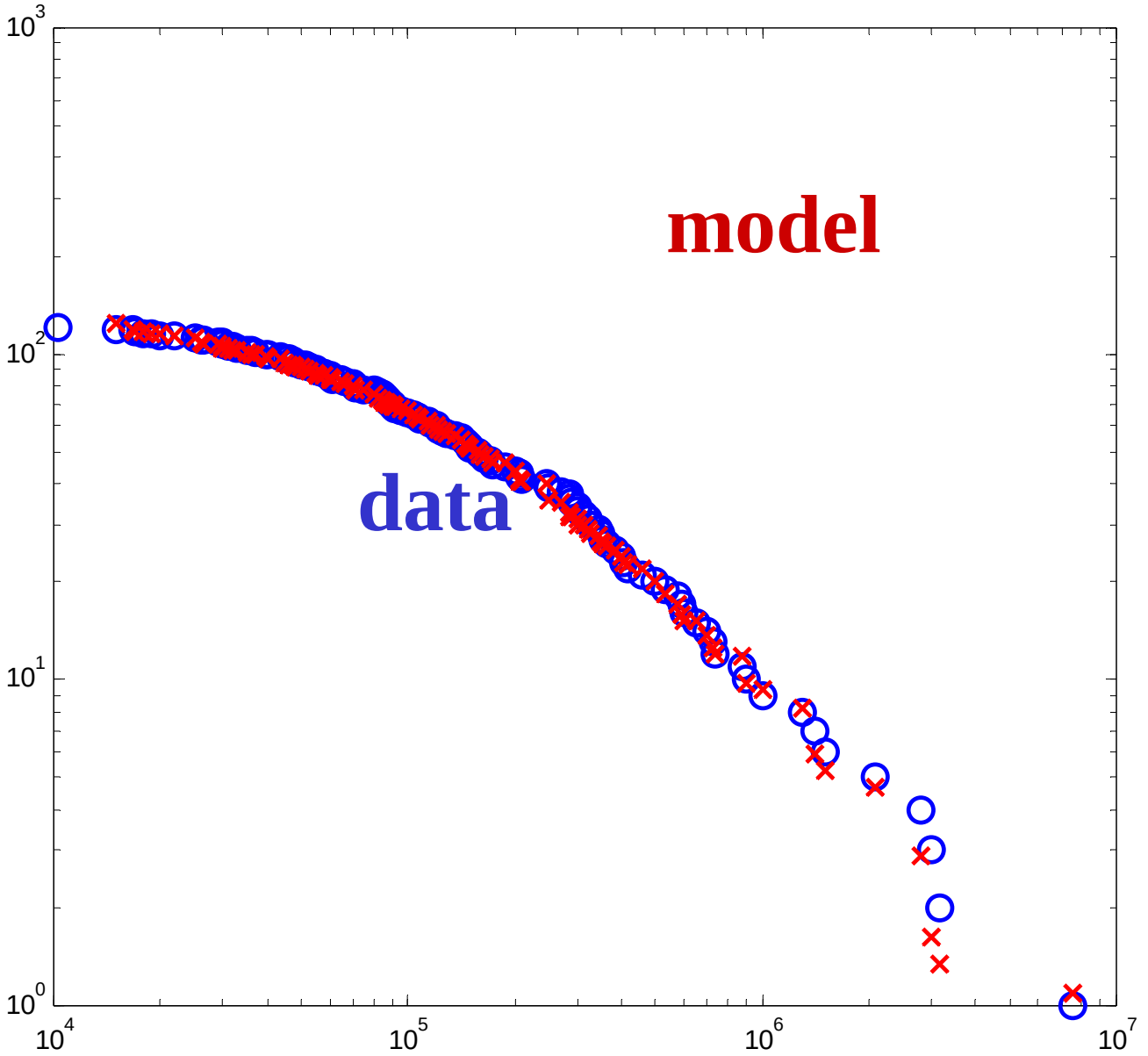
Disturbance Event Analyzer



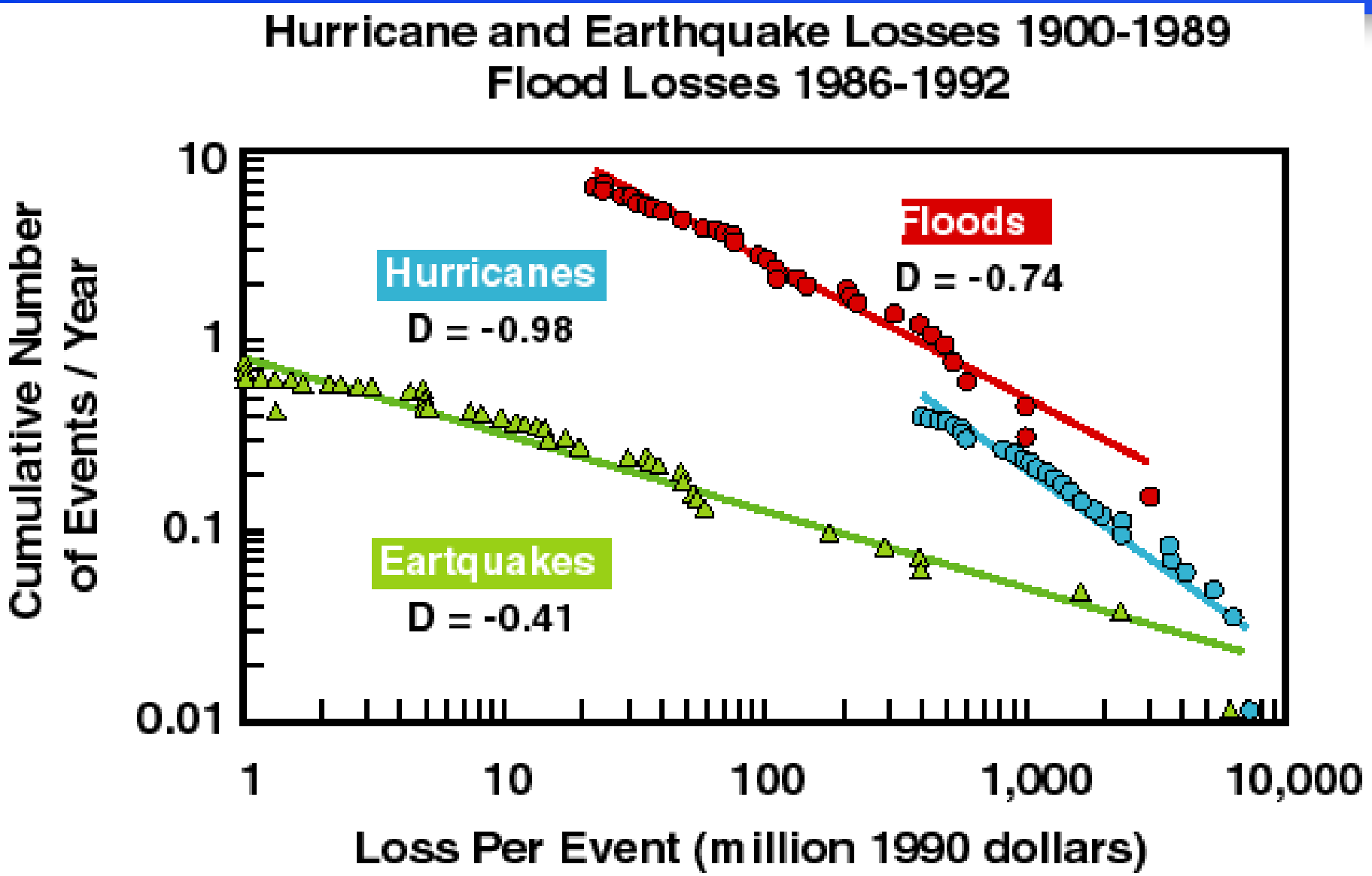
Modeling: Power law distributions

Power system

$\beta = 1$



Power laws and other disasters



Caltech, UCLA, UCSB, MIT, UIUC, Stanford

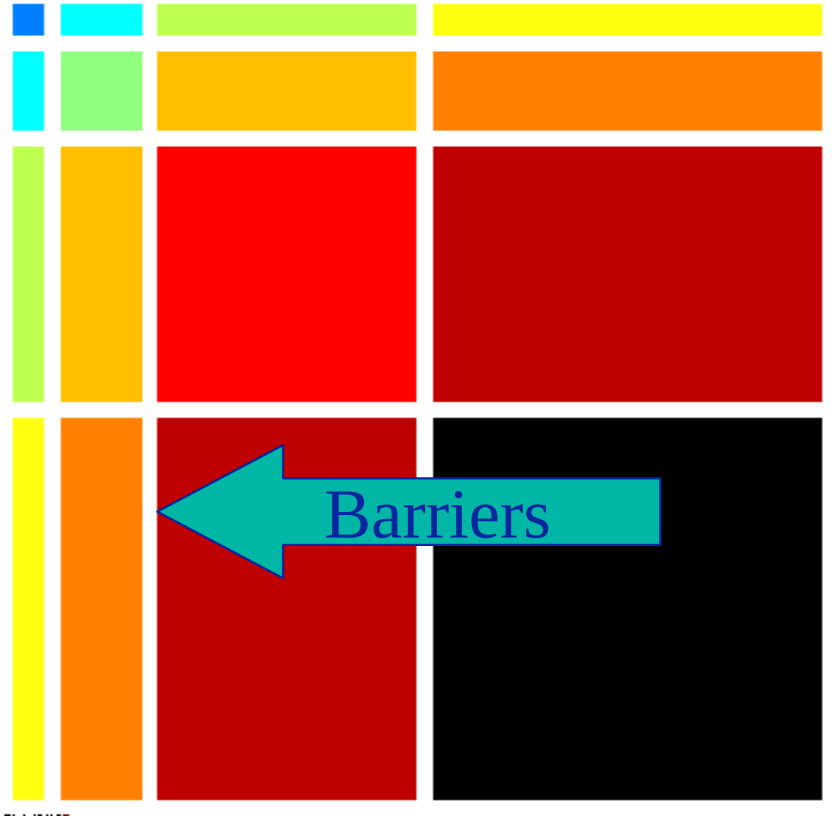
EPRI

Complex Interactive Networks

Failure Propagation on Grid

Percolation

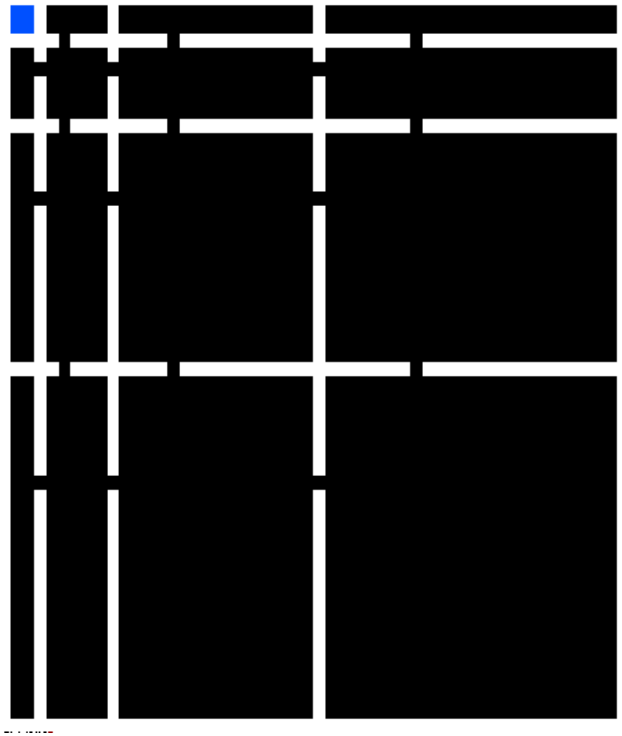
Designed System



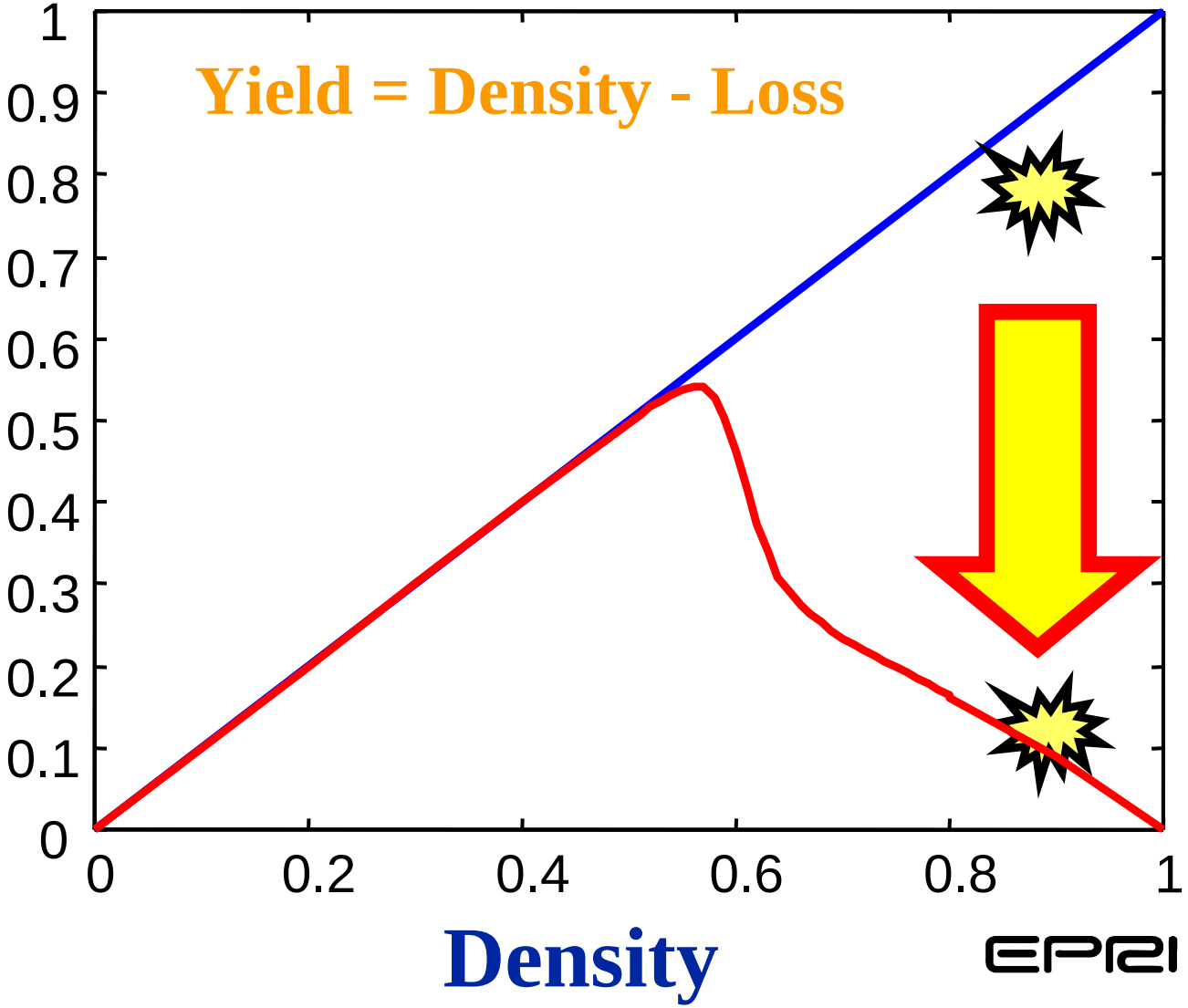
EPRI

Complex Interactive Networks

Failure Propagation on Grid – Topology & Probability



Yield



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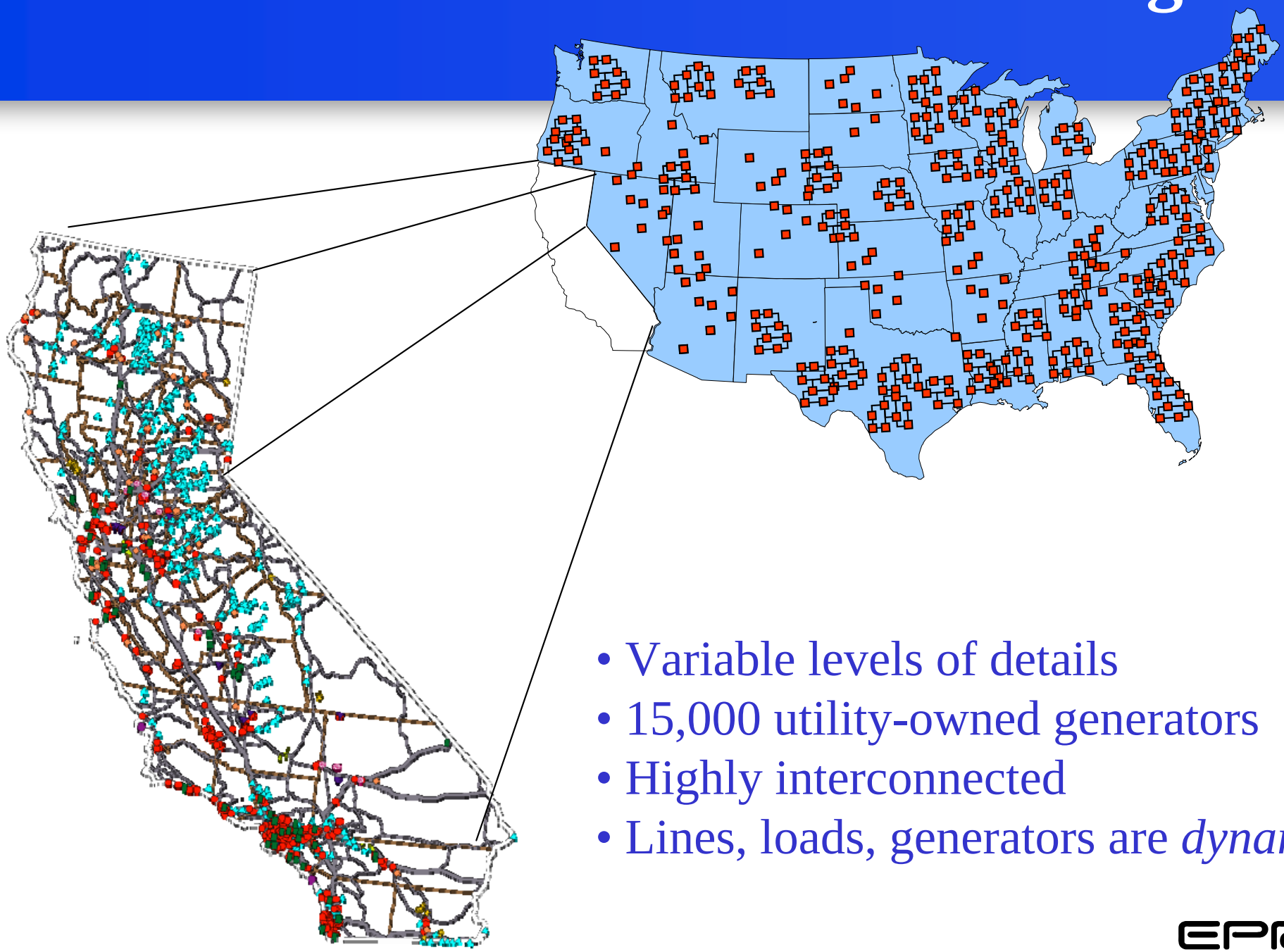
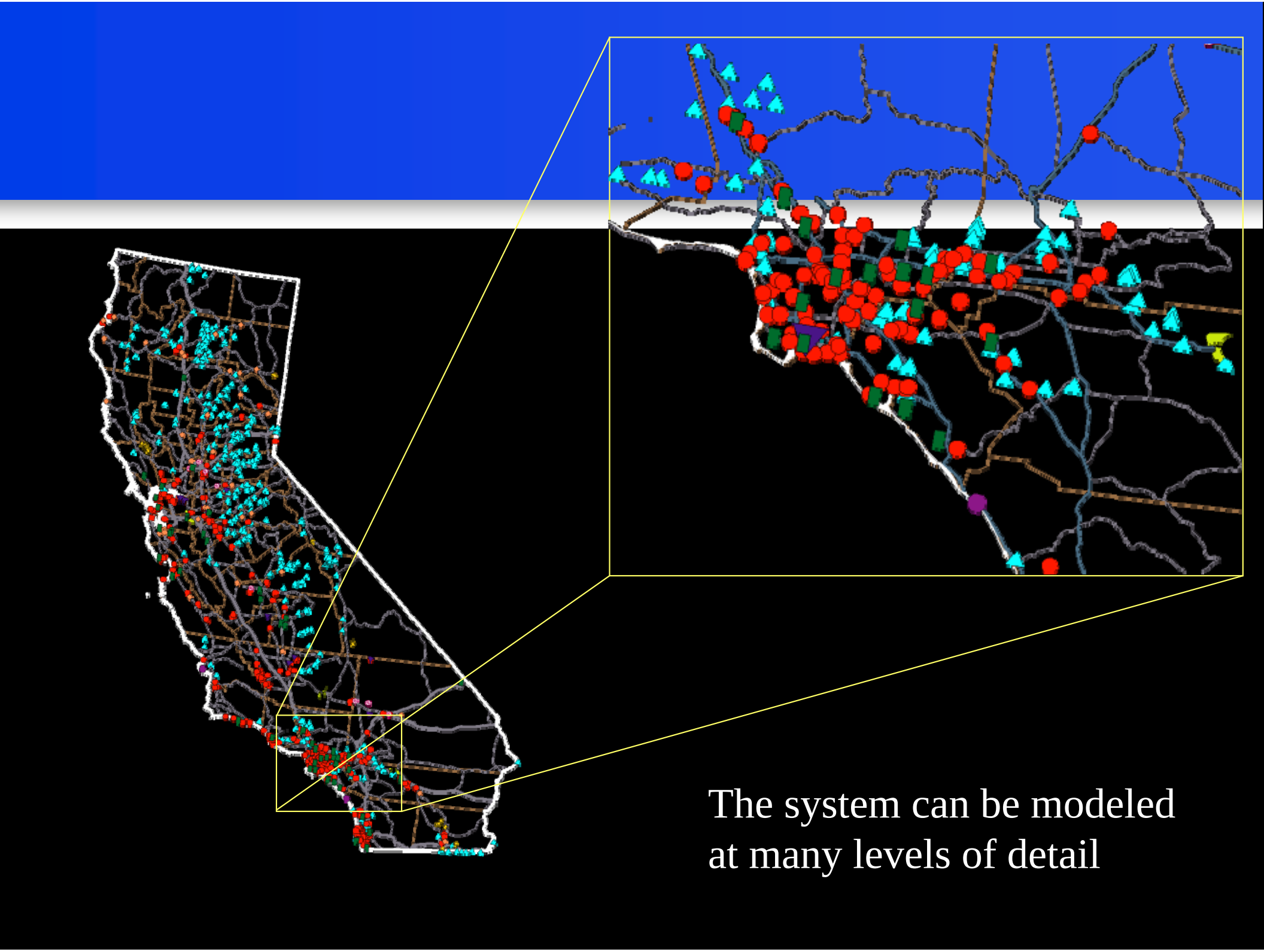
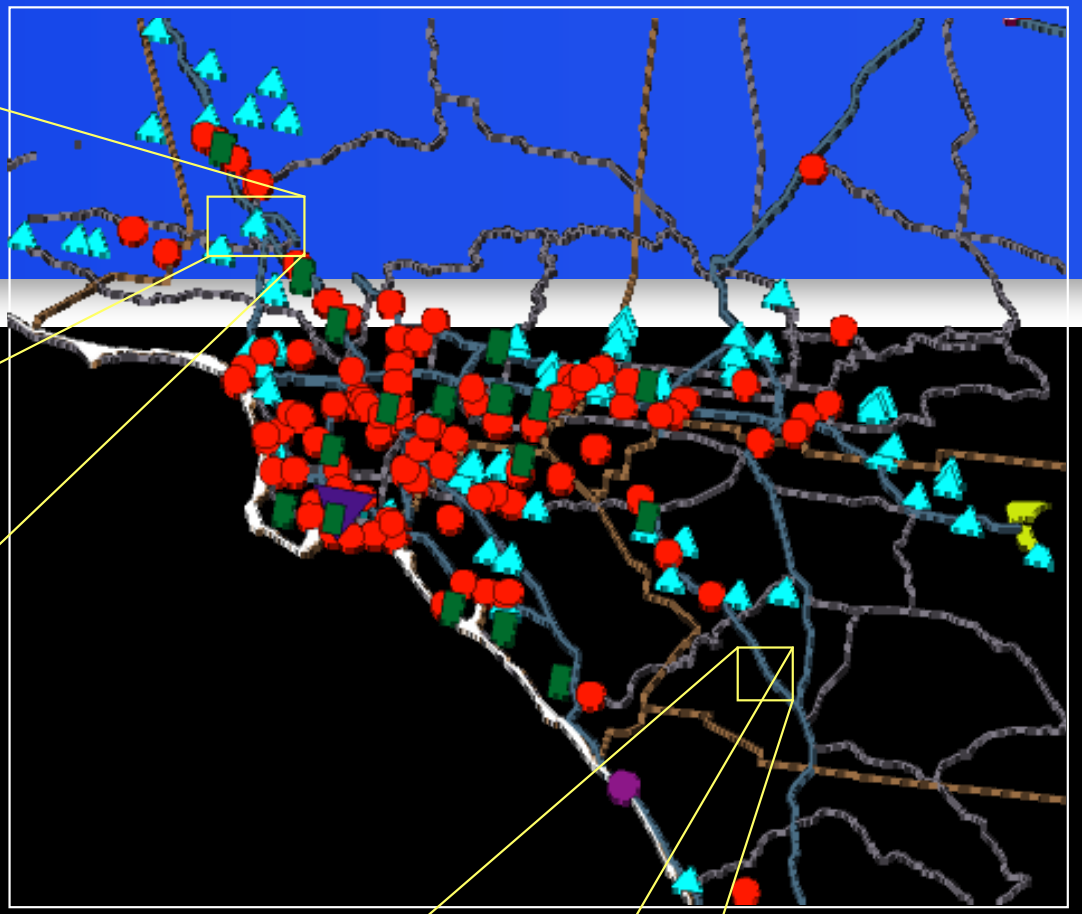
Multi-Resolutional Modeling



- Variable levels of details
- 15,000 utility-owned generators
- Highly interconnected
- Lines, loads, generators are *dynamic*

EPRI

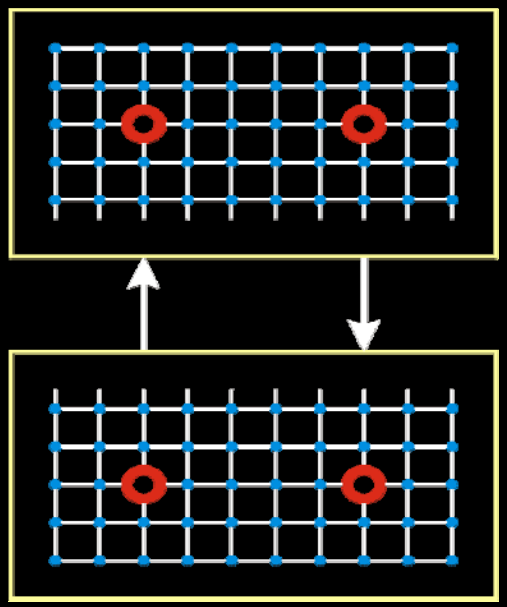

The system can be modeled
at many levels of detail



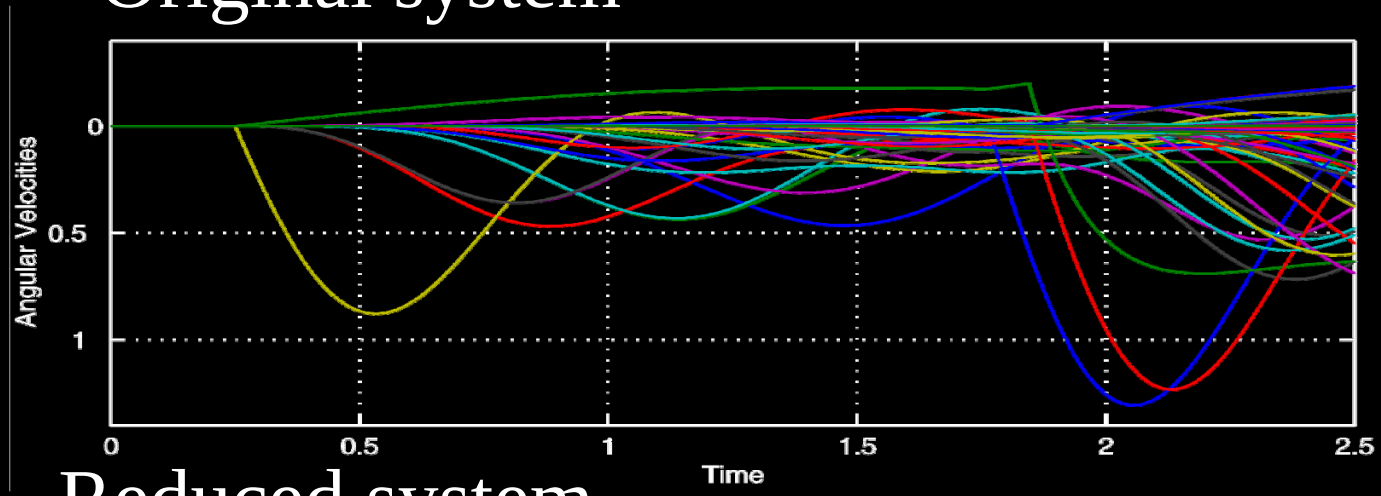
At this level, dynamic models include the *swing equations*

$$m_i\ddot{\delta}_i + D_i\dot{\delta}_i = P_i + \sum_j b_{ij}\sin(\delta_i - \delta_j)$$

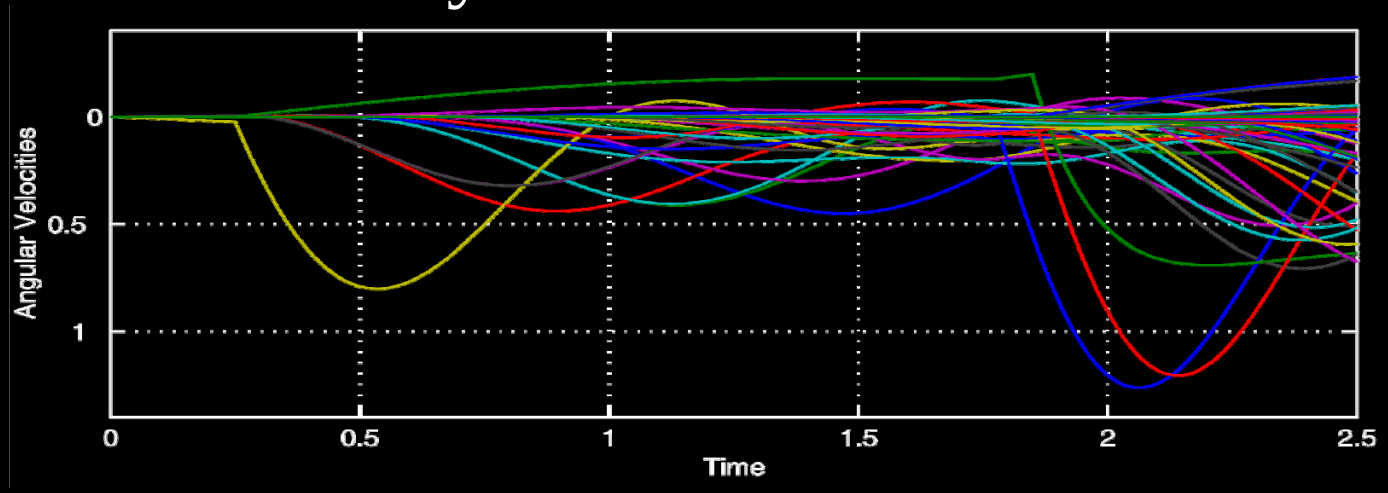
Fast Simulation



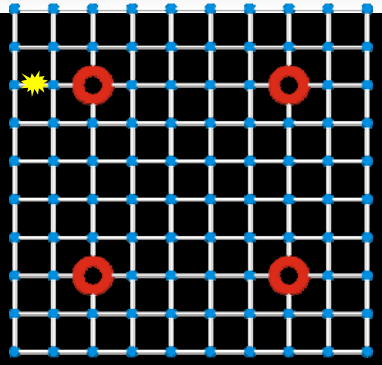
Original system



Reduced system

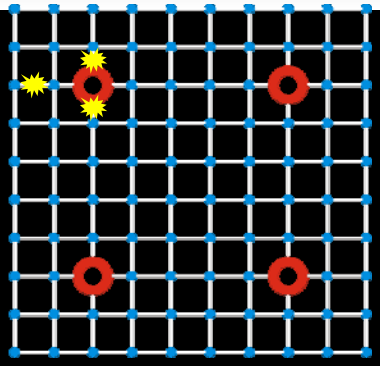


Cascading failures



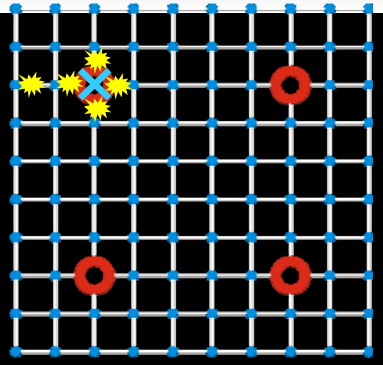
0.25

0.25



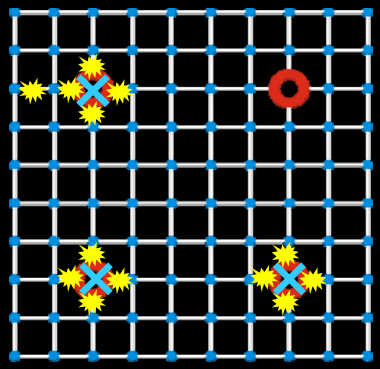
1.764

1.773



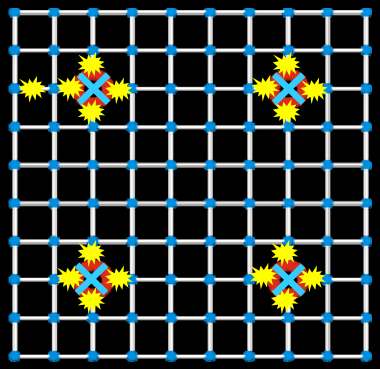
1.845

1.848



2.570

2.574



2.582

2.594

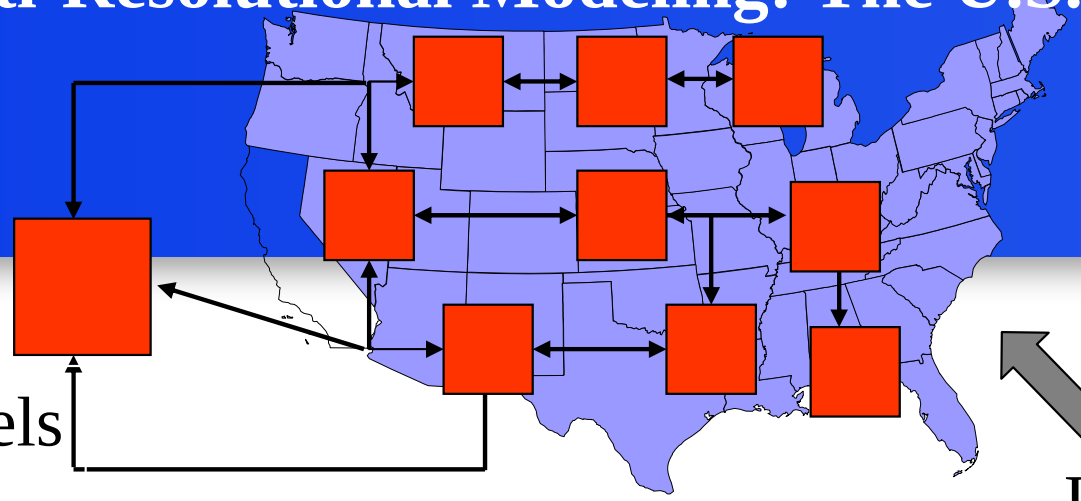
Failure time:

Original system

Reduced system

P. A. Parrilo, S. Lall, F. Paganini, G. C. Verghese, B. C. Lesieutre, J. E. Marsden, 1998

Multi-Resolutional Modeling: The U.S. Power Grid



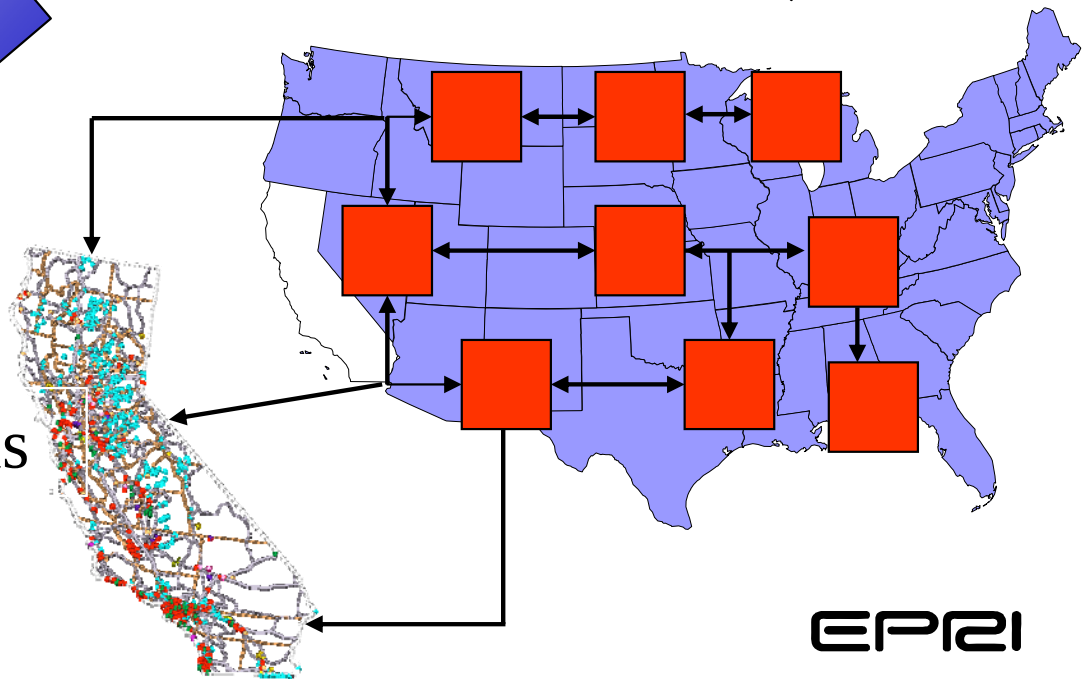
Simplified models

Low-resolution model

MODEL REDUCTION

MODEL REFINEMENT

- Variable levels of details
- Lines, loads, generators are *dynamic*



Detailed models

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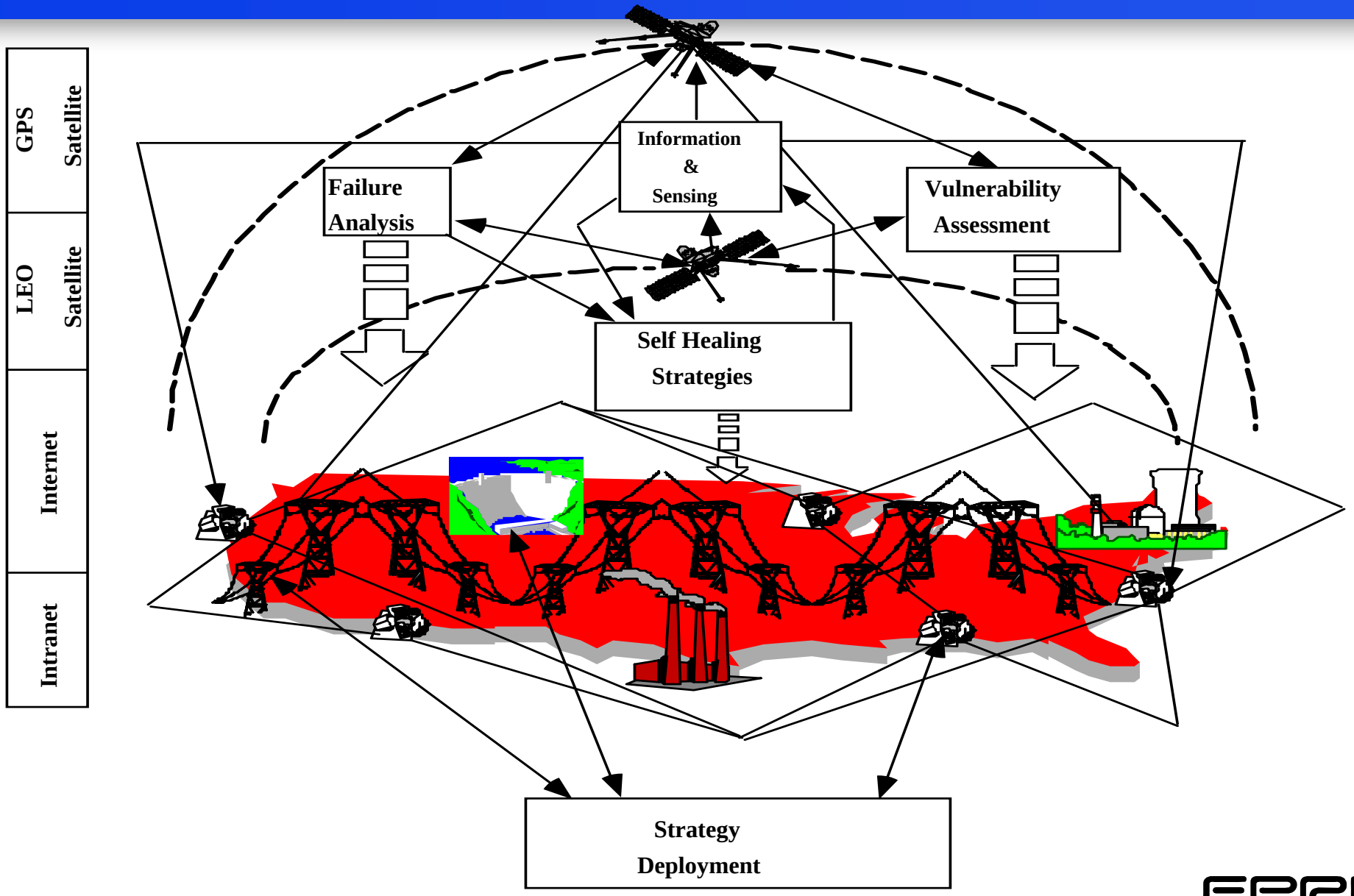
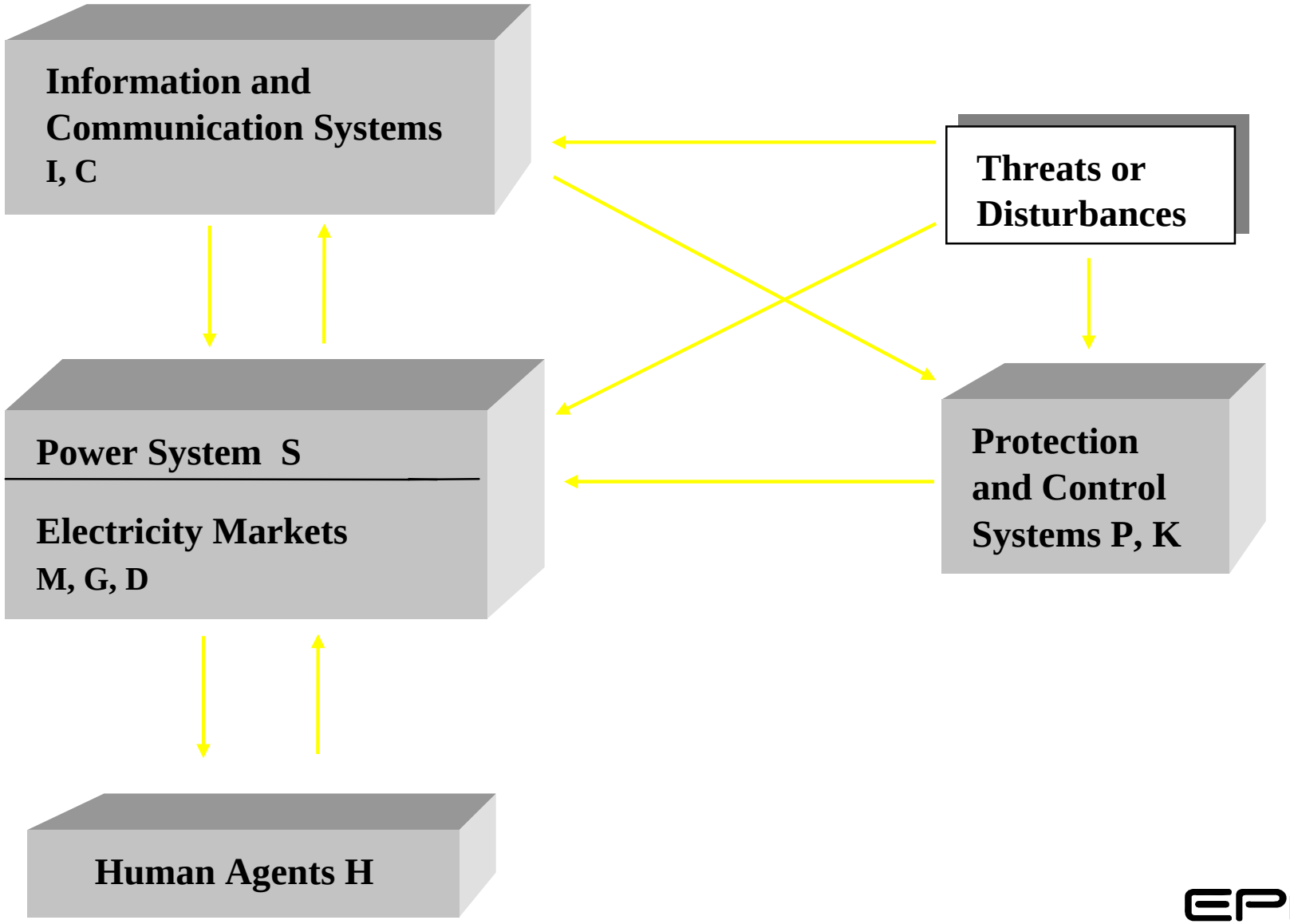
Complex Interactive Networks



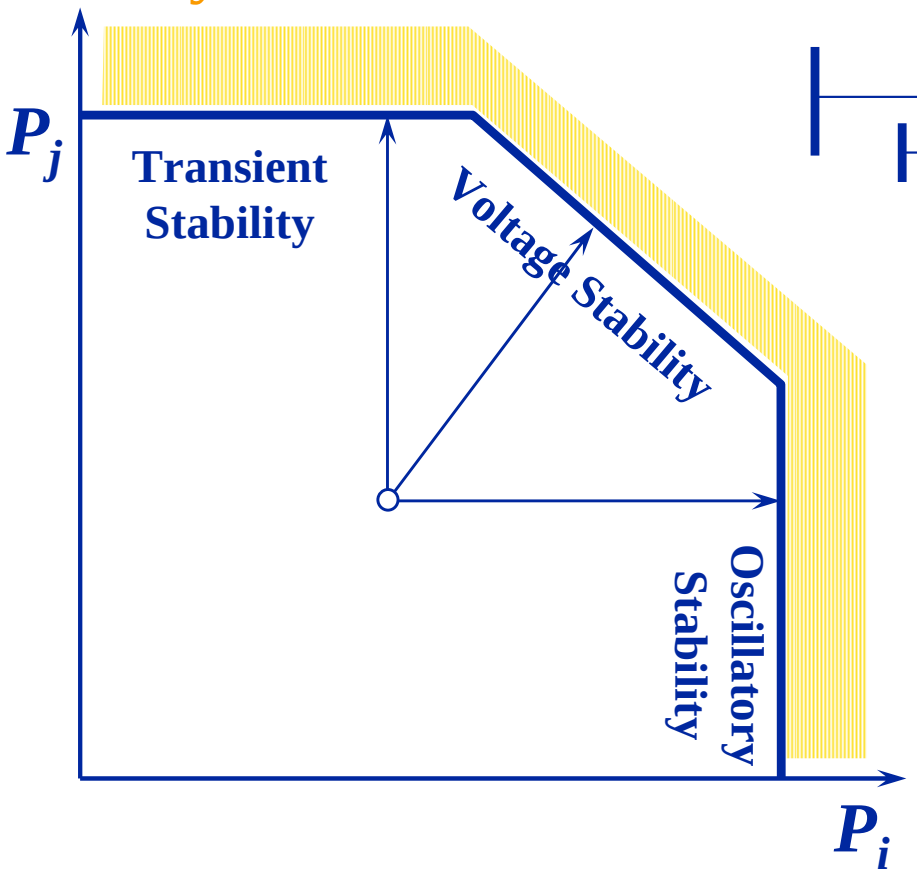
Integrated Protection and Control

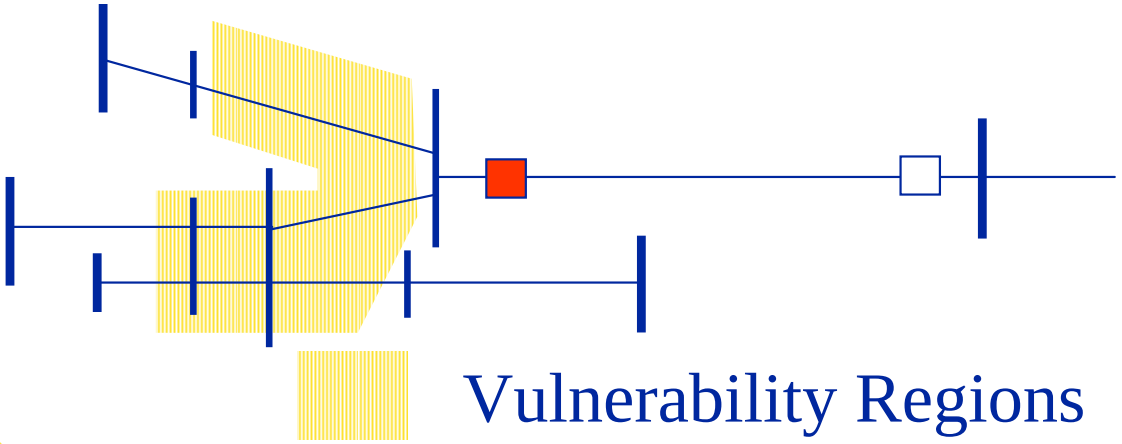


Vulnerability Indices

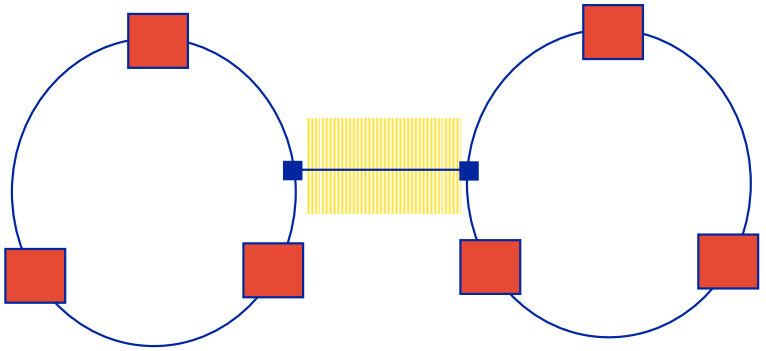
Protection

Dynamics and Control





Vulnerability Regions



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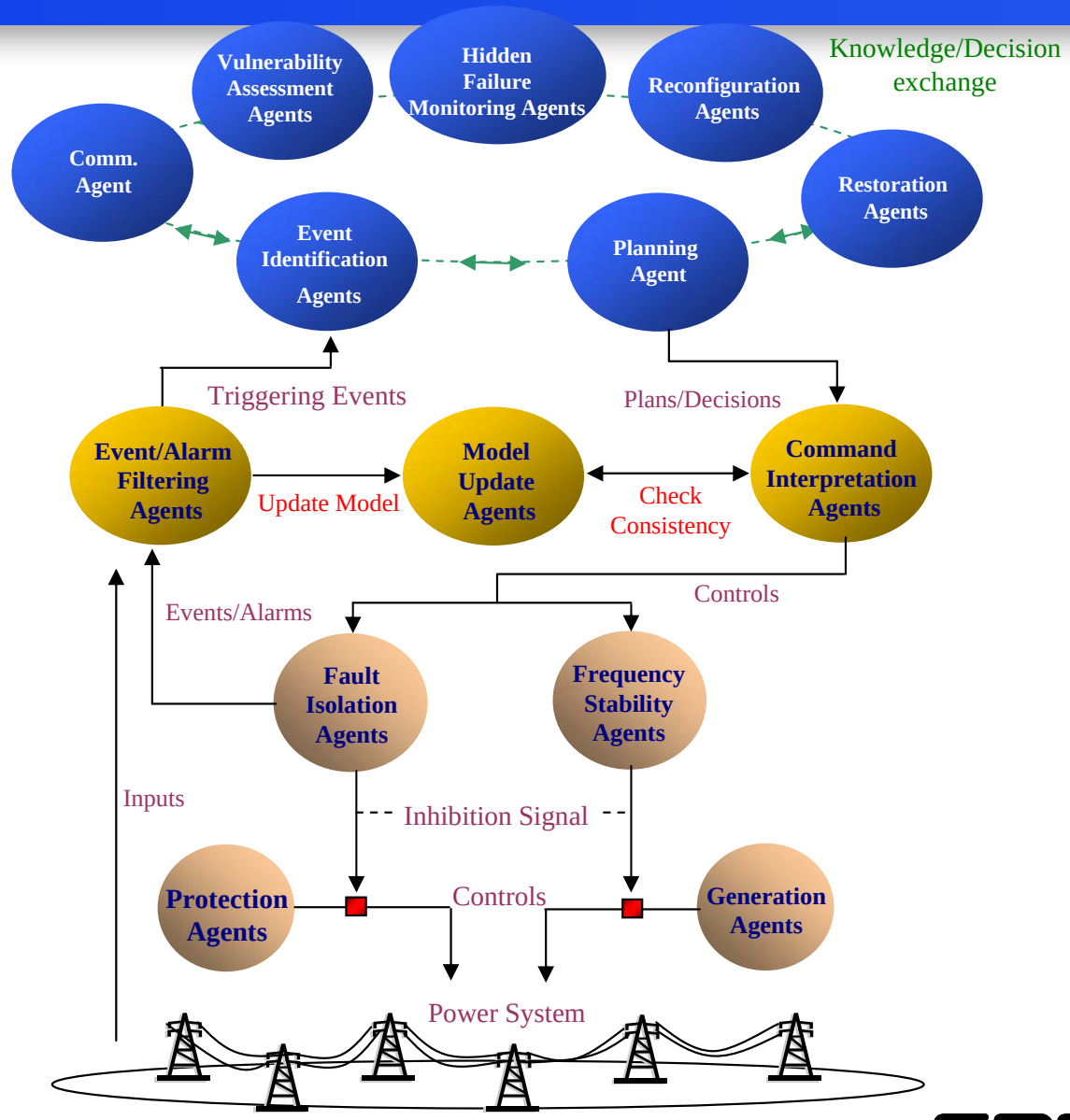
Integrated Infrastructure Protection and Control via Multi-Agent Systems

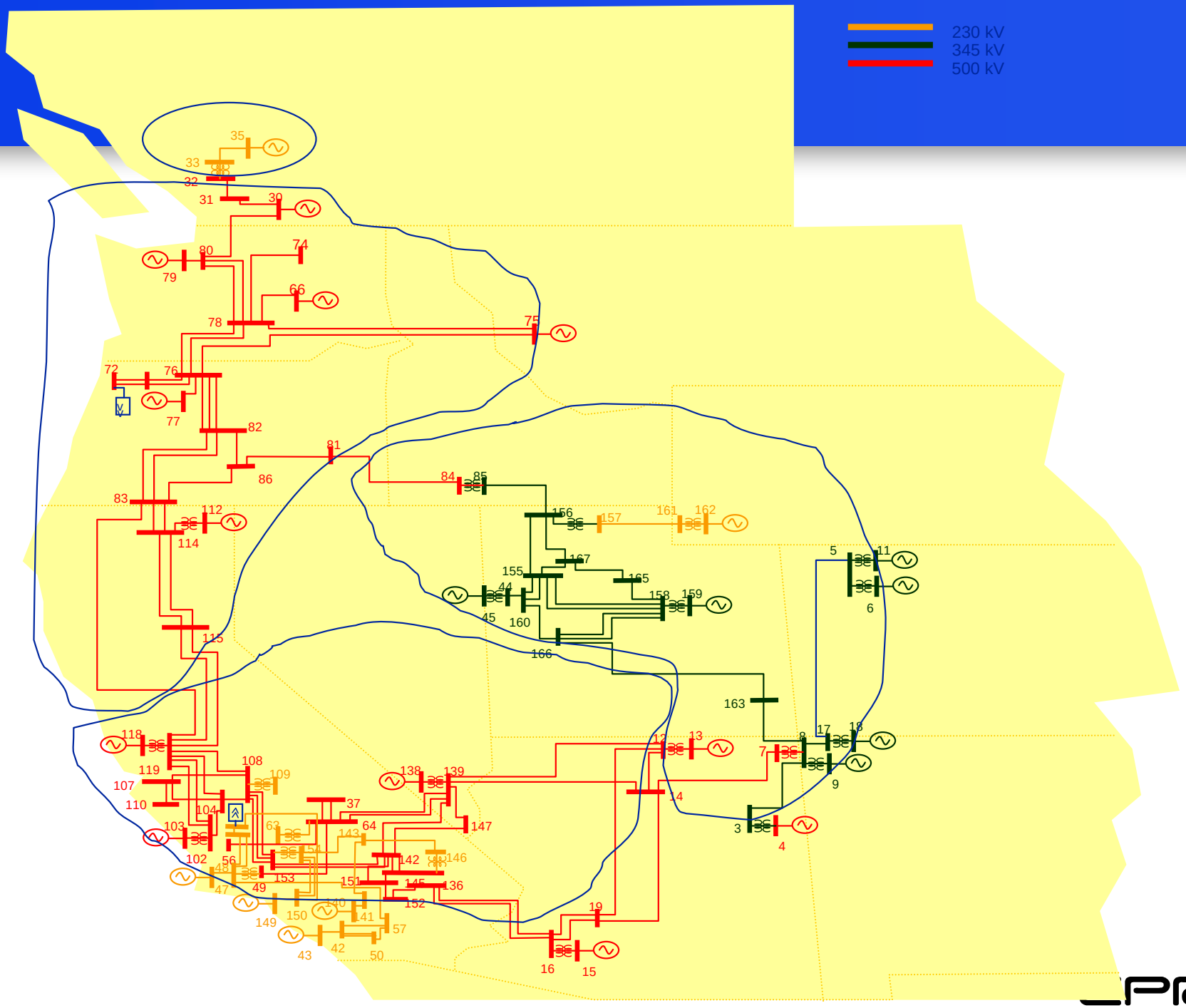
DELIBERATIVE LAYER

COORDINATION LAYER

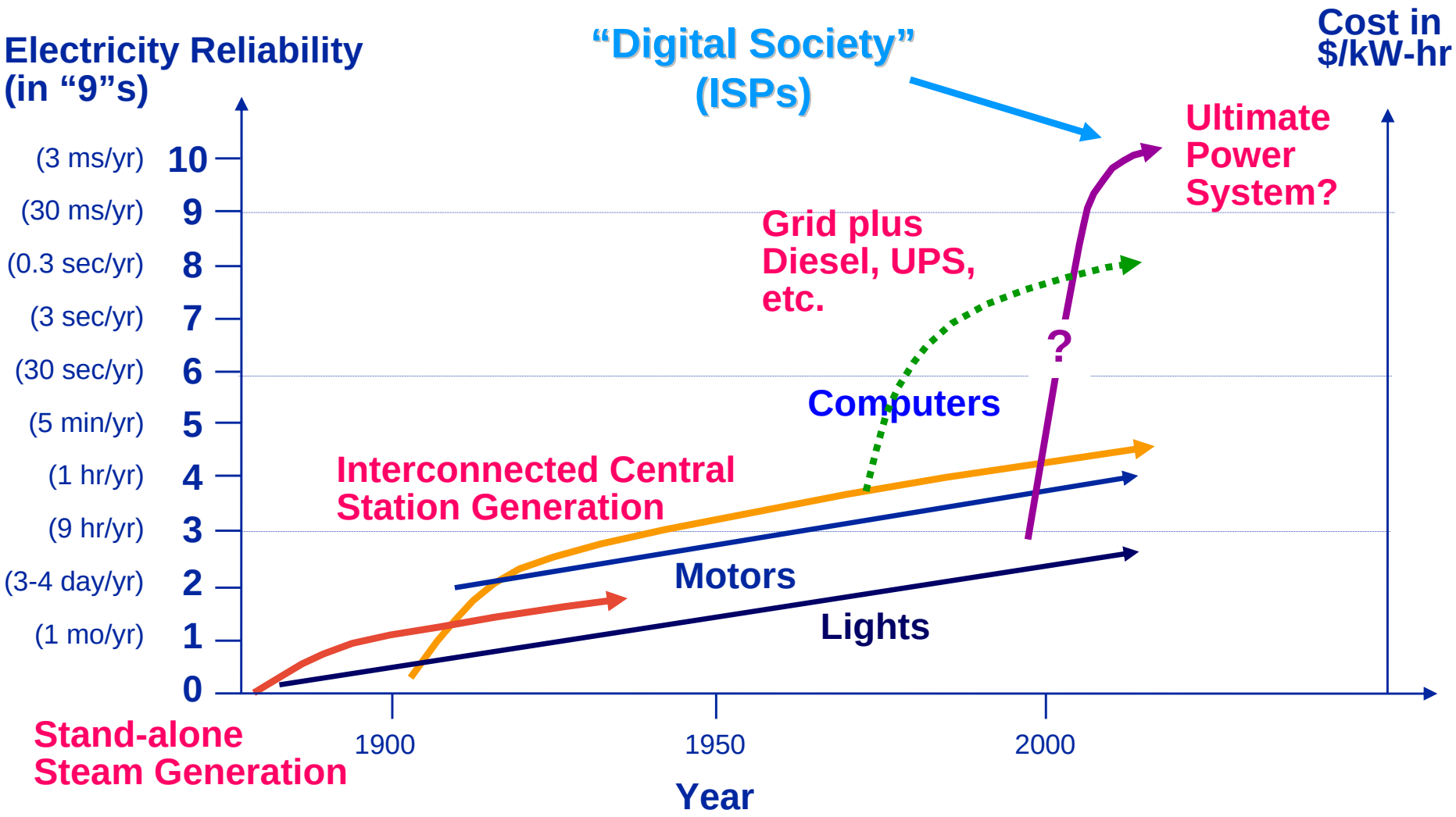
REACTIVE LAYER



Intelligent Adaptive Islanding



Technology Challenge for Powering the Digital Society



How do we make the leap to the next generation?

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