SYNCHRONIZED PHASOR APPLICATIONS FOR POWER GRIDS

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Catastrophic failures in power grids.

Failure mechanisms.

Countermeasures based on Wide Area Measurements (WAMS) with synchronized phasor measurements.

Presentation outline:

- Some past blackouts in North America
- Why do blackouts occur?
- Defensive strategies
- Synchronized phasor measurement systems

- **Some past blackouts in North America**

NORTH AMERICAN SYSTEM AT A GLANCE:

870 GW capacity

Thermal: 71 %
Hydro: 14 %
Nuclear: 13 %

Transmission:
320,000 circuit-km

Transmission
Voltages:
765, 500, 345, 138 kV

SOME MAJOR BLACKOUTS IN HISTORY:

1. North-East blackout of 1965

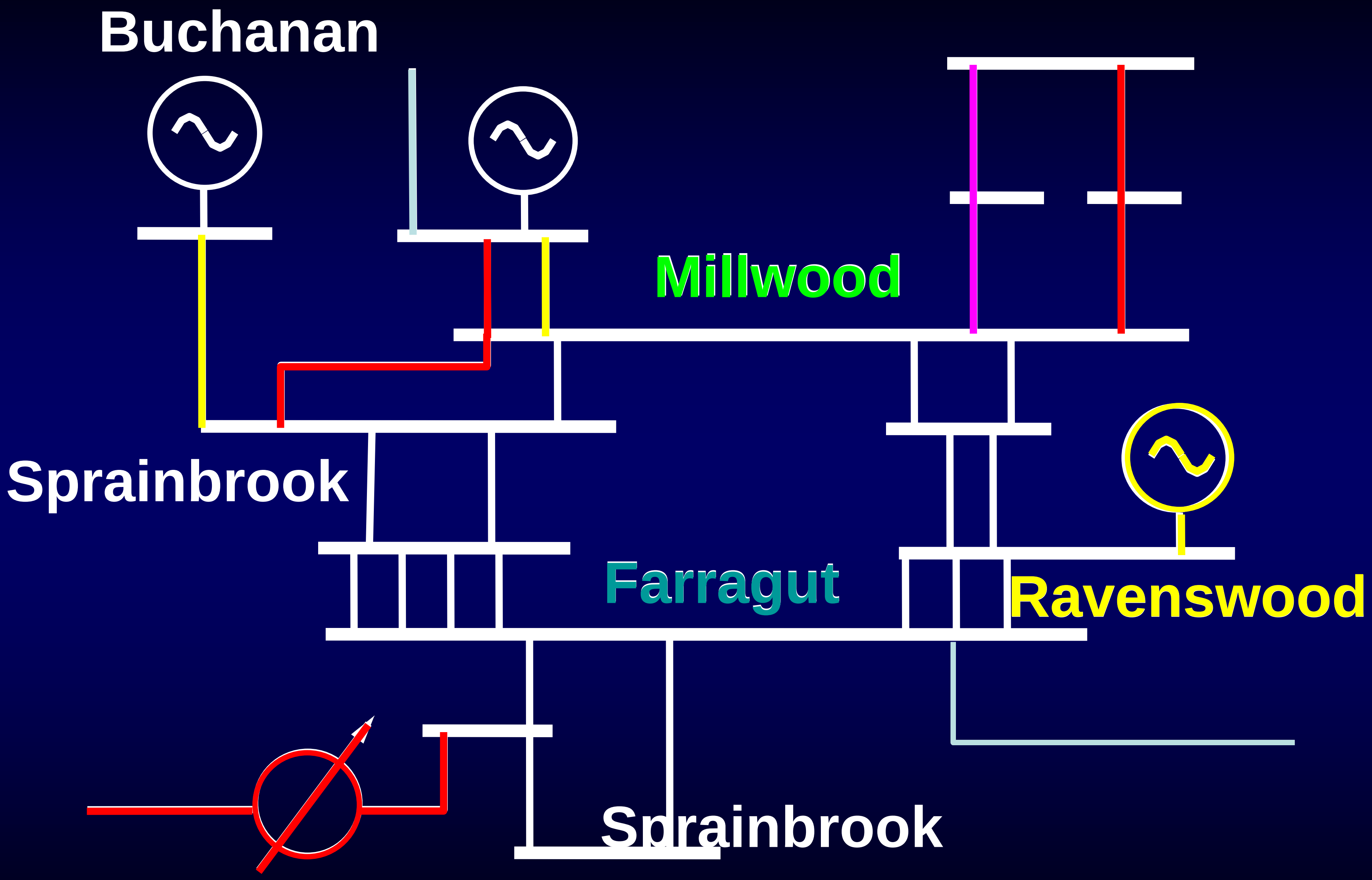
2. New York City blackout of 1977

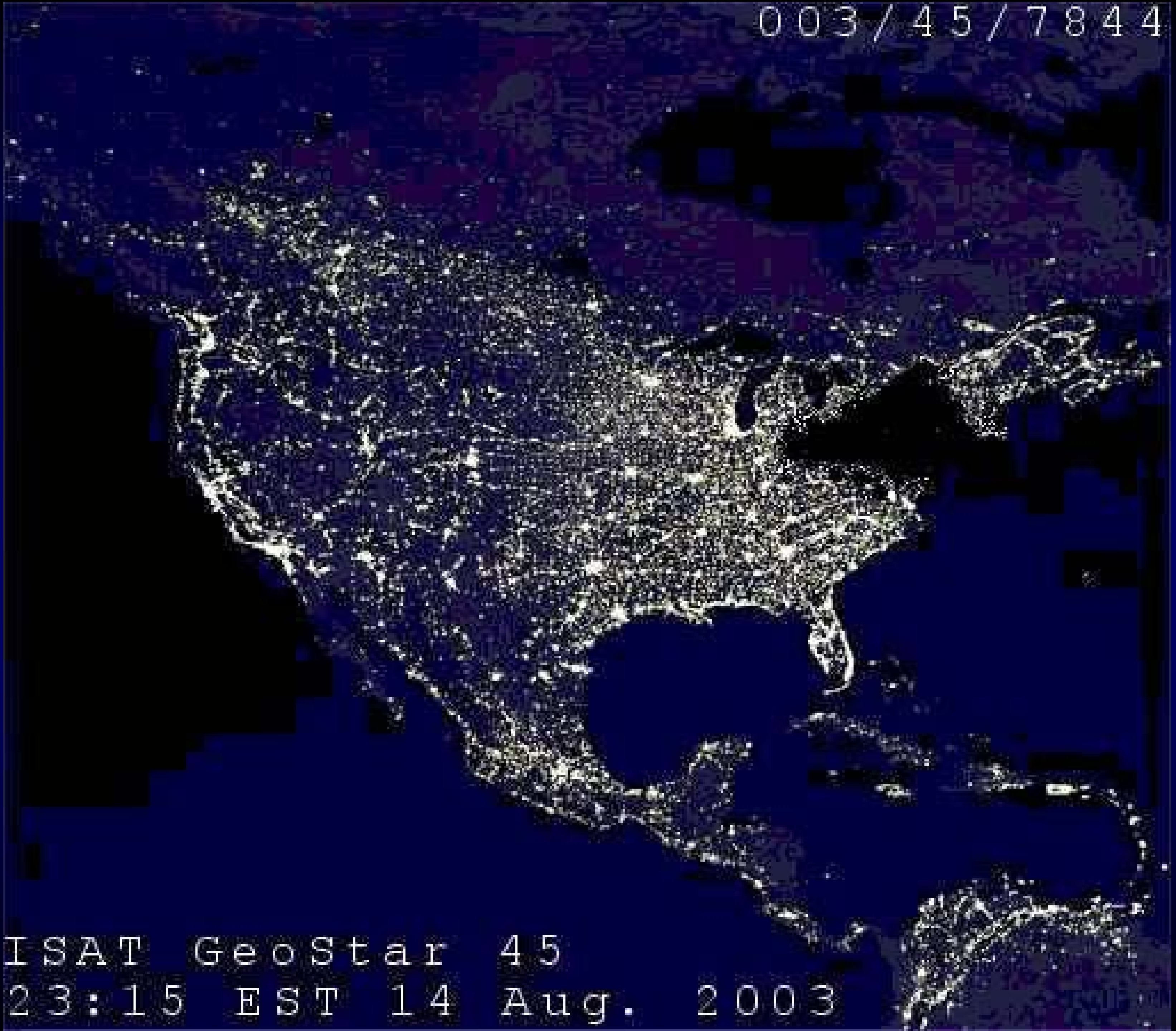
3. Western blackout of 1996

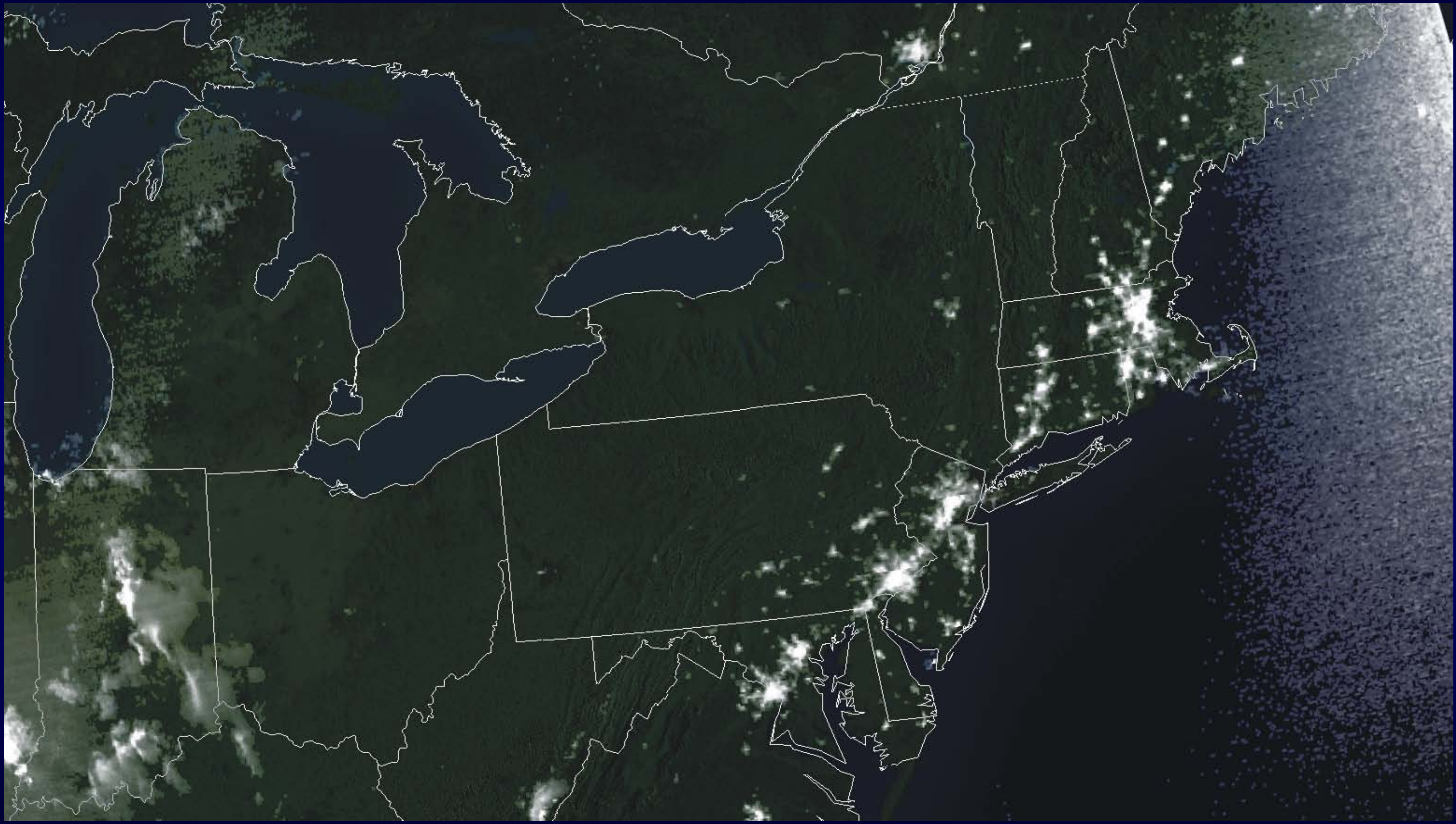
4. North-East blackout of 2003

1. North-East blackout of 1965

2. New York City blackout of 1977

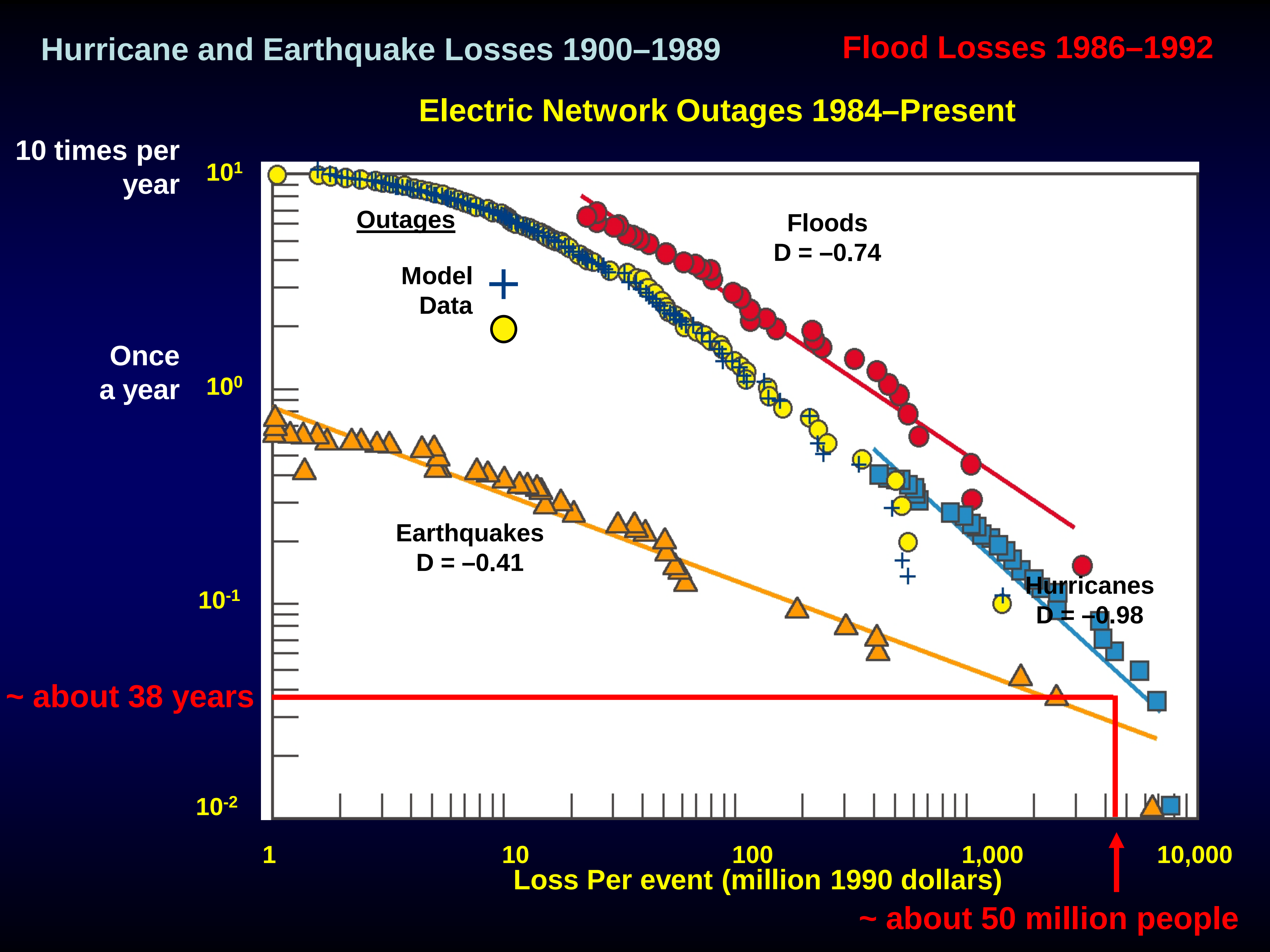

Buchanan
Millwood
Sprainbrook
Farragut
Ravenswood
Sprainbrook


003/45/7844
ISAT GeoStar 45
23:15 EST 14 Aug. 2003



3. Western blackout of 1996

4. North-East blackout of 2003



Hurricane and Earthquake Losses 1900–1989
Flood Losses 1986–1992
Electric Network Outages 1984–Present
10 times per year
Once a year
~ about 38 years
10¹
10⁰
10⁻¹
10⁻²
Outages
Model
Data
Floods
D = –0.74
Earthquakes
D = –0.41
Hurricanes
D = –0.98
1
10
100
1,000
10,000
Loss Per event (million 1990 dollars)
~ about 50 million people

- **Why do blackouts occur?**

WHY DO BLACKOUTS OCCUR ?

Blackouts are Rare Events:

- **Nature of the synchronous AC power system**

Stressed system

↓

Outages

↓

Inappropriate control actions

↓

Cascading

↓

Loss of synchronism and blackout

- **Inappropriate control actions**

(1) Inappropriate protection system operations

(2) Inappropriate control system operations

(3) Inappropriate operator actions

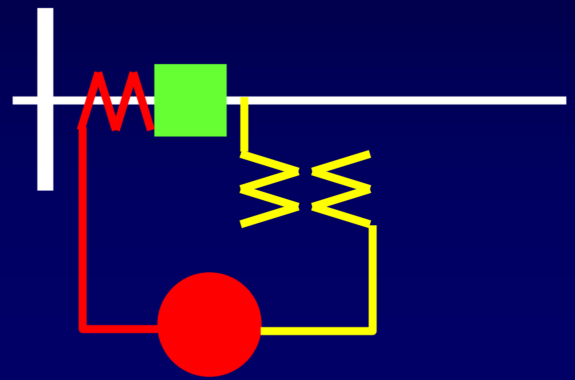
Protection system fundamentals

(1) Protects power apparatus: Lines, Machines, Nodes (buses)

Relays and circuit breakers

Current and voltage transformers

Limit damage to equipment

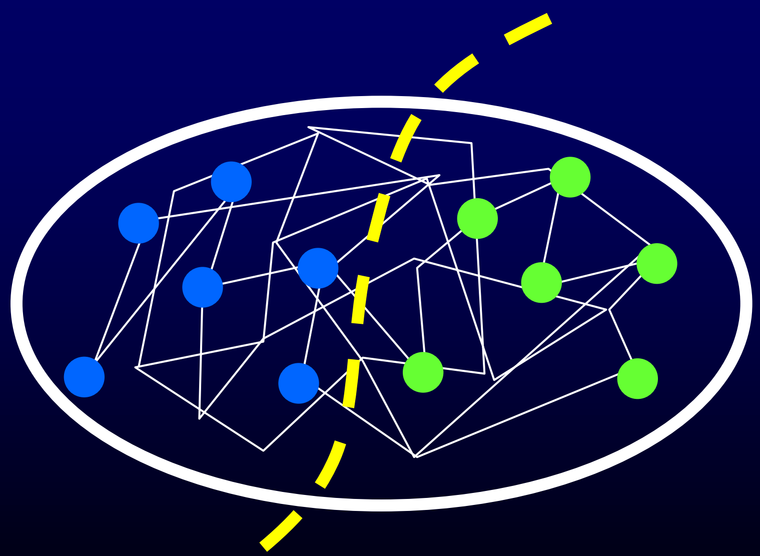


(2) Protects power System

Limit damage to power systems

Loss of synchronization
among generators

Catastrophic failures, blackouts



Protection system fundamentals

(3) Protection system characteristics

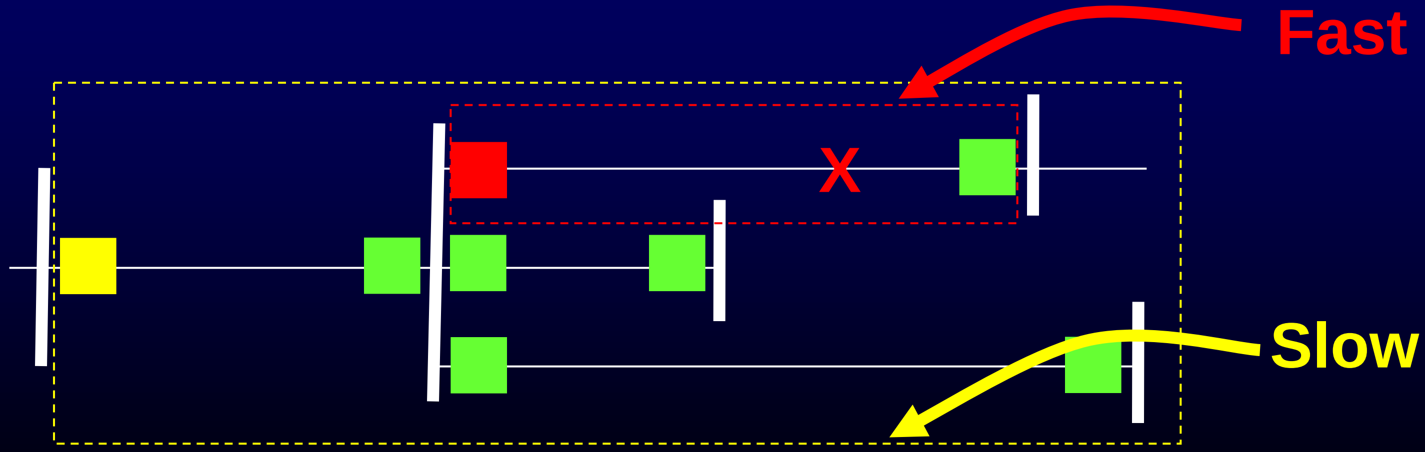
Fast response: 4-20 milliseconds

Autonomous

High dependability

Balanced with high security

(4) Nested protection systems



(1) Inappropriate protection system operations

Some Statistics from NERC Reports

Report Year	Cases with Relay system Involvement
1984	71%
1985	92%
1986	83%
1987	60%
1988	64%

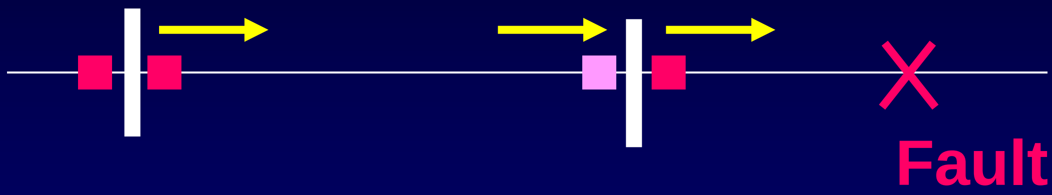
(1) Inappropriate protection system operations

NERC report for 1986 83%

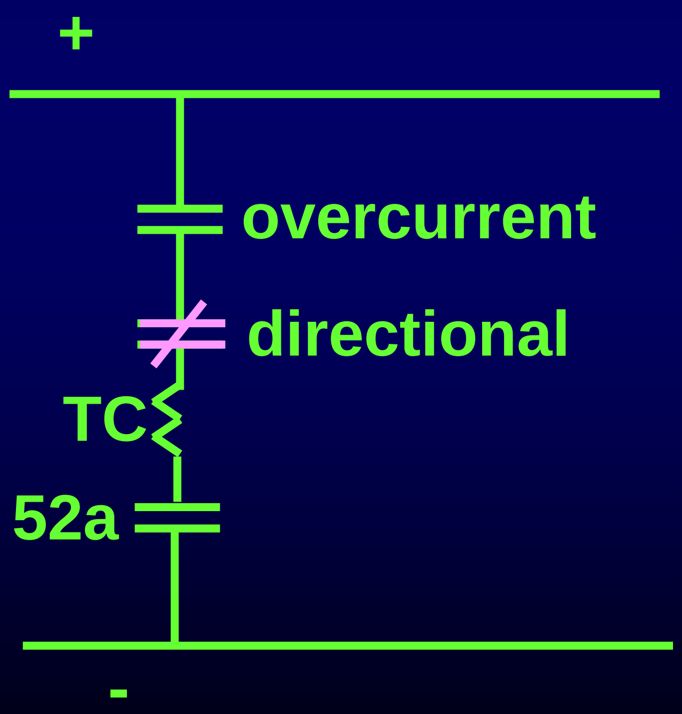
	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6
Power System Facilities		X	X		X	X
Protection Systems	X	X	X	X	X	
System Monitoring	X	X			X	
Operators		X			X	
Operational Planning		X				X
System Reserve Response						
Preventive Maintenance					X	X
Load Relief						
Restoration	X	X				

(1) Inappropriate protection system operations

Hidden failures in a directional overcurrent relay:



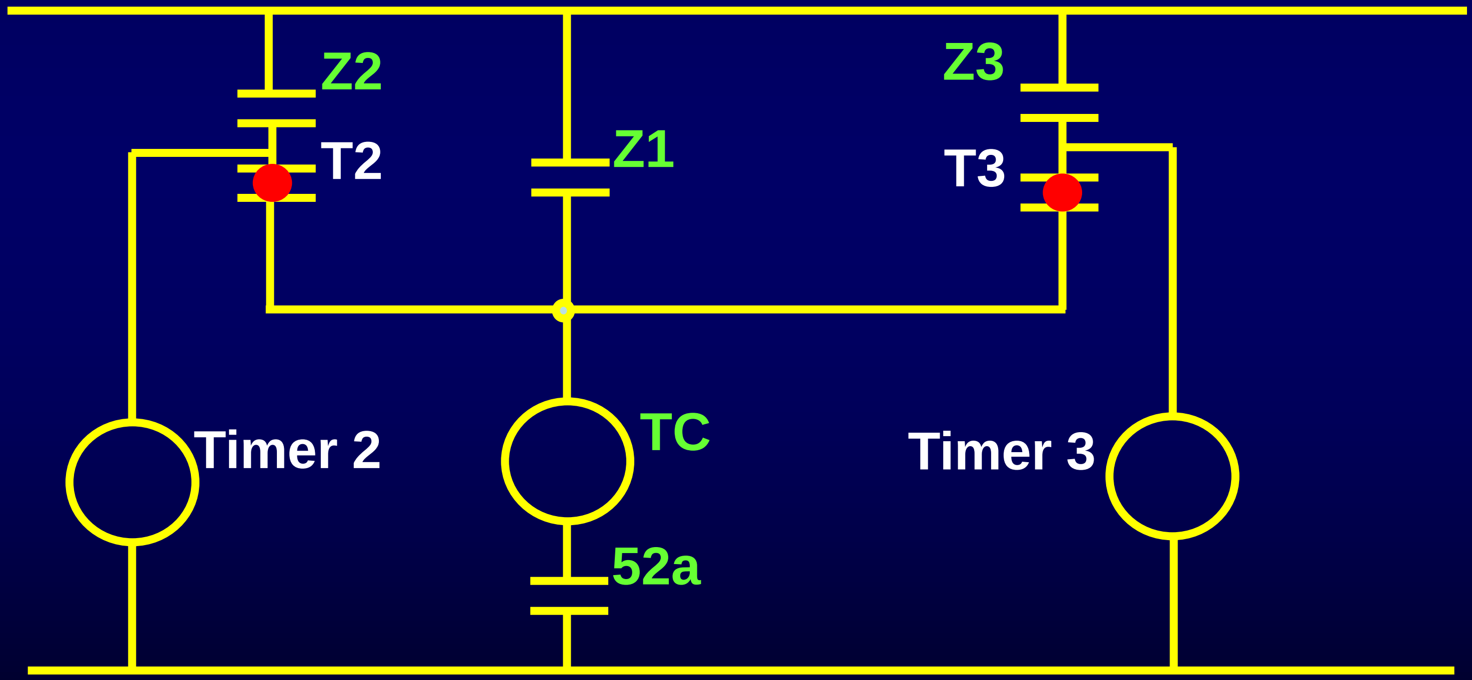
Transmission line with directional overcurrent relaying



Control Circuit

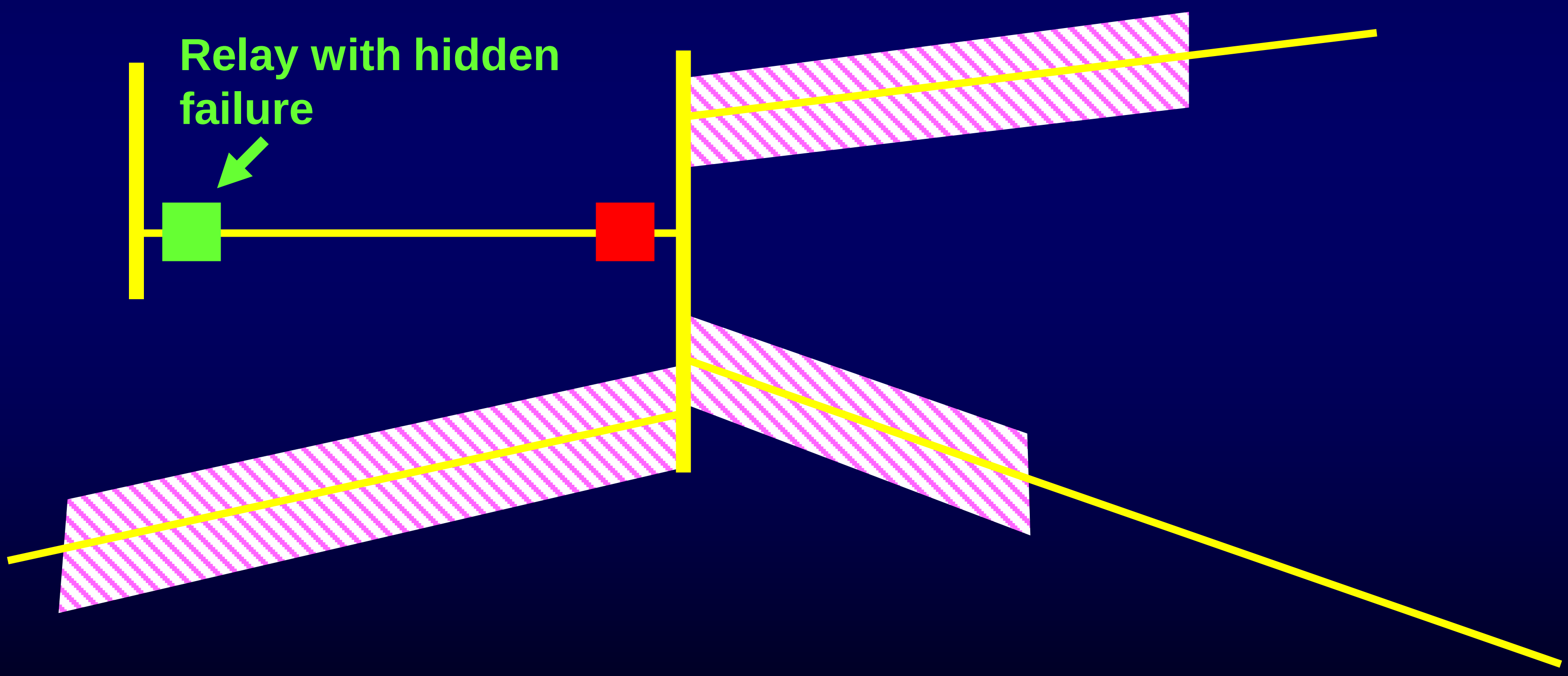
(1) Inappropriate protection system operations

- **Hidden failures in three zone step distance relays**



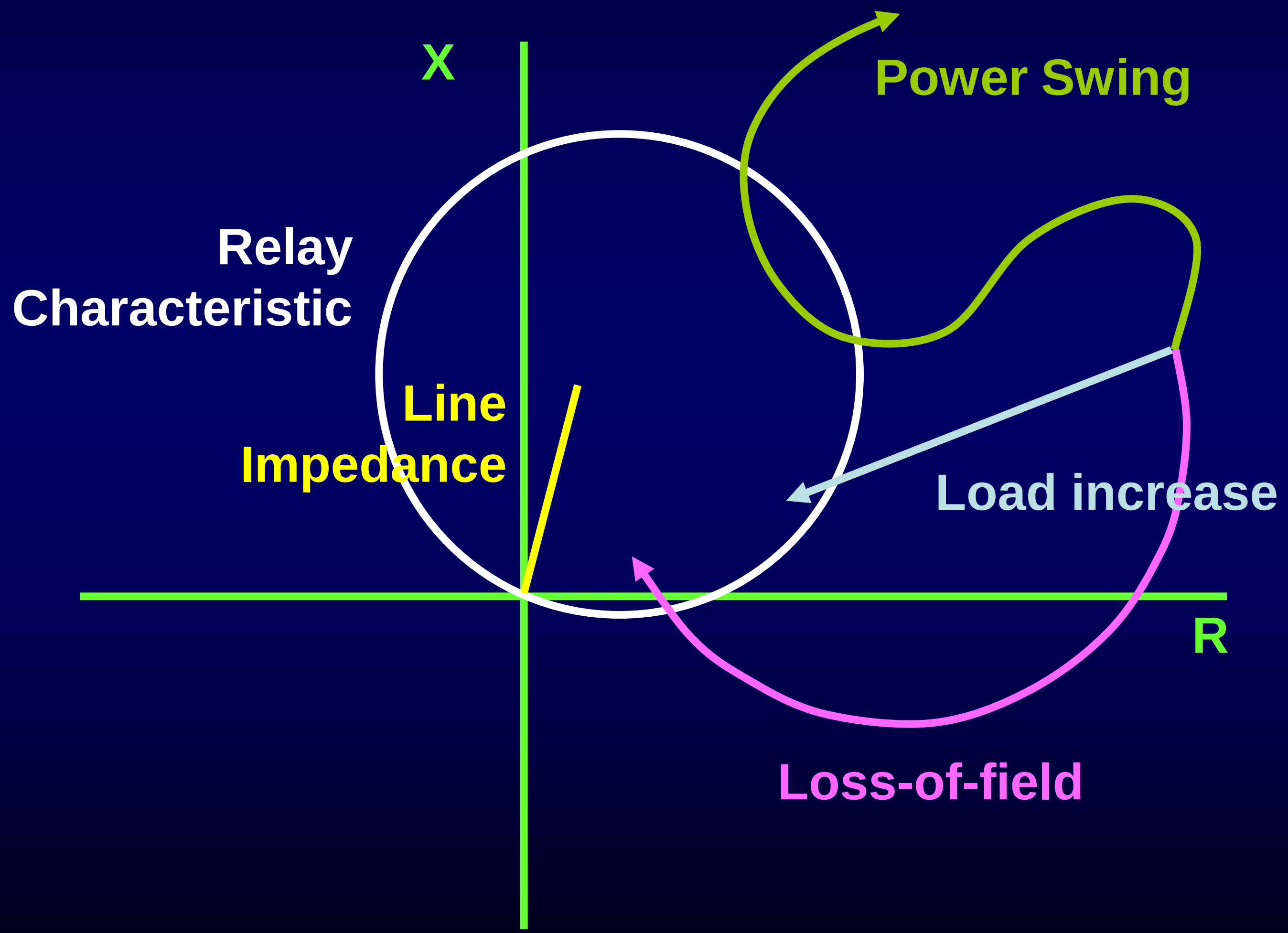
(1) Inappropriate protection system operations

- **Concept of region of vulnerability due to hidden failures**



(1) Inappropriate protection system operations

- <u>Loadability of backup zones</u>



(2) Inappropriate control system operations

- Equipment malfunctions: excitation systems, HVDC, FACTS, SVC
- Tap changer controls
- Faulty control circuits: lockouts, etc.
- Faulty synchronizing controls

(3) Inappropriate operator actions

Usually a contributing factor in all blackout scenarios.
Recent examples:

- New York City blackout of 1977
- August 14, 2003 blackout in North America
- Post-maintenance energization sequences (AEP)
- Inappropriate manual intervention (AEP)

- **Defensive strategies**

CAN BLACKOUTS BE MADE LESS LIKELY ?

Stressed system
↓
Outages
↓
Inappropriate control actions
↓
Cascading
↓
Loss of synchronism and blackout

Power system design to make stress less likely

Random events beyond control

More intelligent controls

Design of a ductile system instead of a brittle system

Power system design to make stress less likely

- These are long term solutions, well known to power system engineers:

  - Sufficient generation margin
  - Adequate transmission access to load centers
  - Adequate reactive support
  - Accurate real-time monitoring
  - Security against N-k contingencies

More intelligent controls

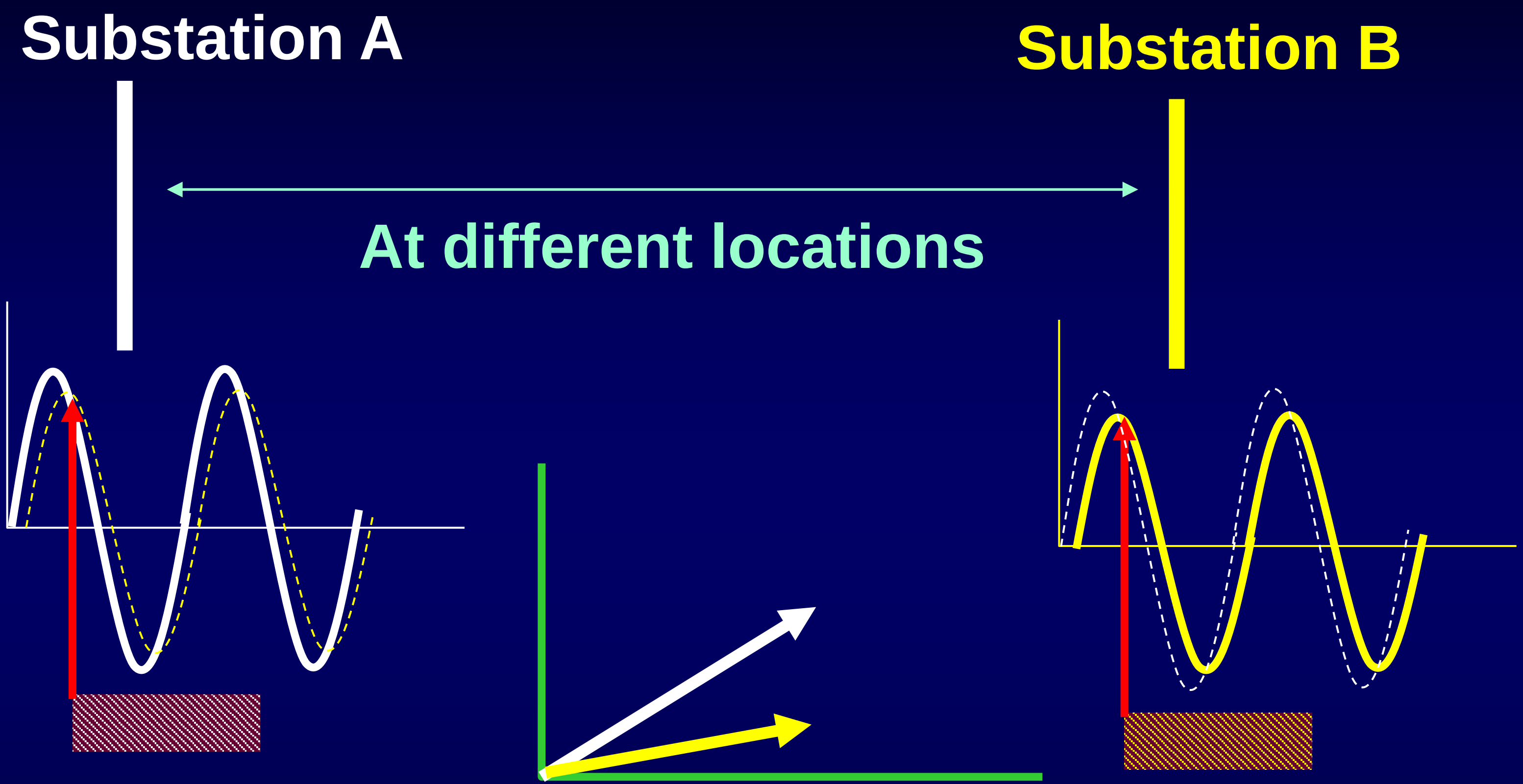
(1) Use of wide area measurements

(2) Remedial action schemes

(3) Adaptive protection

WAMS ~ Wide Area Measurement Systems

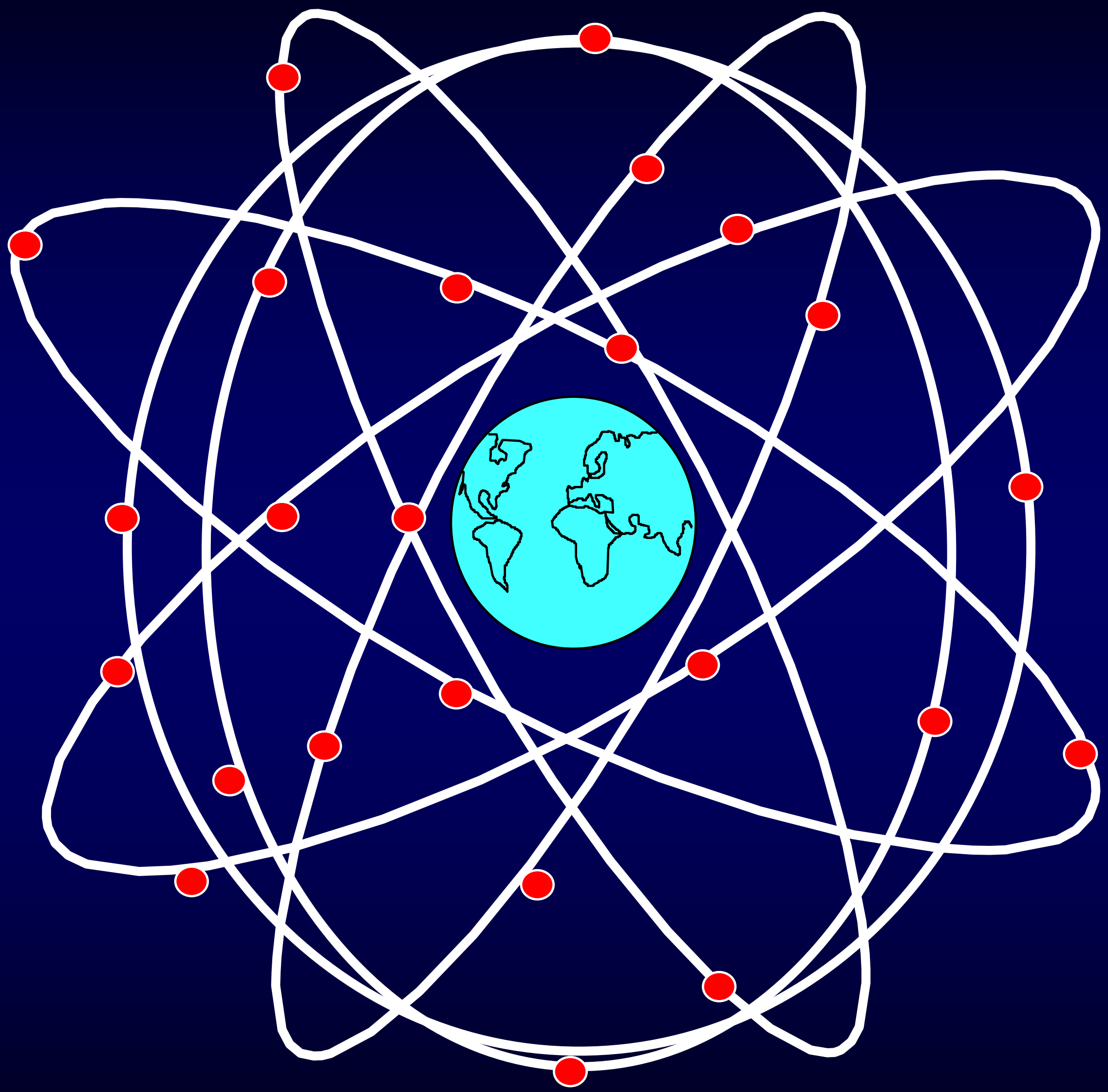
- **Motivation for synchronization**



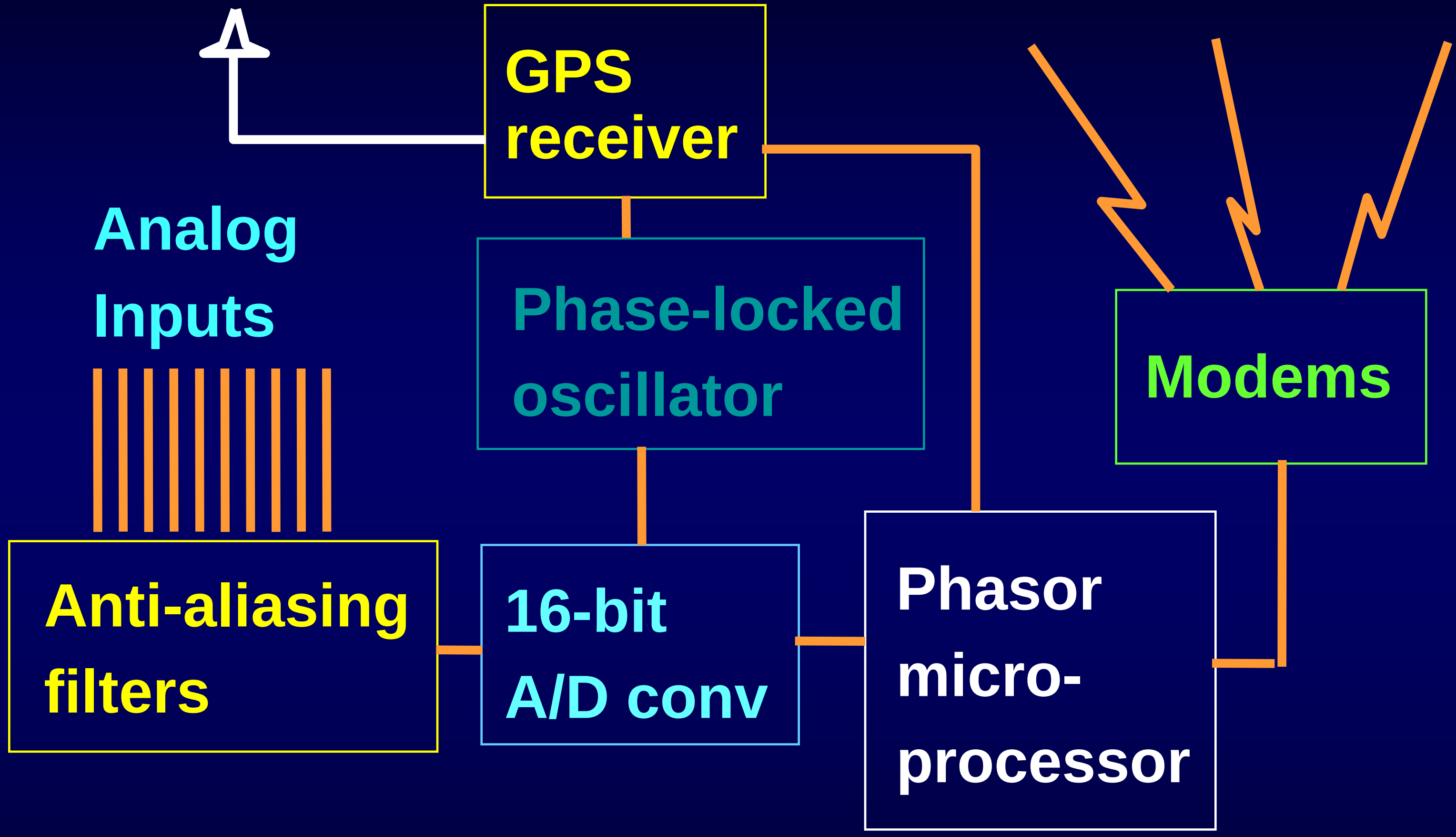
By synchronizing the sampling processes for different signals - which may be hundreds of miles apart, it is possible to put their phasors on the same phasor diagram.

- **Sources for Synchronization**

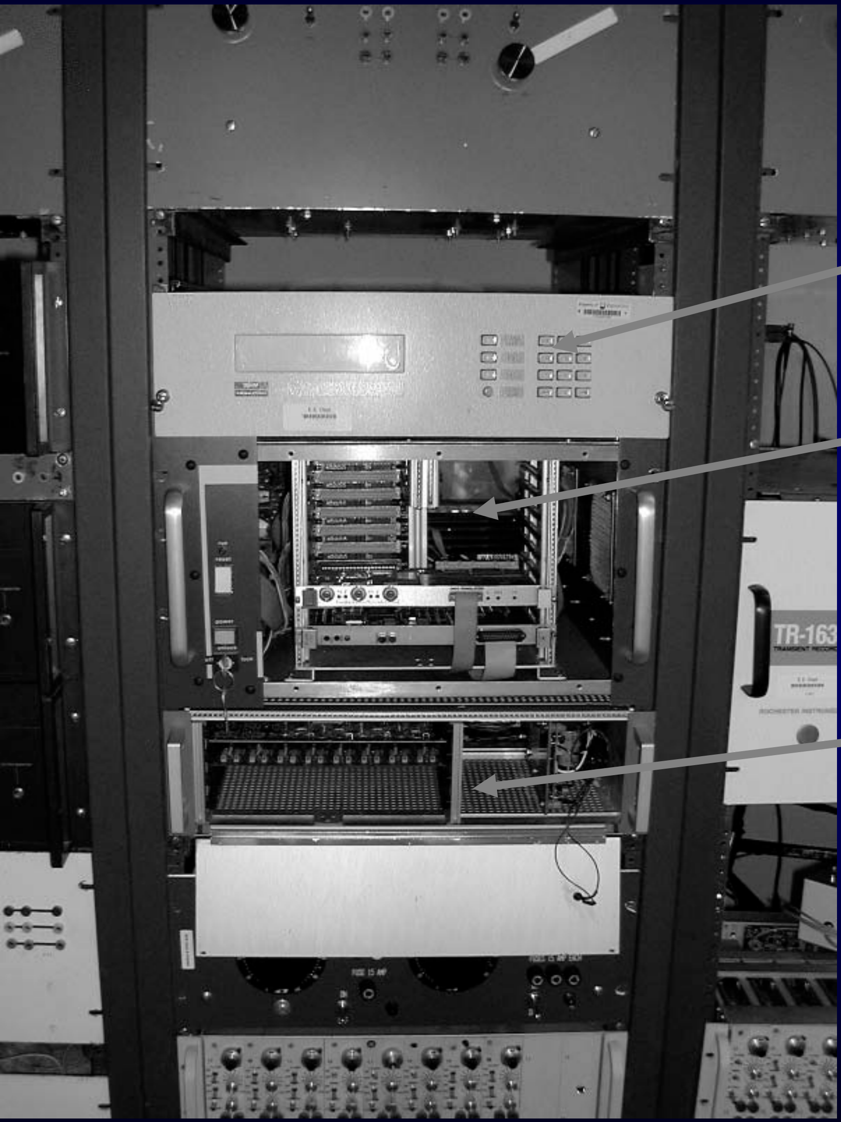
- **Pulses**
- **Radio**
- **GOES**
- **GPS**



- **A phasor measurement unit**



World’s first PMUs at Virginia Tech, early 1990s.

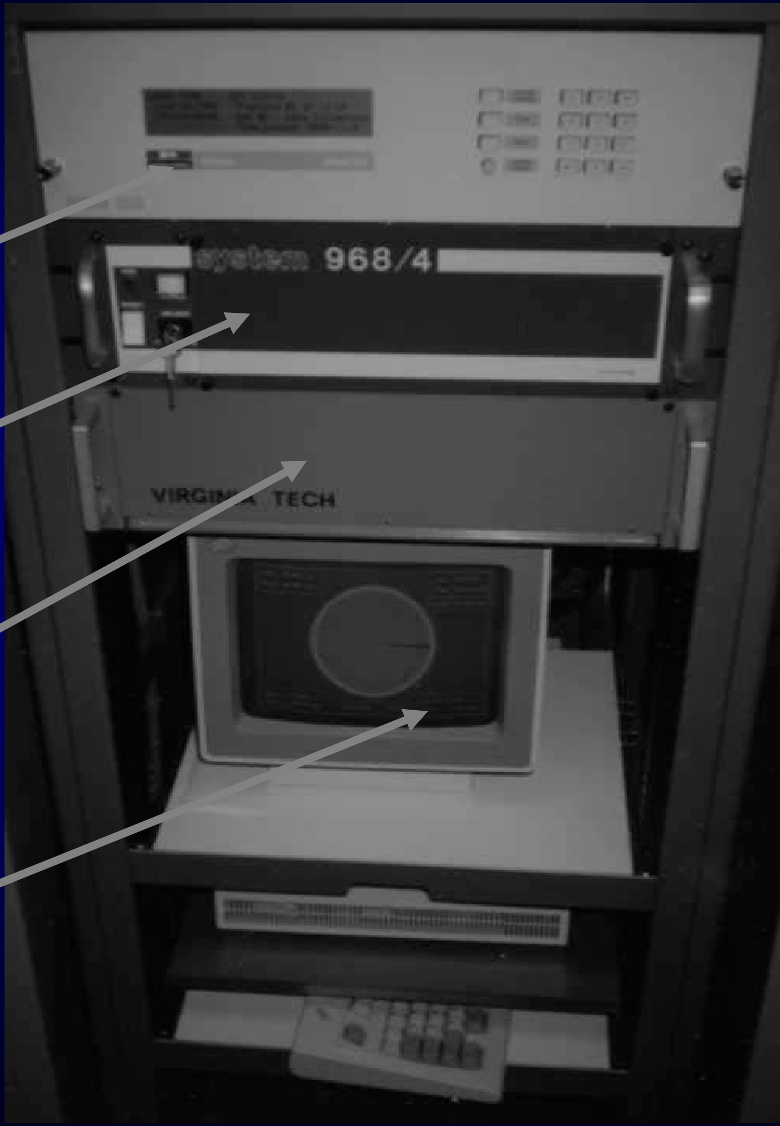


GPS receiver

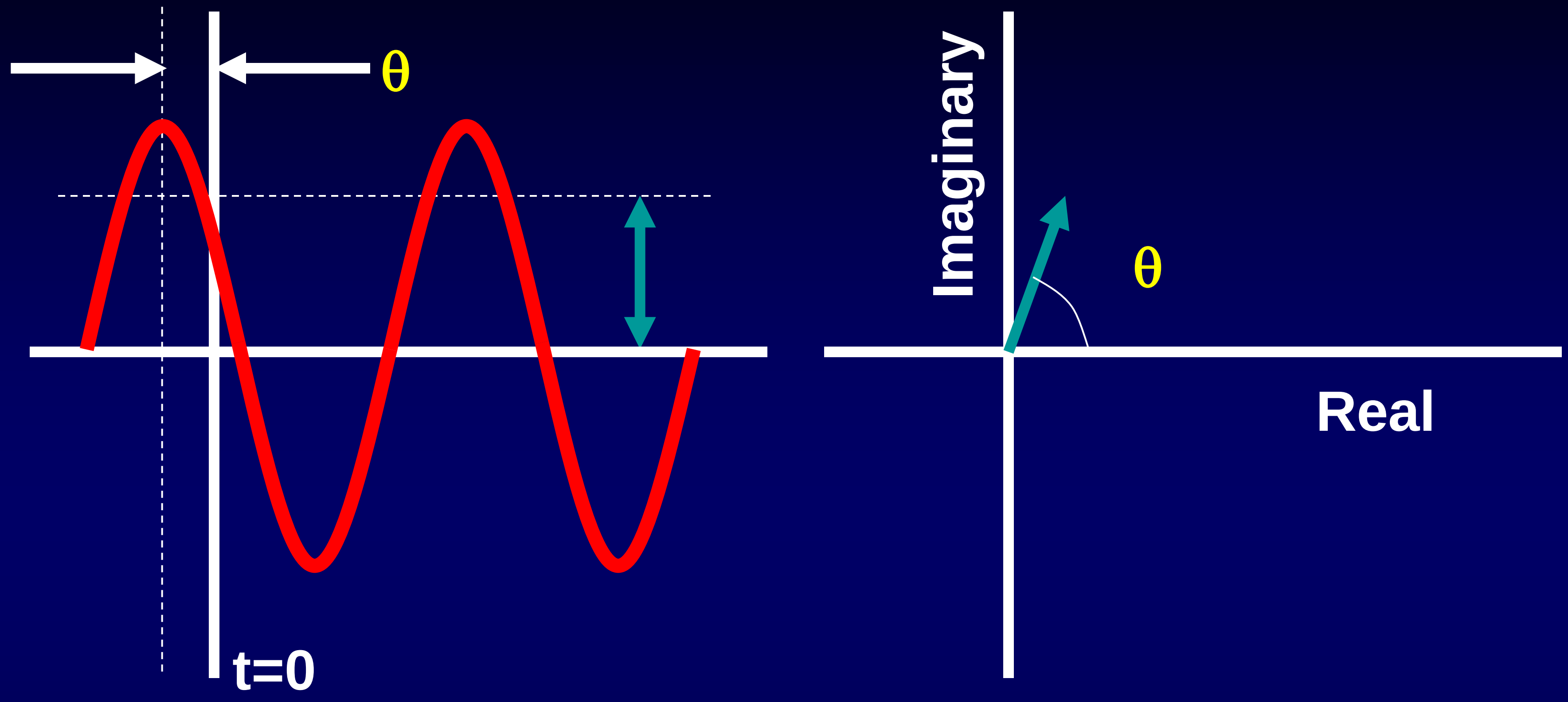
PMU

Signal conditioning unit

User Interface



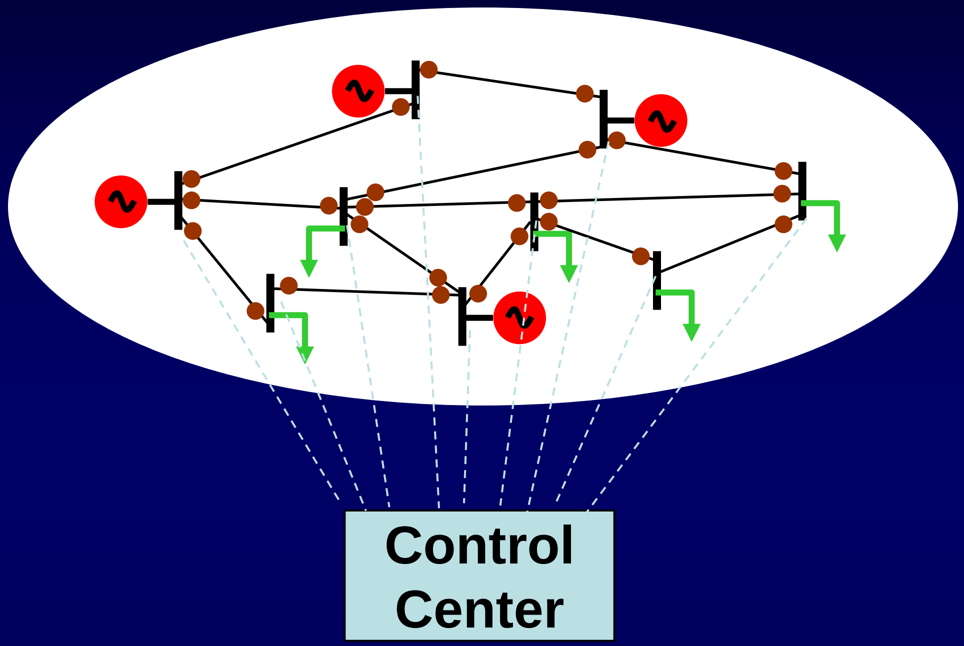
- Introduction to phasors



- The starting time defines the phase angle of the phasor.
- This is arbitrary.
- However, differences between phase angles are independent of the starting time.

- **State estimation with phasor measurements**

Present practice



Measurements are scanned and are NOT simultaneous

Measurements are primarily P, Q, |E| = [Z]

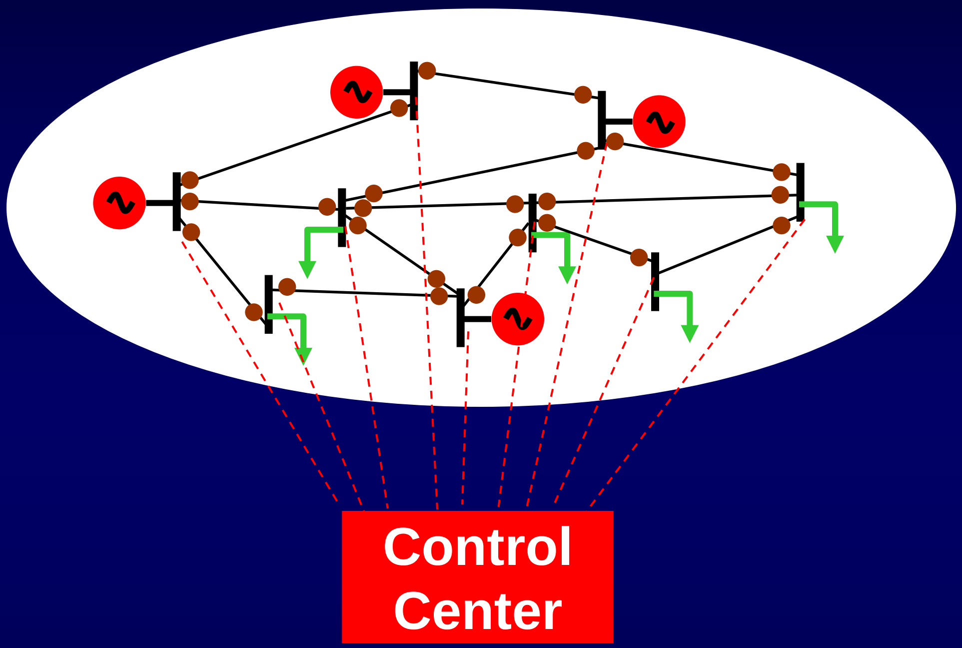
Measurements are non-linear functions of the state E :
Z = h(E)

Iterative weighted least square solution

$$[Z - Z_k] = \left[\frac{\partial h}{\partial E} \right]_k \Delta E_k$$

- **State estimation with phasor measurements**

Estimation with phasors



Positive sequence Phasors are the state vector

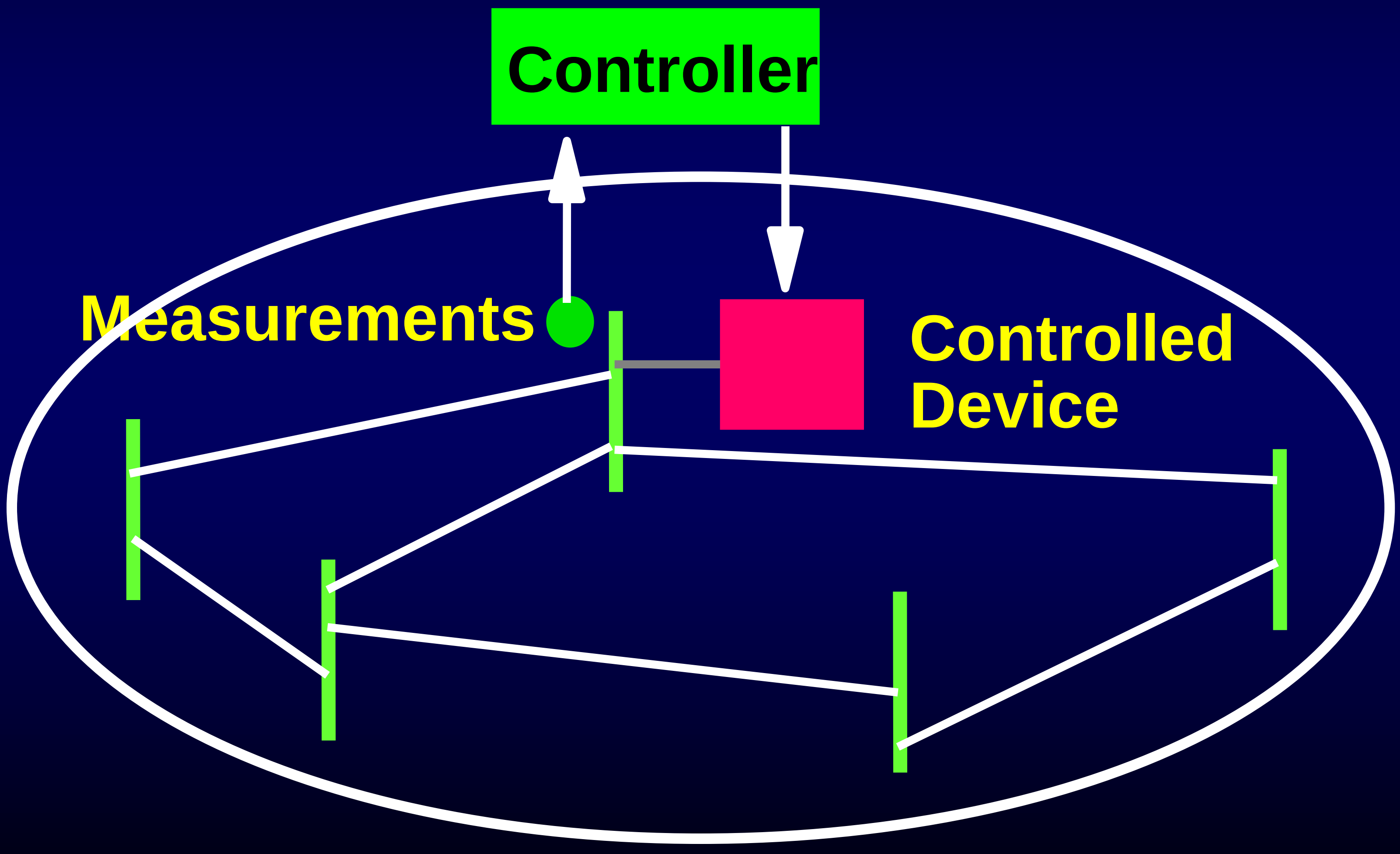
Because they are synchronized at source, they are simultaneous regardless of the speed of communication

Redundancy in measurement is provided by the positive sequence current measurements

USES OF PHASOR MEASUREMENTS

ADVANCED CONTROL FUNCTIONS

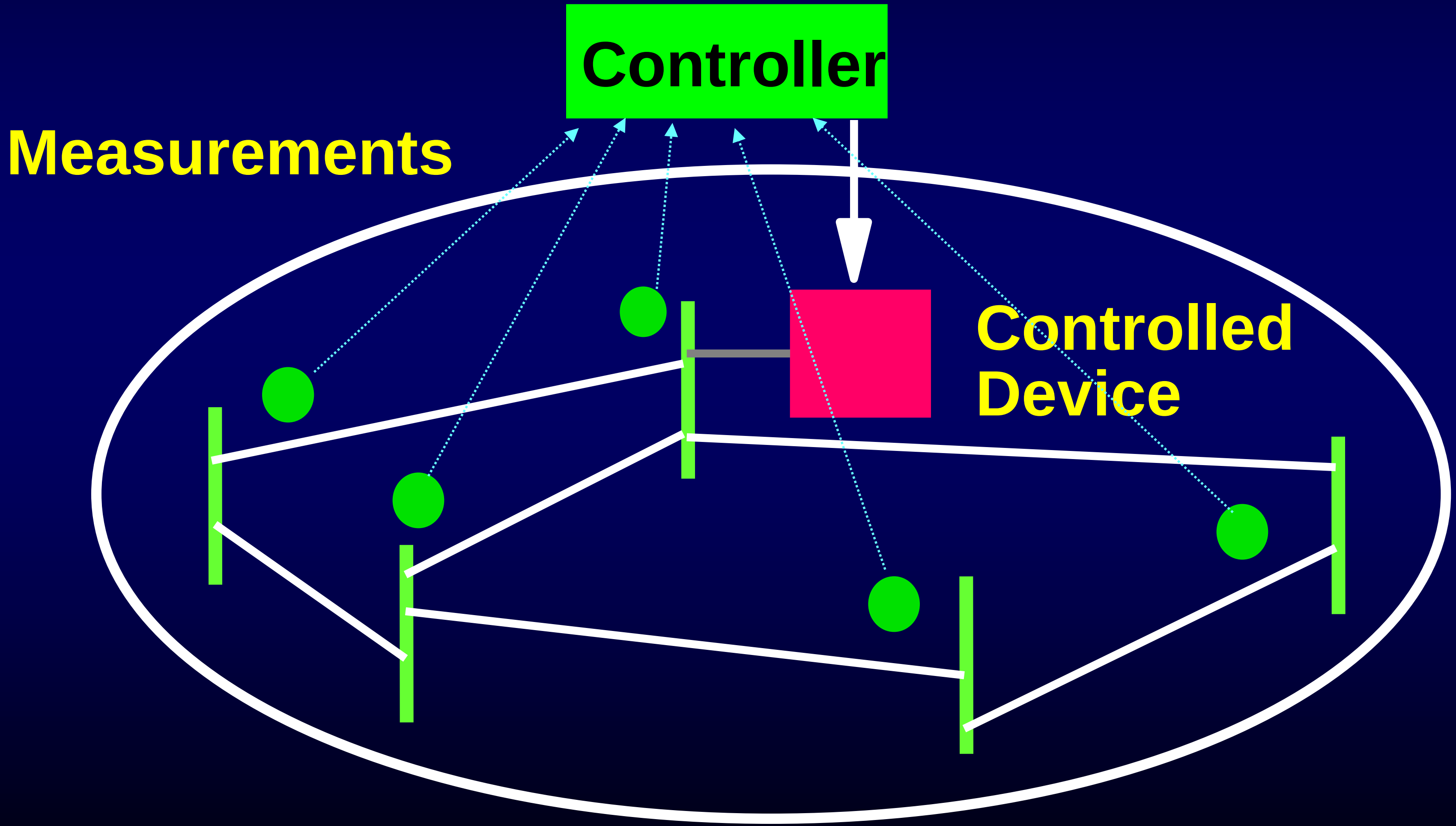
Present system: model based controls



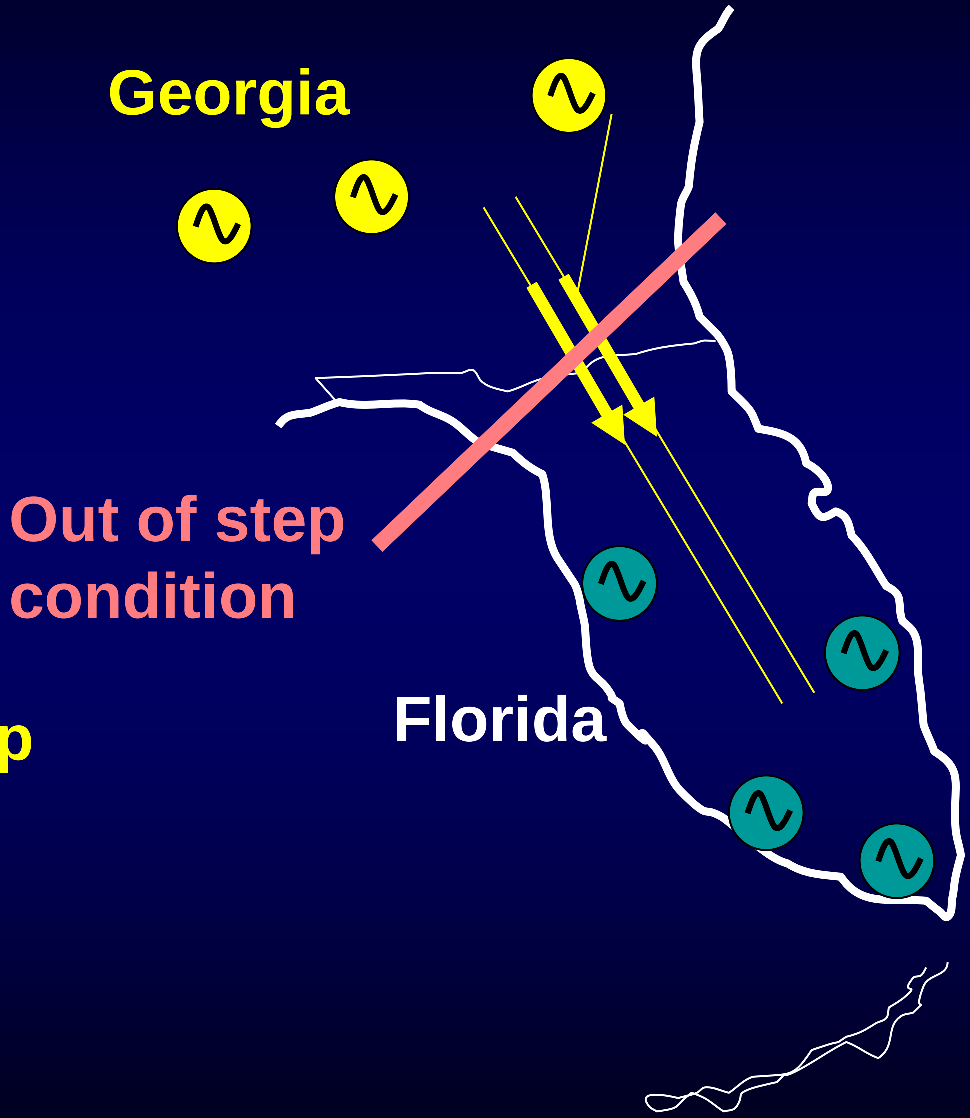
USES OF PHASOR MEASUREMENTS

ADVANCED CONTROL FUNCTIONS

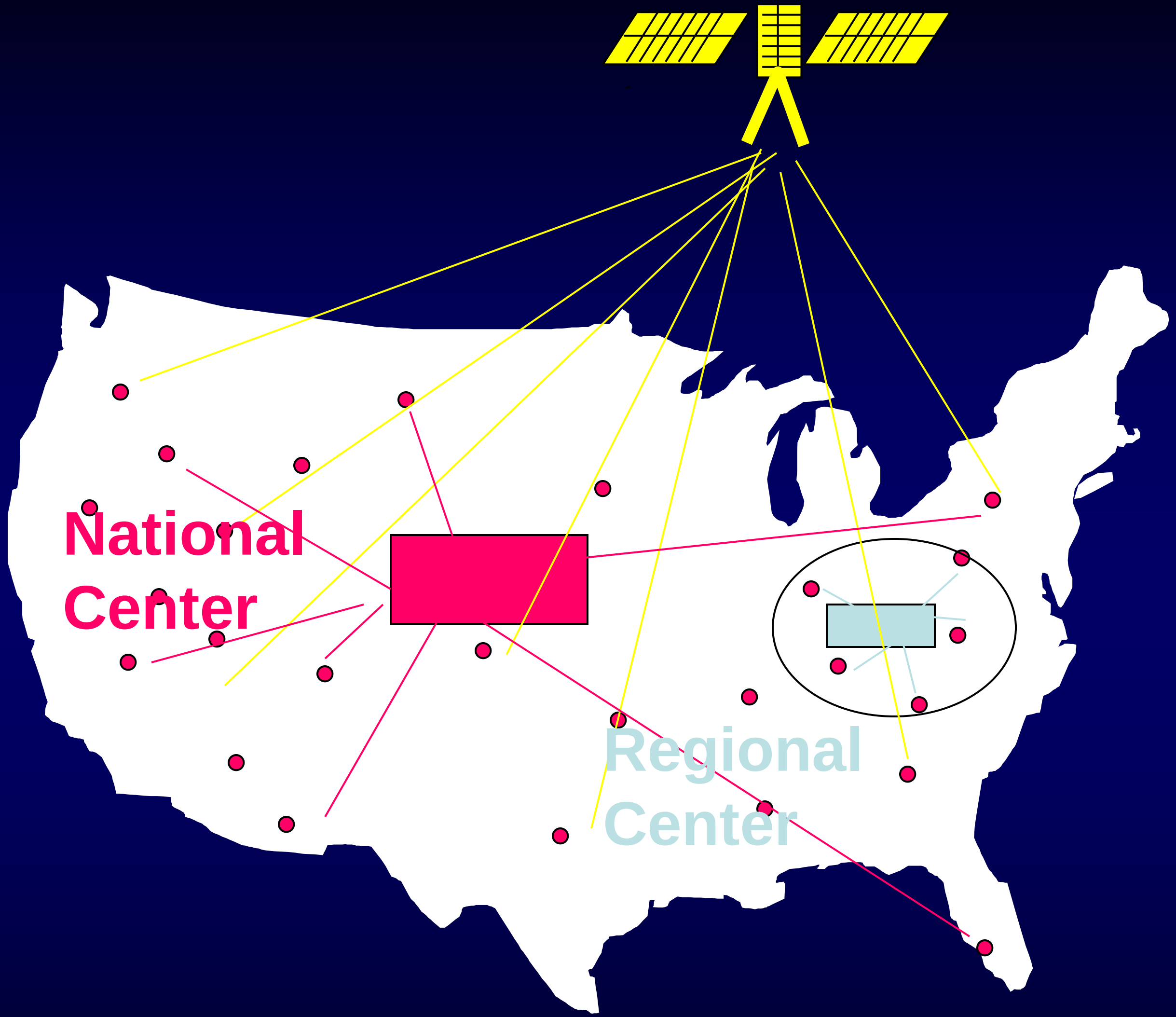
Phasor based: Feedback based control



- **Stabilizing a network**

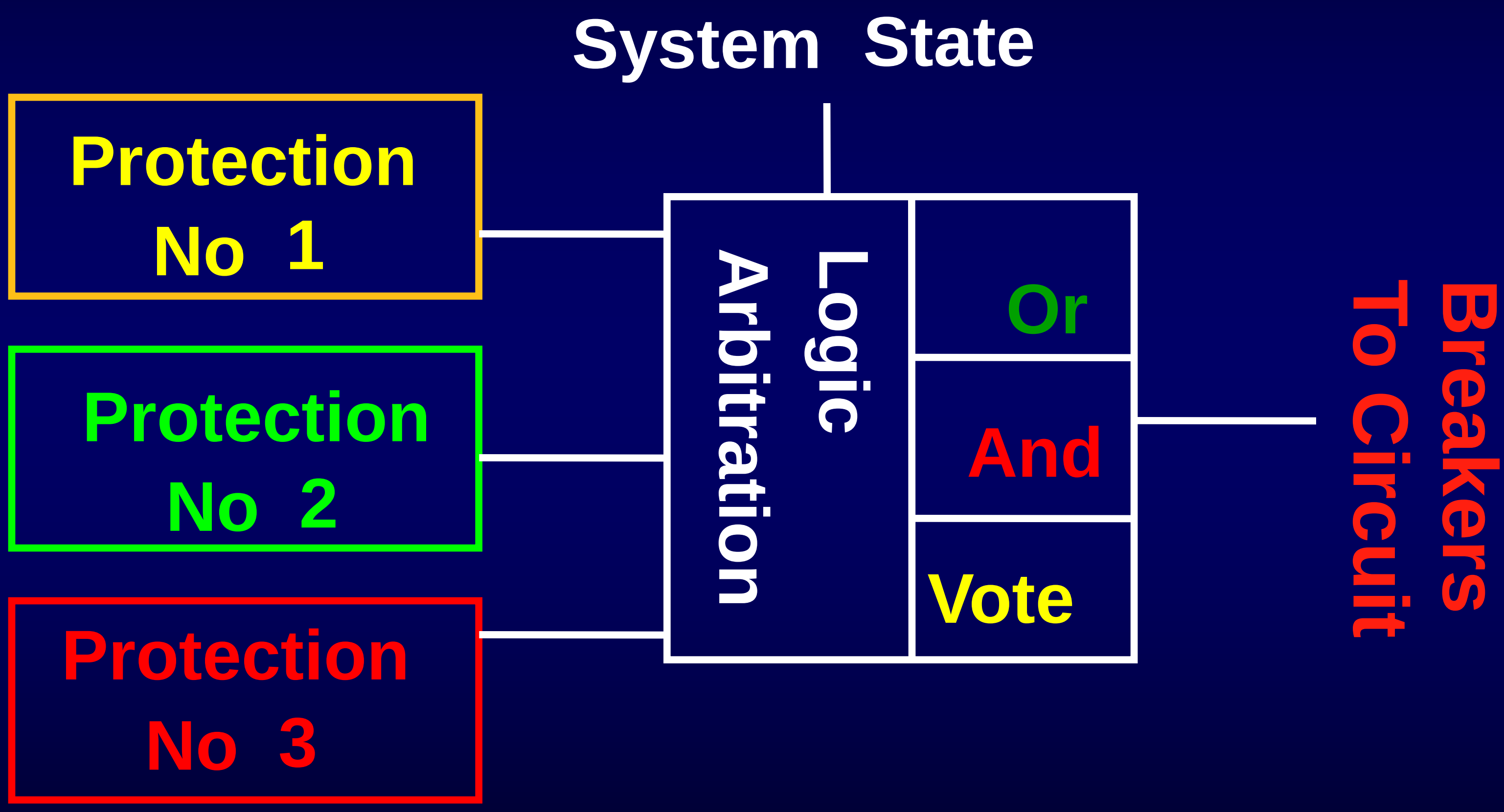


Out of step relays detect incipient instability


National
Center
Regional
Center

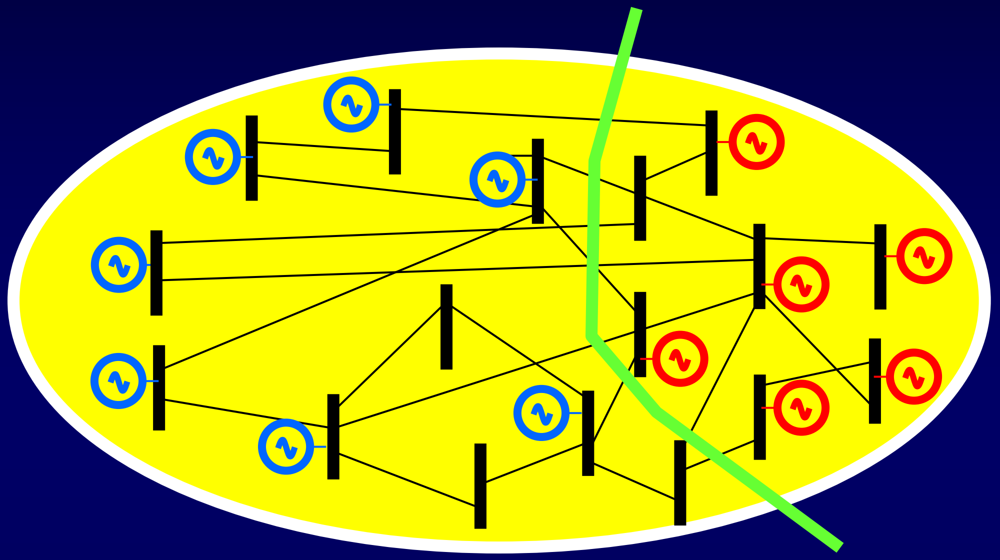
Adaptive Relaying

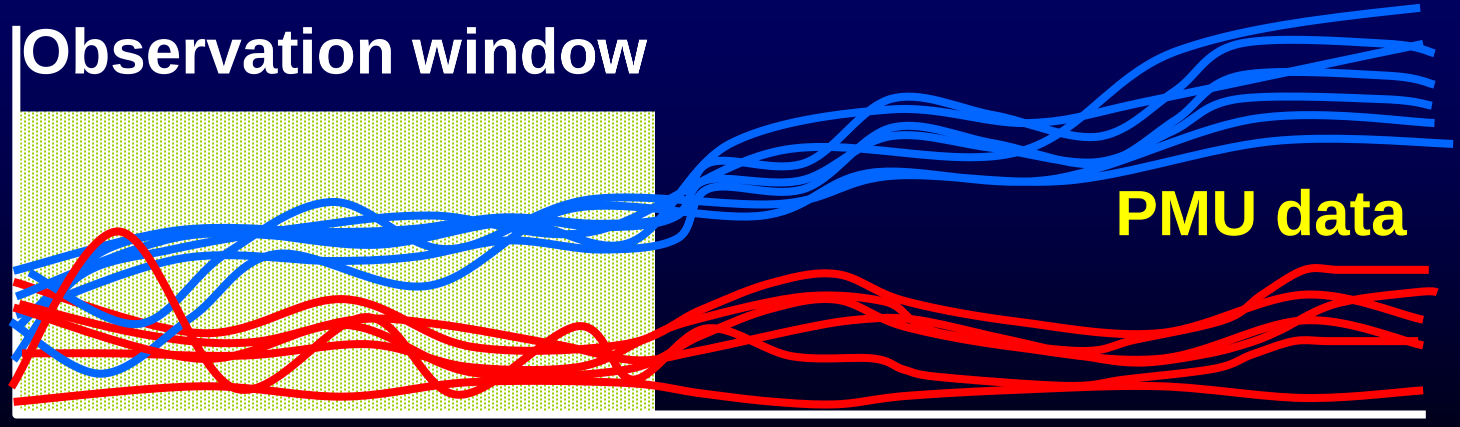
- **Controlled Security & Dependability**



• Intelligent islanding possibilities

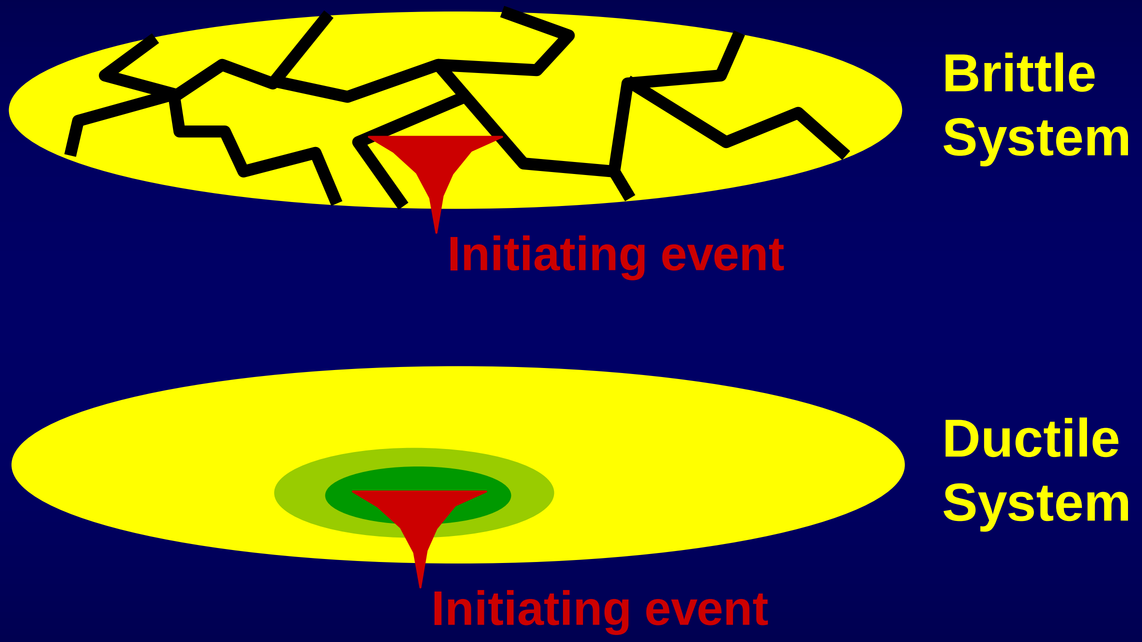
(3) Real-time coherency determination





Design of a ductile system instead of a brittle system

Ductile and Brittle structures



To achieve ductility,

- New network elements
- New configurations
- Renewable architectures

Concluding remarks

- Blackouts of 2003
- Post-mortem analysis
- NERC directives
- Energy policy
- ARRA and Stimulus funding for energy systems