Autonomic Mishap Management:
Toward Smart Self-healing Critical Infrastructures

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S&T Innovation and the Economists

What's really important!

Schumpeter 1883-1953
What's missing? The role of innovation and business 'cycles'

Innovation and 'creative destruction'

Robert Solow (MIT)

Quantitative power of technology in the economy

Technology drives 60% of US economy!

Paul Romer (Stanford Univ.)

The biggest 'force' in wealth creation is not accounted for

Interaction of people and ideas

Overview: Initiatives and Programs I developed or led at EPRI (1998-2003)

1999-2001	**Y2K**→2000-present	2002-present	2001-present
EPRI/DoD Complex Interactive Networks (CIN/SI)	**Enterprise Information Security (EIS)**	**Infrastructure Security Initiative (ISI)**	**Consortium for Electric Infrastructure to Support a Digital Society (CEIDS)**
Underpinnings of Interdependent Critical National Infrastructures Tools that enable secure, robust & reliable operation of interdependent infrastructures with distributed intel. & self-healing	▪ Information Sharing ▪ Intrusion/Tamper Detection ▪ Comm. Protocol Security ▪ Risk Mgmt. ▪ Enhancement ▪ High Speed Encryption	**Response to 9/11 Tragedies** ▪ Strategic Spare Parts Inventory ▪ Vulnerability Assessments ▪ Red Teaming ▪ Secure Communications	▪ Self Healing Grid ▪ IntelliGrid™ ▪ Integrated Electric Communications System Architecture ▪ Fast Simulation and Modeling

Recent Directions: EPRI/DOD Complex Interactive Network/Systems Initiative

"We are sick and tired of them and they had better change!"
Chicago Mayor Richard Daley on the August 1999 Blackout

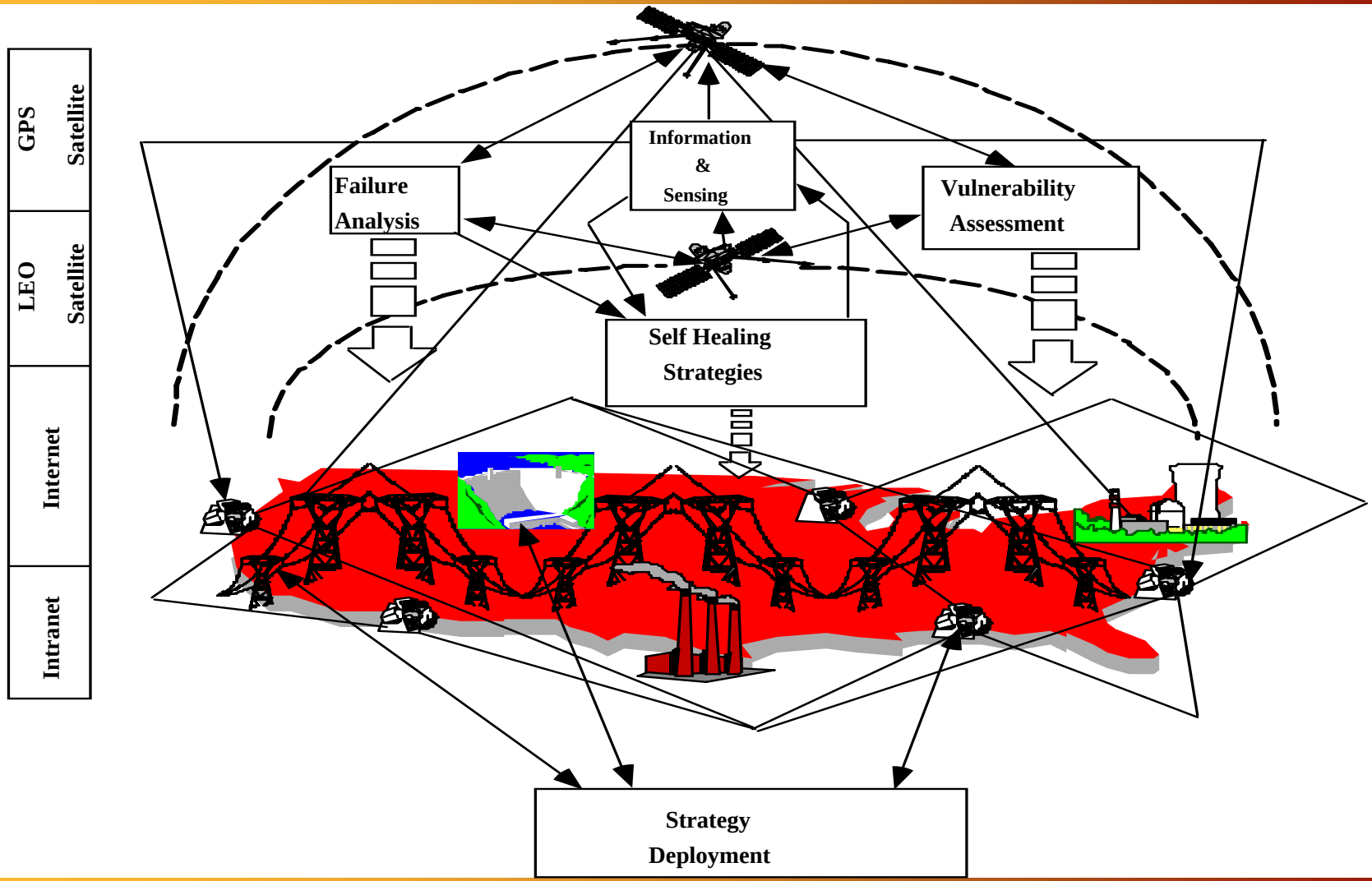
Complex interactive networks:

- *Energy infrastructure*: Electric power grids, water, oil and gas pipelines
- *Telecommunication:* Information, communications and satellite networks; sensor and measurement systems and other continuous information flow systems
- *Transportation and distribution networks*
- *Energy markets, banking and finance*

1999-2001: $5.2M / year — Equally Funded by DoD/EPRI

Develop tools that enable secure, robust and reliable operation of interdependent infrastructures with distributed intelligence and self-healing abilities

Complex Interactive Networks



CIN/SI Funded Consortia

107 professors in 28 U.S. universities are funded: Over 360 publications, and 19 technologies extracted, in the 3-year initiative

- U Washington, Arizona St., Iowa St., VPI
- Purdue, U Tennessee, Fisk U, TVA, ComEd
- Harvard, UMass, Boston, MIT, Washington U.
- Cornell, UC-Berkeley, GWU, Illinois, Washington St., Wisconsin
- CMU, RPI, UTAM, Minnesota, Illinois
- Cal Tech, MIT, Illinois, UC-SB, UCLA, Stanford

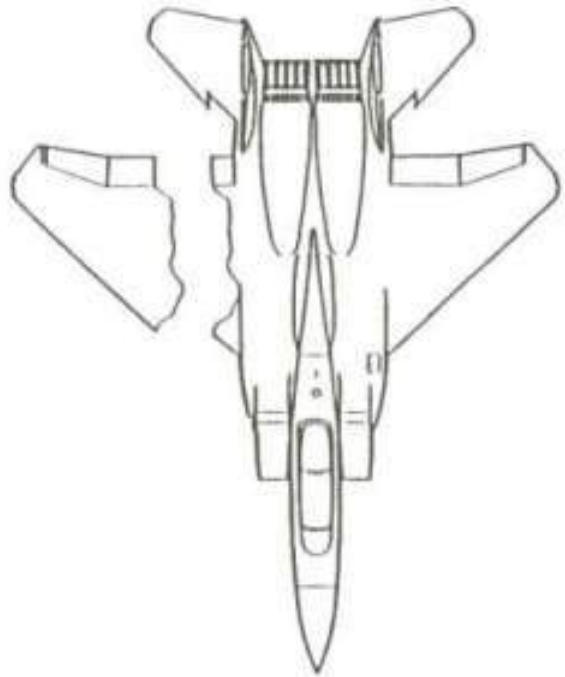
- Defense Against Catastrophic Failures, Vulnerability Assessment
- Intelligent Management of the Power Grid
- Modeling and Diagnosis Methods
- Minimizing Failures While Maintaining Efficiency / Stochastic Analysis of Network Performance
- Context Dependent Network Agents
- Mathematical Foundations: Efficiency & Robustness of Distributed Systems

Background:
The Self Healing Grid

Background:
The Case of the Missing Wing

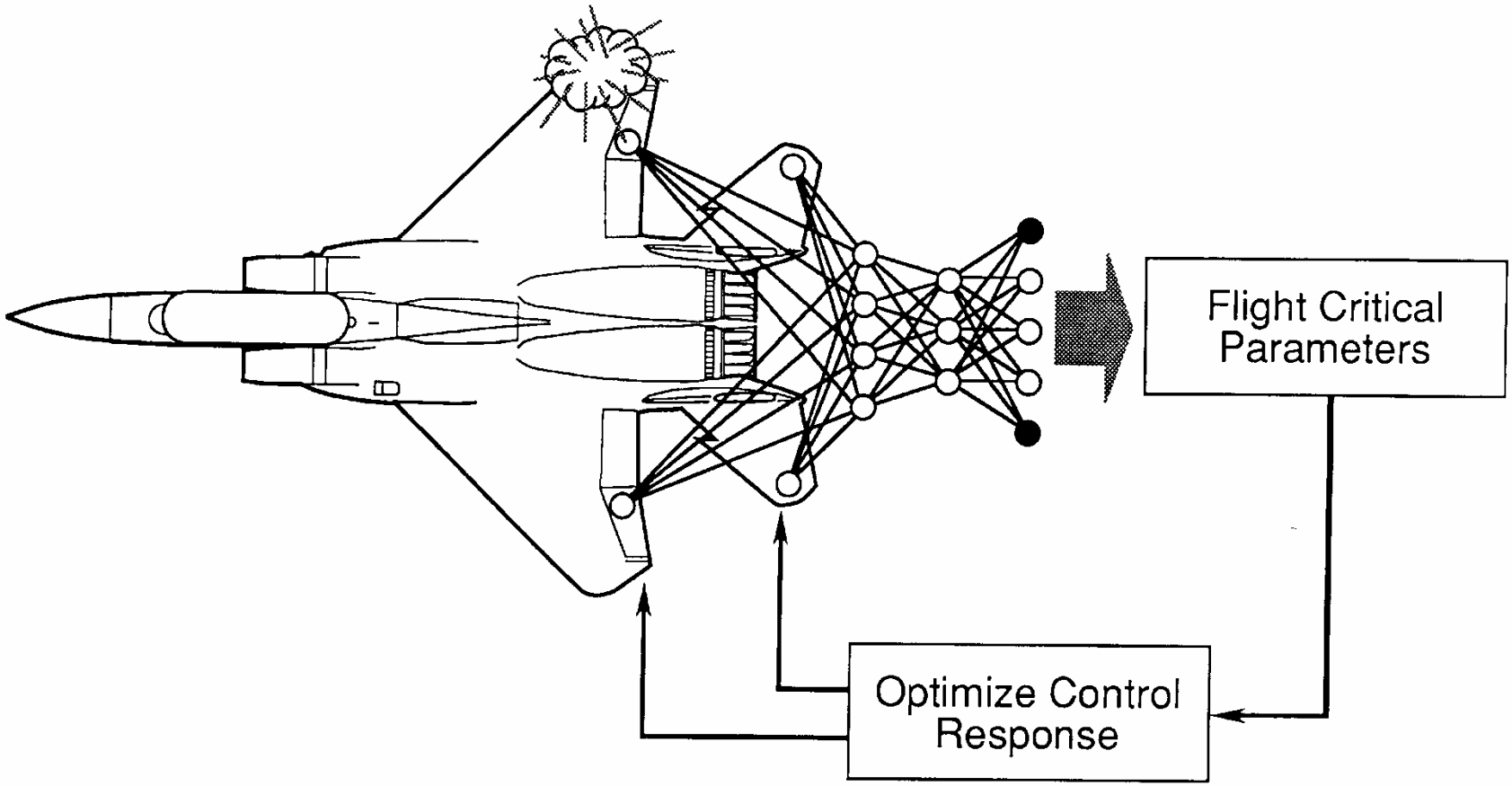
Believe it or not, this one made it back! This F-15, with half its wing missing, is a good example of what is currently considered an "unflyable" aircraft. However, the pilot's success in bringing it home helped to inspire a new program at Aeronautical Systems Division's Flight Dynamics Laboratory aimed at enabling future fighter pilots to fly aircraft with severely damaged control surfaces. The pilot of this F-15 configured in unusual ways the control surfaces that were still working to compensate for the damaged wing. The FDL program will make this "survivors" reaction automatic to the aircraft. Therefore, flying a damaged aircraft will be much easier on the pilot. Through a self-repairing flight control system nearing development, a computerized "brain" will automatically reconfigure such surfaces as rudders, flaperons, and ailerons to compensate for grave damage to essential flying surfaces, according to FDL.

Only smart work by the pilot and the unique combination of interworking control surfaces on the F-15 brought this one back alive. With old-fashioned conventional ailerons and horizontal stabilizer, it couldn't have happened.



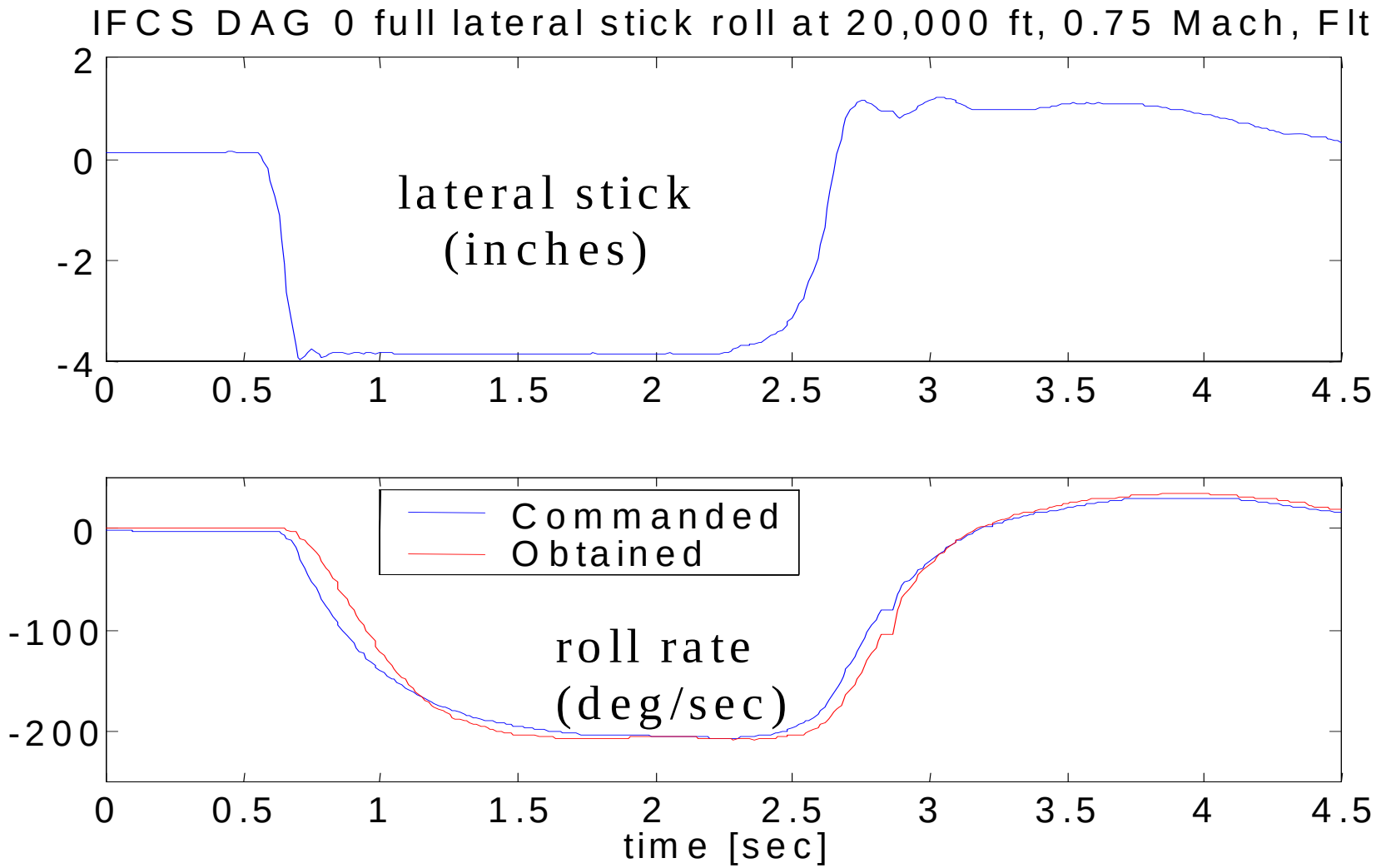
NASA/MDA/WU IFCS: NASA Ames Research Center, NASA Dryden Flight Research Center, Boeing Phantom Works, and Washington University in St. Louis.

Goal: Optimize controls to compensate for damage or failure conditions of the aircraft*



NASA/MDA/WU IFCS

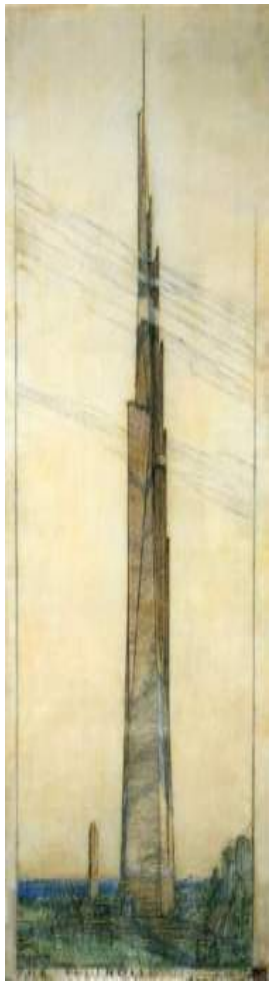
Roll Axis Response of the Intelligent Flight Control System



Accomplishments in the IFCS program

- The system was successfully test flown on a test F-15 at the NASA Dryden Flight Research Center:
  - Fifteen test flights were accomplished, including flight path control in a test flight envelope with supersonic flight conditions.
  - Maneuvers included 4g turns, split S, tracking, formation flight, and maximum afterburner acceleration to supersonic flight.
- Stochastic Optimal Feedforward and Feedback Technique (SOFFT) continuously optimizes controls to compensate for damage or failure conditions of the aircraft.
- Flight controller uses an on-line solution of the Riccati equation containing the neural network stability derivative data to continuously optimize feedback gains.
- Development team: NASA Ames Research Center, NASA Dryden Flight Research Center, Boeing Phantom Works, and Washington University.

Self-healing Grid

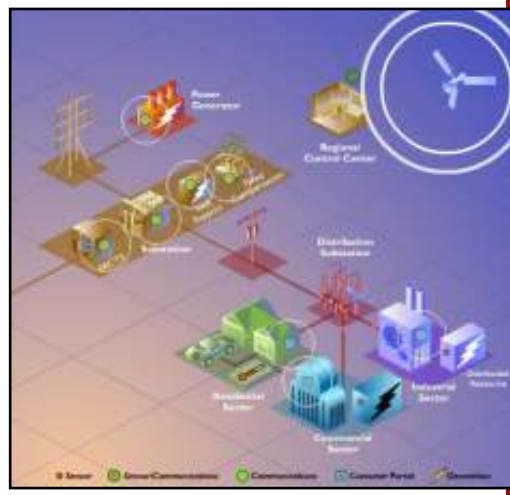


Building on the Foundation:

- **Anticipation of disruptive events**
- **Look-ahead simulation capability**
- **Fast isolation and sectionalization**
- **Adaptive islanding**

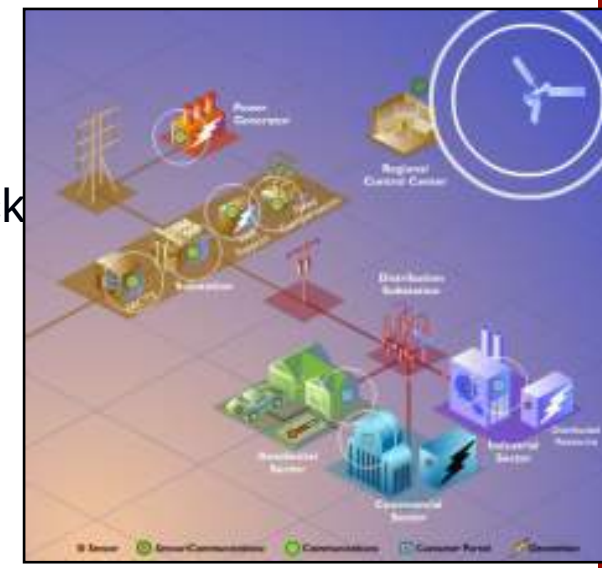
What are we doing about it? Enabling Technologies

- Monitoring: WAMS, OASIS, SCADA, EMS:
  - Wide-Area Measurement Systems (WAMS), integrate advanced sensors with satellite communication and time stamping using GPS to detect and report angle swings and other transmission system changes.
- Analysis: DSA/VSA, PSA, ATC, CIM, TRACE, OTS, ROPES, TRELSS, market/risk assessment…
  - Information systems and on-line data processing tools such as the Open Access Same-time Information System (OASIS); and Transfer Capability Evaluation (TRACE) software--determine the total transfer capability for each transmission path posted on the OASIS network, while taking into account the thermal, voltage, and interface limits.



What are we doing about it? Enabling Technologies (cont.)

- Control: FACTS; Fault Current Limiters (FCL)., …
  - Flexible AC Transmission System (FACTS): Up to 50% more power controlled through existing lines.
  - Fault Current Limiters (FCLs)-- large electrical “shock absorbers” for a few cycles
  - Intelligent Electronic Devices with security built in-combining sensors, computers, telecommunication units, and actuators-- "intelligent agent" functions
- Materials science: High-temperature superconducting cables, advanced silicon devices and wide-bandgap semiconductors for power electronics.
- Distributed resources such as small combustion turbines, solid oxide and other fuel cells, photovoltaics, superconducting magnetic energy storage (SMES), transportable battery energy storage systems (TBESS), etc.



Enabling Technologies (cont.)

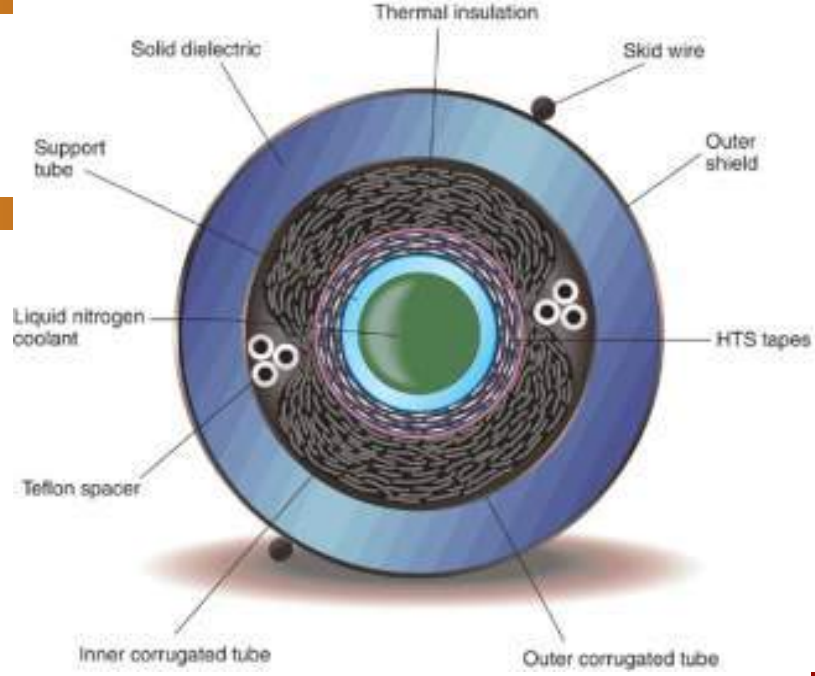
An example of a static VAR compensation installation.

A gas insulated transmission line tunnel in Switzerland.

Technology Solutions: Maximize Utilization

Superconducting Cables

- 2 to 5 times the current
- Can be used to retrofit existing ducts and pipes
- Need to reduce cost, improve reliability of cryogenic system and gain more operating experience

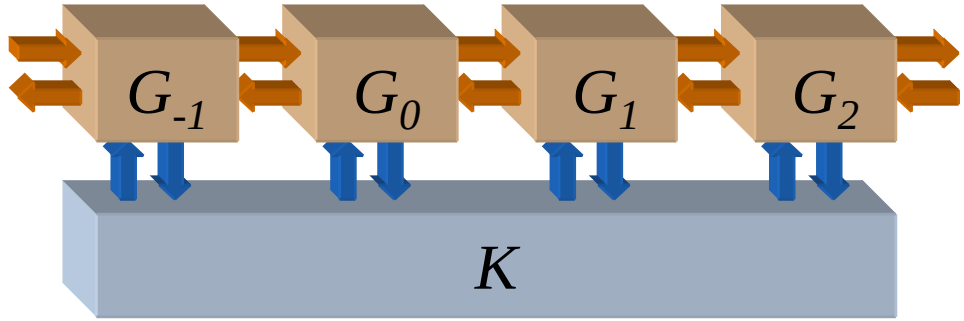


Look-Ahead Simulation Applied to Multi-Resolution Models

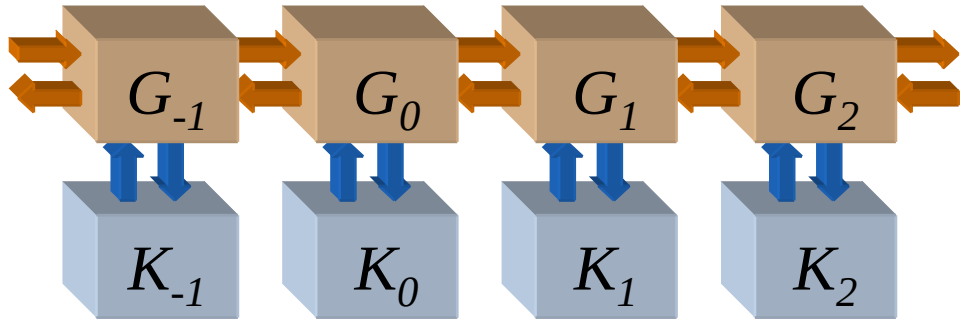
- Provides faster-than-real-time simulation
  - By drawing on approximate rules for system behavior, such as power law distribution
  - By using simplified models of a particular system
- Allows system operators to change the resolution of modeling at will
  - Macro-level (regional power systems)
  - Meso-level (individual utility)
  - Micro-level (distribution feeders/substations)

Control Strategies

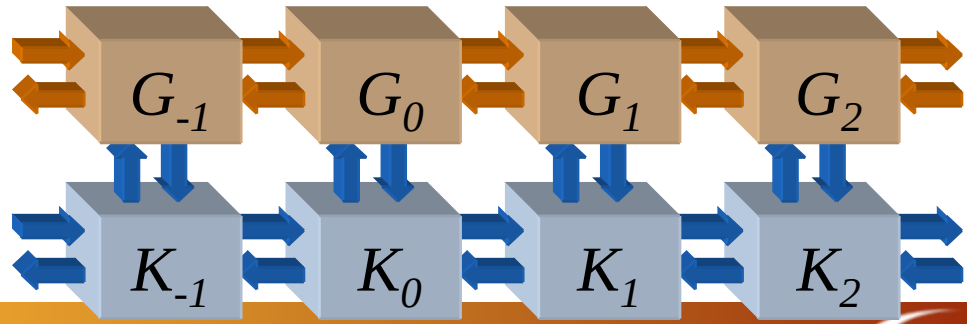
- Centralized



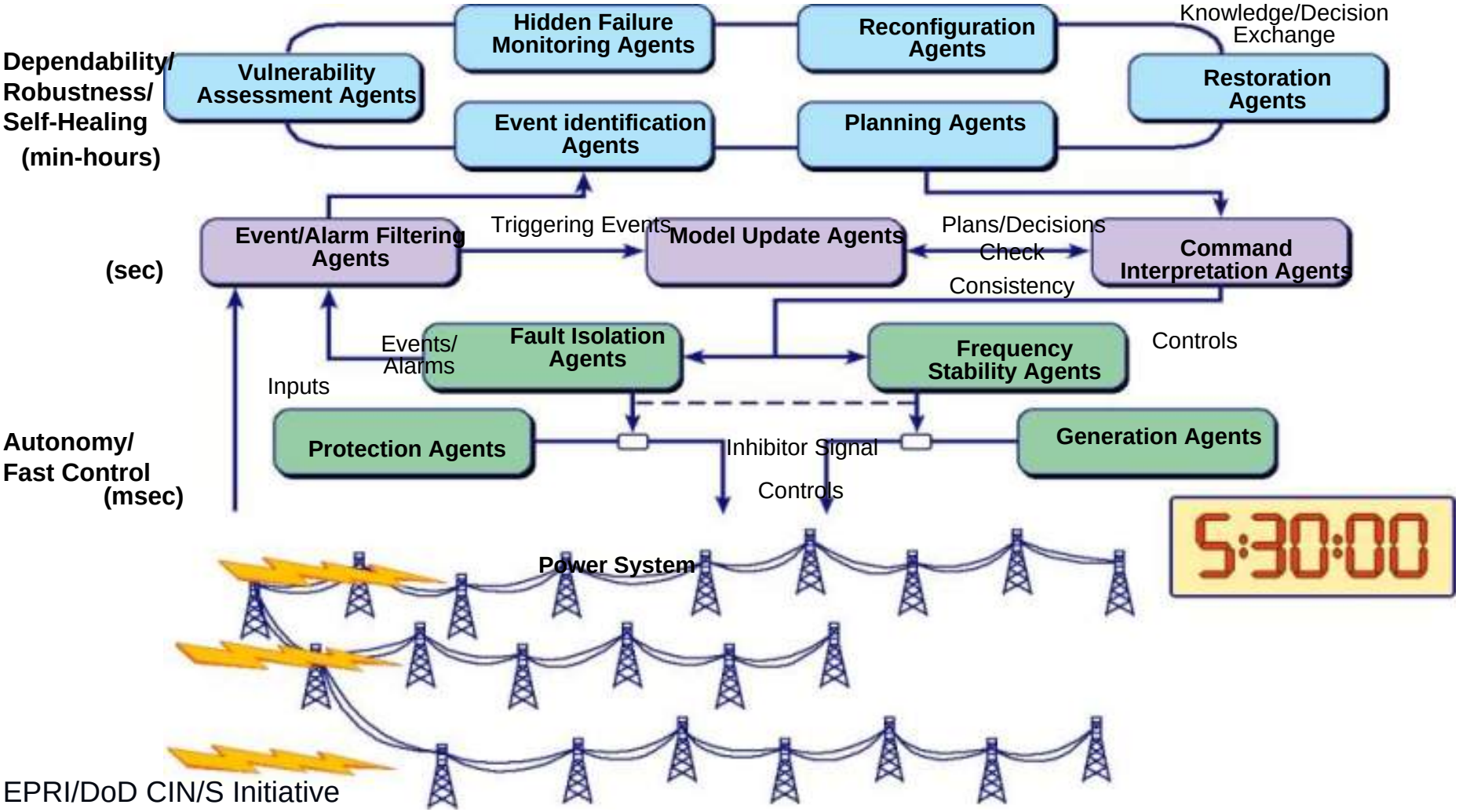
- Perfectly decentralized



- Distributed

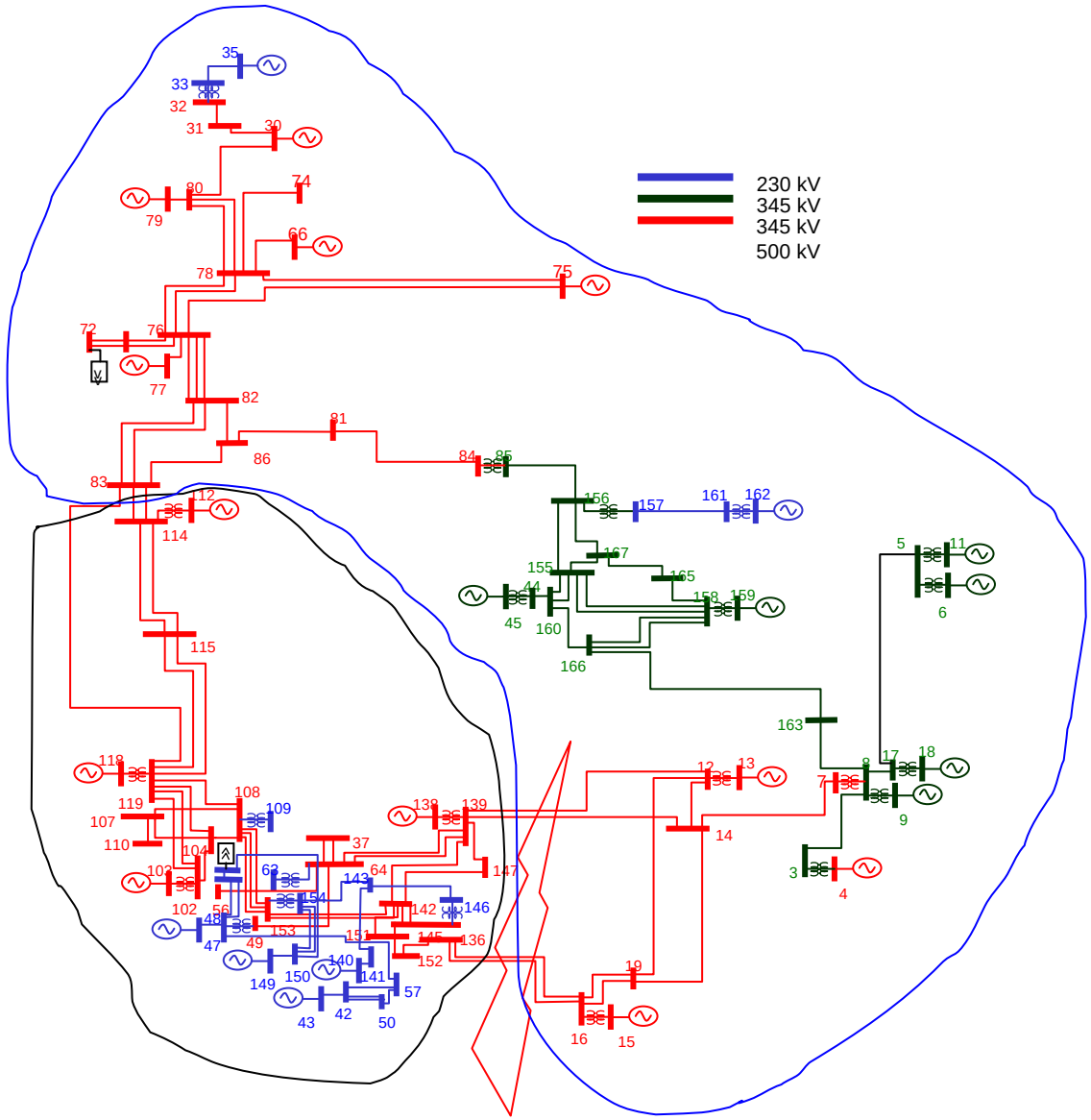


Background: The Self-Healing Grid

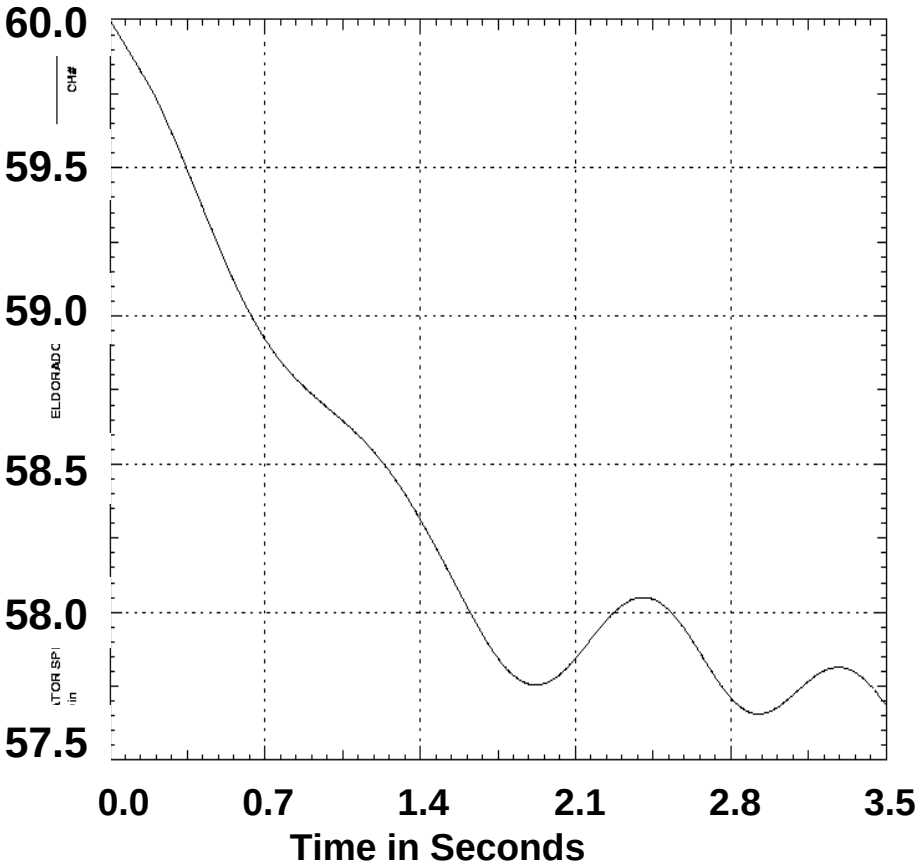


EPRI/DoD CIN/S Initiative

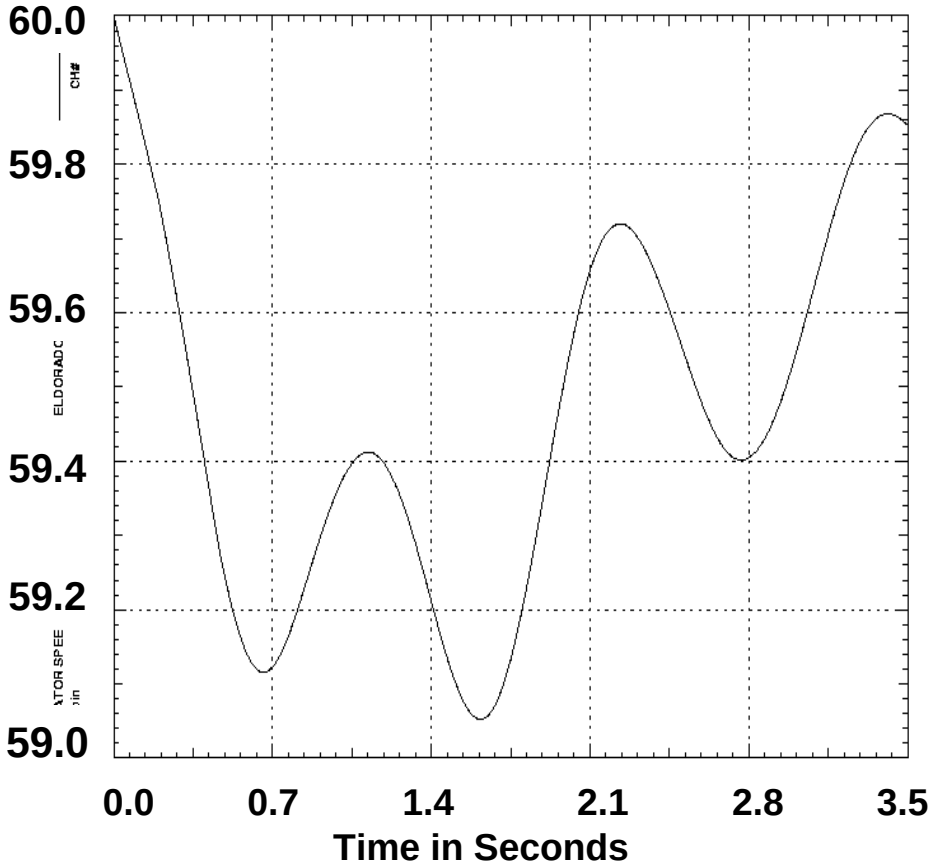
Background: Intelligent Adaptive Islanding



Background: Simulation Result

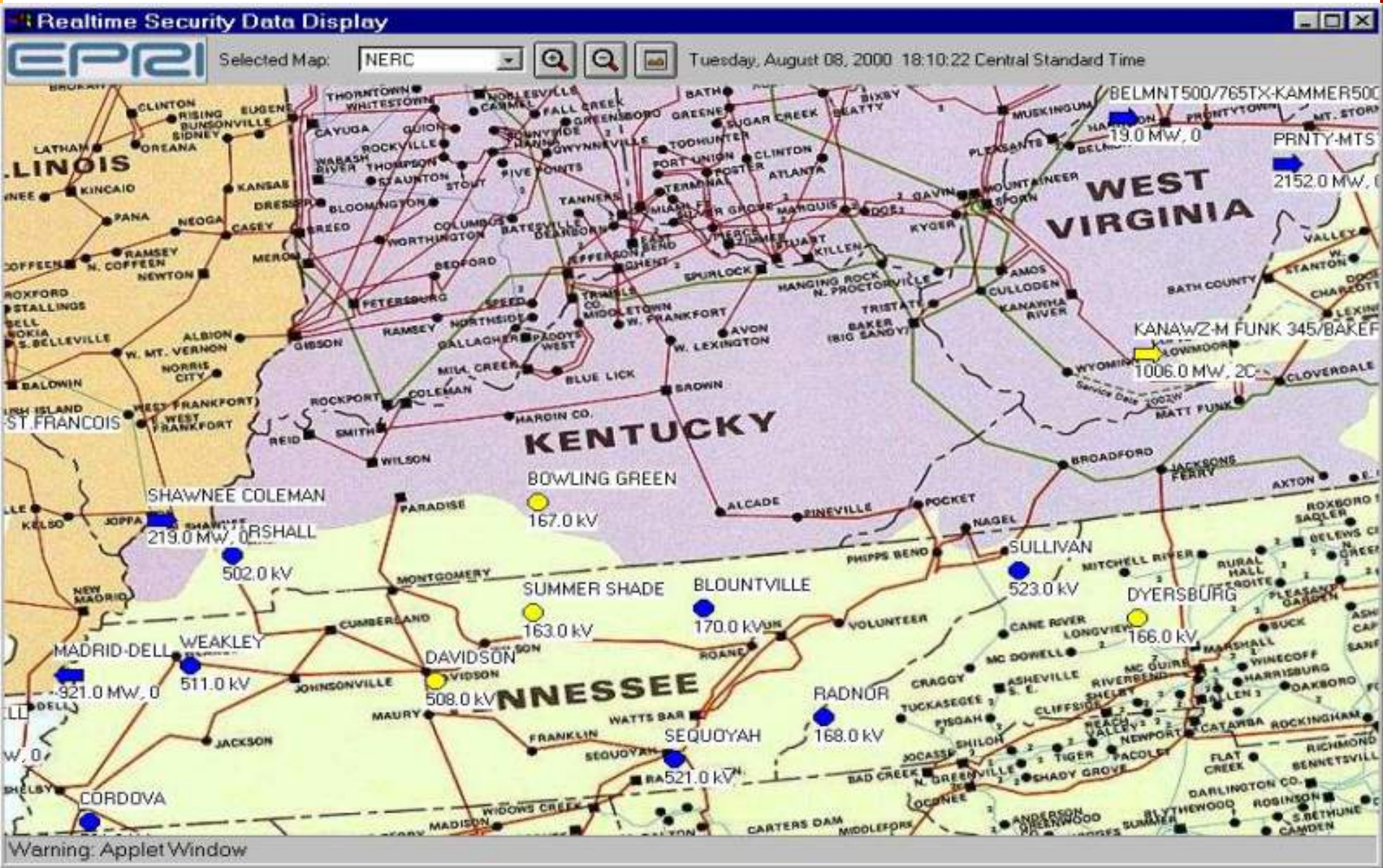


No Load Shedding Scheme

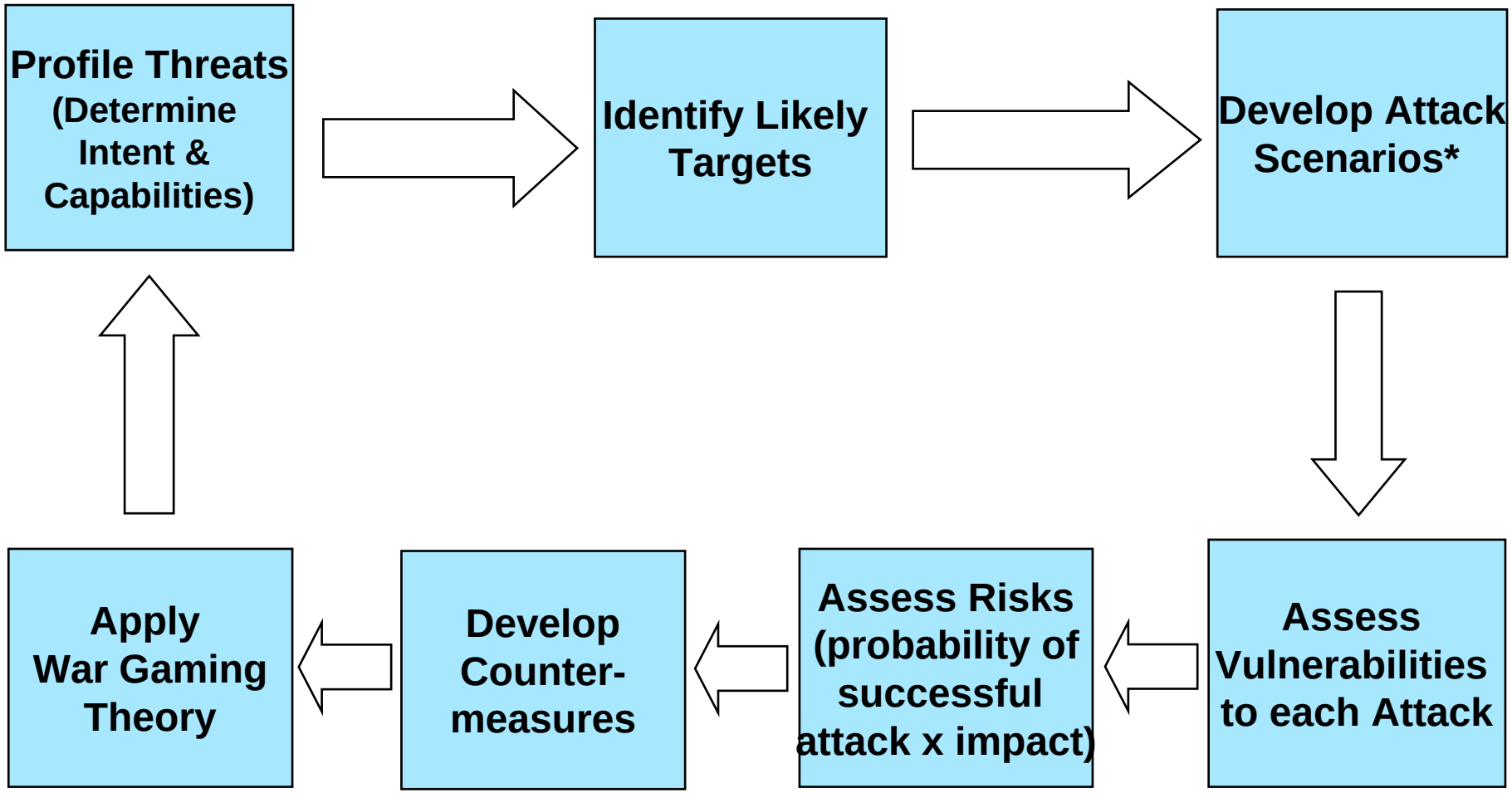


New Scheme

EPRI's Reliability Initiative-- Sample Screen of Real-time Security Data Display (RSDD)



What can be Done?
Vulnerability Assessment

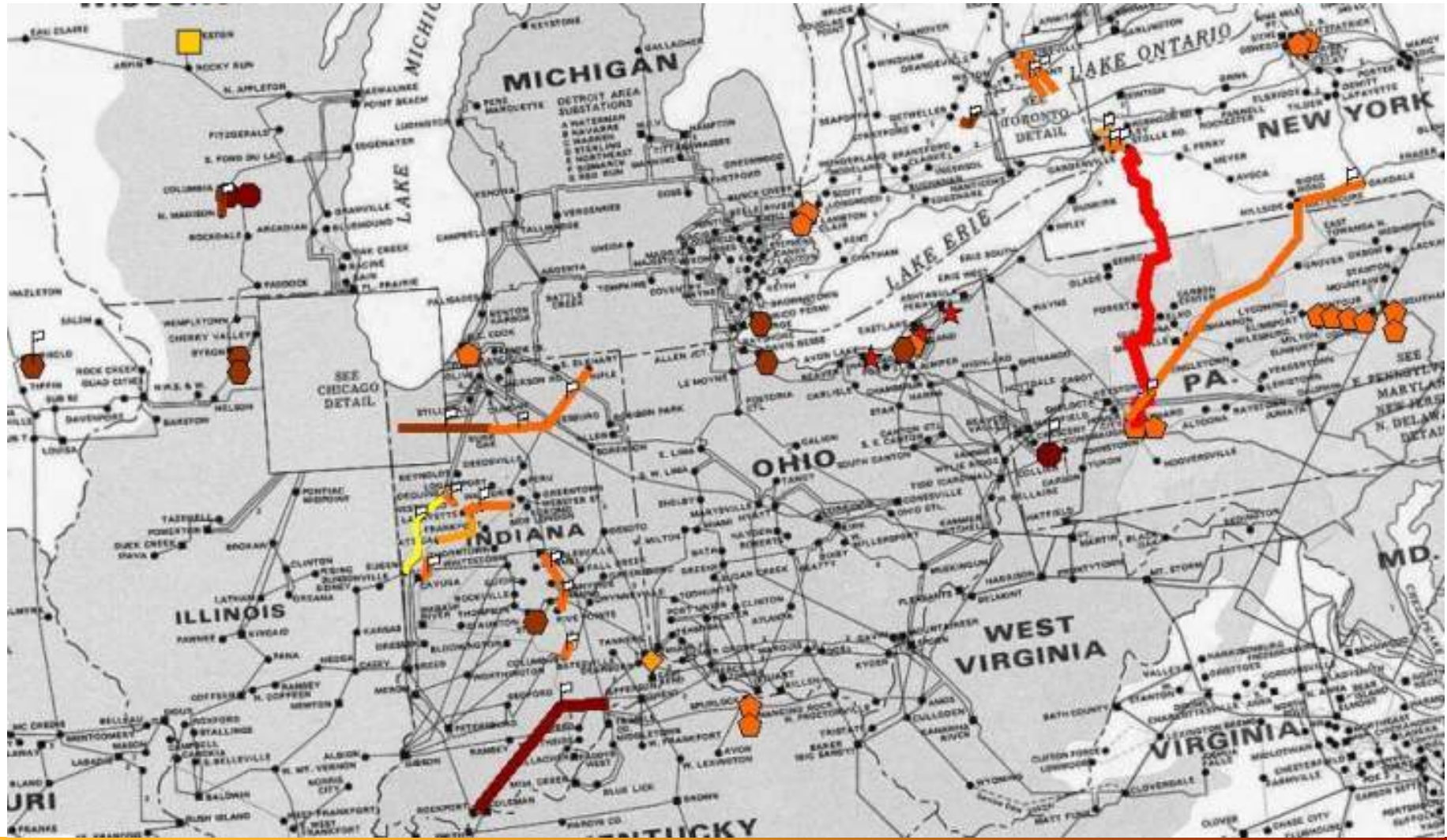


*Evolving spectra of targets and modes of attack

Probabilistic Risk Assessment (PRA) - In Depth

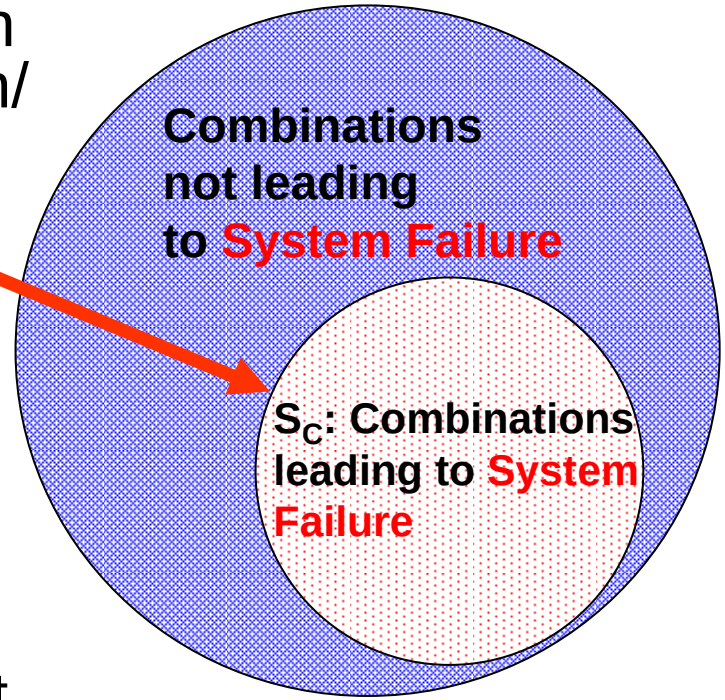
Voltage Root Causes (October 2001)

Sensitive



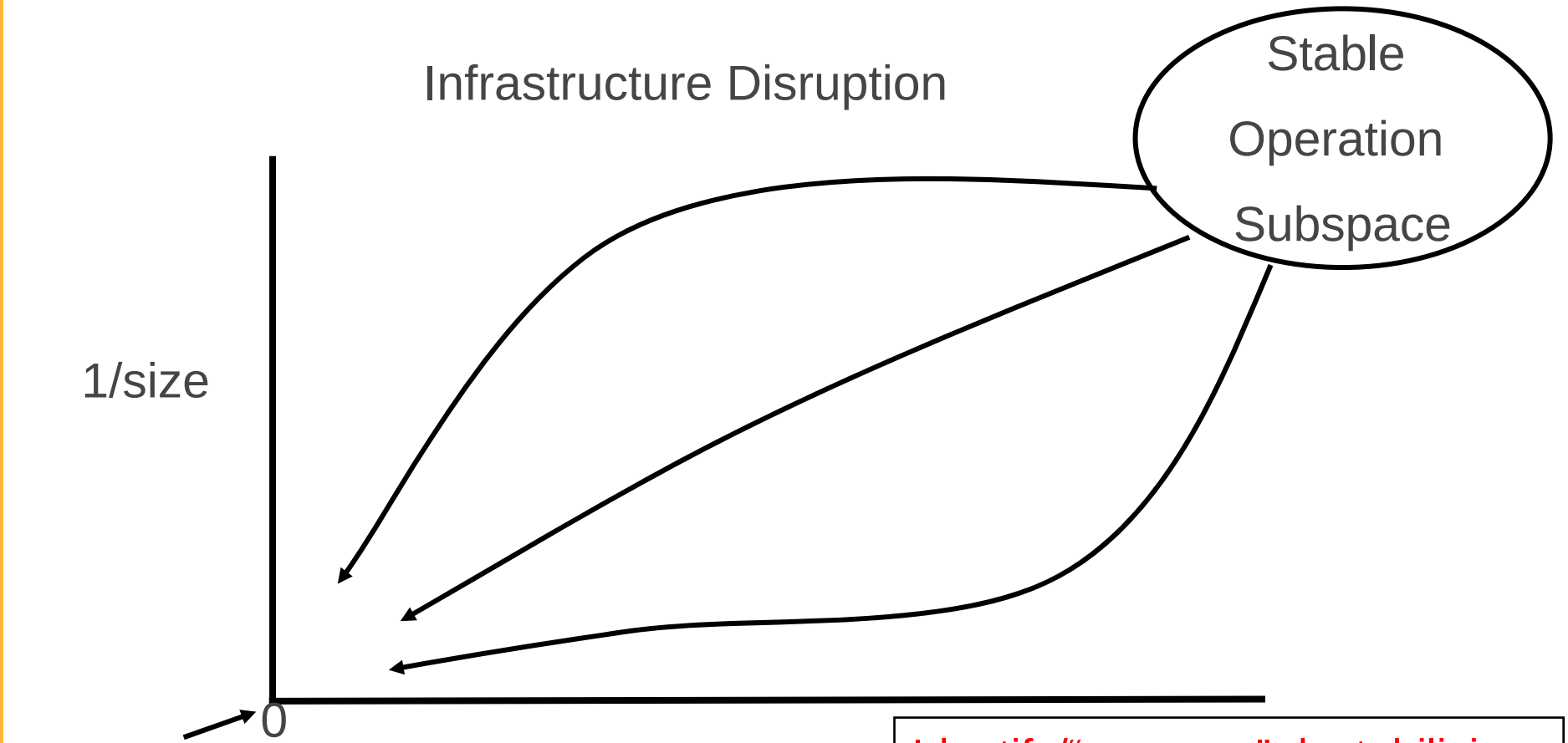
Systems Control Challenge

- Enhancing Reliability and Security of Network Operation via quantification of the system state and its “direction/ speed/momentum” toward a major failure
- Making Network Availability (quick restoration) a key requirement
- Introducing Quality of Service as an additional constraint
- Ultimately, enabling operators to act more efficiently and with greater confidence in difficult (sometimes unclear, unexpected or even conflicting) circumstances



Which trajectories lead to catastrophic failures?

An Assessment Methodology



Identify/“measure” destabilizing trajectories and impacts

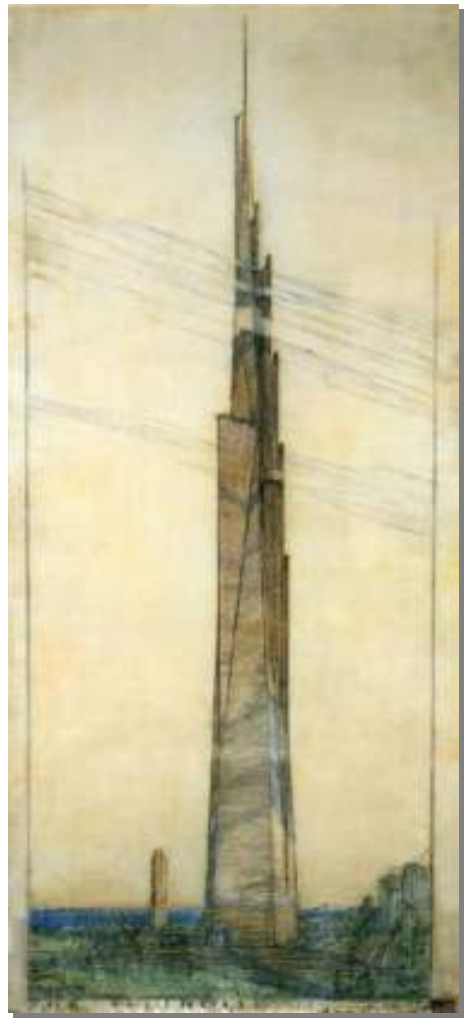
One of my research areas: S&T Assessment, Scan and Map
(April 2005-Feb 2006; Galvin Electricity Initiative)

Objectives:

- Identify the most significant Science & Technology innovations which would meet energy service needs over the next 10 or 20 years;

- Determine Science & Technologies areas and concepts which address customer aspirations and hopes; when conceived, they will lead to:
  - Technologies that encourage job creation and address the needs of the society;
  - An energy system so robust and resilient that it will not fail;
  - A totally reliable, secure communication system that will not fail.

Source: Galvin Electricity Initiative www.galvinelectricity.org



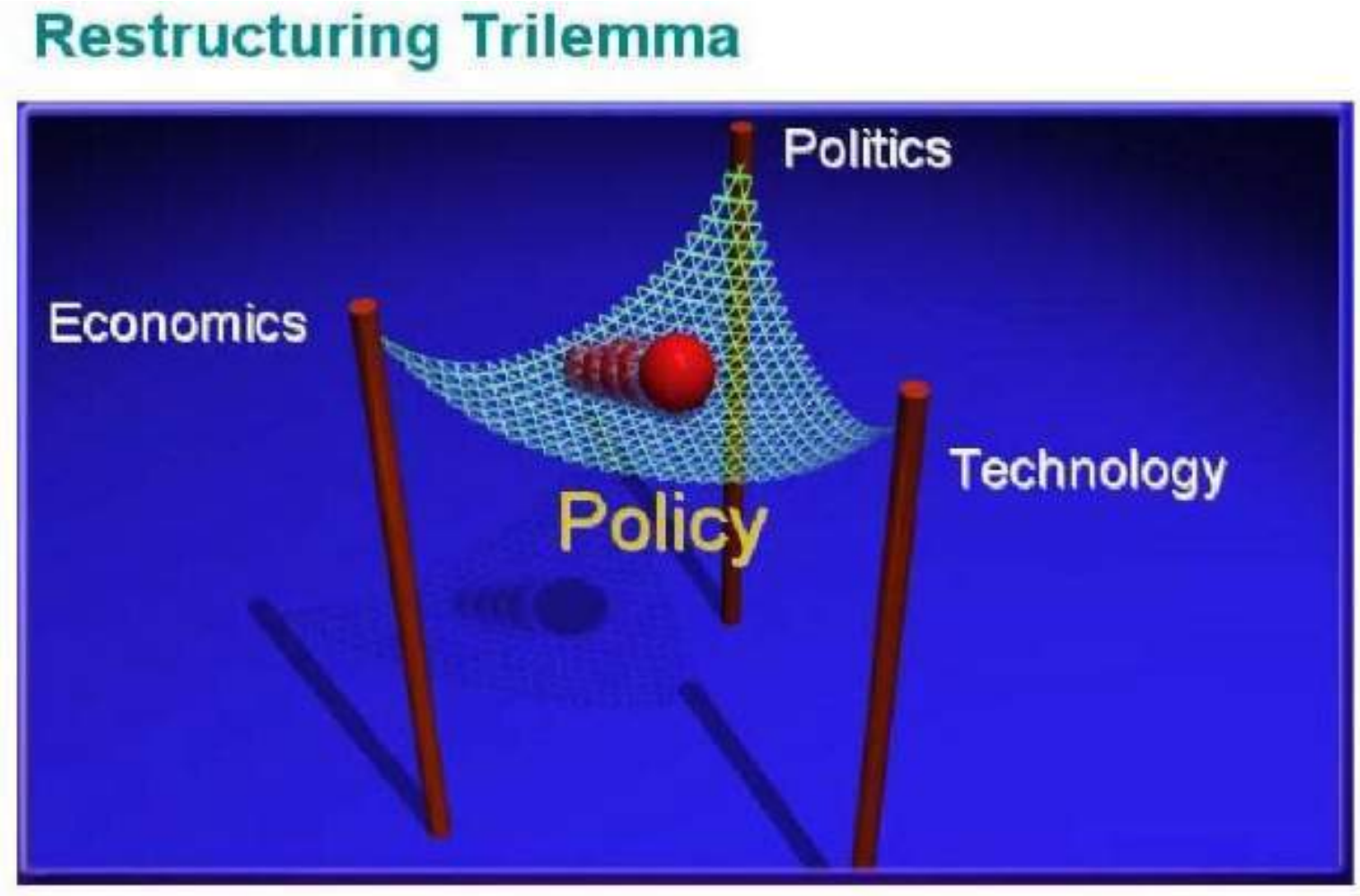
S&T Policy Challenges

Adopted from Prof. Neal Lane, Rice Univ.

Four Threats To U.S. Science and Technology In The Future –ALL OF WHICH ARE, IN PART, 'POLITICAL'

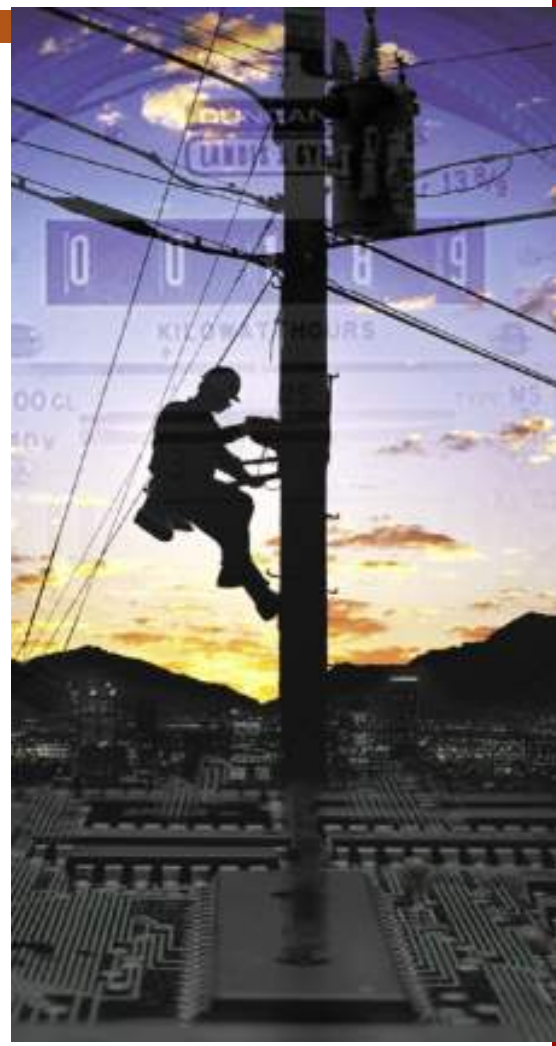
- MONEY TO FUND Science and Technology
- PEOPLE TO DO Science and Technology
- PUBLIC UNDERSTANDING AND TRUST In Science
  - – LEADERSHIP and SUSTAINED COMMITMENT
- INTERNATIONAL COOPERATION
  - – PARTICULARLY DIFFICULT IN A POST 9/11 WORLD

Unresolved Issues Cloud Planning for the Future



Recommendations

- Establish the “Smart Grid” as a national priority
- Authorize increased funding for R&D and demonstrations of the “Smart Grid”
- Revitalize the national public/private electricity infrastructure partnership needed to fund the “Smart Grid” deployment



Discussion and the Road Ahead

- What are the key security issues facing the world, our nation, MN and industry?
  - **What is your vision for the future– what will it look like or how securely will it perform in 2008-2020?**
  - **What are the difficult challenges to overcome to achieve your vision?**
  - **What enabling security technologies and policies are needed to address these?**
  - **What critical issues should we consider in beginning plans for in 2008 and beyond?**


Thank you