Evolution of Energy Control Centers

Energy Management Systems - EMS

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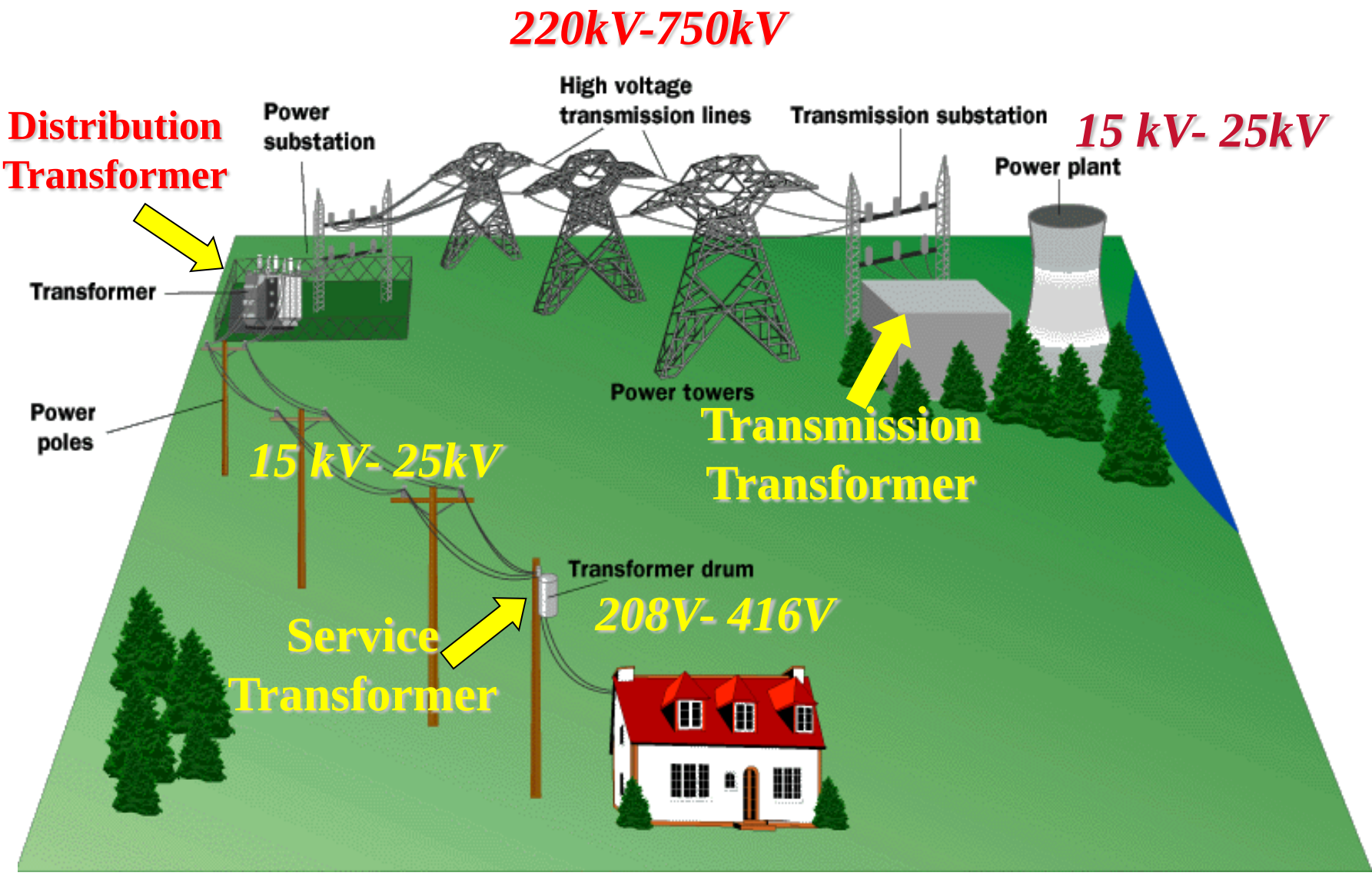
Greatest Engineering Achievements: Of the 20th Century

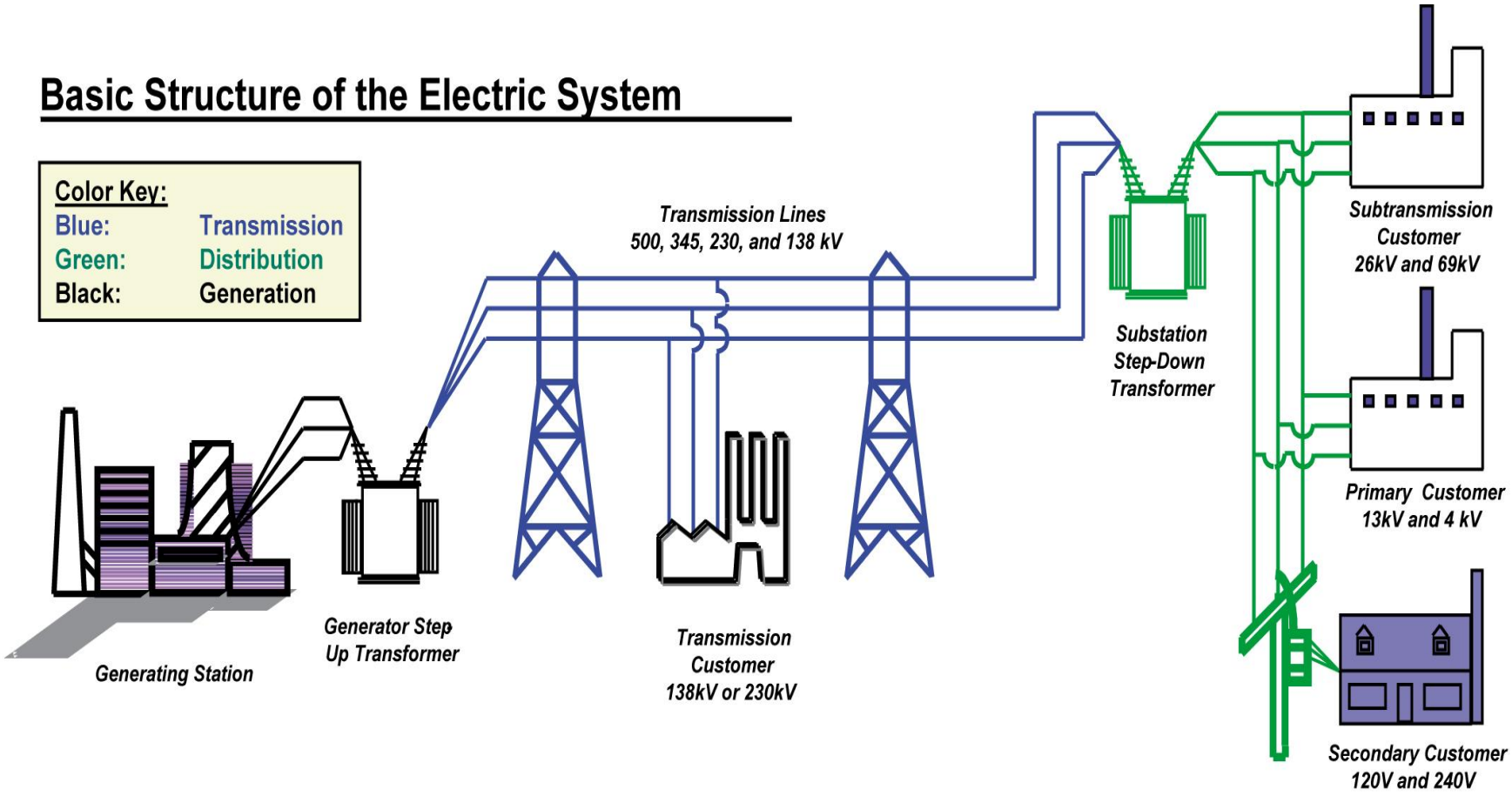
20. High-performance materials
19. Nuclear technologies
18. Laser and fiber optics
17. Petroleum and petrochemical technologies
16. Health technologies
15. Household appliances
14. Imaging
13. Internet
12. Spacecraft
11. Highways
10. Air conditioning and refrigeration
9. Telephone
8. Computers
7. Agricultural mechanization
6. Radio and television
5. Electronics
4. Water supply and distribution
3. Airplane
2. Automobile

#1. Electrification

»*As voted by the US National Academy of Engineers*



Overview of the Electric System



$250+ Billion Business in the US

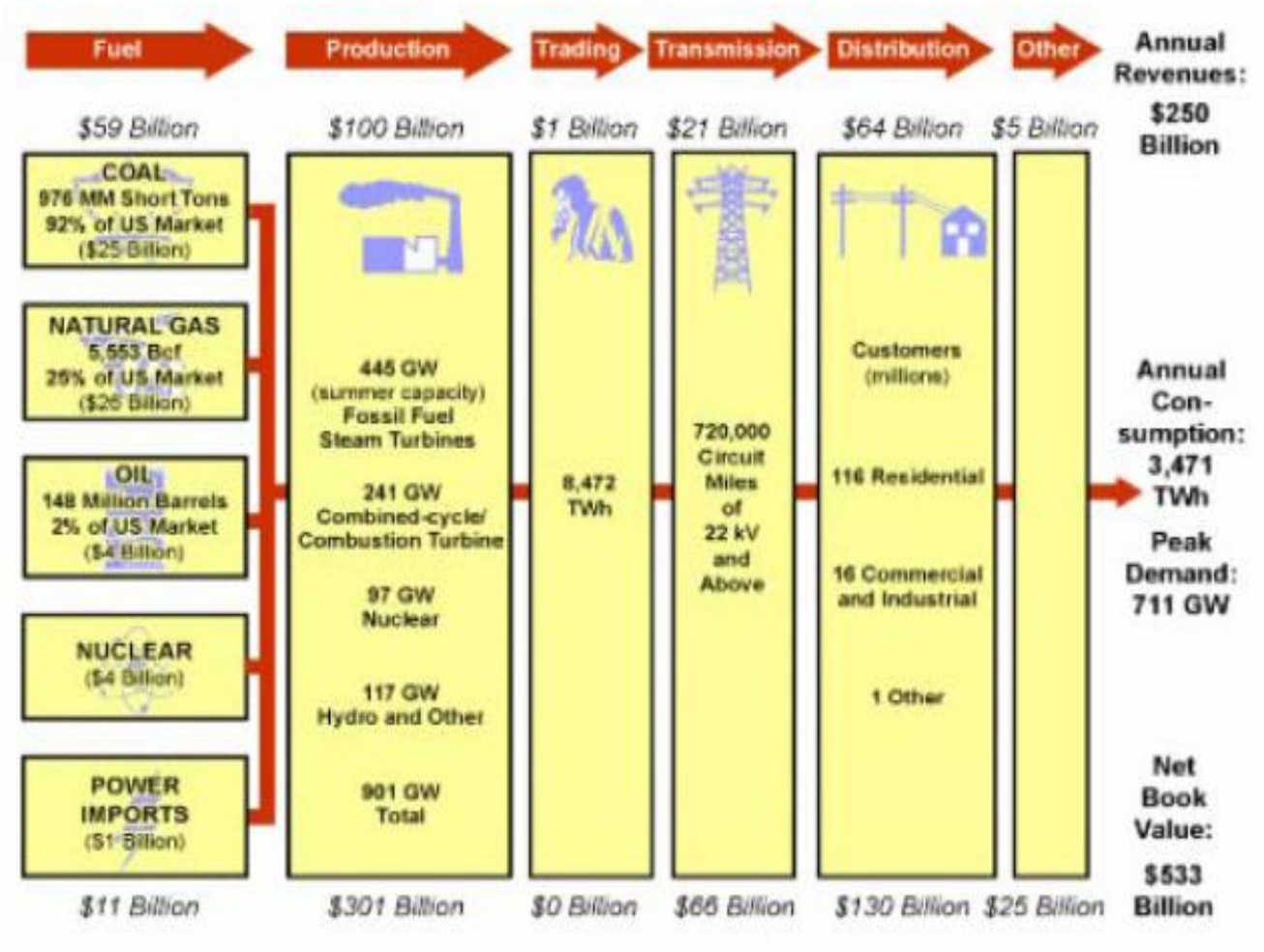
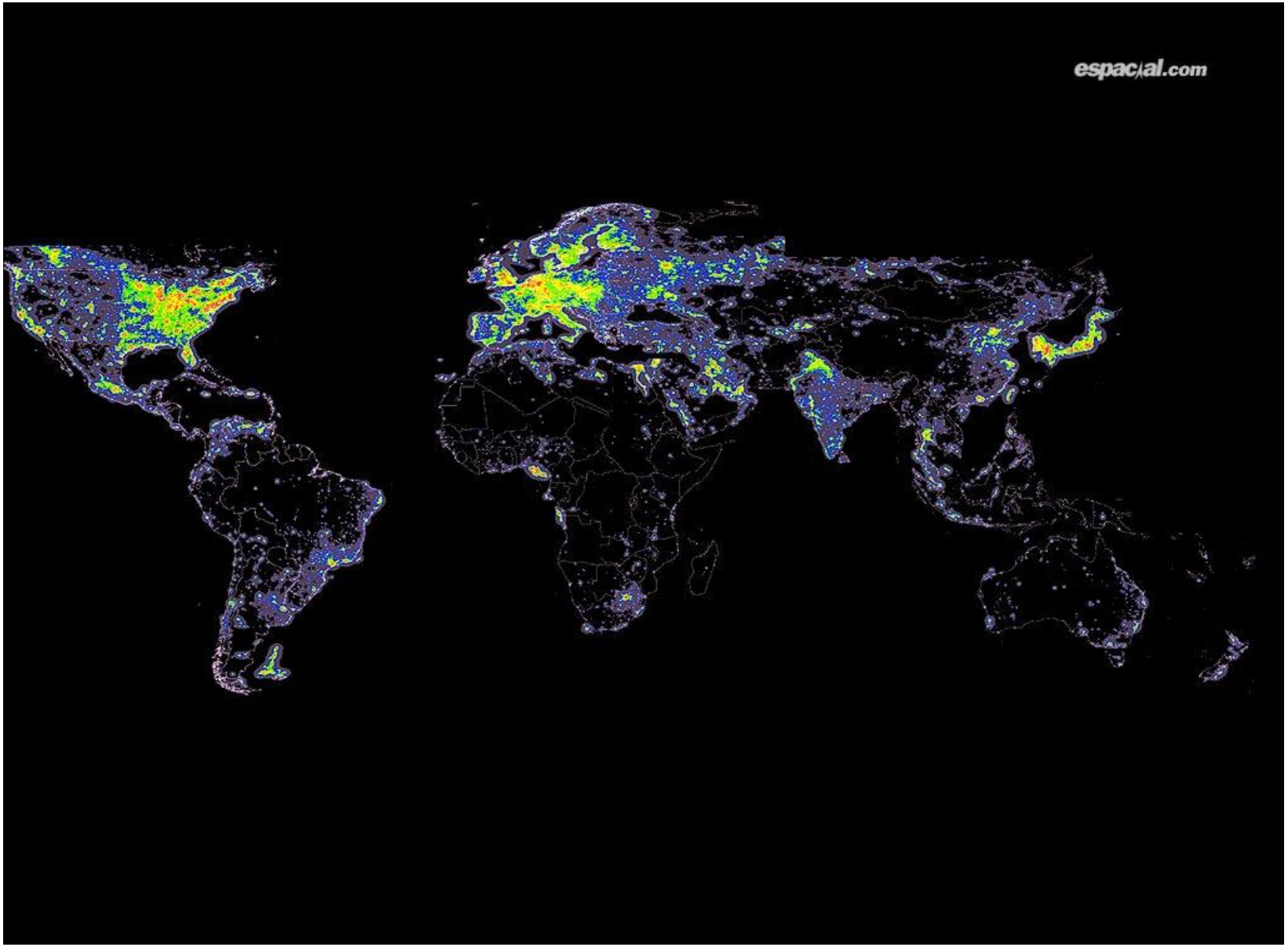


Figure 1: The U.S. electricity business value chain in 2002 (source: Cambridge Energy Research Associates)

North American Electric Power Industry

- More than 3000 Electric Utilities
- 2000 Independent Power Producers
- 100 Related Organizations
- 120 Million Residential Customers
- 16 Million Commercial Customers
- 700,000 Industrial Customers
- 700,000 Miles of High-Voltage Transmission Lines - Owned be 200 Organizations - Valued at $160 billon
- 5 Millions Miles of Medium Distribution Lines - 22, 000 Substations - Owned by 3,200 Organizations – Valued at $140 billion

World at Night



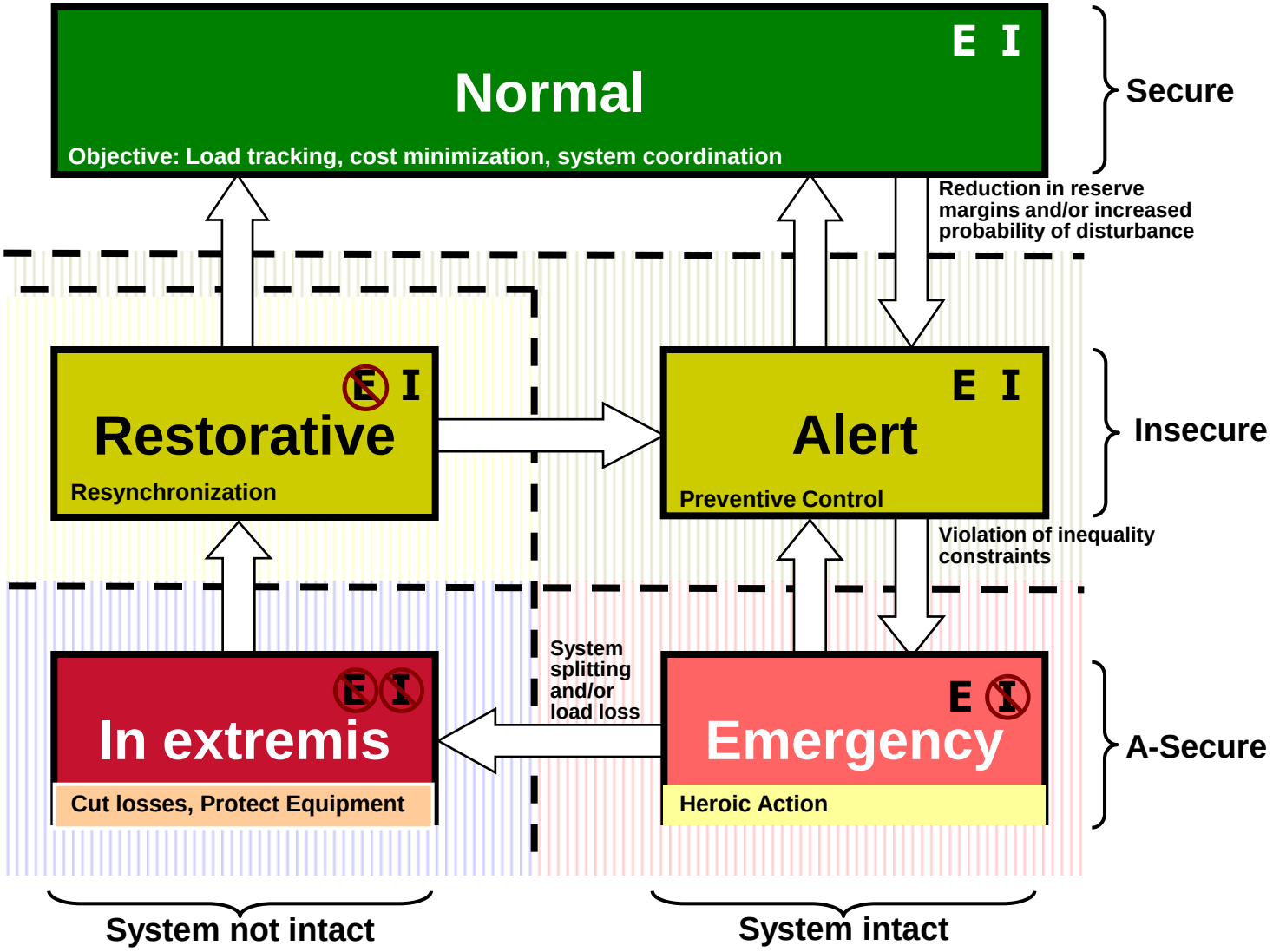
The Beginnings of the Energy Management System "The Big Bang"

1965 Blackout of the Northeast US

- Lasted over 13 hours for many…
- 30 million people, 80,000 sq. mi.
- Billions of $ in lost business
- A wake-up call to US public
- Resulted in creation of:
  - NERC (North American Reliability Council)
    - In 1968: Developed reliability standards for regions and relied on peer-pressure and mutual respect for ‘soft’ enforcement
    - In 2006, has applied to become the FERC-endorsed Electricity Reliability Organization (ERO) to impose ‘hard’ Mandatory Reliability Standards with consequential penalties.
  - EPRI (Electric Power Research Institute)
    - Centralized, pooled R&D for electric utilities

Power System Grid Operating States

E = Demand is met
I = Constraints are met



L. Fink, K. Carlsen, IEEE Spectrum, March 1978

Sources of Grid Vulnerability

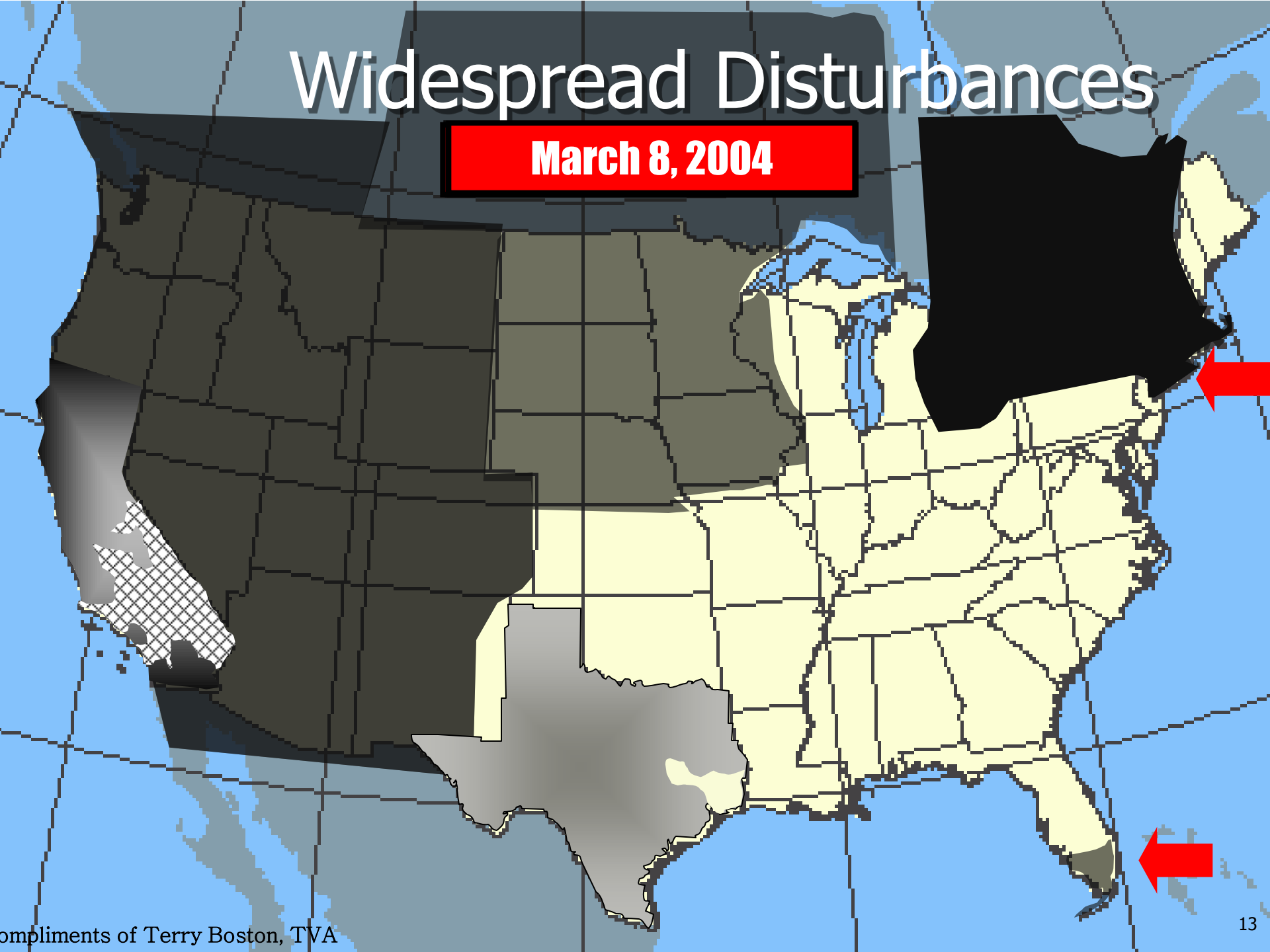
- Natural calamities
- Component failures
- Protection and control failures
- Breaks in communication links
- Faults
- Human errors
- Inadequate security margin
- Gaming in the market
- Sabotage or intrusion by external agents
- Missing or uncertain information

Challenges

- *Vulnerability assessment is computationally intensive process*
- *Assessments need to be continually repeated*
- *On-line assessment is a challenge*
- *Measurements and operating conditions are noisy*
- *Available knowledge is in historical examples*

Widespread Disturbances

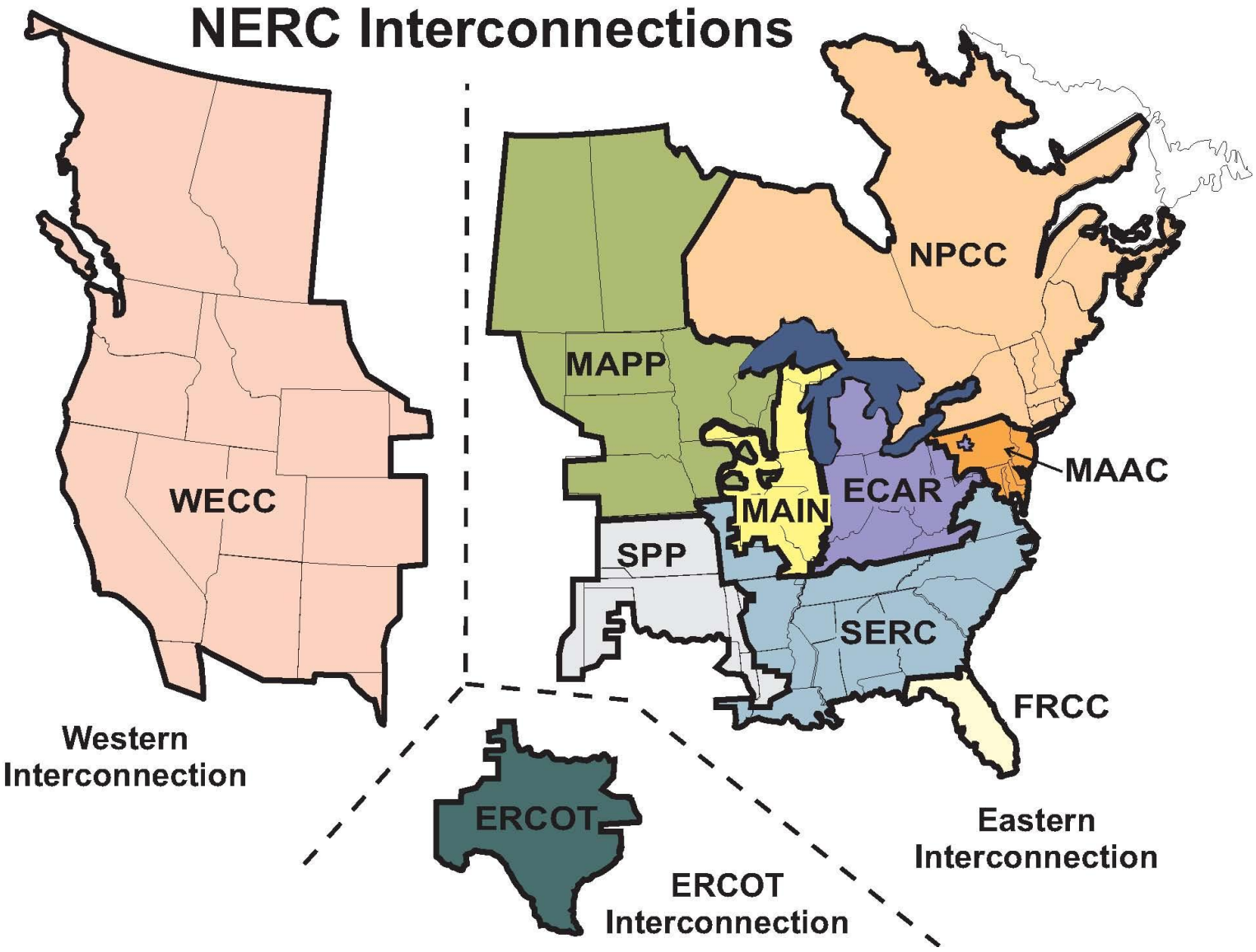
March 8, 2004



ompliments of Terry Boston, TVA

Major Interconnections and Reliability Councils

Courtesy: NERC



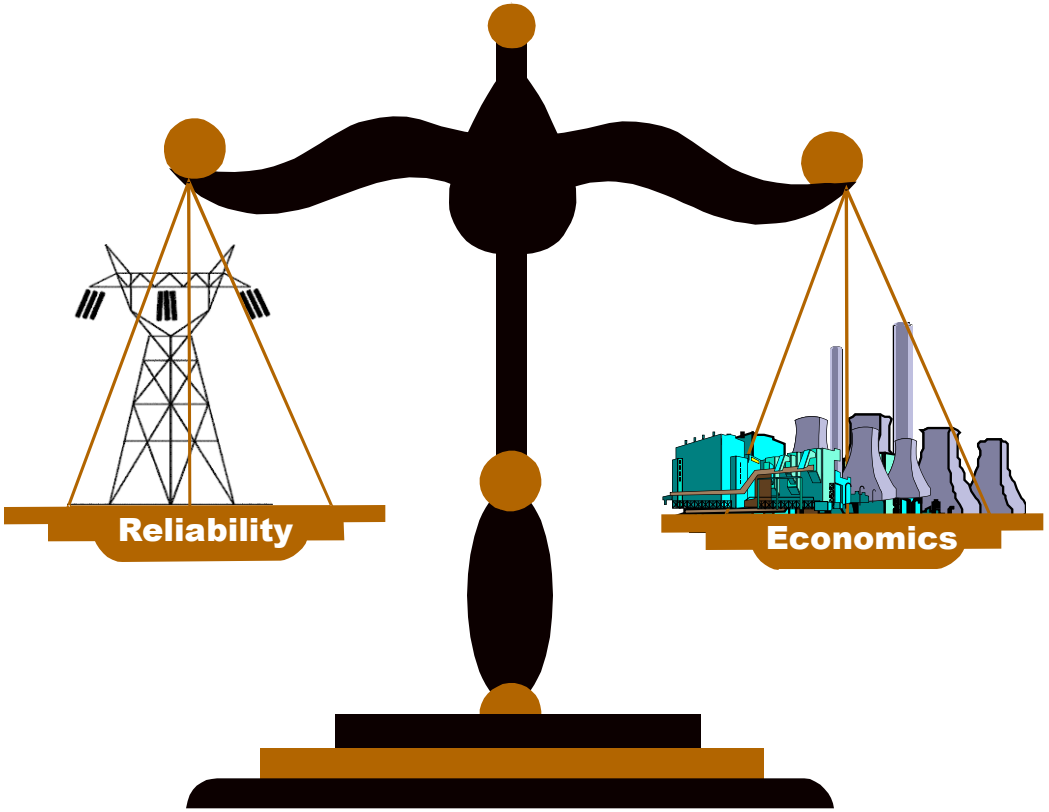
The Reality We Face….

- **"Blackouts will occur again in the future"….**
  - **Our power grid is too complex to make it fail-safe!**
  - **In the past decade:**
    - **Investment in generation far exceeded transmission….**
    - **Making it more of a barrier to transfer energy….**
    - **Means More Congestion….**
- **Our challenge is:**
  - **To Prevent the Cascading, Uncontrolled Spread of an initiating blackout!**
  - **And more importantly:**
    To Restore power to affected customers ASAP!

The Big Challenge!

- **Electricity as a Commodity Cannot be Stored!**
- **Electricity Demand changes from instant to instant**
- **Supply needs to change instantaneously to meet Demand…**
- **If supply does not equal demand, Frequency goes off-normal (not 60Hz)… which results in:**
  - **Protective relay trips of generating units, loads, etc.**
  - **Potential for a cascading blackout..**
  - **And your electric alarm clocks would not keep correct time! ☺**

Electric Utilities Ultimate Goal – Balancing Reliability and Economics



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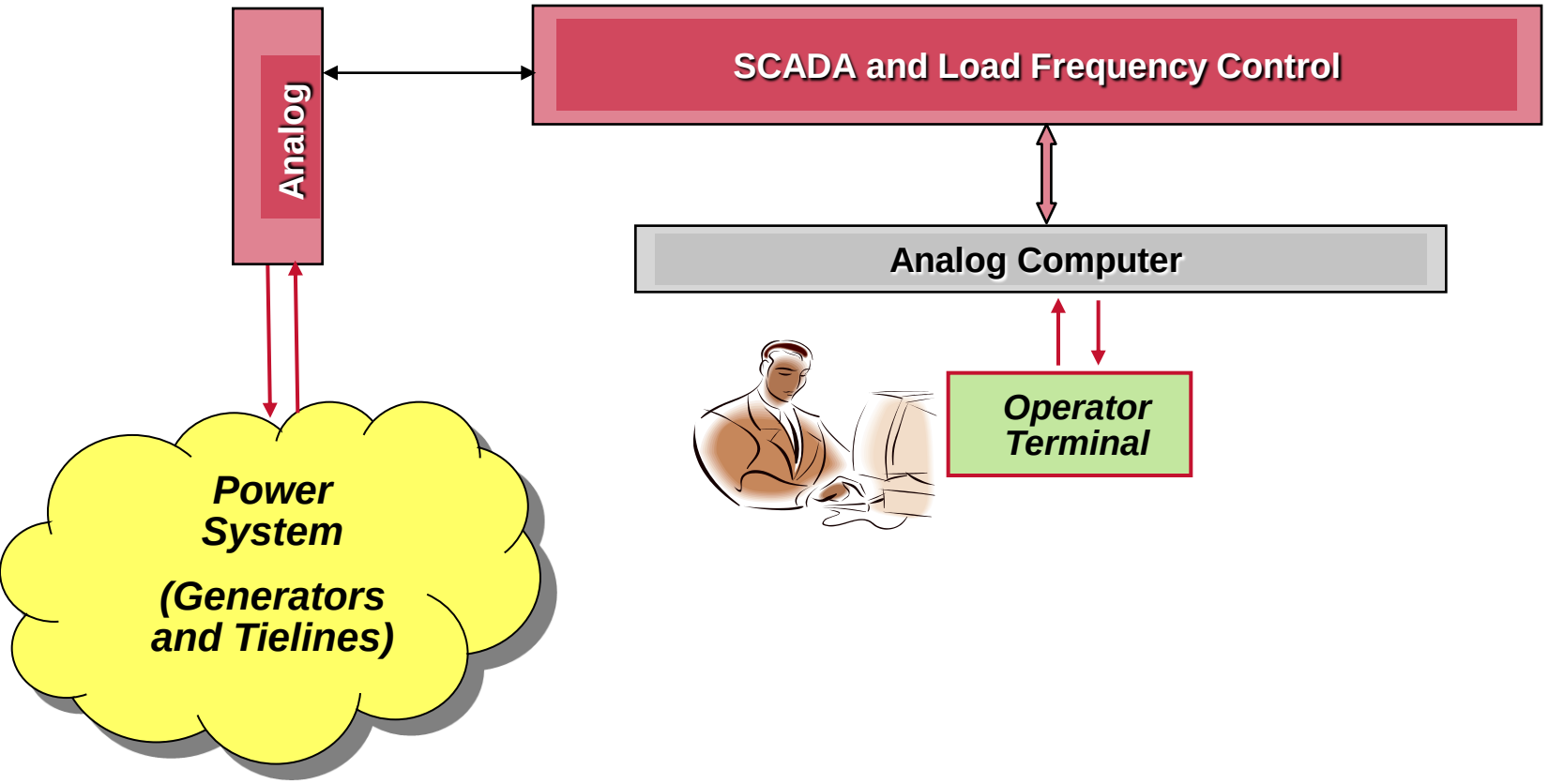
Energy Management System EMS

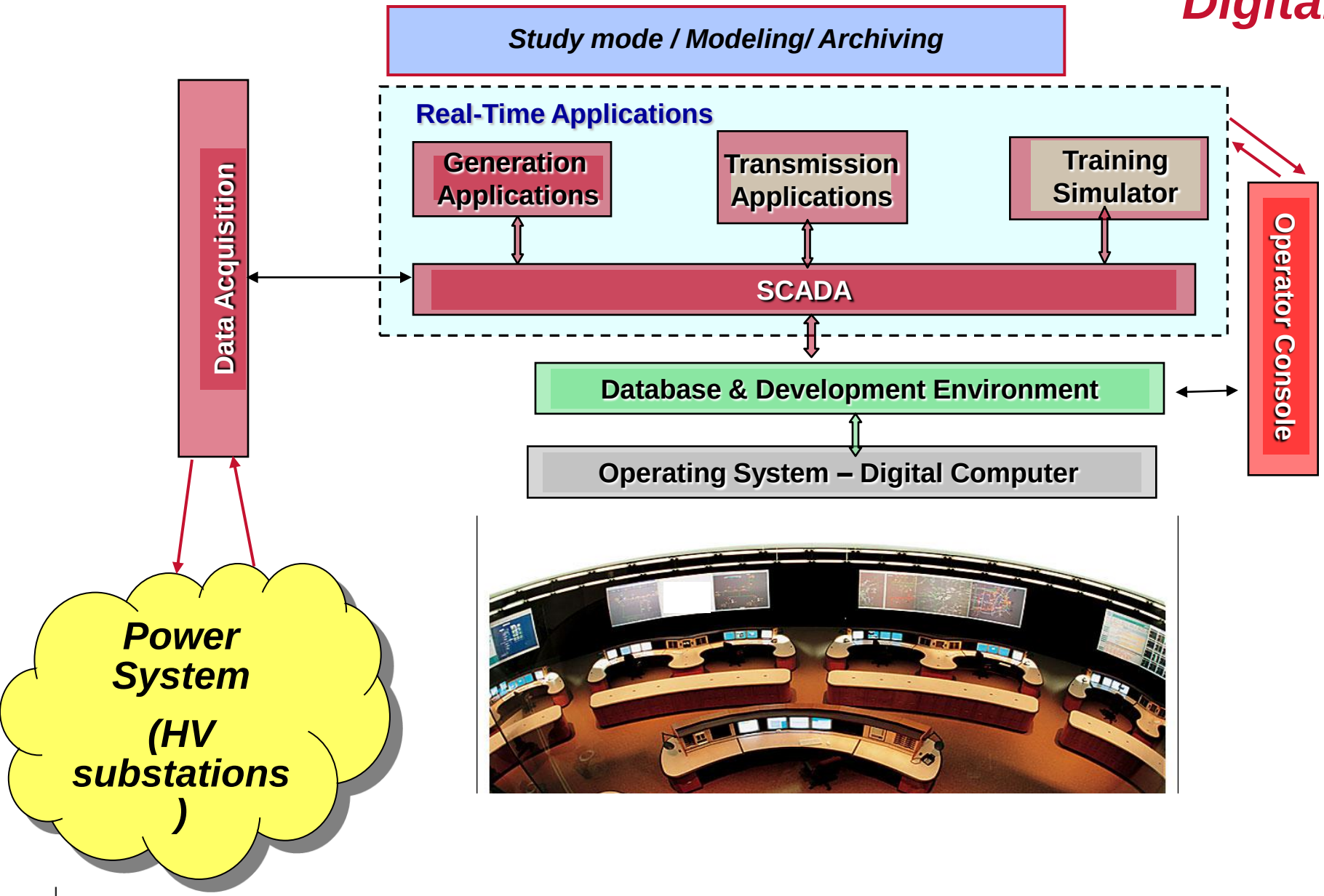
- **EMS capabilities have evolved over the past five decades (since the 1965 blackout)**

- **EMS manage the flow of electricity in the grid.**
  - **Operate the electric grid within safe limits**
  - **Operate the system reliably – "Prevent Blackouts"**
  - ***Keep the Lights On!!***
  - **Automatically adjust generation to follow Instantaneous customer load changes (Remember, Electricity Cannot be Stored….)**
  - **Identify potential risks and take preventive action**
  - **Expedite restoration of customers after an emergency**

EMS – 60's & 70's
Analog, hardwired



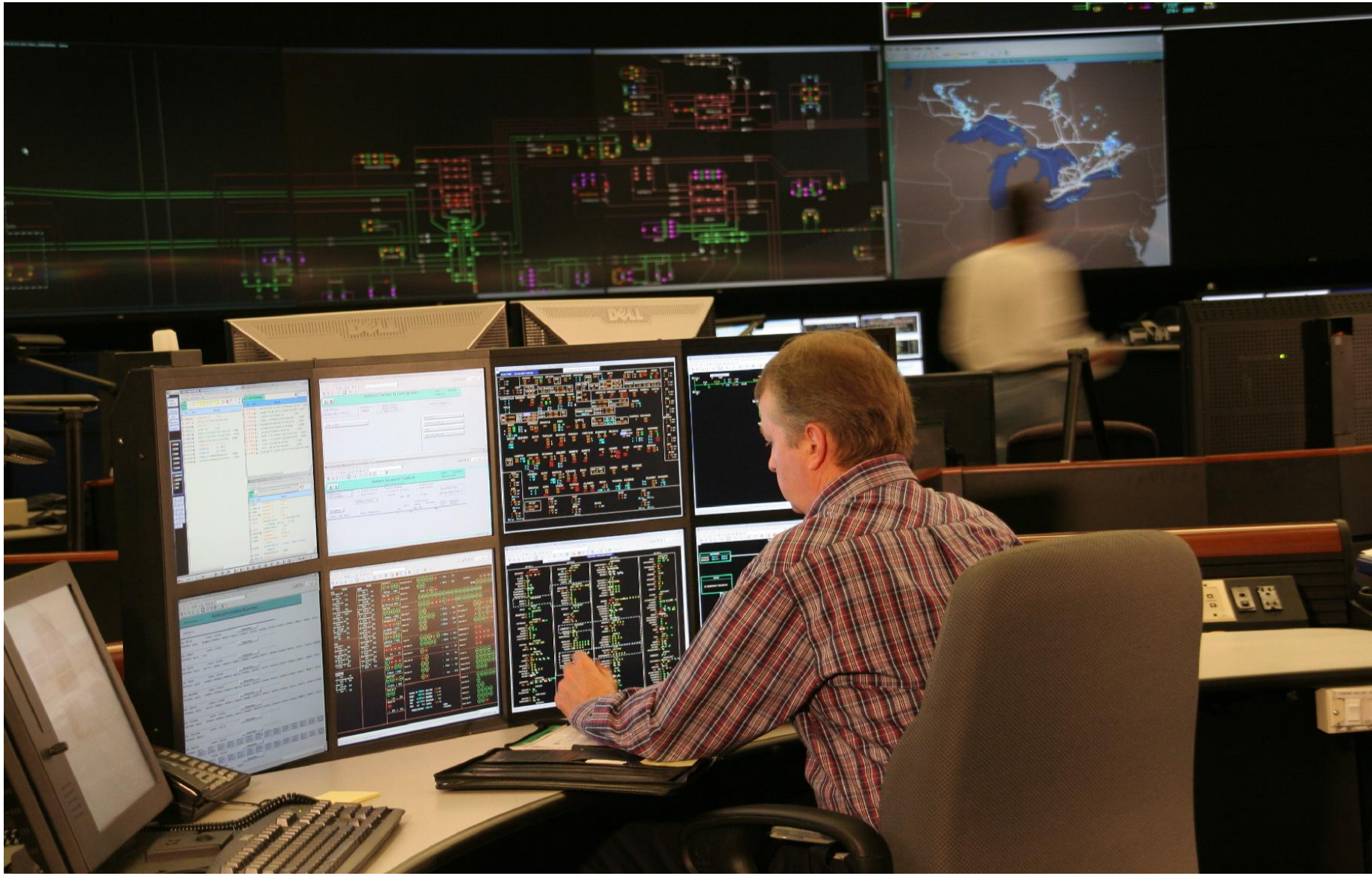
EMS – 80's and 90's Digital



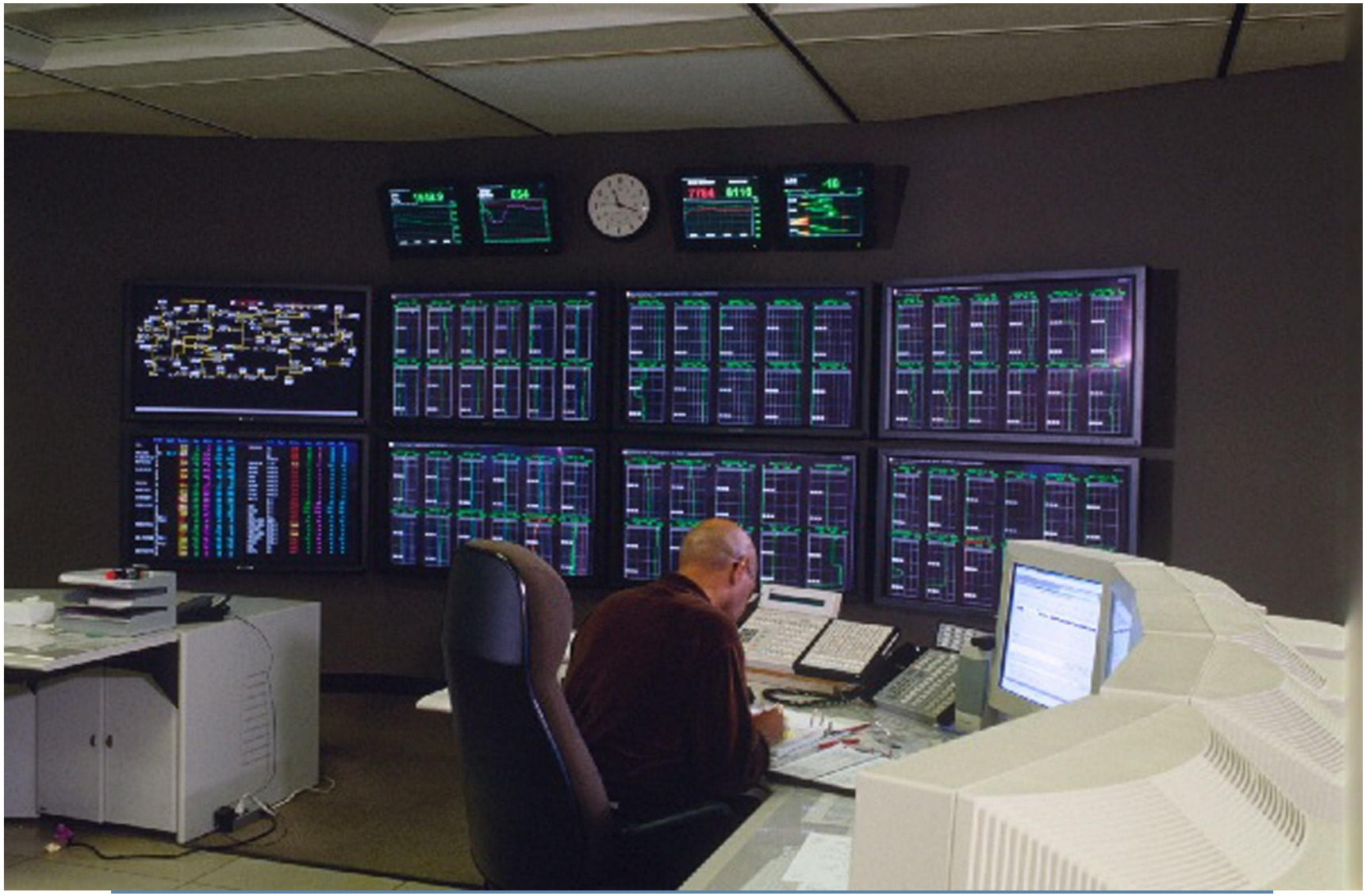
EMS Control Centers

Control Systems dedicated to the management of energy networks

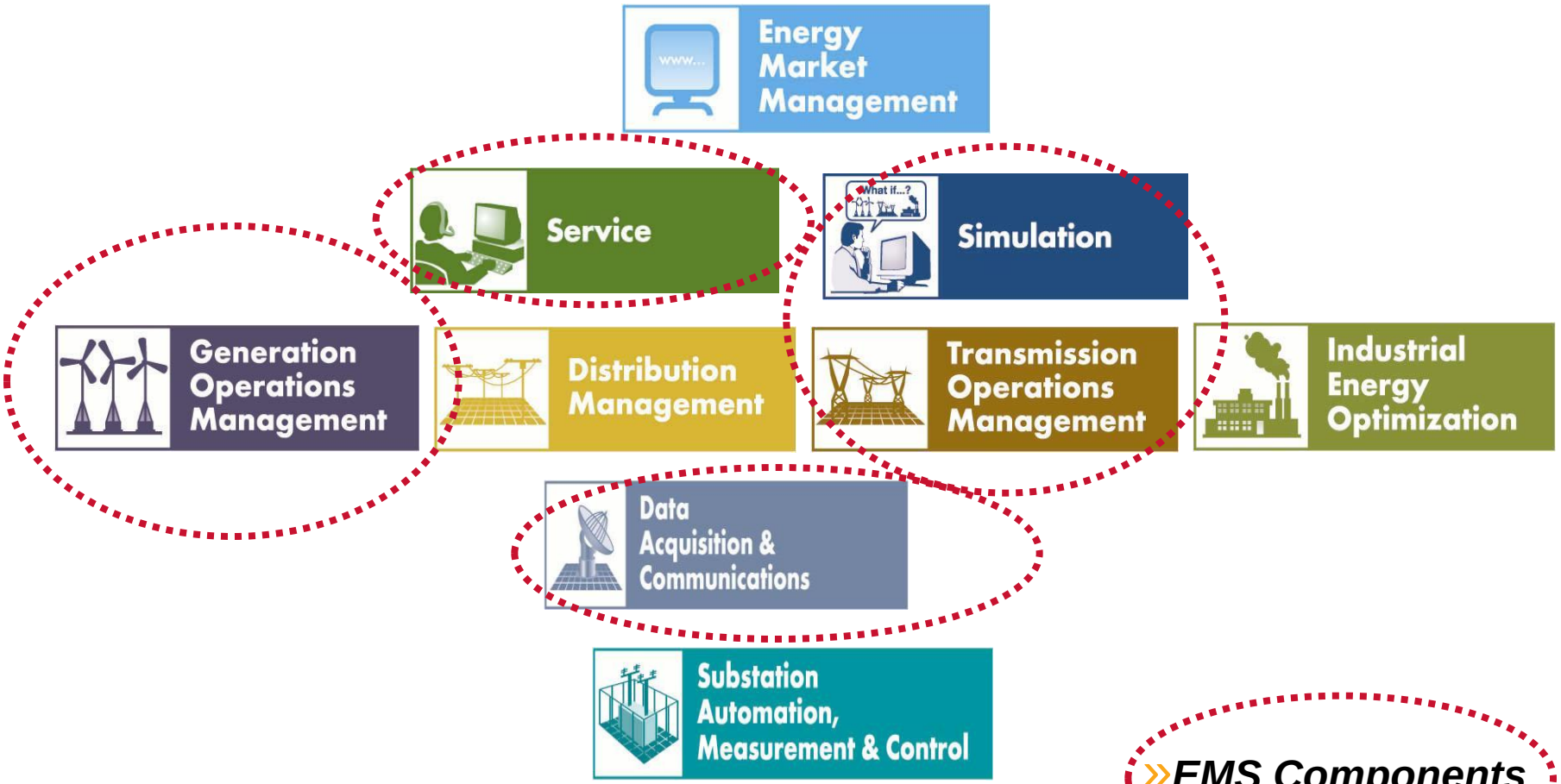
Control Center Operator



Mapboards and Stripcharts



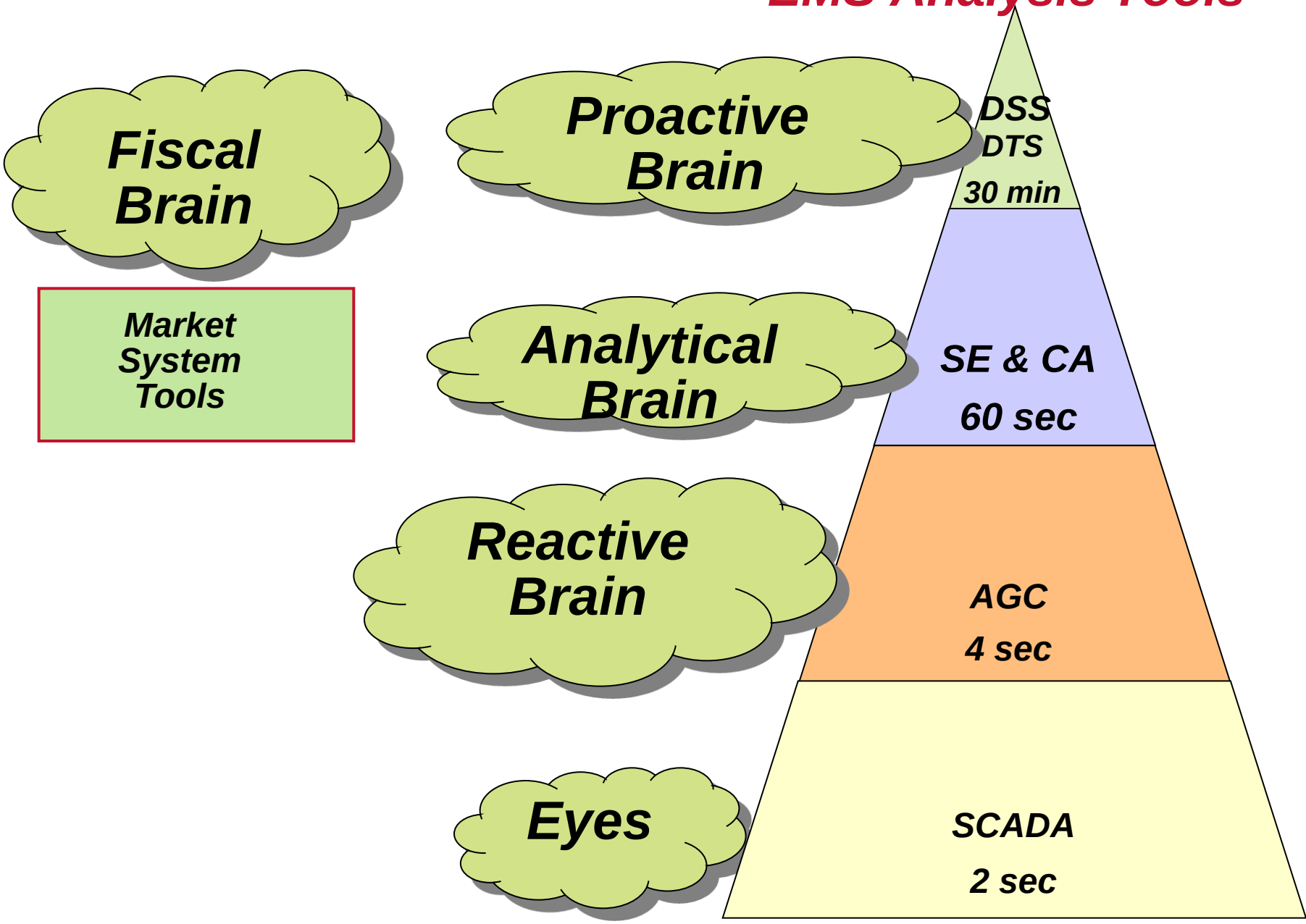
Automation Products
‘Meter to Market’



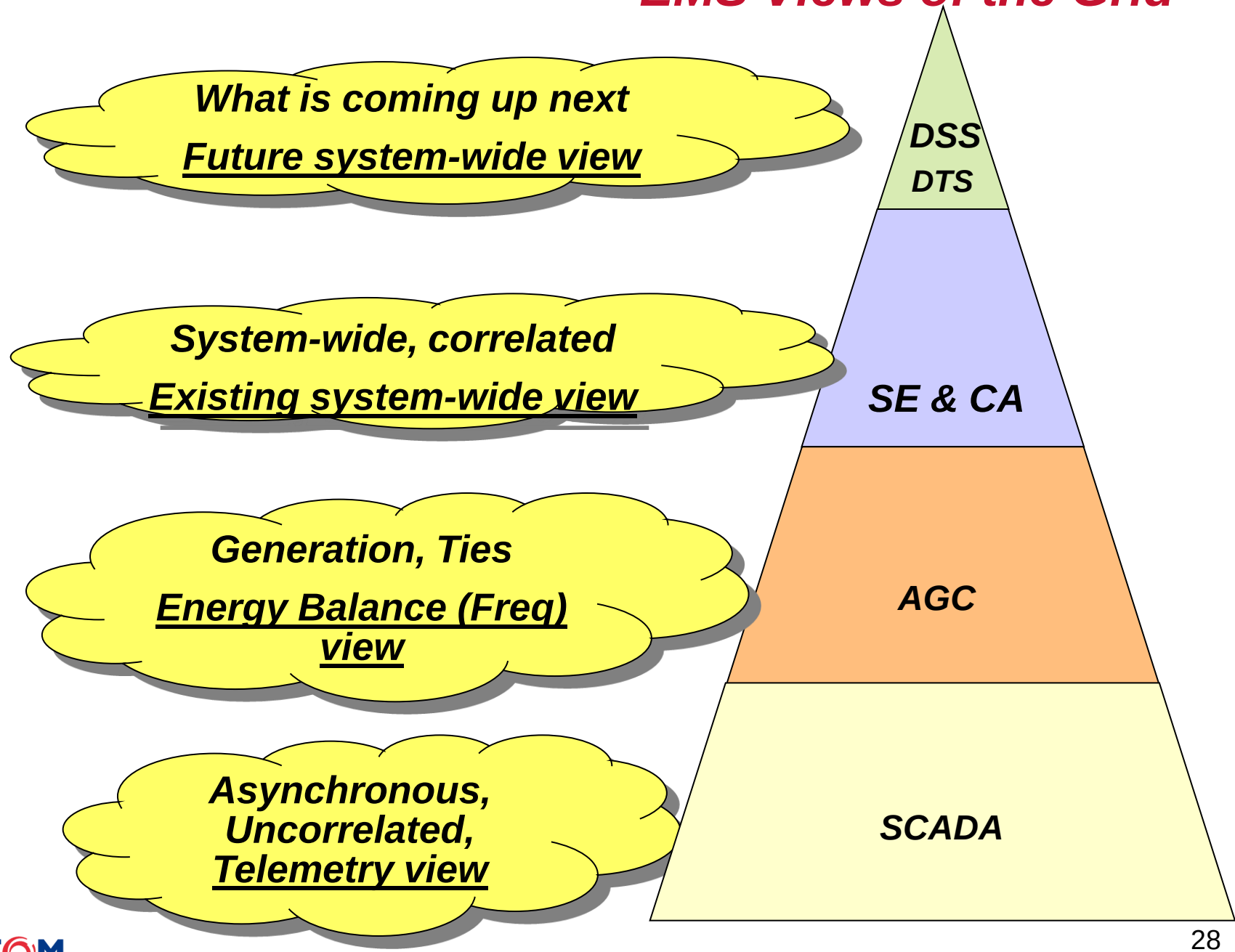
- **Supervisory Control and Data Acquisition (SCADA)**
  - Monitor physical system conditions in real time (2-4 sec)
  - Perform supervisory controls
  - Exchange data with external functions
- **Generation Scheduling & Dispatch**
  - System load forecast (SLF)
  - Generation/Interchange scheduling
  - Real-time economic dispatch (ED) & reserve monitoring
  - Real-time automatic generation control (AGC)

- **Transmission Grid Management**
  - State Estimation (SE) for real-time transmission system
  - Network Security Analysis: real time contingency analysis (CA) for N-1 system security
  - System Optimization: remedial actions, volt/var control
- **Dispatcher Training**
  - Dispatcher Training Simulator (DTS) of historical and hypothetical scenarios
- **Others Business Functions:**
  - Energy accounting,
  - Modeling and database management

EMS Analysis Tools



EMS Views of the Grid



Current New Influences

- Types of Customers
  - Central markets (ISOs, RTOs, etc)
  - Market Participants (Gencos, retail, traders)
  - Network & Operations planning
  - Distribution management
- Mandates from FERC
  - RTOs (very large networks, UI, robustness)
  - Transmission planning & Congestion management
- Technologies & Tools
  - Software advances:
    Artificial Intelligence, optimization engines, visualization engines, integrated development/UI environments, Desktop applications
  - Economical communication and standardized device protocols
  - Web-enabled IT systems
  - New types of synchronized, fast measurements

Current Challenges

New Constraints:

Resulting in greater uncertainty in operation!

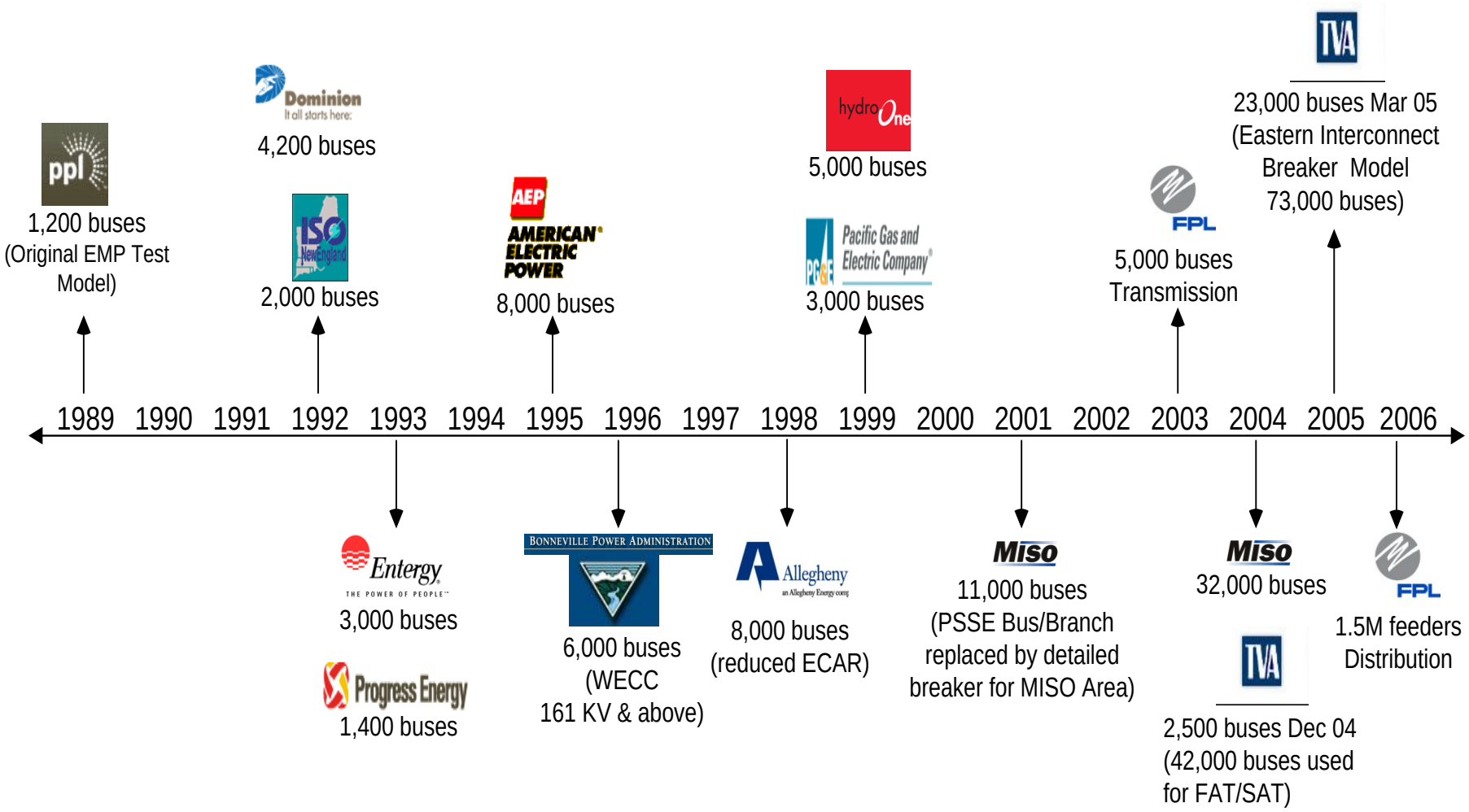
- **Aging of operators – Lower skill level and experience**
  - **50% eligible for retirement by 2010…**
- **Aging transmission system infrastructure; Low new investment**
  - **Increased congestion; Restricting operating limits**
  - **Deferred maintenance; lack of integrated system planning.**
- **Deregulated environment – Less predictable system loading**
  - **Exchange of data RTOs; Market driven scheduling/ operation**
- **Cyber security threat (Intrusion, Viruses)**
  - **Authorization / Authentication of Users; Protection against attacks**
- **Terrorism threat (Physical security)**
  - **Protection of sites; Protection of data**
- **Financial auditing threat (Sarbannes – Oxley)**

Current Challenges (contd)

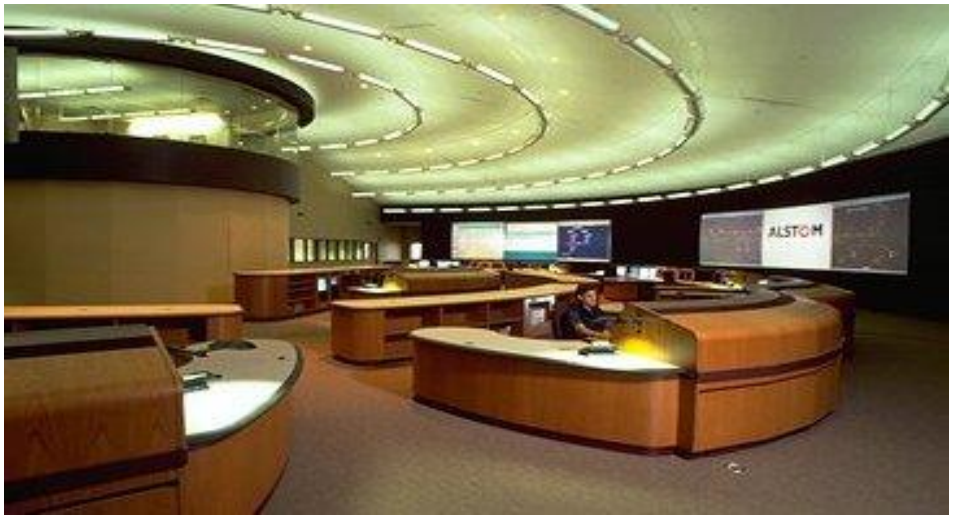
- **Are US R&D Budgets for Electricity R&D enough?**

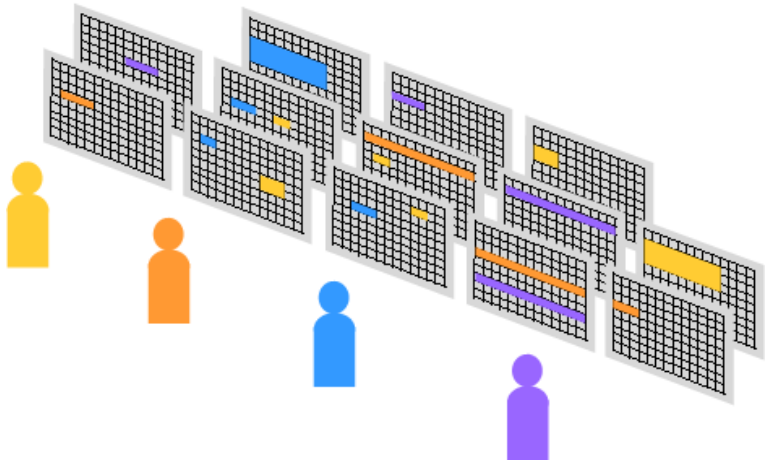
- **"US annual budget for Electricity R&D is less than what we spend on R&D for pet food"**
  (Nora Brownell, FERC Commissioner, EPAct mtg, Feb 2nd, 2006)

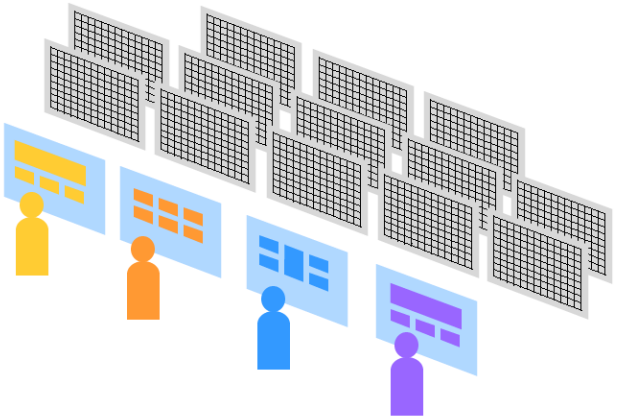
Evolution of Network Model Sizes



Operators' Needs Evolving
More Information, Less Data



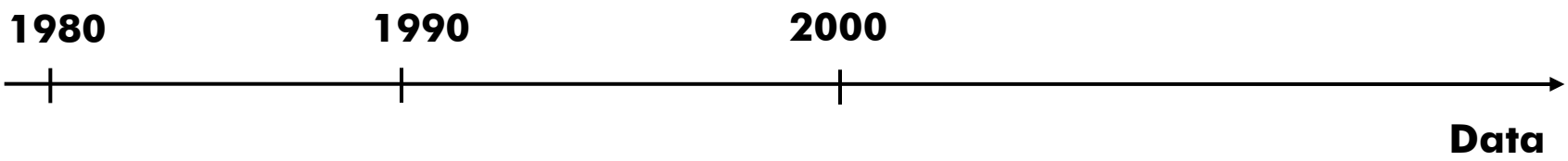




Operators see Data

They need Information

Visualization
The problem



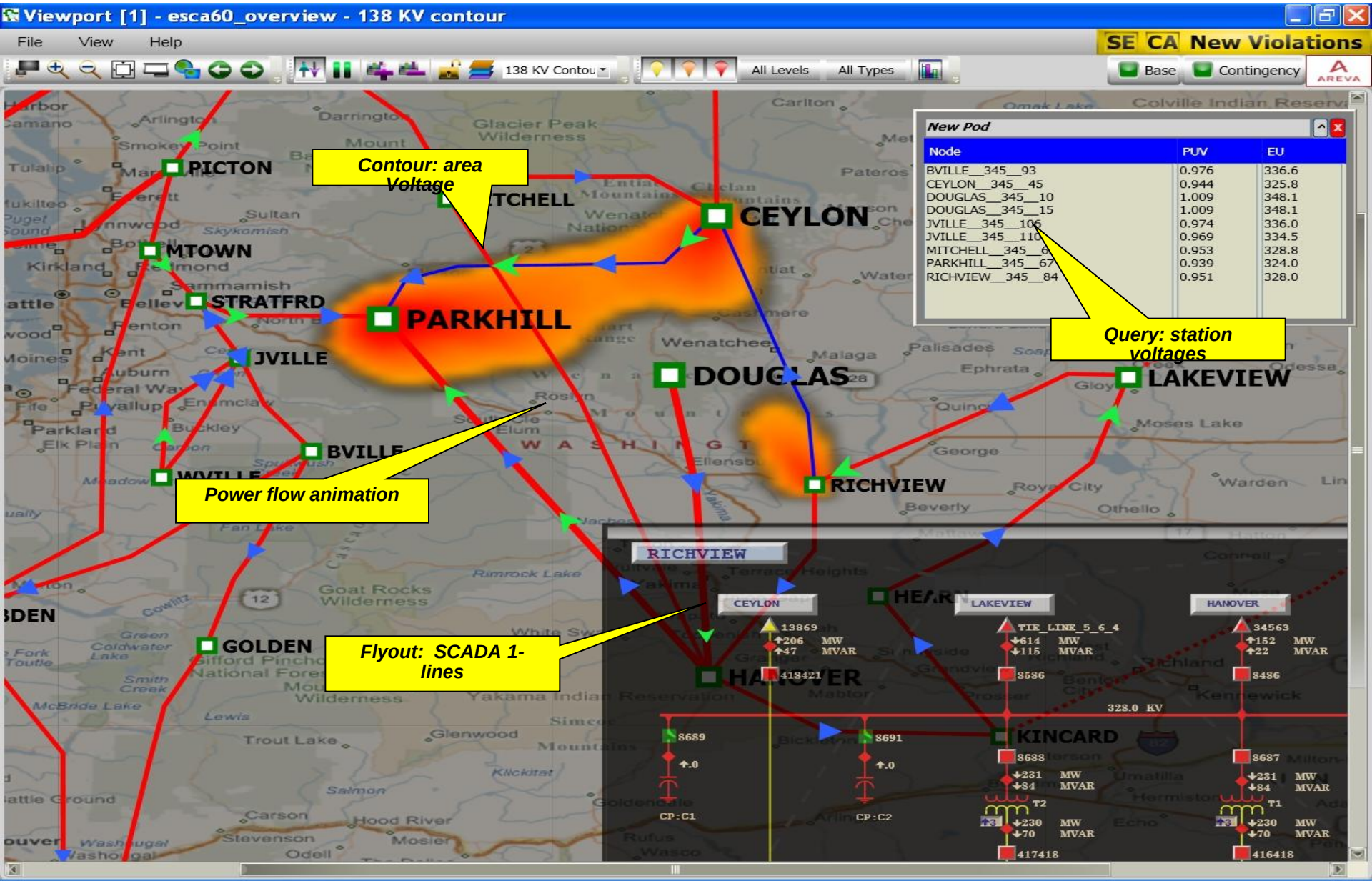
Huge volume of data

Situational Awareness…

Handling a deluge of data…

- **Miller's Magical Number Seven, plus or minus two (Miller, 1956)**
  - **Operators can only handle 7 (plus/minus 2), 'chunks of information'**
- **Hence, although "a picture is worth a thousand words"**
  - **The "correct picture" is worth a million words!!**

Integrated SCADA & GIS Displays



Voltage Stability – Locations & Controls

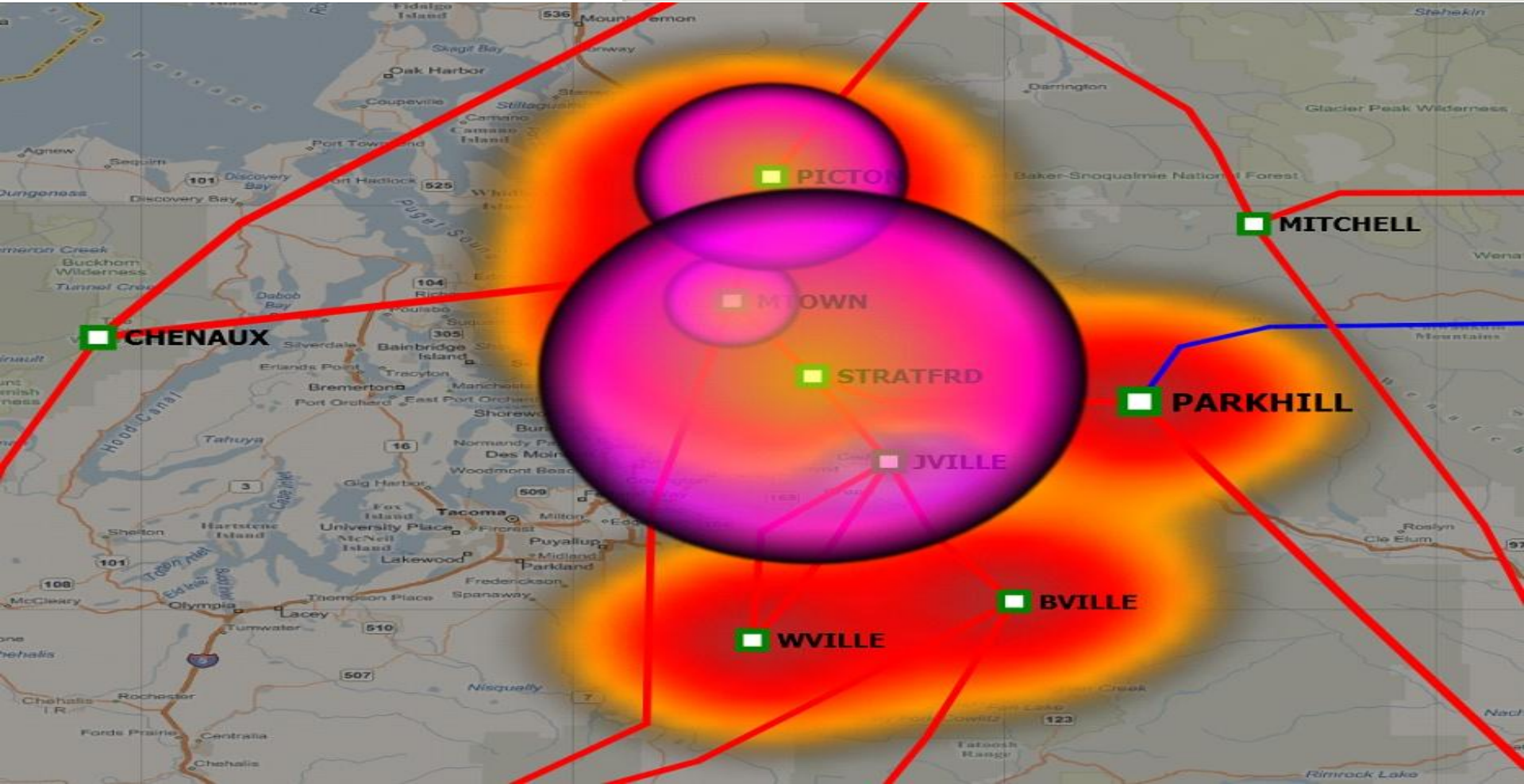
VSAT Context Panel

VSAT Scenarios

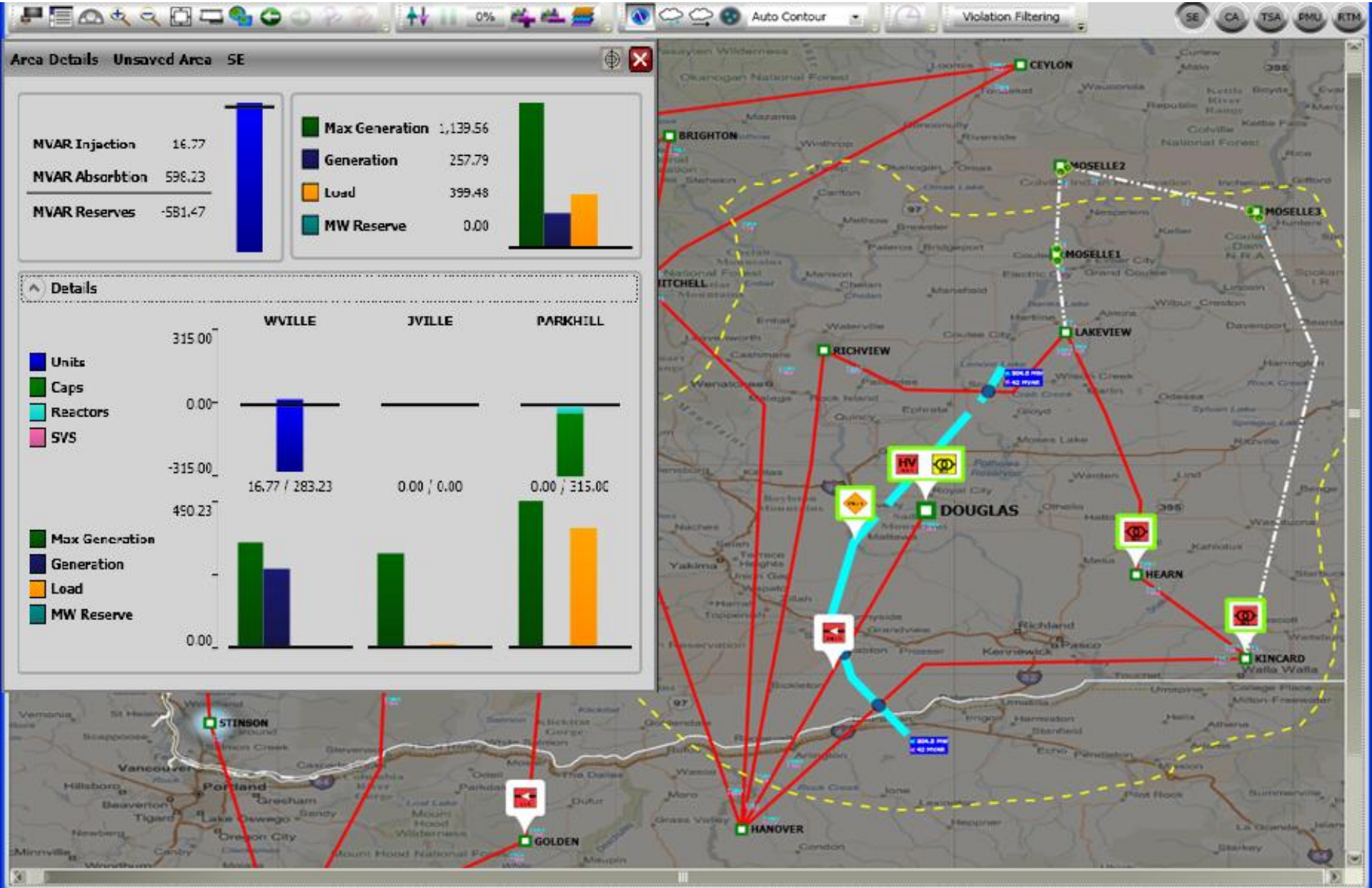
Scenario	Source	Sink	Transfer Size	Size of Limit	Last Run	Next Run	Status
Scenario3	Area1	Area2	500	91%	22:11:30	--:--:--	Complete
Scenario1	Area51	Area53	500	85%	00:12:34	00:13:04	Pending
Scenario2	Area21	Area3	500	11%	13:23:35	00:23:35	Idle

Limiting Contingency
LAKEVIEW-RICHVIEW,345
Violation Type: Thermal

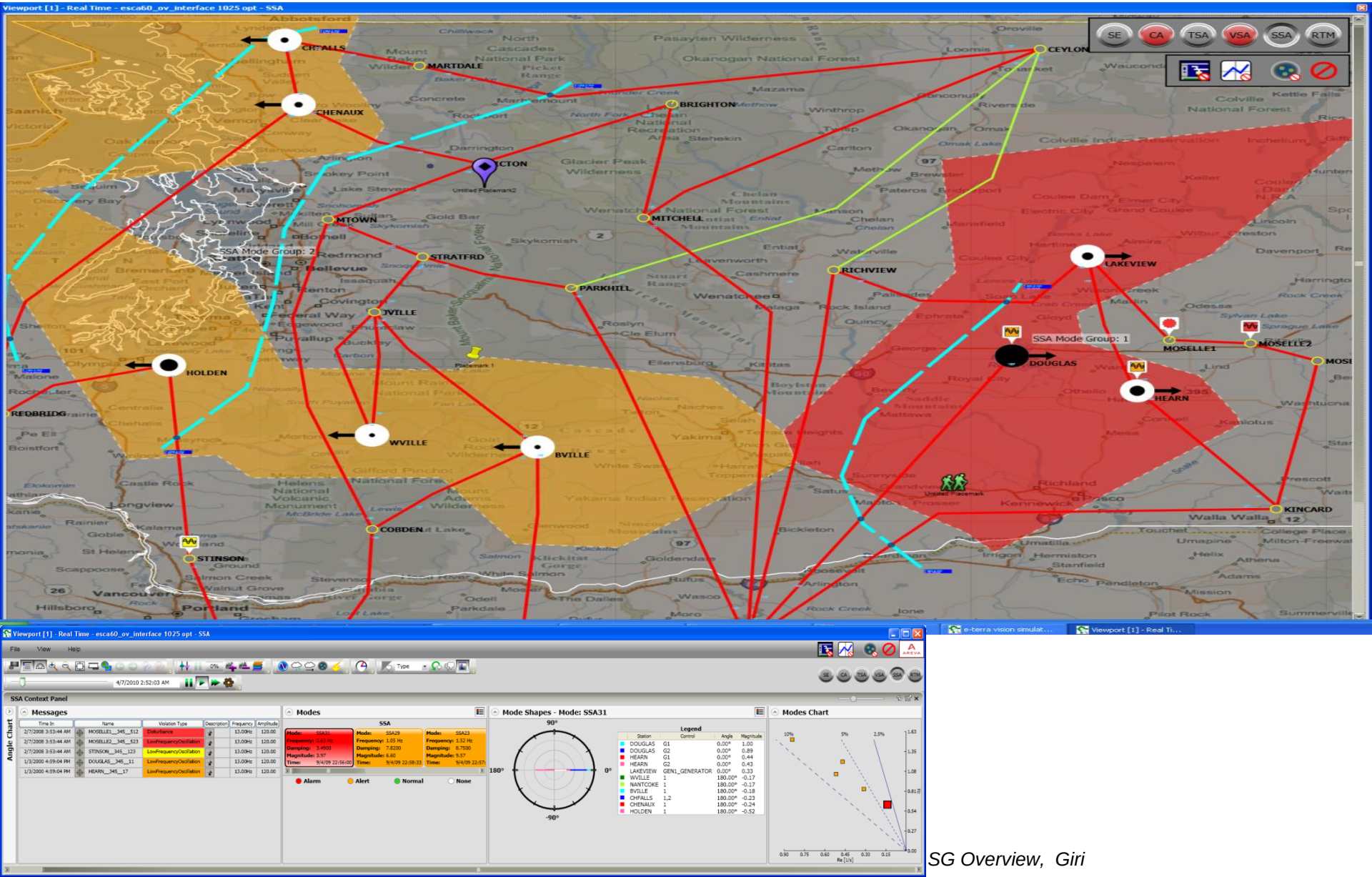
0 100 200 300 400 500



Where are the VAR sources?

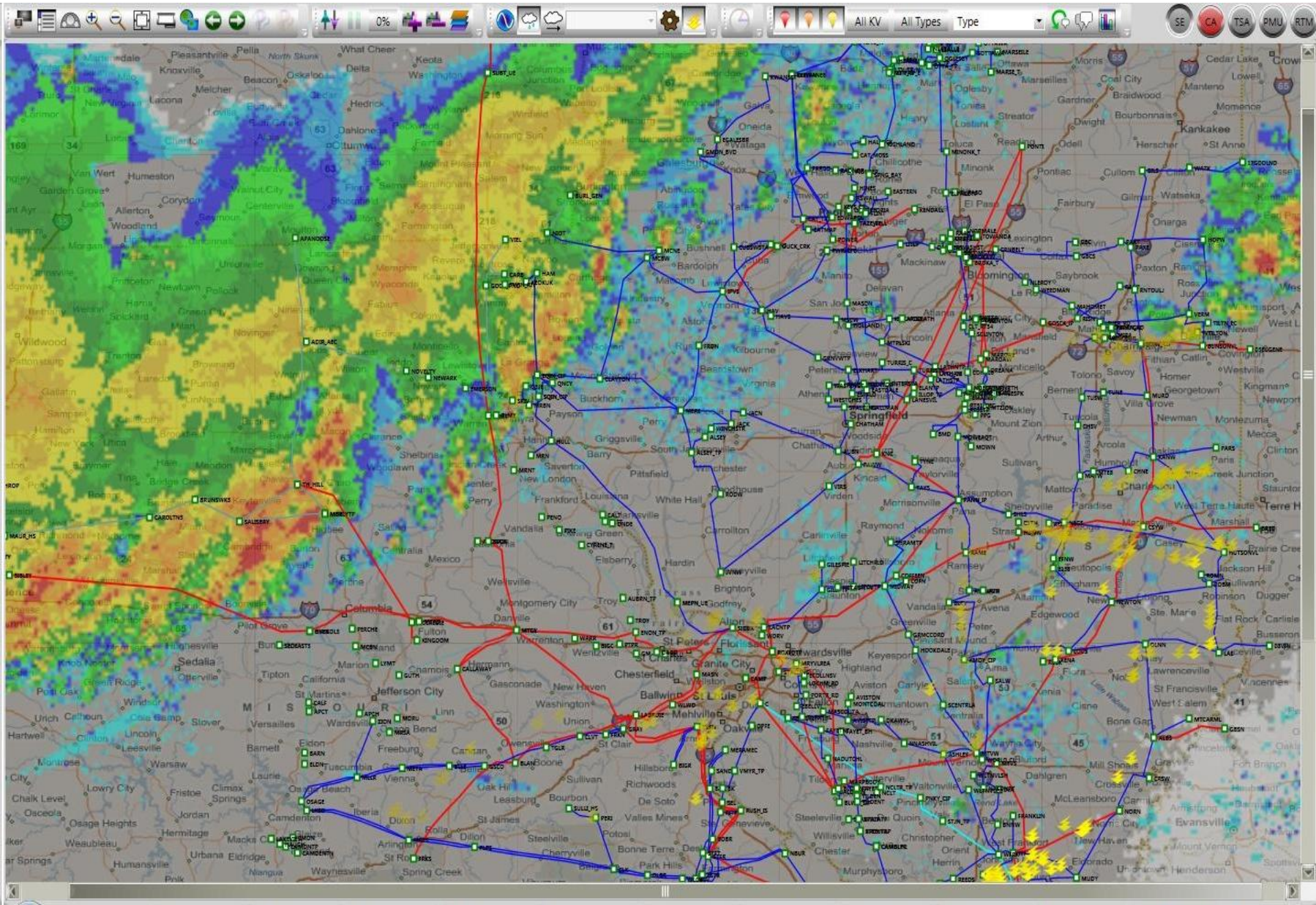


Oscillation Modes & Damping

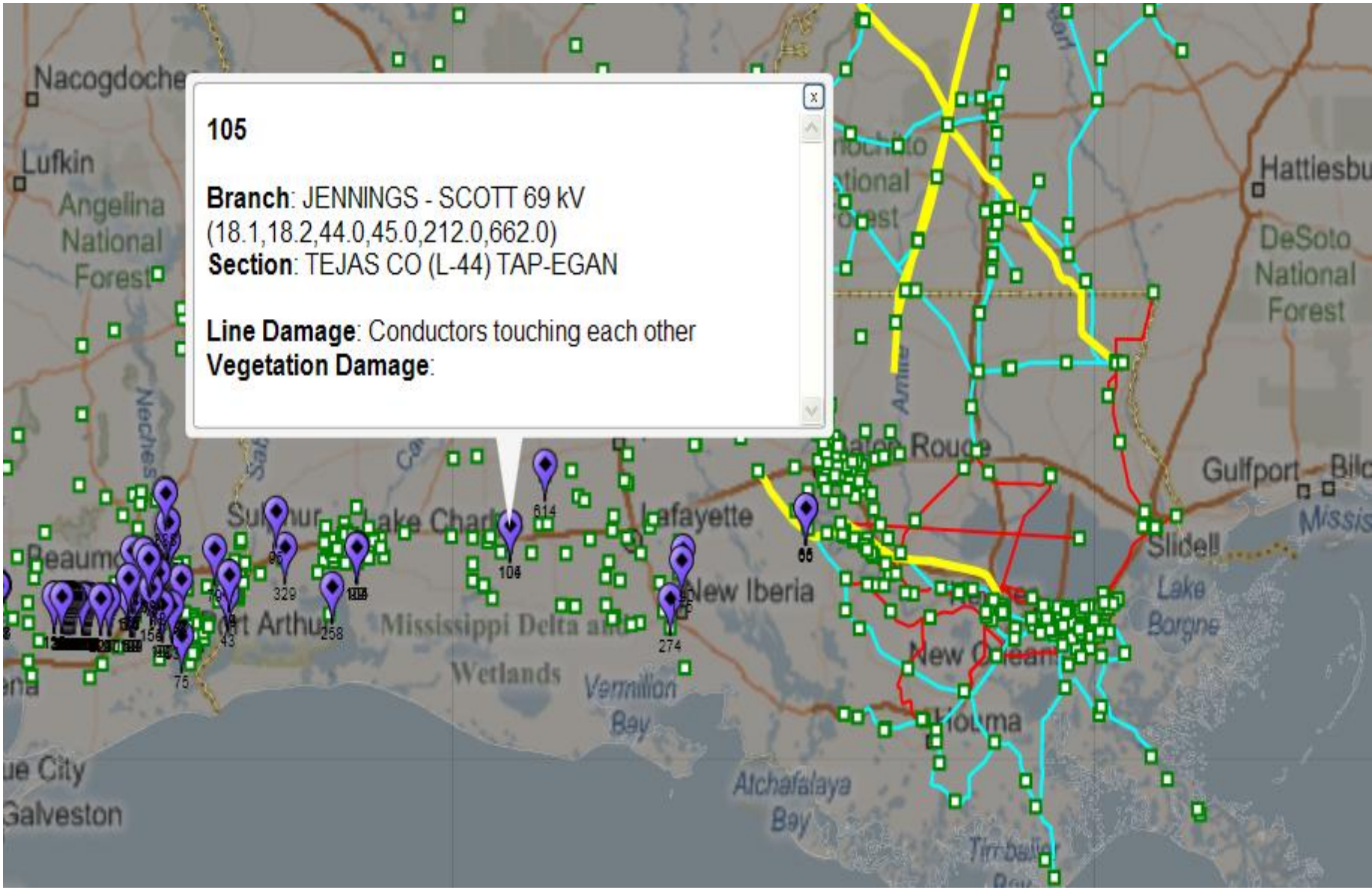


SG Overview, Giri

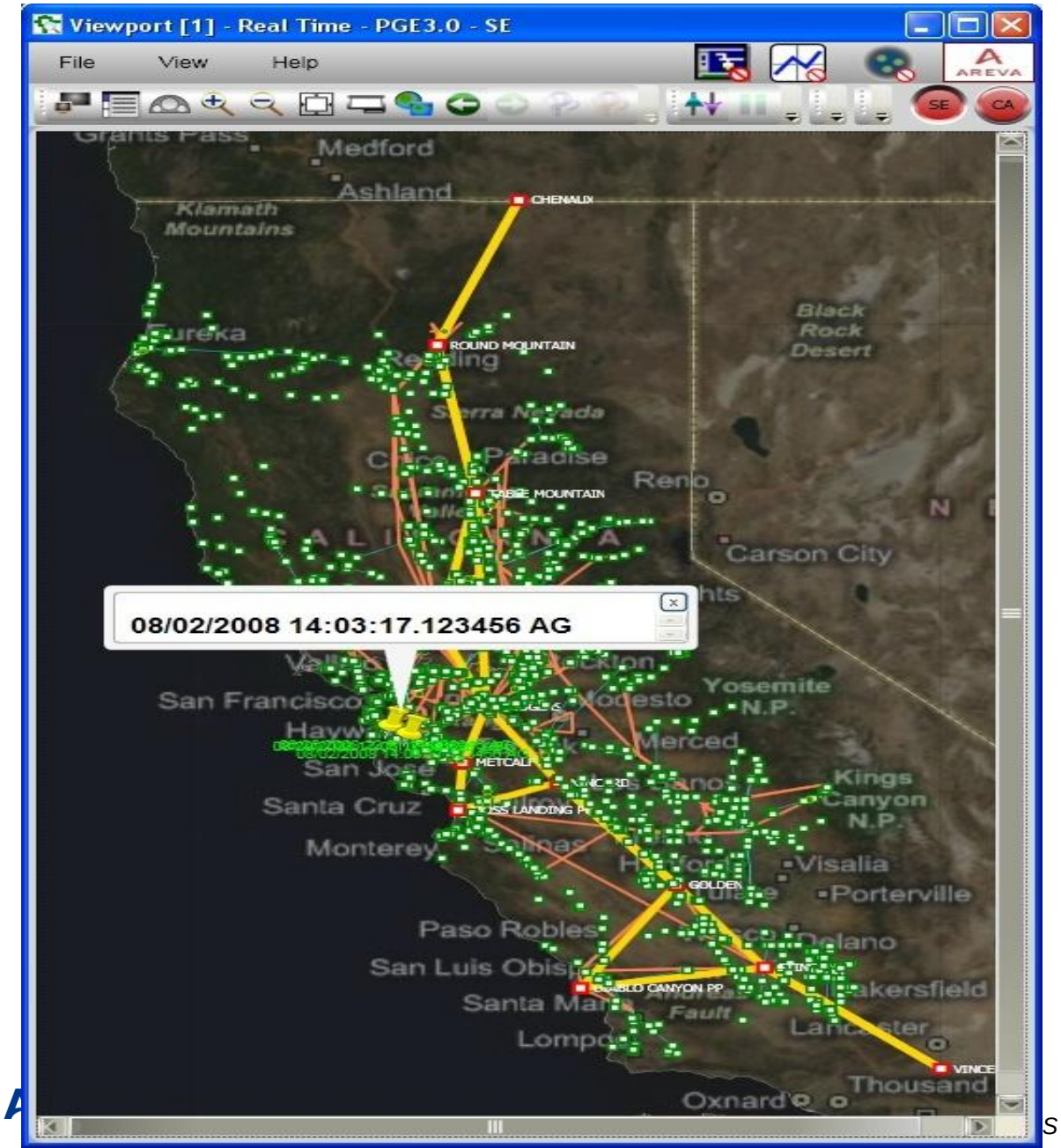
Weather Radar Overlay



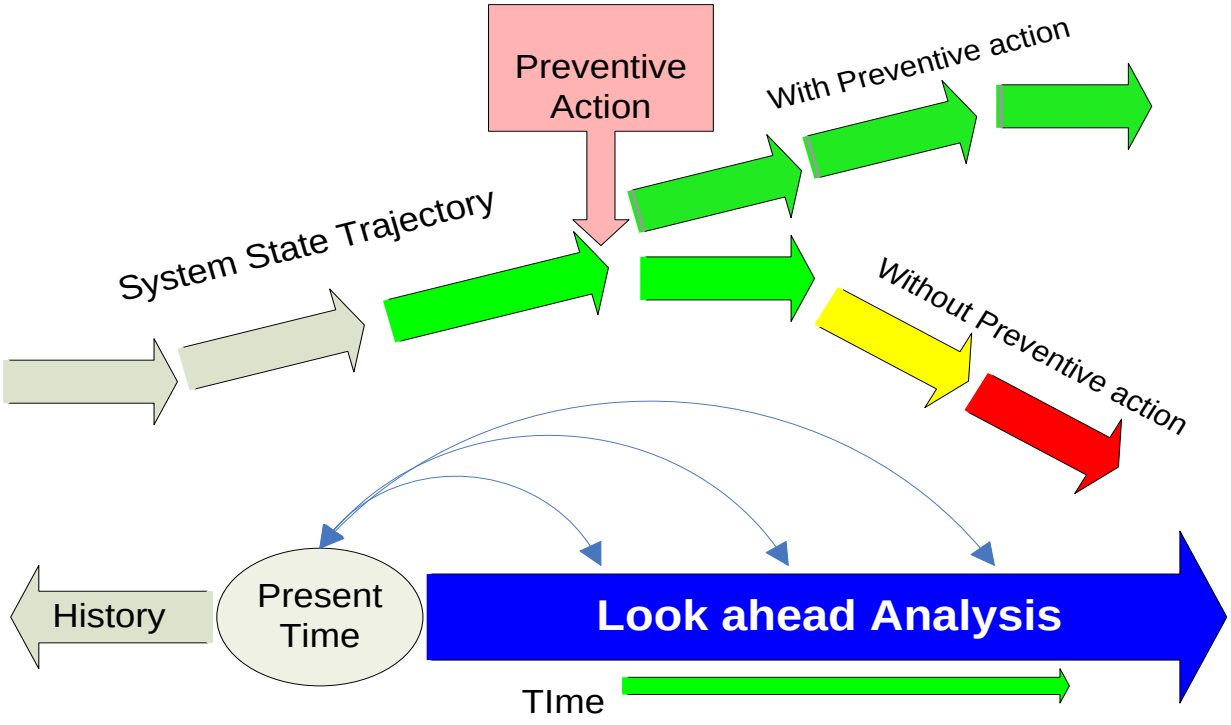
Fault Location Overlay



Disturbance Location Overlay



Look-ahead Visualization, Projection…



The full energy value chain will be impacted

Energy management MUST be smarter at all levels

Generation	Grids	Consumption
• Renewable Energy Sources • Flexible generation	• Renewable Energy Sources integration • Storage integration • Increased stability and quality issues • New interconnections • Demand-side management / Meter Data management	• DG integration • Smart meter • Electric vehicle

ALSTOM

ALSTOM Smart Grid Initiatives

Smart Dispatch

- Generation Portfolio Management including renewable
- Full Integration of pricing and demand/supply principles to manage the grid
- Demand response management

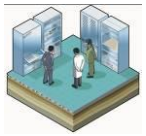
Smart Transmission Grids

- On-line Asset Management
- On-Line Stability Analysis & Defense Plans
- Power Electronic Controls (HVDC, FACTS, SVC…)

Smart Distribution Grids

- Automatic Meter Management System
- Integrated Distributed Management Systems
- Renewable and load management integration

Smart Substation



- Substation Protection & Control Architectures
- Self-adaptive Defense Plans
- Secondary Distribution Applications

Visualization, Situation Awareness and Decision Support Tools

System Architecture including Common Information Model

Secure, deterministic and reliable data communication

DOE Smart Grid Investment Grants (SGIG)

- **$3.4B total to over 100 awardees:**
  - **Notification October 2009**
  - **DOE contracts signed in the past month**
  - **3 year duration**
  - **50% cost sharing**
- **$200M+ related to synchrophasor (PMU) deployments**
  - **Deployment of additional ~700 PMUs in next 3 years**

What is SynchroPhasor Technology?

Phasor Measurement Units (PMUs)

- **Next generation measurement technology.**

  (voltages, currents, frequency, frequency rate-of-change, etc)

- **Higher resolution scans**

  (e.g. 30 samples/second).

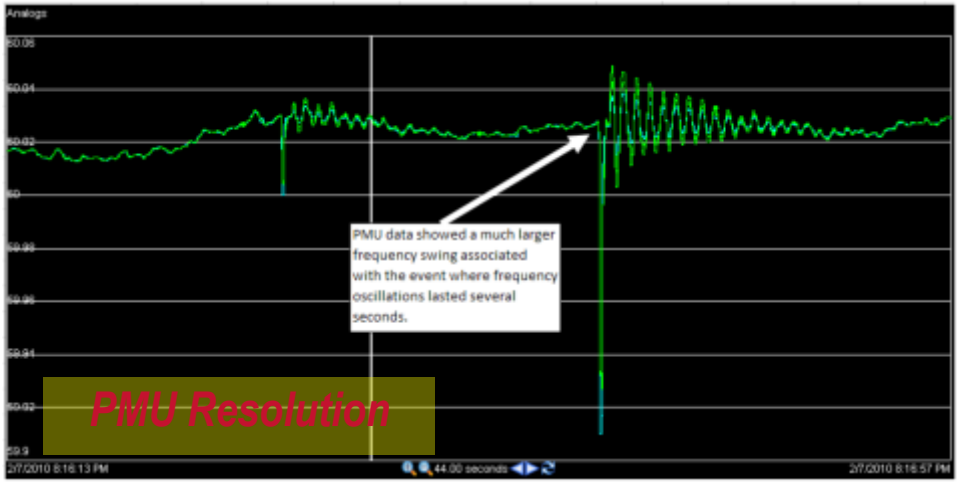
  – ***Improved visibility into dynamic grid conditions.***

  – ***Early warning detection alerts***

- **Precise GPS time stamping.**

  – ***Wide-area Situational Awareness.***

  – ***Faster Post-Event Analysis.***



"MRI quality (3-D color) visibility of power system, compared to X-ray (2-D b/w) quality visibility of SCADA" ***– Terry Boston (PJM)***

Leverage Enabling Technologies…
e.g. PMU or Phasor Data

Courtesy EIPP, NASPI PMUs measure voltages & currents - magnitudes & angles

SCADA data	**Phasor data (PMU)**
Refresh rate 2-5 seconds	Refresh rate 30 samples/sec
Latency and skew	Time tagged data, minimal latency
'Older' legacy communication	Compatible with modern communication technology
Responds to quasi-static behavior	Responds to system dynamic behavior
Freq change means: Sudden Gen-Load MW imbalance somewhere in the grid	**Angle-pair change means**: Sudden MW change in a specific location of the grid
X-ray	**MRI**

Earlier Information for Better Decisions

GRID | ALSTOM

The changing landscape

- **Synchrophasor measurement devices are being deployed aggressively in the US and globally**
  - **By 2012, will be a five-fold increase in PMUs across US – over 1000 PMUs deployed**
  - **Each PMU provides 10-12 separate sub-second measurements**
  - **Measurements include voltages, currents and frequencies**
  - **Augments traditional 2-4 second SCADA**
- **Facilitates wide-area monitoring systems (WAMS) and future wide area control (WAC) - self-healing grid**
- **This is the next SCADA frontier – "fast, sub-second measurements and fast, automated controls"**

Synchrophasor Impact on Grid Operations

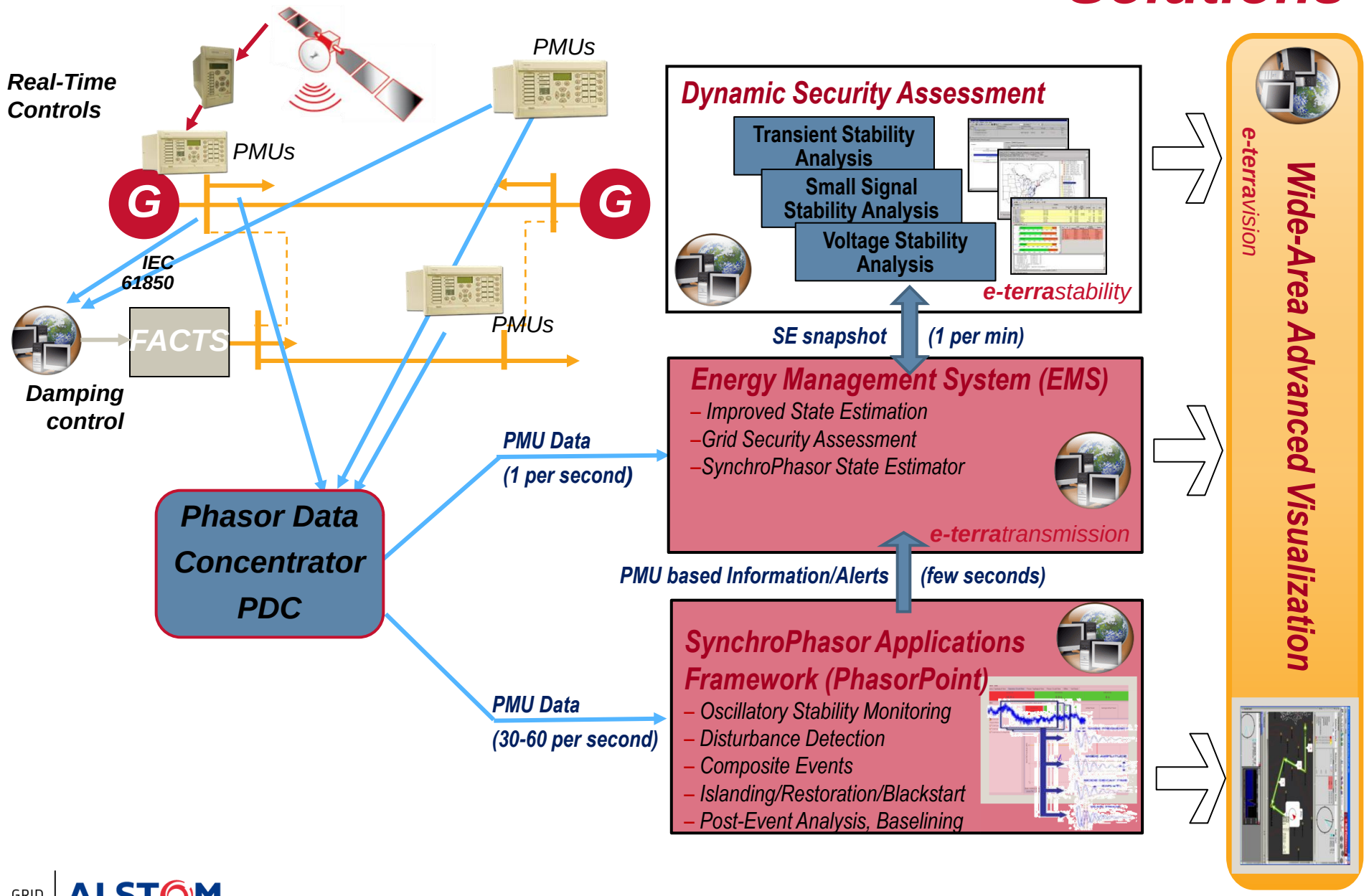
"An <u>Unprecedented Transformational Change</u>

to help operate the grid

More efficiently, reliably and

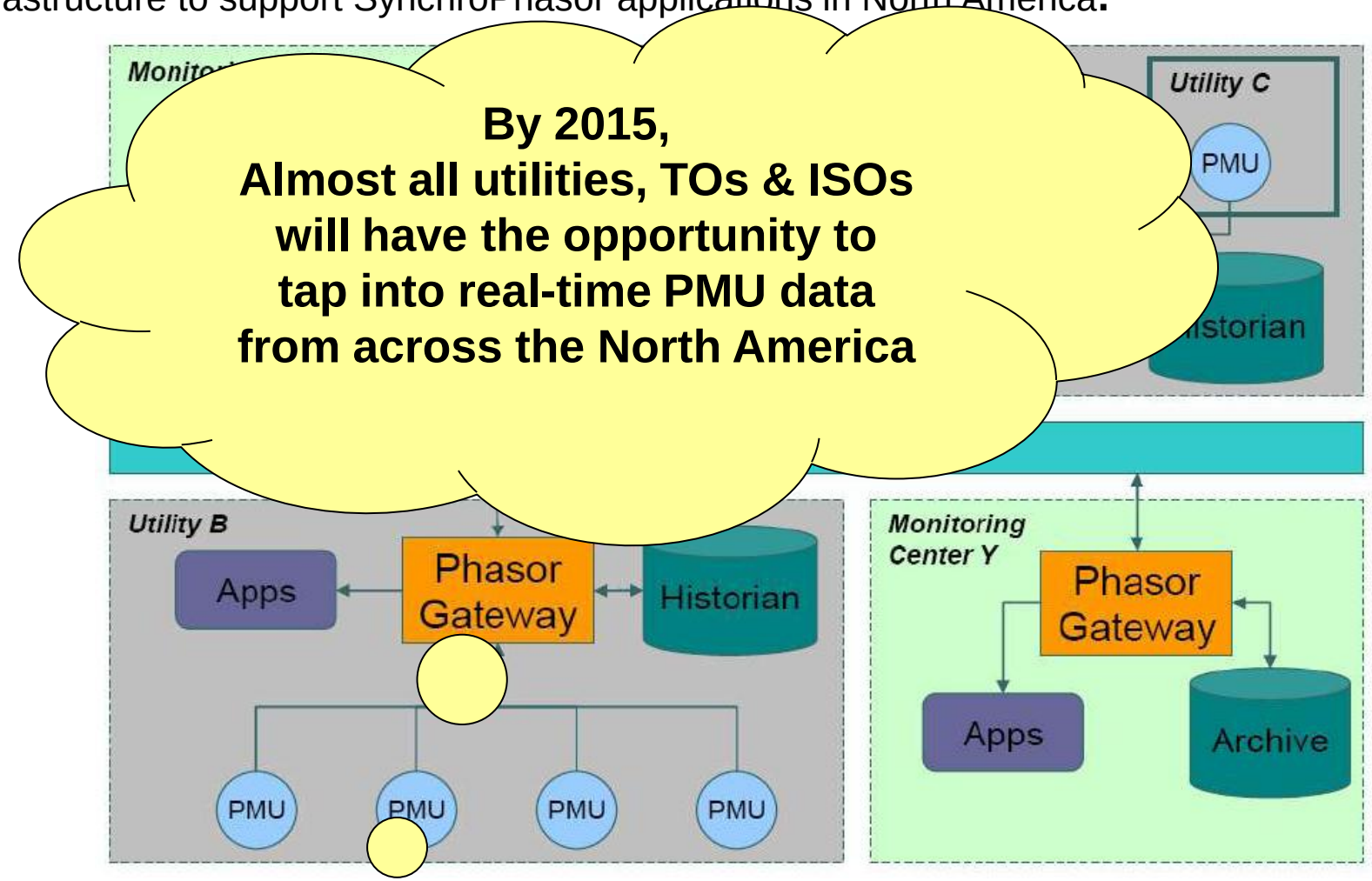
to facilitate integration of Green energy resources"

EMS Integrated with SynchroPhasor Solutions



Communication Network (NASPInet Vision)

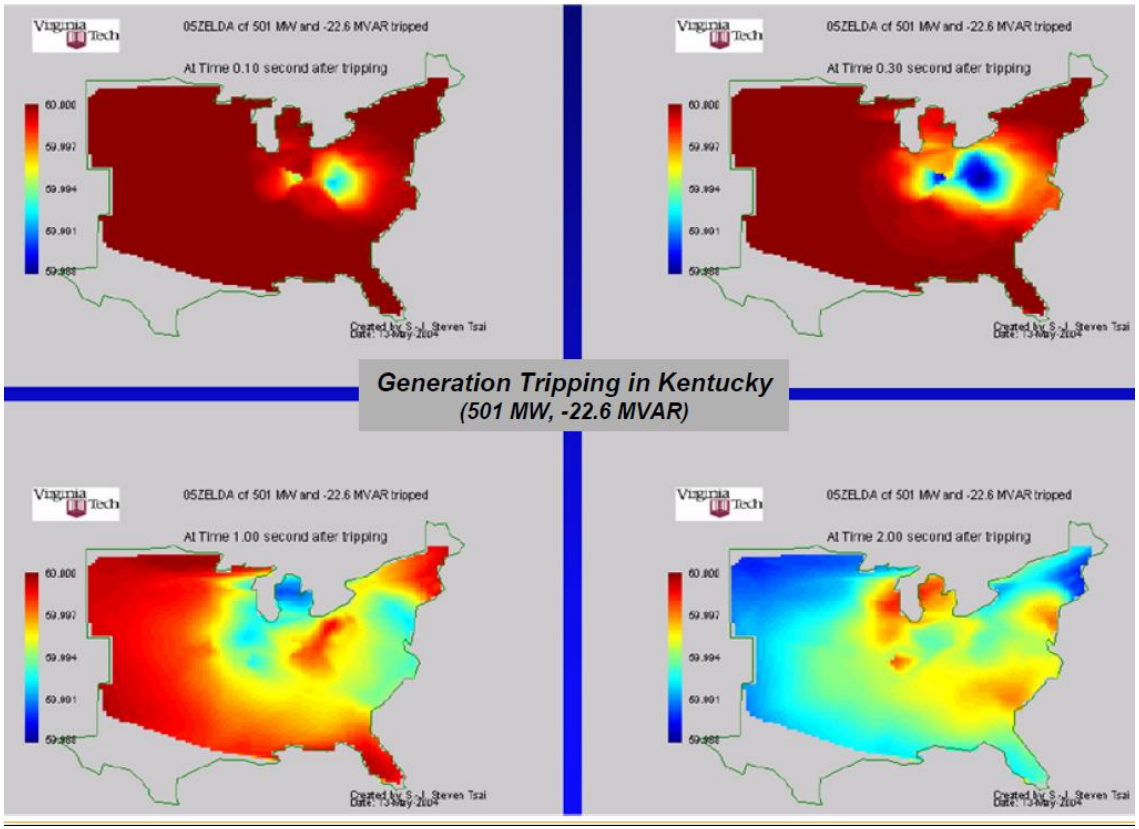
GOAL: Develop an "industry grade" secure, standardized & distributed data communications infrastructure to support SynchroPhasor applications in North America**.**

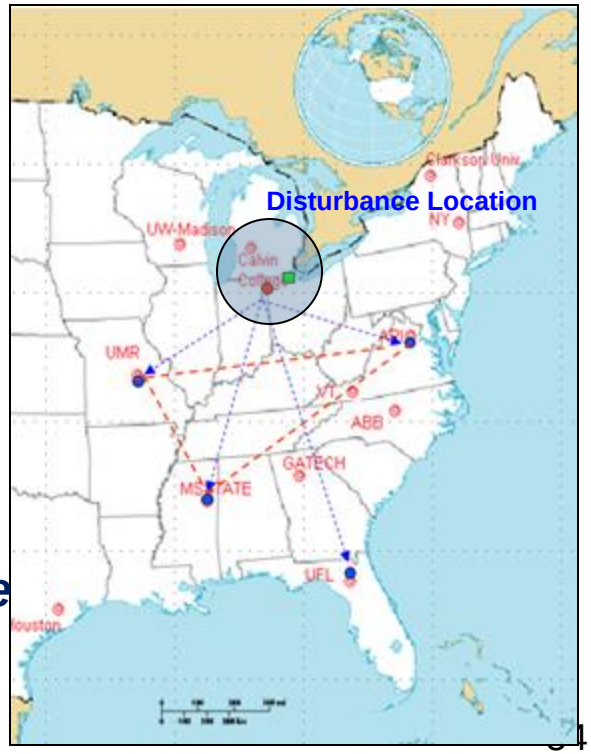


Truly an interdisciplinary problem requiring power engineering, communications, data management & systems integration expertise

Disturbance Location

A sudden disturbance causes a traveling wave that can be detected by PMU data across the grid:



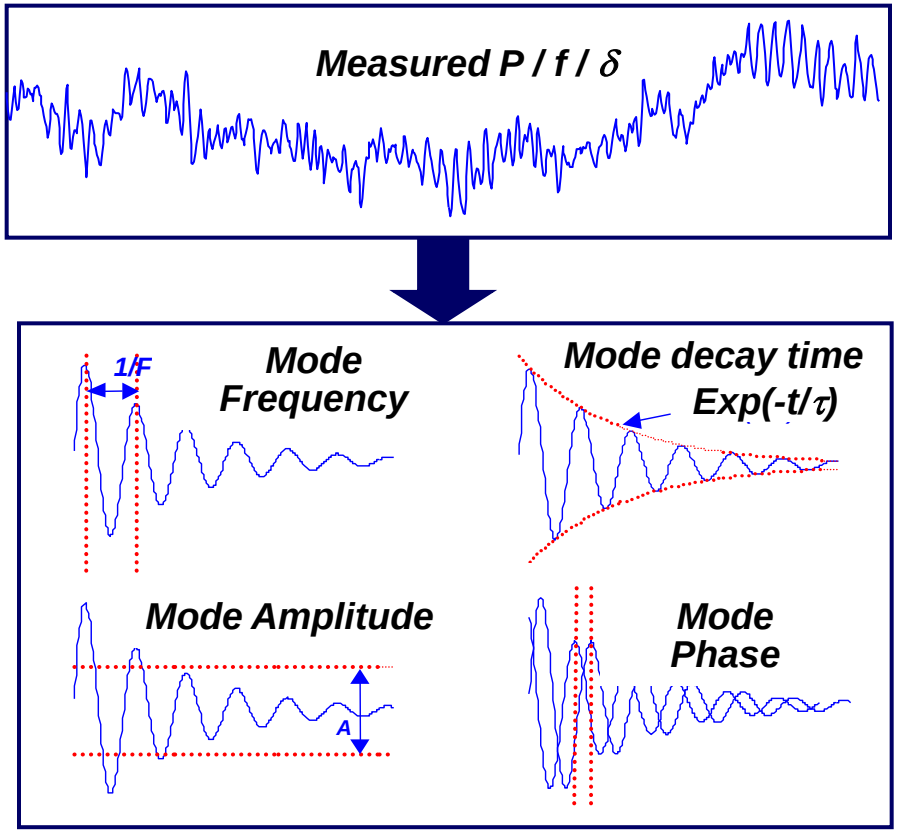


Use PMU and to triangulate & precisely locate the origin of the disturbance

Source: VirginiaTech FNET

Oscillatory Stability Management

Simultaneous multi-oscillation detection and characterisation direct from measurements



Fast Modal Analysis: Alarms

Trend Modal Analysis: Analysis

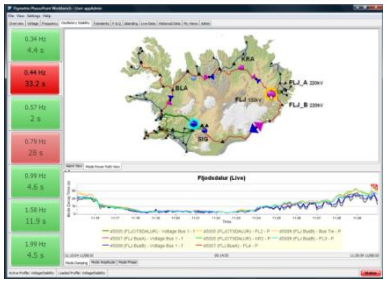
Operations

Early warning of poor damping (two level alarms)

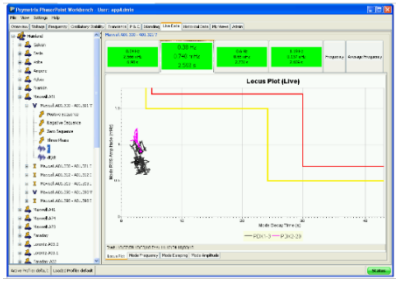
Unlimited oscillation frequency sub-bands

Individual alarm profiles for each sub-band

For each oscillation detected, alarm on:
mode damping and/or
mode amplitude for



Wide area mode alarms



Mode locus plot with alarm thresholds

Planning & Analysis, Plant Performance

Post-event analysis

Dynamic performance baselining

Dynamic model validation

Damping controller performance assessment

Oscillation Source Location

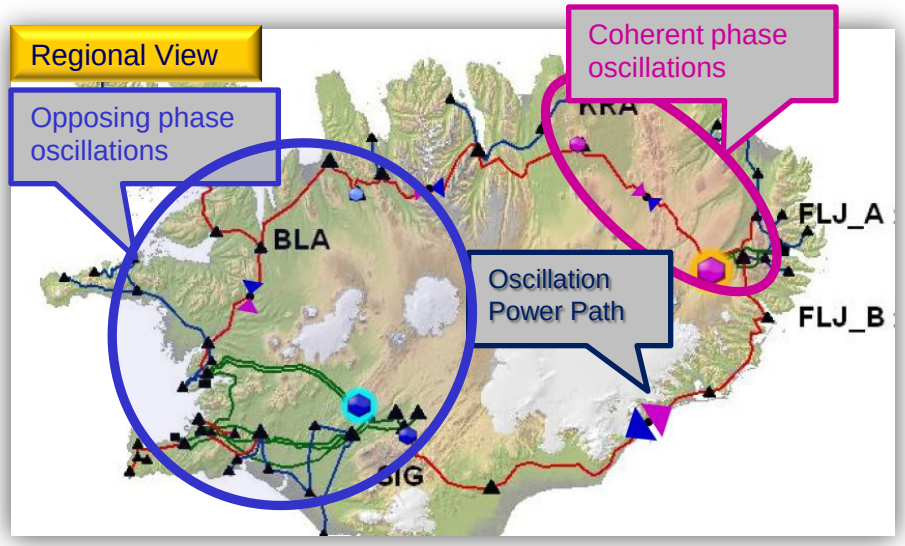
Mode Power Path

Identify contributions from regions

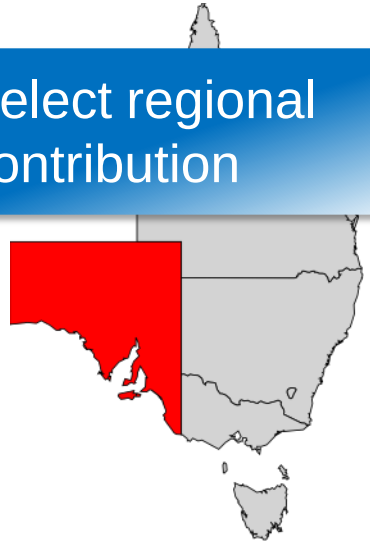
Uses only PMU data

All region boundaries monitored

“Regions” can be any size



1 Select regional contribution



2 Identify local contribution

3 Action guidelines

Auto-Report

GRID ALSTOM

Today: Schemes to protect grid reliability…

- **Local, Device protection:**
  - **Transformers, lines, bus structures, generating units, etc**

- **<u>System-wide, Grid protection</u>:**
  - **AGC (maintains system frequency) –**
    one of the first 'smart grid' applications - since the '60's…
  - **Remedial action schemes (RAS), special protection schemes (SPS), etc.**
    Drawbacks are:
    - **Logic is fixed and does not adapt to current conditions**
    - **Are conservative by design;**
      have to work for a wide range of 7/24 operating conditions

Tomorrow:
"Adaptive Wide Area Control"
To intelligently protect the entire power grid

- **Interconnection-wide protective control schemes that dynamically adapt to current power system conditions, and issue fast controls automatically, to preserve the integrity of the entire grid entity .**

The Grid of the 21st century: towards a bi-directional flow of energy and information

A "Smarter" network

From a traditional top-down network …

Centralized generation

Centralized consumption

… to a meshed network integrating all modes of generation and consumption safely and efficiently

New elements impacting the network

Renewable Energy

Energy Storage

Smarter Homes

Electric Vehicles

Micro Grid

New solutions to be developed

Smarter Data Management

Smarter Equipment

ALSTOM

Future Vision of the Energy Ecosystem

An Energy Ecosystem Driven by Innovation

Thank you…