Smart Solutions, Practical Results

Power Grid Reliability - Improvements with Wide Area Monitoring, Protection and Control

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Podfrekventno Rasterećenje Elektroenergetskog Sistema : Magistarski rad, 1987

Author: Damir Novosel

Mentor(s): Sejid Tešnjak/Željko Zlatar

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Edition/Format: Large print book : Croatian

Summary:

U ovom radu prikazana je fizikalna slika procesa promjene frekvencije. Izabran je simulacijski model dugotrajne dinamike za analizu dogadjaja u sistemu nakon pojave neravnoteže djelatne snage proizvodnje i djelatne snage potrošnje.Model podfrekventne zaštite je prilagodjen da bi se mogla izvršit icjelovita analiza djelovanja programa automatskog podfrekventnog rasterećenja.

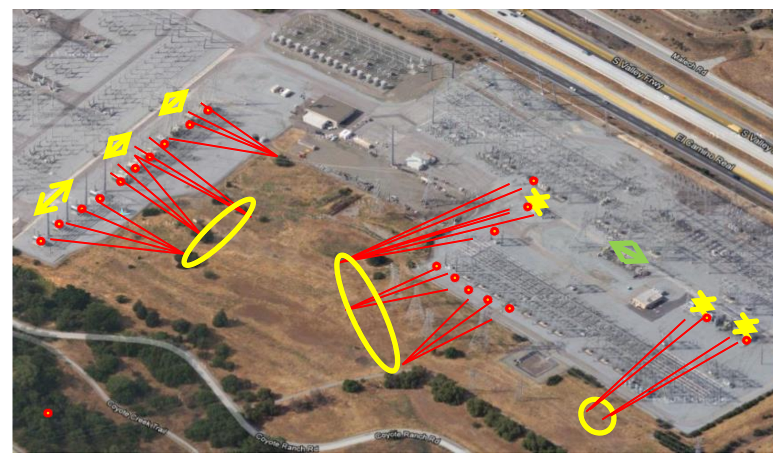
Outline

- Industry Trends
- Microgrids
- Blackout Prevention - Wide Area Monitoring Protection and Control (WAMPAC)
- Synchronized Measurement Deployment

Emerging Trends: Holistic Approach

Complex grid structures require "Smart Grid" solutions

- El. Grids in need of upgrading - Asset Management: Aging Infrastructure and Workforce
- Reliability and Regulation
  - Improved response to natural disasters
  - Address physical and cyber vulnerability
- Natural Gas Interdependency with Electric Power
- Energy consumption is changing with technology and environmental drivers
  - Micro-grids, DER
  - Electricity Storage
  - Electric Vehicles
  - Energy efficiency/DR



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Power Industry Trends and Needs

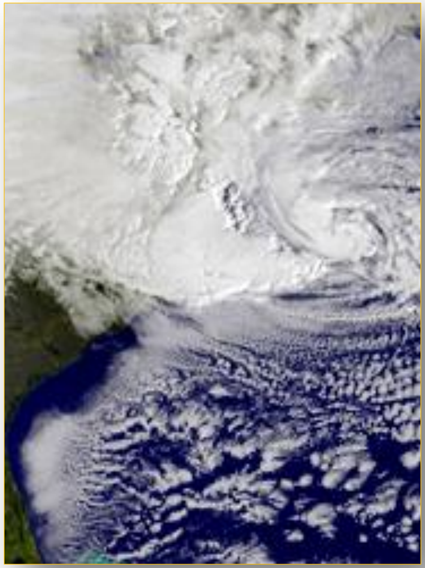
Power

- Manage grid dynamic behavior - e.g. frequency response, oscillations, voltage support and mgmt., power quality
- Need for improved models
- Regional markets require regional monitoring
- On-line limits - confidence through monitoring
- More complex SIPS/RAS
- System restoration

EMS/IT

- Next generation of EMS to be more integrated, incl. PMUs and dynamics; CIM use
- Emergence of Cloud Computing; Open source use
- "Supercomputers" are affordable
- Data management (mining SG data)

Major Weather Events Strategies

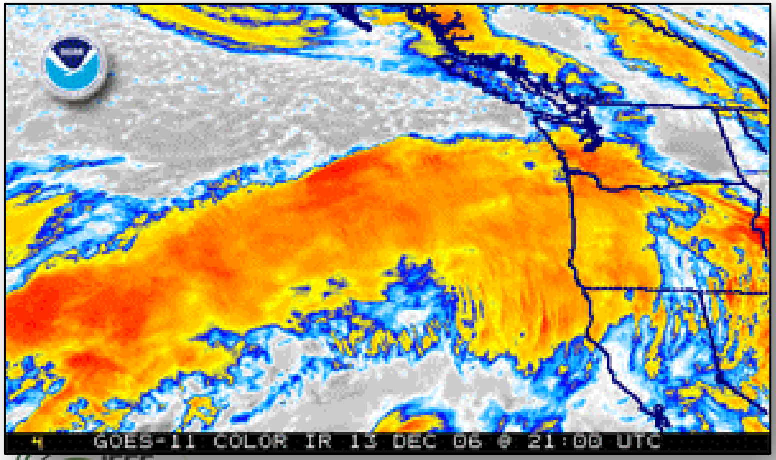


Reduce damage from severe and shorten restoration time

- **System Adaptation:** Preventing future damage with innovative approaches and technologies
- **System Survivability:** Maintain basic level of resiliency and delivery service during the storm
- **System Restoration**

Northeast Region - 2012 Hurricane Sandy

Pacific Northwest Wind Storms December 2006



Windstorm Categories
(Office of Washington State Climatologist)

Average Peak Instant Gust (mph)	Windstorm Category	Approximate Return Interval
39-44	Minor	Several per year
45-54	Moderate	Annual
55-64	Major	Every 2–3 years
65-74	Extreme	Every 5–10 years
75+	Phenomenal	Every 25–50 years

Why Microgrids?

- **Capacity, Reliability and Power Quality**
  - A low-cost augmentation/alternative to a utility system
  - Better power quality and outage management for critical, premium and remote customers (e.g., for weather related events)
- **Sustainability –** Enables optimal dispatch of renewables and high customer involvement
  - Emissions reduction
  - Green marketing
  - Community management
- **Cost Savings –** Portfolio of resources managed locally, but optimized on the system level
  - Enables a hedge against fuel cost increase
  - Net-zero model (still relies on the grid)

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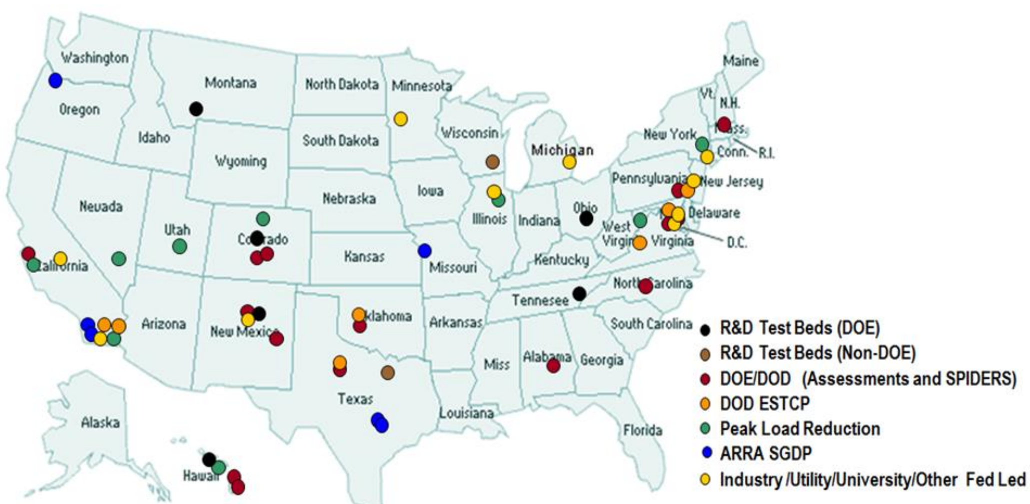
Optimized Hybrid Microgrids

- Energy Efficiency and Asset Management – lower OPEX:
  - Reduced equipment utilization and losses as generation supplied closer to the load
  - Peak load shaving – in conjunction with market pricing
- Utility grid as backup – Neither the MG nor the traditional system can fulfill all the needs of the local service, e.g. serving all the load, all the time – They must work synergistically
- New tools – Not easy to design and operate



Current Microgrid Landscape in USA (source: DOE)

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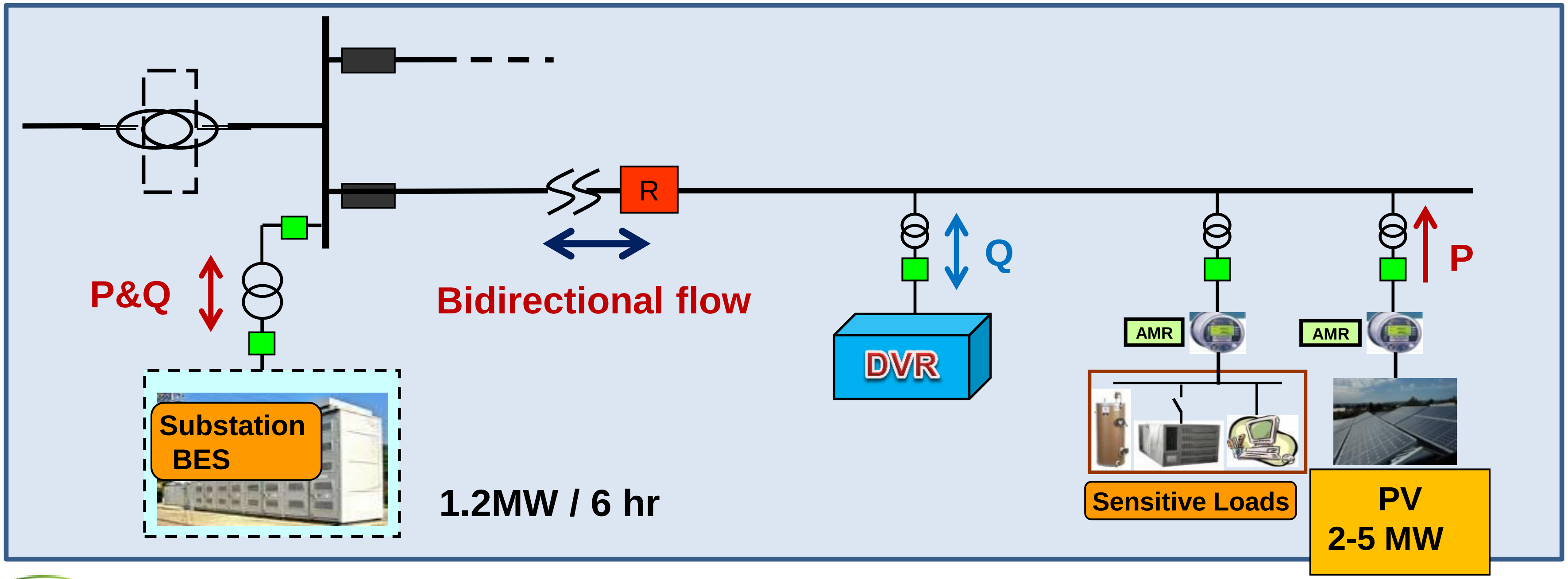
Early Adopters Value Proposition

- Who is best positioned to optimize use of microgrids?
  Life cycle costs, efficiency, reliability, safety, grid resiliency, etc.
- Gain experience with different types of storage technologies
- Interconnection standards



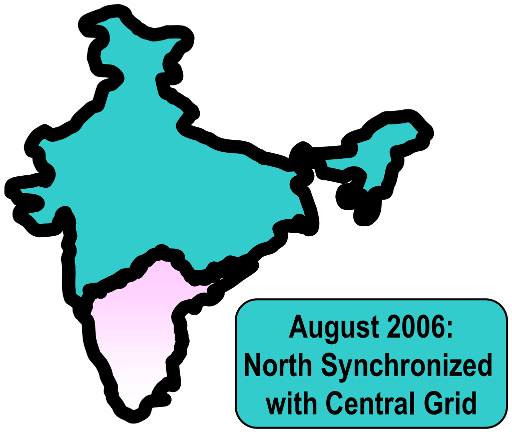
Preventing Large Blackouts

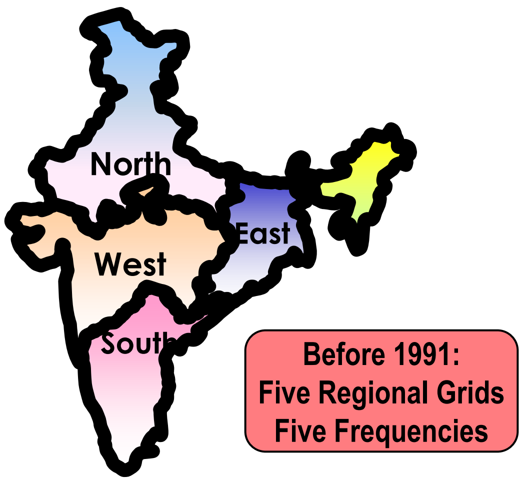
Multiple Contingencies with Complex Interactions

- System operated outside the limits
- Usually no "single" cause
- Sequence of low probability events difficult to predict accurately
- Infinite number of operating contingencies, different from the expectations of system designers
- Operators cannot act fast enough for fast developing disturbances

Wide Area Monitoring Protection and Control (WAMPAC)

India Blackout – July 2012





- Weak Inter-regional Corridors due to multiple outages of transmission lines in the West-North interface
  - 400 kV Bina-Gwalior-Agra, the only main AC circuit between West-North interface prior to the disturbance
- High Loading on 400 kV Bina-Gwalior-Agra link due to unscheduled interchange
  - Inadequate response to reduce loading
- Loss of 400 kV Bina-Gwalior link on Zone-3 distance relay caused the North to separate from the West

Source: Report from the Enquiry Committee on Grid Disturbances in Northern Region, India, September 2012

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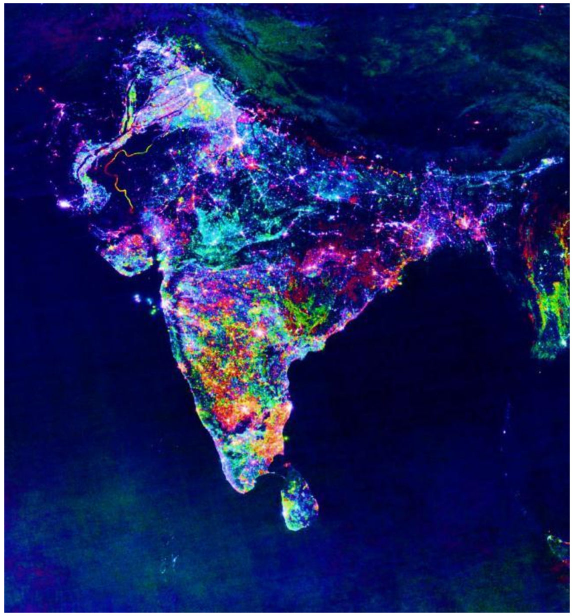
India Blackout – Key Findings

- Better visualization and planning of the corrective actions
- Deployment of WAMPAC
- Better regulation of interchanges
- Better coordinated planning of outages of state and regional networks, specifically under depleted condition of the inter-regional power transfer corridors

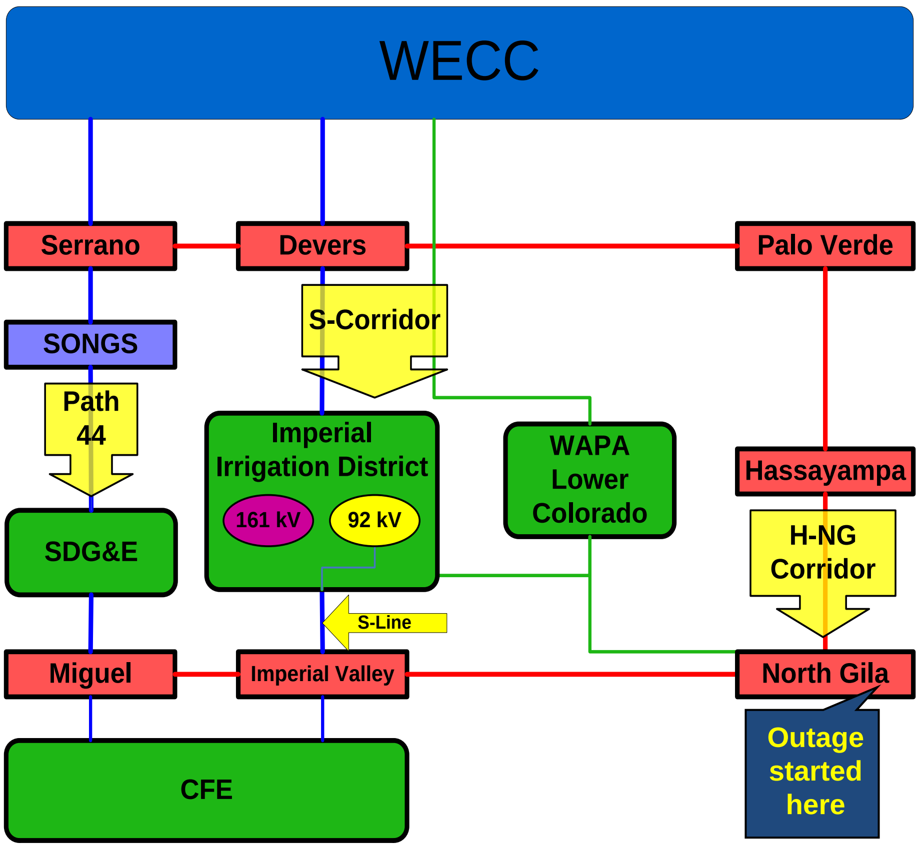


- Activation of primary frequency response of Governors
- Adequate reactive power compensation, specifically dynamic
- Under-frequency and df/dt-based load shedding
- Avoid miss-operation of protective relays

Source: Report from the Enquiry Committee on Grid Disturbances in Northern Region, India, September 2012

San Diego Blackout – Sep. 2011

Over 30 'major element' operations in 11 minutes



- Weaknesses in two broad areas
  - Operations planning
  - Real-time situational awareness
- Contributing factors
  - Not studying impact of sub 100 kV facilities parallel to EHV
  - Failure to recognize IROLs
  - Not studying/coordinating effects of protection systems and RASs during contingency scenarios
  - Not providing effective operator tools and instructions for reclosing lines with large phase angle differences

Source: Bob Cummings, NERC

WAMPAC Recommendations

November 4, 2006 Disturbance - UCTE Final Report

Recommendation 4 - UCTE has to set up an information platform allowing TSOs to observe in real time the actual state of the whole UCTE system in order to quickly react during large disturbances.

August 14, 2003 Outage: U.S.-Canada Power System Outage Task Force Report

"Recommendation 12a – The reliability regions, coordinated through the NERC planning committee, shall within one year define regional criteria for application of synchronized recording devices in power plants and substations…

Preventing Blackouts

New York City on October 31, 2012
Photographer Iwan Baan
Image published in New York Magazine

- Widespread electric outages are a symptom of strategies for grid management
- Analysis of recent disturbances reveals common threads
  - Learn from the past and proven methods to mitigate
  - Blackout propagation should be arrested
  - Restoration time could be reduced
- **Use of Synchronized measurements for Improved Situational Awareness and Control**
- Not possible to avoid multiple contingency initiated blackouts

HOWEVER…

Preventing Blackouts

The *Probability,*

***Size* and**

***Impact* of**

Wide Area Blackouts

can be

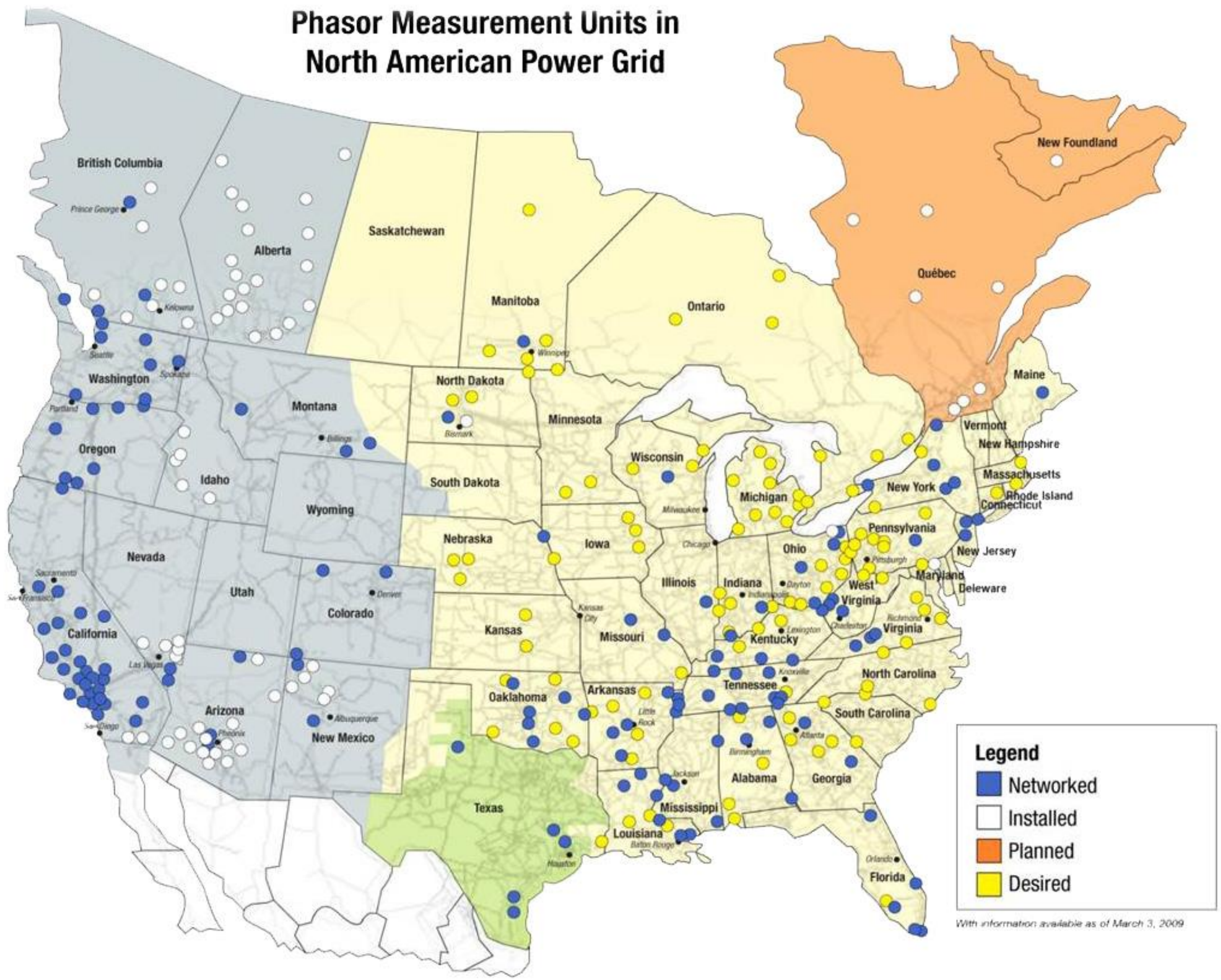
***REDUCED* …… !!**

Synchrophasor Deployment

U.S. and Canada 2009

Precise grid measurements (within 1 μs) using GPS signals - Phasor Measurement Units (PMUs)

Dynamic wide-area network view at high speed (e.g., 60 -120 observations/s) for better indication of grid stress



Source: NASPI

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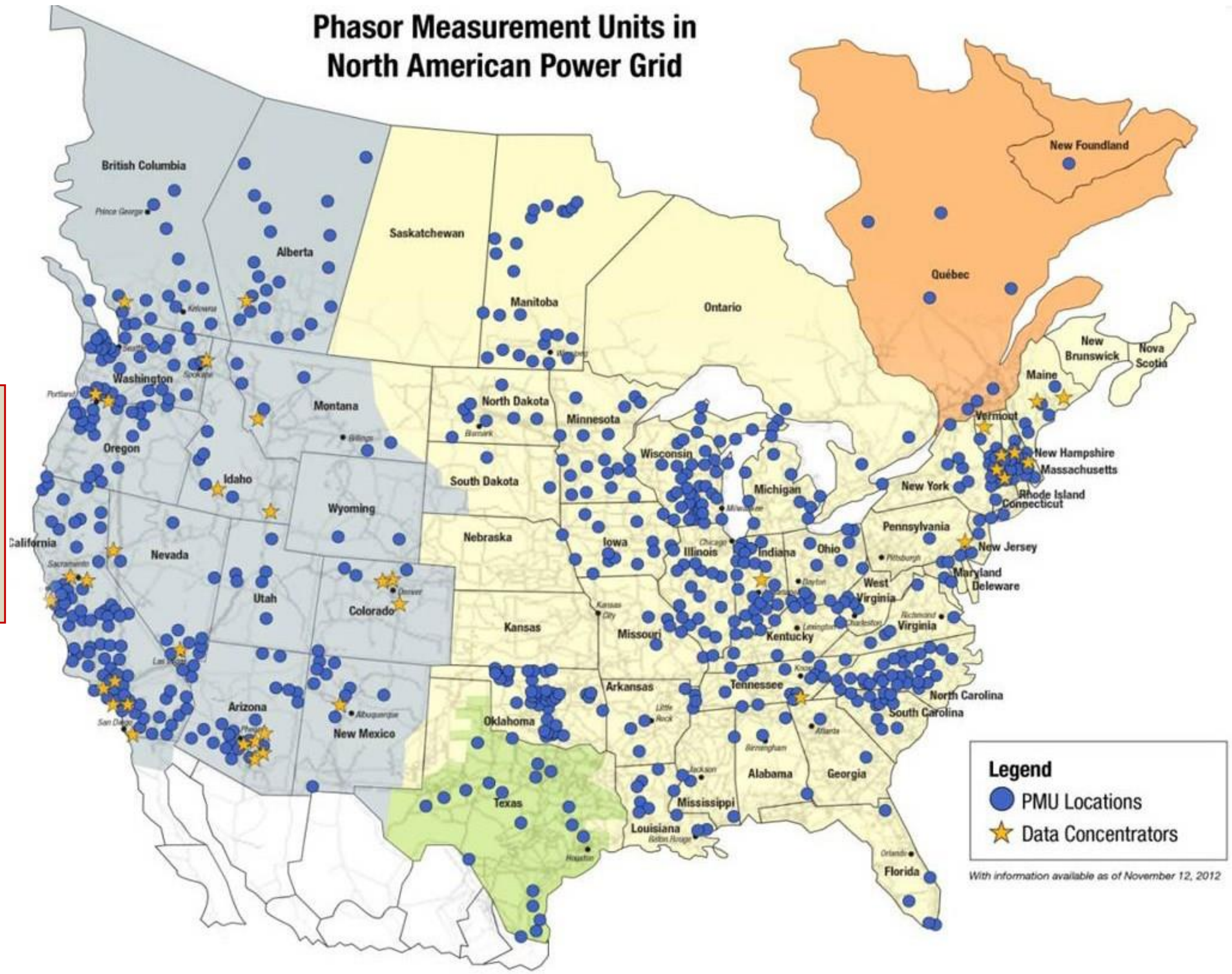
Synchrophasor Deployment

U.S. and Canada 2013



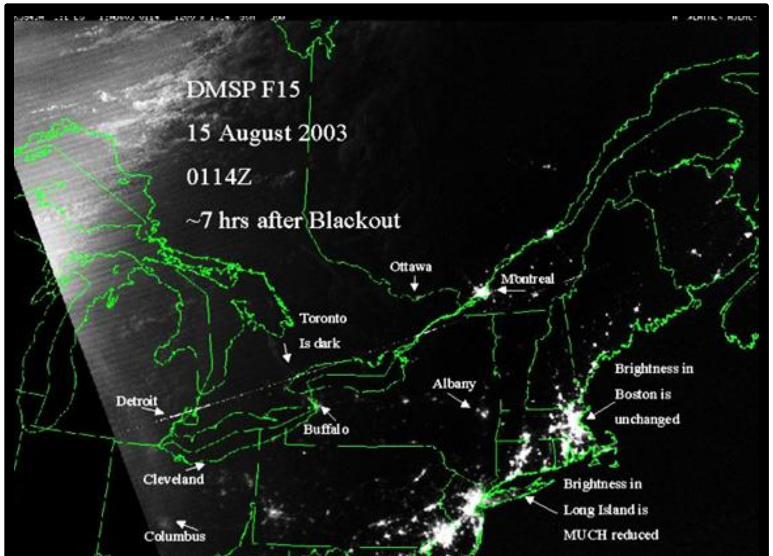
1,700 PMUs, most networked, funded by SGIG grants and private sector funds

Source: NASPI

Source: NASPI

Synchronized Measurements Key Benefit Areas

A Must for Smart Grid



Benefits of using the same infrastructure for variety of applications

- **Data Analysis and Visualization**
  - ➔ ***Significant benefits achieved***
- **System Operations and Planning, Modeling**
  - ➔ ***Enables paradigm shift***
- **System Reliability: Outage Reduction, Blackout Prevention**
  - ➔ ***Huge societal benefit***
- **Market Operations: Congestion Mgt. & Location Marginal Pricing**
  - ➔ ***Large potential financial benefit***

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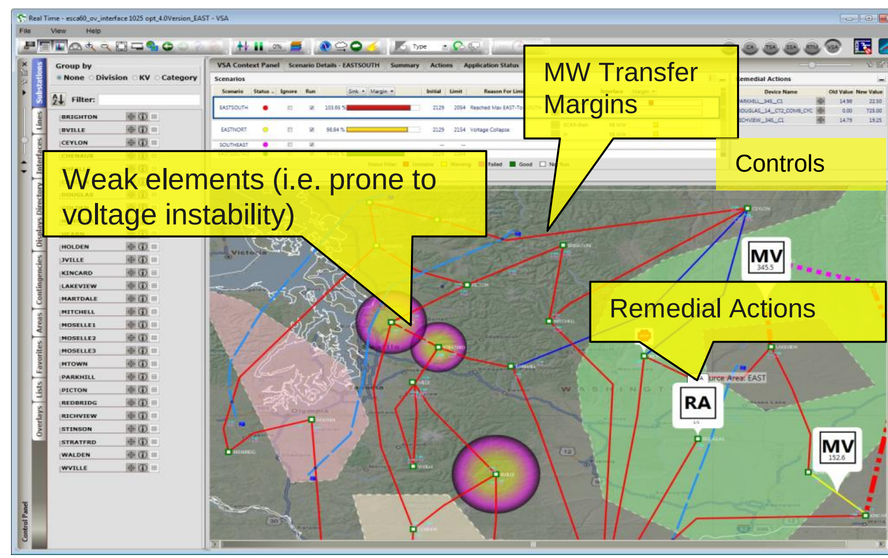
Operational Use Example

- Voltage angle differences across 4 regions (NYISO, PJM, MISO, IMO)
- The traffic lights representing the key metric elements
  - Left is internal NYISO control area,
  - Right is external control areas – Angle difference under the Health column should be equaled to zero and lights up if the sum of the four angles exceeds a certain threshold
- Violation message indicator also appears on the EMS SCADA system

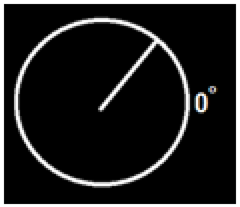
Source: NYISO

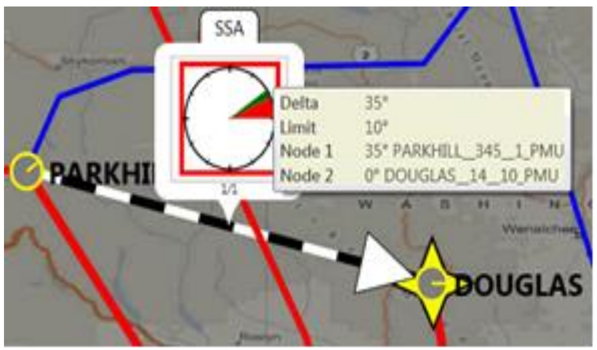
Pacific Gas & Electric Applications

- Situational Awareness, Visualization and Alarming (angles and voltages; overloads and oscillations)
- Voltage Stability Management
- Enhanced Energy Management Systems
  - Adding synchrophasor measurements to existing SE
  - Tracking dynamic changes and contingency analysis
- System Restoration
- Post-Disturbance Event Analysis, including Fault Location
- Operator and Engineering Training, Dispatch Training Simulator
- Provide interfaces with EMS and with third parties



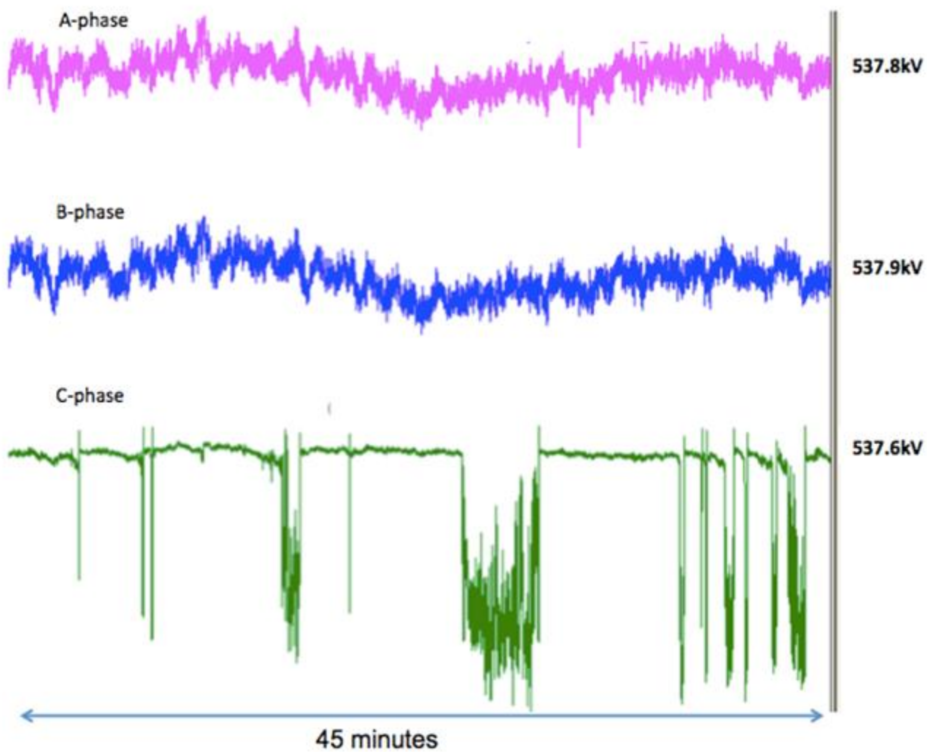
Phase Angle Monitoring and Alarming





- Relative Angles with respect to common reference
  - The difference between the measured voltage angle by and the voltage angle measured at a “reference” bus
- Angle Differences between a pair of nodes
  - Computed as difference in the voltage angle between two locations: typically between the “source” and “sink” areas of the system, or across a known corridor or interface
- Angle Rate-of-Change to detect sudden disturbances in the system
  - Computed as change in voltage angle over a user-defined time period (e.g. 1 s)
  - Represents relatively fast changing angles in time (e.g. pre- and post-event angle change during a disturbance)

Dominion Equipment Monitoring



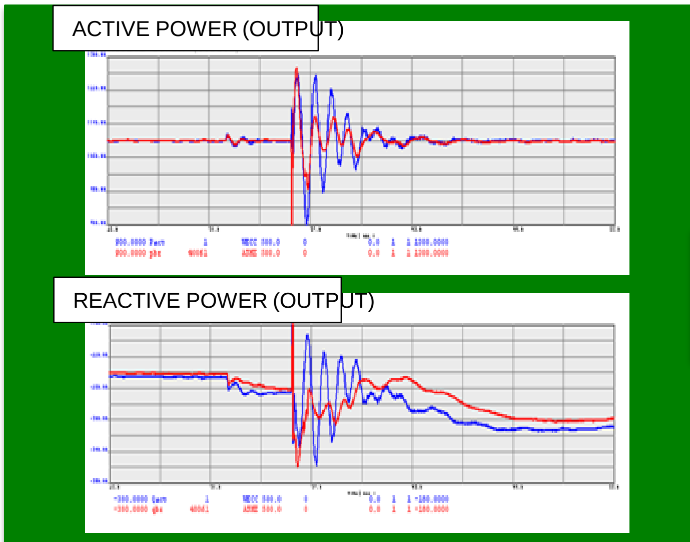
CCVT failure detected 4 days before relay triggered failure alarm

- Estimating CT/PT Ratios
- Signal-to-Noise Ratio
- Geomagnetically Induced Currents (GIC)
- Transformer Health Assessment

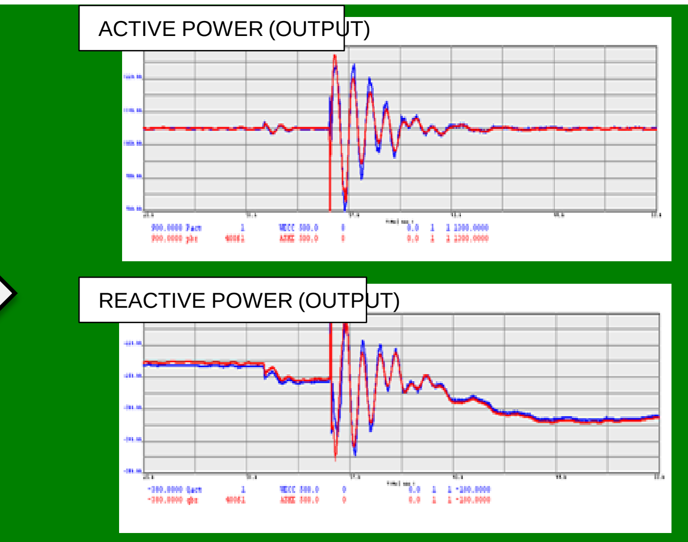
Source: Dominion

Data to Calibrate Generator Models

Improved conformance between predicted (red) and measured (blue) generator outputs



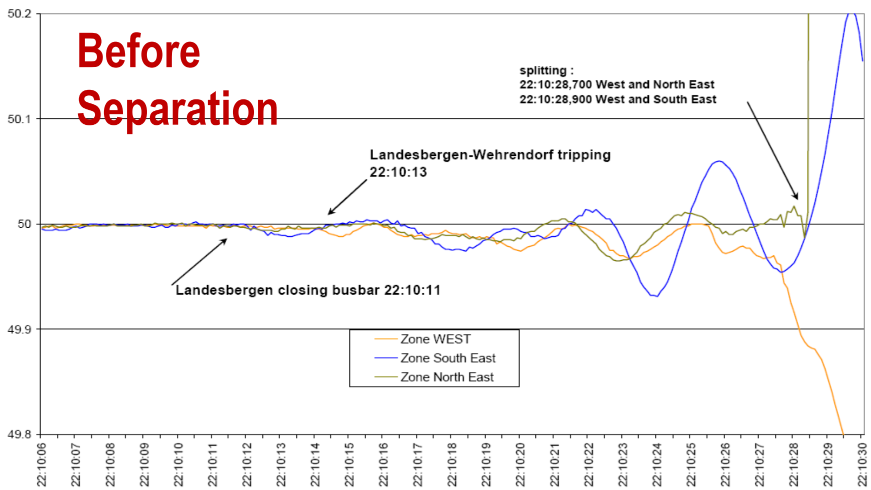
PMU-based model improvement

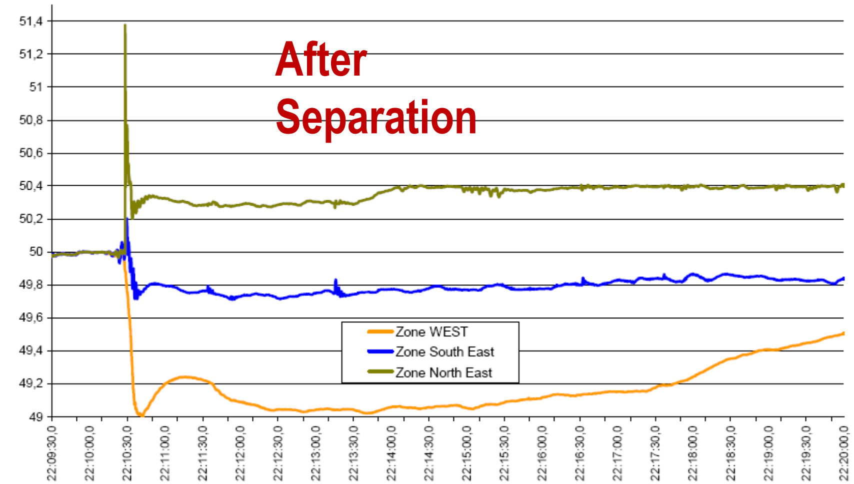


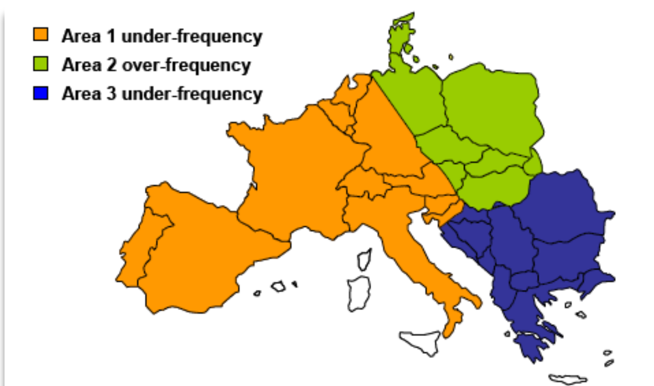
Calibrated the Columbia Generation Station unit online, avoiding a $100K to $700K cost to bring the unit down

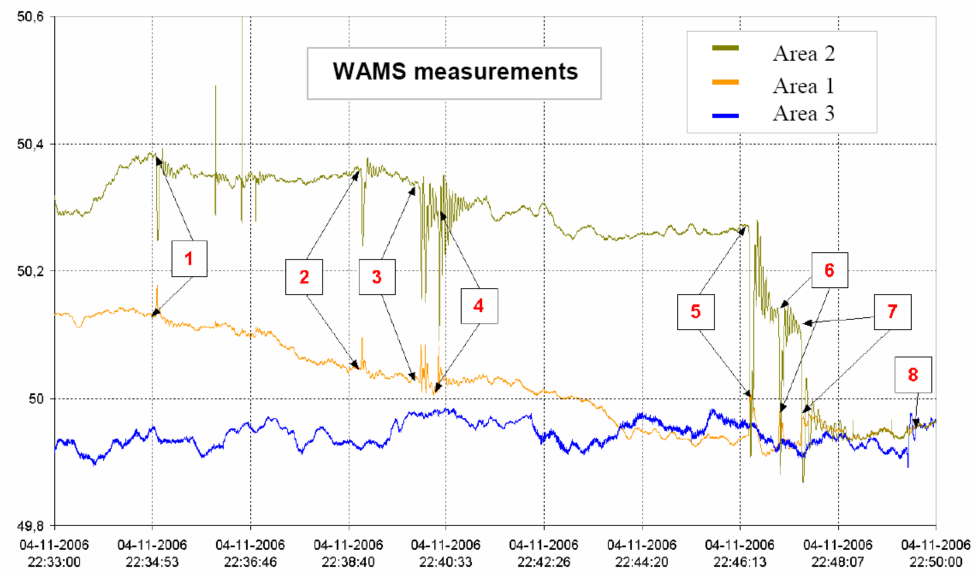
Source: WISP Project Update, 7 August 2012.

November 2006 Europe: Synchronized Data

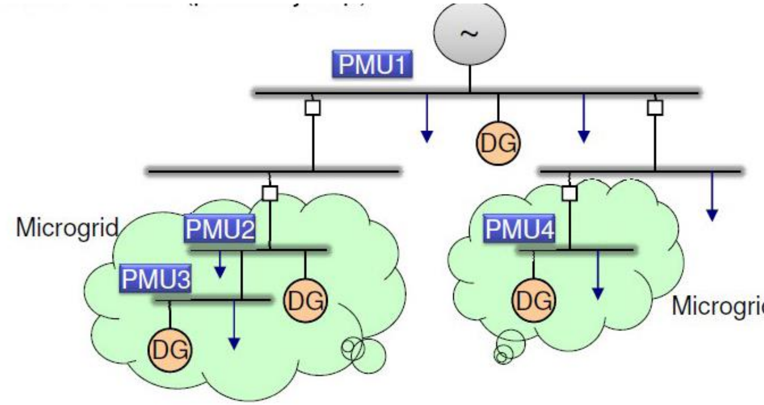








Applications in Distribution

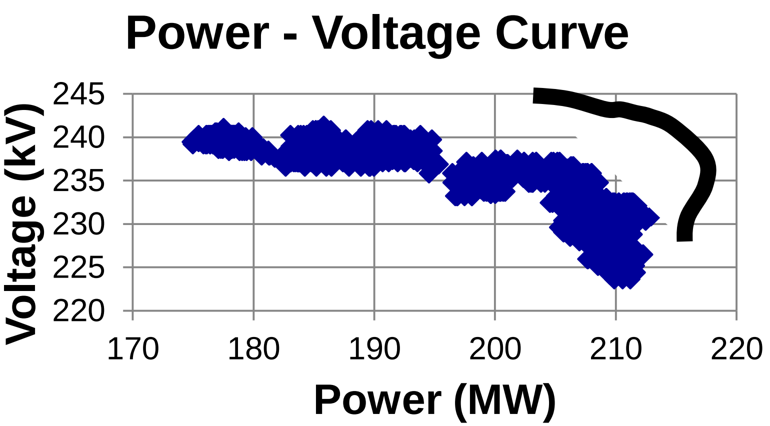


- Islanding detection and formation and re-synchronization
- Distribution state estimation
- Post mortem analysis
- Load modeling & Parameter estimation
- Adaptive fault location & detection (high-impedance fault)
- Power Quality (harmonic estimation)
- Volt / VAR Optimization
- Voltage and transient stability monitoring, incl. FIDVR
- Closed-loop feeder operation
- Condition monitoring & Dynamic rating

Voltage Stability Monitoring & Assessment 2 (2)

Measurement-based indicators:

- Monitor available reactive power levels (capacitor/reactor reserves, tap-changers)
- Singular Value Decomposition (SVD)
- Sensitivity analysis
- Distance of the load's apparent impedance to the Thevenin impedance (VIP, REI, RVII)

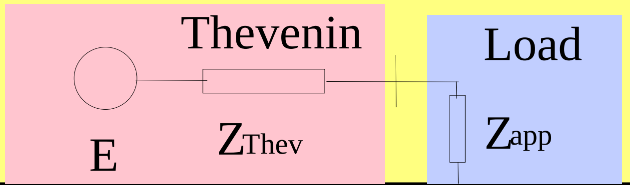


(Source: BPA)

Maximum power transfer

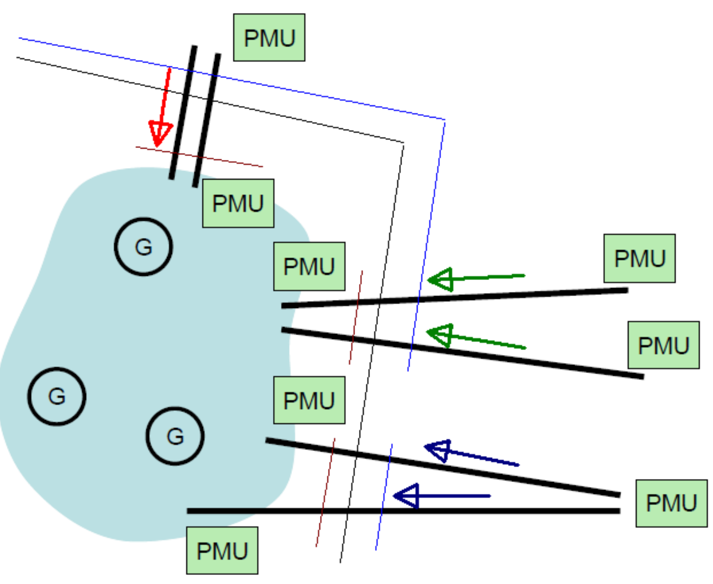
$\Leftrightarrow |Z_{app}| = |Z_{Thev}|$

Point of collapse



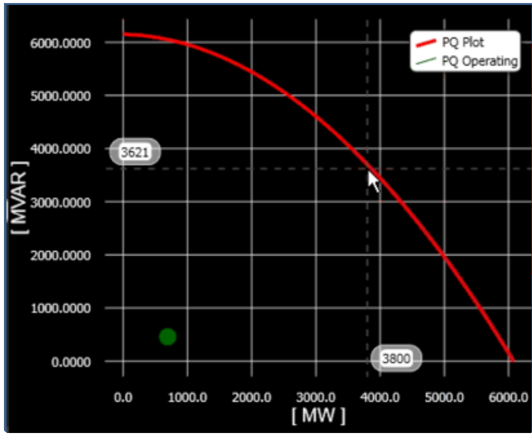
Real-time Voltage Instability Indicator (RVII)

- Model-free, fast tracking of both slow changes and system dynamics - using available PMU (10 -120 frames/s) and SCADA data
- Implementation in several variants: bus, load center, transmission corridor
  - Calculate Q-margin & other indices for proximity to voltage collapse
- Implementation in Control Centers and local IEDs, combined with other methods
  - Reactive power monitoring for situational awareness
  - Initiate model-based contingency analysis
  - Addition to SIPS



Comprehensive Voltage Stability Management

Real-Time Voltage Instability Indicator



Estimate Reactive Power Margins to Instability

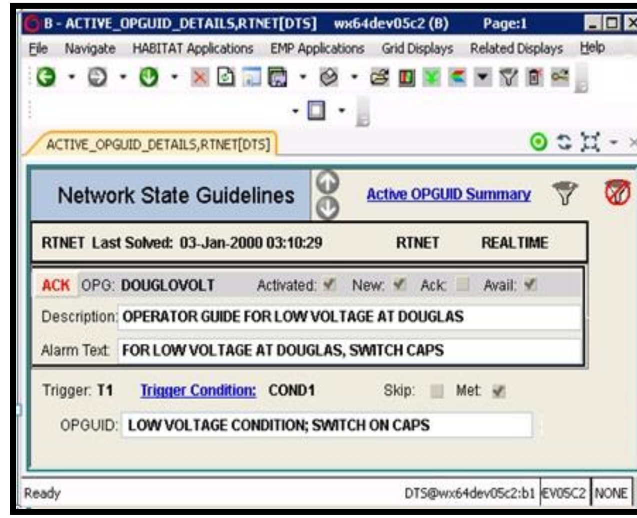
Indicate the simultaneous occurrence of Low Voltage over a broad region.

Reactive Reserve (MVAR) monitoring for user-defined areas in EMS.

Detect WHEN to Take Action... and HOW to Respond!

AND /OR

Operator Guides in EMS



Decision making:

- Operator Guides (e.g. “Switch On Capacitor Banks”).
- “Arm” Special Protection Schemes

Source: PG&E

System Testing and Data Conditioning is Critical

Proof-of-Concept Facility

Source: PG&E

Instrumental in gathering the knowledge to provide the industry with direction and a fast track process for maturing the standards such as the IEEE C37.118.2, C37.238, C37.242, C37.244, and IEC-61850-90-5

- Risk management: Identifies and remedies product and system integration issues
- Fine tuning applications for functionality and performance
- Online Data Conditioning
  - Mitigate bad/missing data
  - Linear State Estimator is used for front end data conditioning (Dominion)
- Transition from development to operation for training future users
  - System simulator
  - Training simulators

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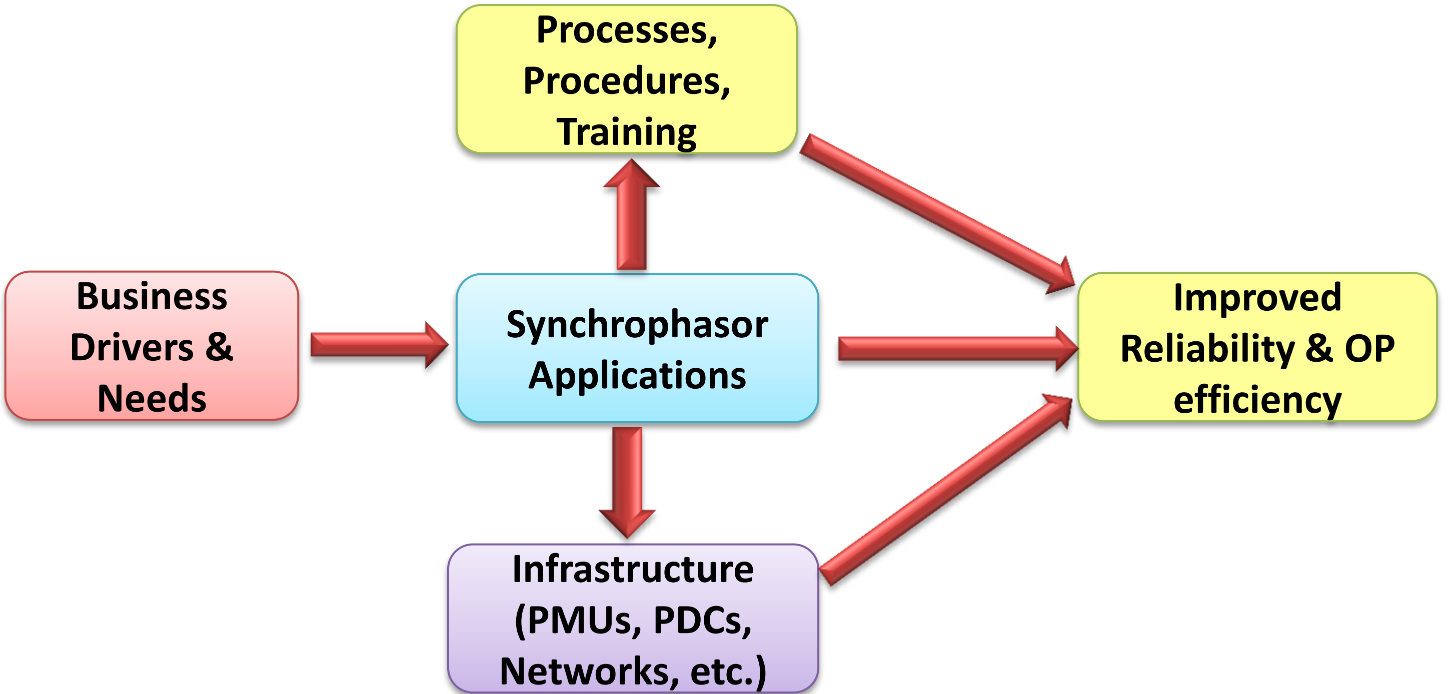
Roadmap Process

- Needs and requirements of various stakeholders
- Corporate policies and preferences
- Regulatory requirements in place or in the pipeline

Cost-benefit analysis to develop Near-, Mid- and Long-term plans with an impact level: *Low, Medium, High*

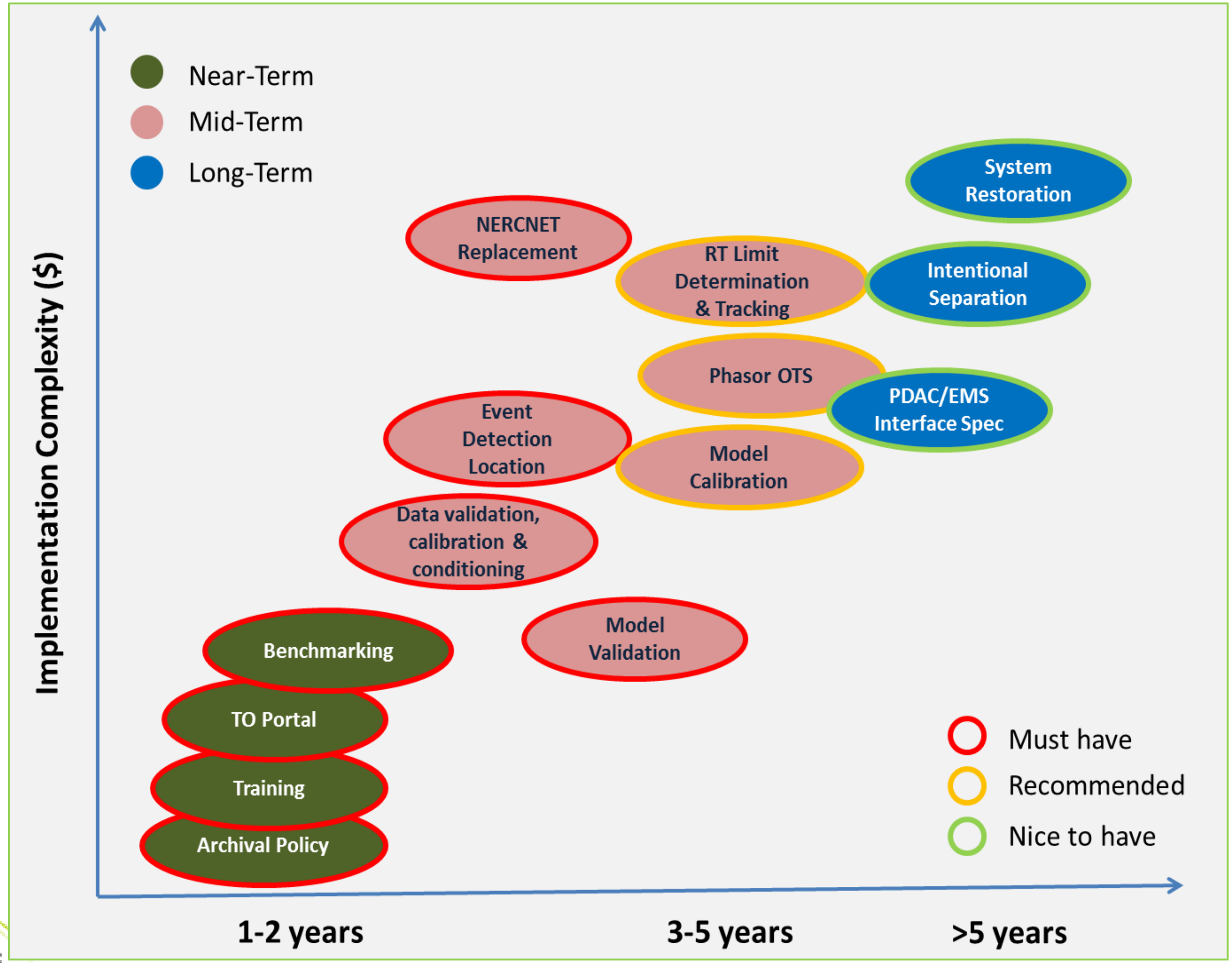


Near-Term Roadmap

Impact	INFRASTRUCTURE	APPLICATIONS	PROCESSES
HIGH	▪ Full production-grade system: QA/Staging & Training/Test environments ▪ Redundant ISO-TO communication network ▪ Enhanced DQMS ▪ CIP compliant measures ▪ Displays sharing with TOs	(1) ▪ Fast and accurate post-event analysis ▪ Generation and Load dynamic model validation ▪ PhasorPoint operational use ▪ ROSE operational use ▪ Online oscillation (< 10Hz) detection and mitigation	▪ Processes, procedures & training for items in (1)
MEDIUM	▪ Initial data exchange with some neighbors ▪ Initial EMS integration ▪ TO expand PMU coverage to lower voltage levels and generation stations ▪ Initial ISO-NE access TO DFR/DDR data	▪ PMU only SE (345 kV) – Feasibility demonstration ▪ Online calibration and status monitoring of PMUs	
LOW	Initial integration with other ISO-NE systems (e.g. GIS, OMS)		

Source: ISO NE

NYISO Roadmap – Big Picture

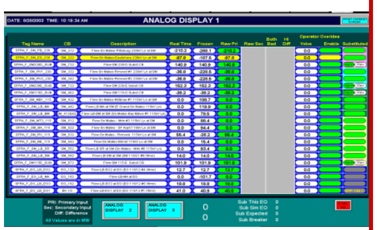


Source: NYISO

Synchronized Measurement Progression

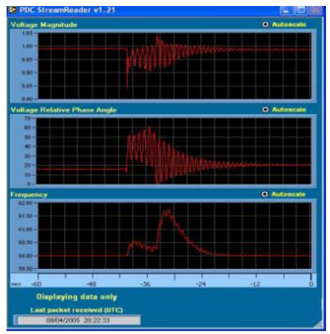
Before

First PMU



Analog Displays

Products Now



2014

Standard feature (relays, DFR, controllers, monitors)

On major interconnections and generators

Standard SW tools included in EMS/SCADA

Primary use for monitoring, event analysis

Interoperability standards deployed

Some distribution PMUs

Improvements in communication infrastructure

2018

Thousands of synchronized measurements world-wide

Integrated in standard business and operational practices

Fully integrated with EMS/SCADA or Independent system

Higher data rates

Fully in Distribution

Distributed comm. and processing architecture

Fast Control and Adaptive Protection

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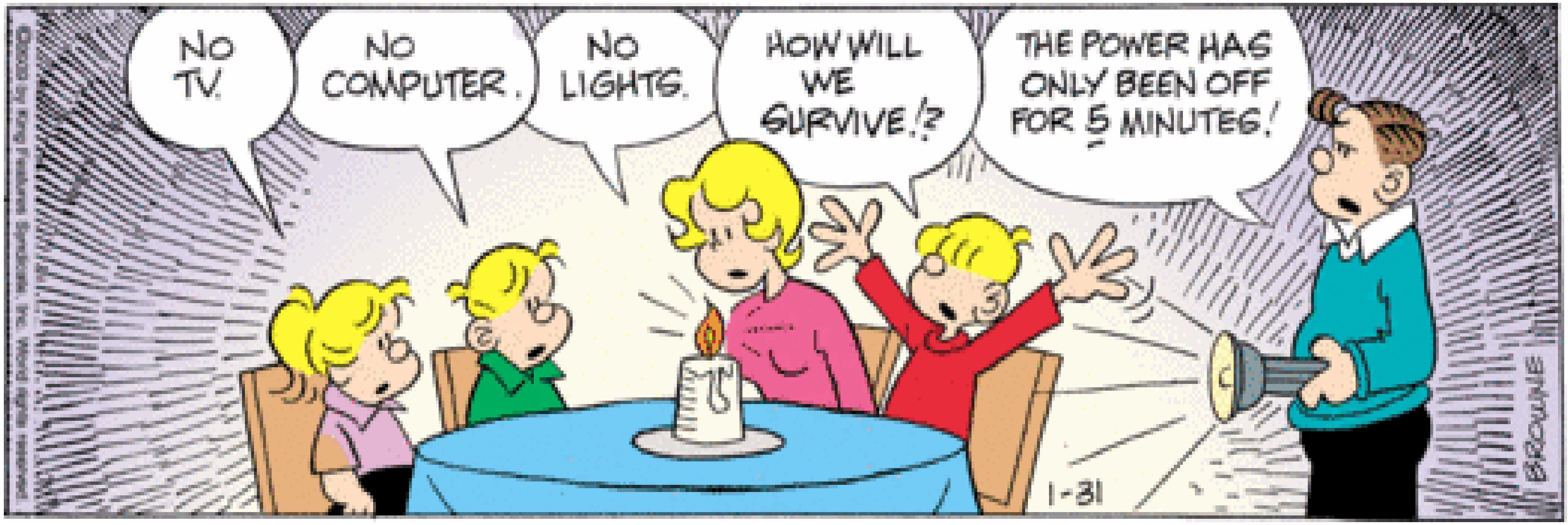
Key Deployment Success Factors

- Present synchrophasor deployment is only "tip of the iceberg" for on-going reliability improvements and benefit realization

Finding a killer application!?

- Assure Life-cycle Quality of Measurements – Requires TOs to take Ownership and Realize own Benefits
- Baselining to Provide Norms: Historical Data/Simulations
- Updates of Application and Design Roadmaps
  - System expandability as measurements & applications grow
  - System integration with other enterprise systems
- Engineering and Operator Guidelines and Training
- Data and Information Exchange Across Interconnections



Thank you

Questions?