NASPI North American SynchroPhasor Initiative

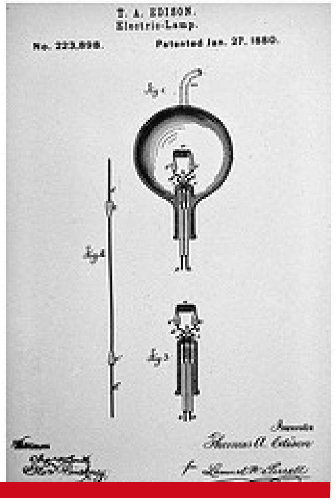
Damir Novosel

Quanta Technology President and Founder

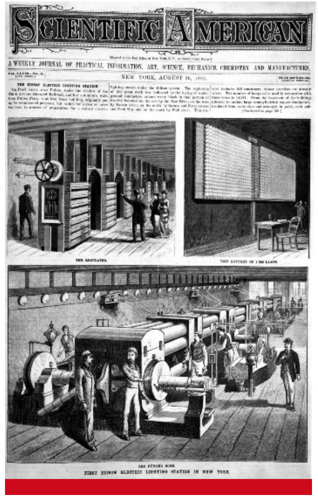
September 26, 2023

Past. Present. Future ➡➡➡

A New Industry: Electric Power and Light

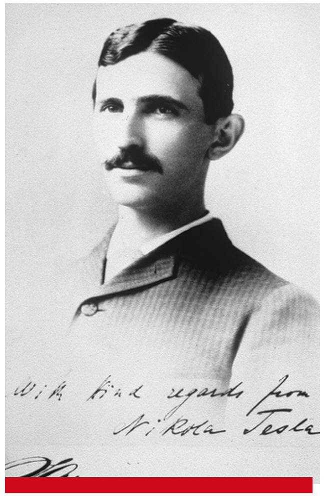


Thomas Edison and his incandescent light patent



Edison's first commercial plant, Pearl St., NY 1882

Samuel Insull built the reliable "power pool", reducing production costs, and rates, and increased efficiency



Nikola Tesla designed the induction motor and a comprehensive system for polyphase AC power

- Edison opened his first electric power plant in New York in 1882. ***Was it a microgrid?***
- Within a decade, electric power had spread to every corner of the globe, with many new applications!
- Why was the grid interconnected throughout the years?

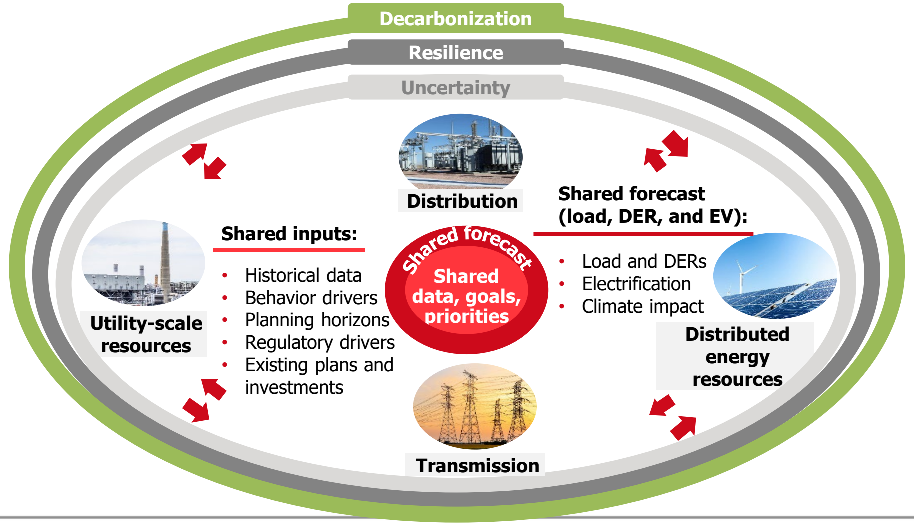
Future: **Distributed vs. Centralized Generation?**

Role of Synchronized Measurements

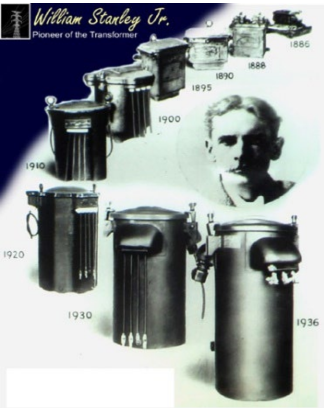
Cost-effectiveness

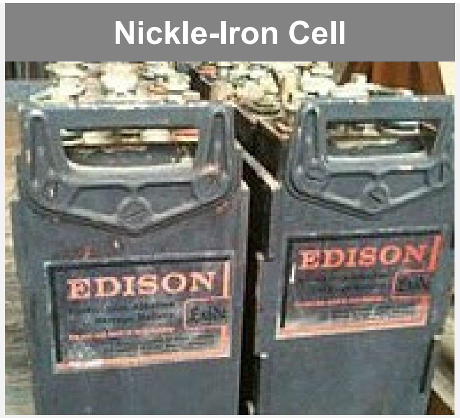
Reliability

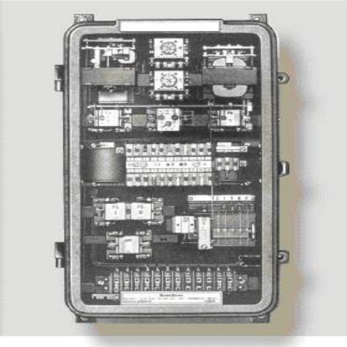
Safety

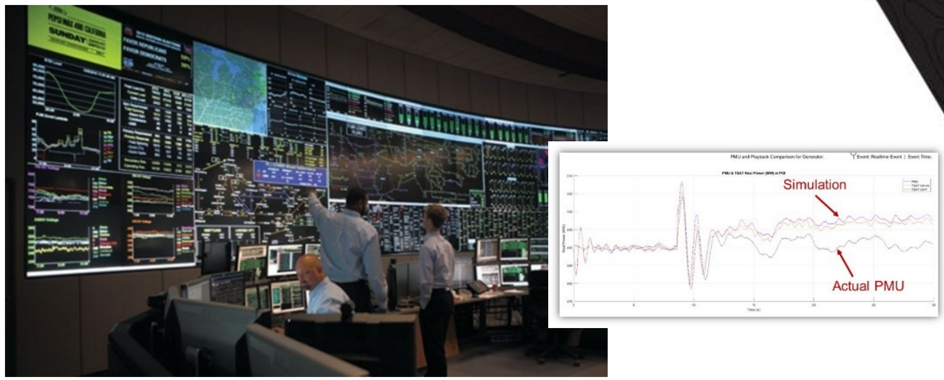


If Edison and Tesla Returned…





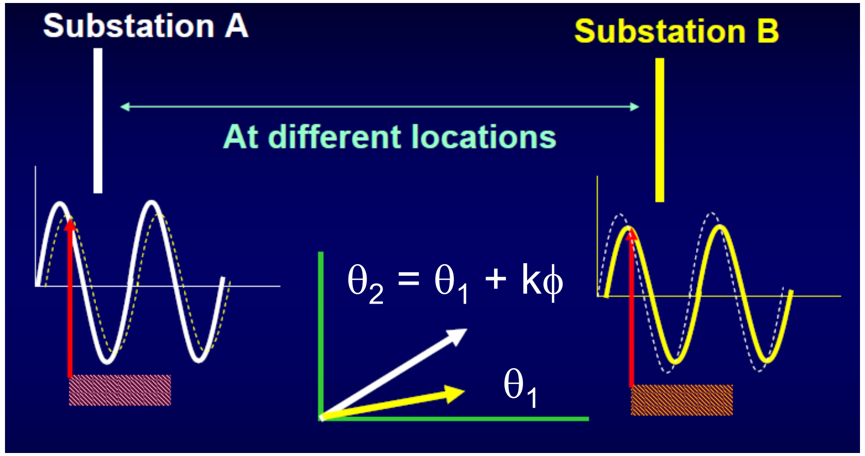




Arun Phadke and Jim Thorp - Joint Franklin Award Recipients

Life Has More Light With
Arun, Jim & PMUs

"Working in a team, does not reduce contribution and importance of an individual; it makes it much stronger"



Example: *Past - August 14, 2003 North American Blackout Need for Phase Angle Monitoring and Control*

Needs:

- Provide operators with real-time angle and angle change
- Avoid incorrect out-of-step operation
- Improved planned power system separation

Benefits:

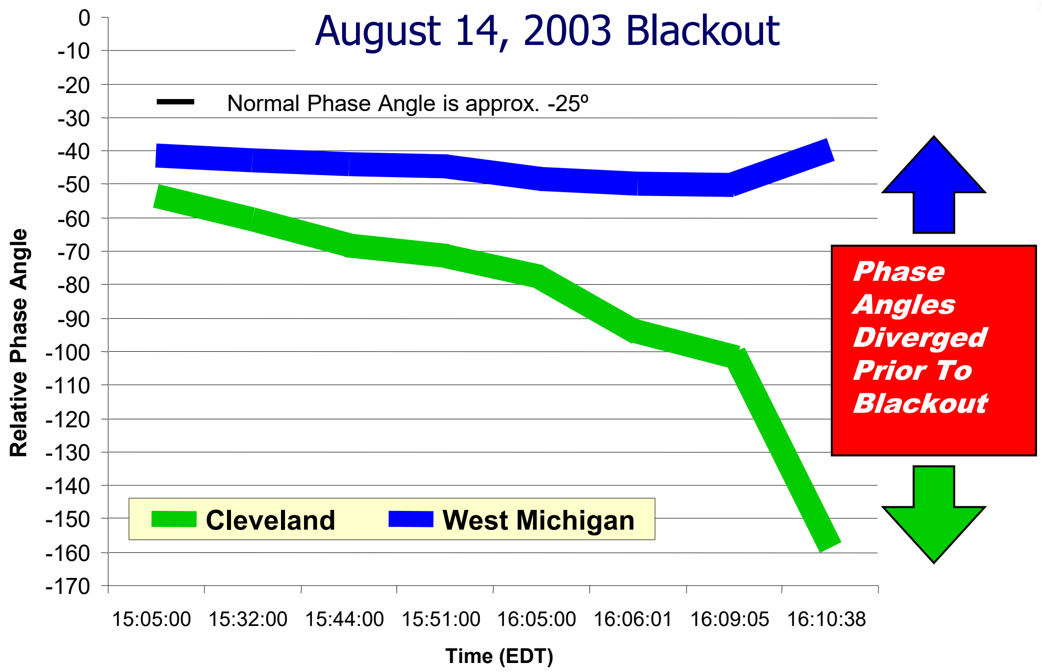
- Improved real-time awareness, incl. neighboring systems
- Improved out-of-step tripping and blocking
- Separate the system on most-balanced way
- Assist operator during manual reclosing of tie lines

Technology:

- Synchrophasor visualization tools
- Advanced algorithms using wide-area information
- Smart algorithms for instability and coherency detection, separation boundary identification

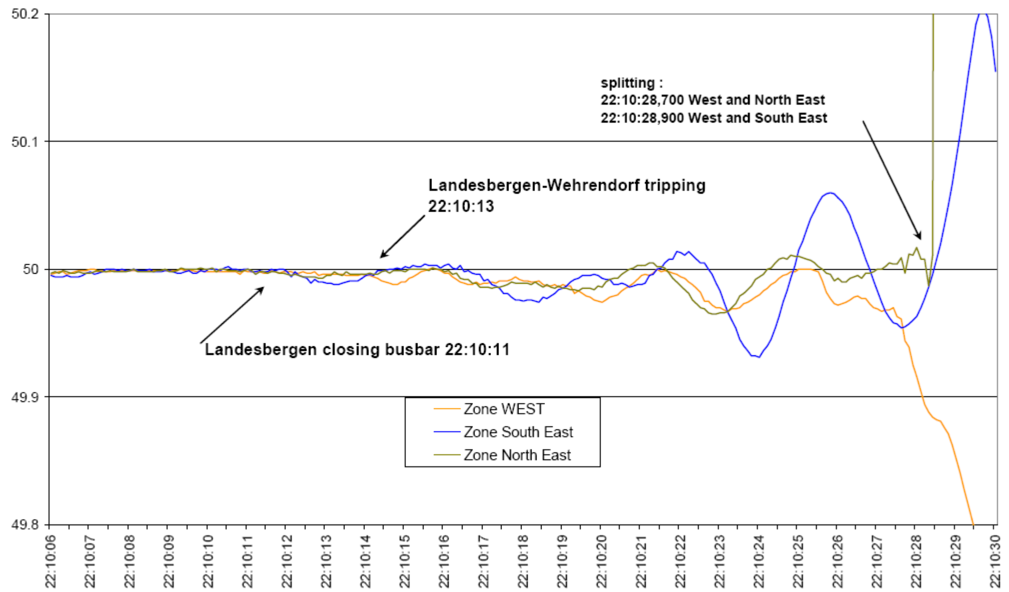
Gap:

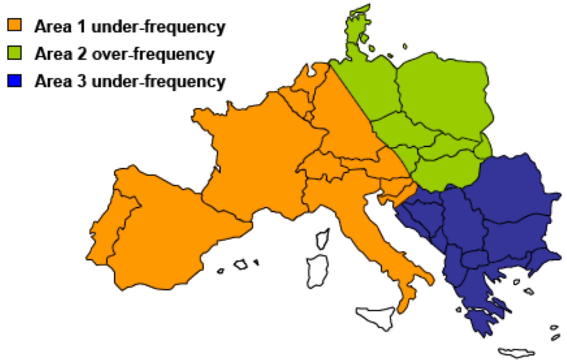
- Operator acceptance, incorporation in the utility/ISO process/rules
- System studies and testing



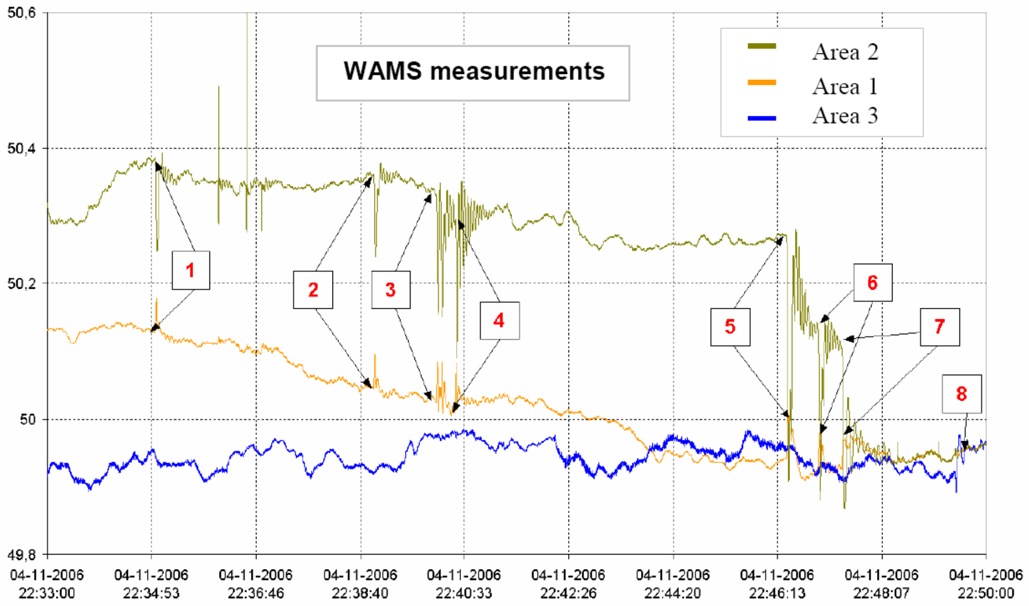
Source: TVA

Example: *Past - Nov ’06 Disturbance, Europe*

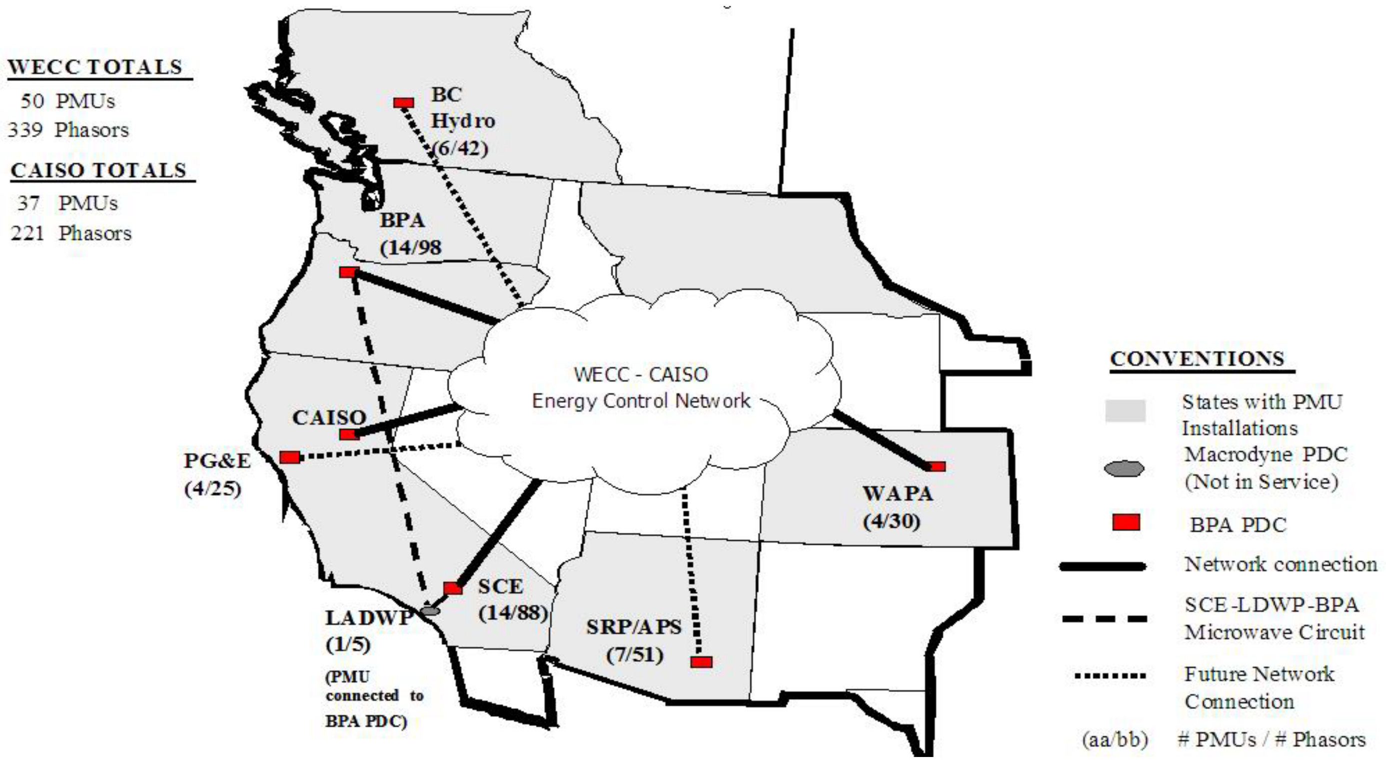




- Resynchronization attempts:
  - [7]: difference of 180mHz and 10 degrees
  - [8]: difference of 40mHz
- System re-established in 2 hours

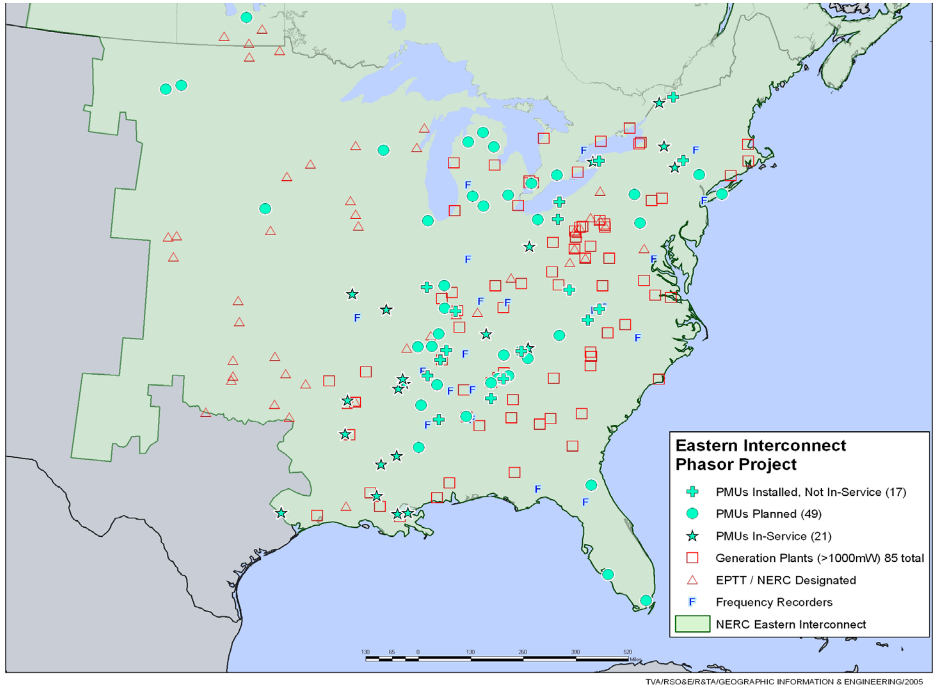


WECC and EIPP Synchronized Phasor Network - 2005



EIPP PMU Companies*

- Ameren, AEP, American Trans. Co.,ConEdison, Entergy, Exelon/ComEd, Exelon/PECO, First Energy, Hydro 1, LIPA, Manitoba Hydro, METC, MISO, NYISO / NYPA, PPL, Southern Company, TVA
- 57 connected PMUs



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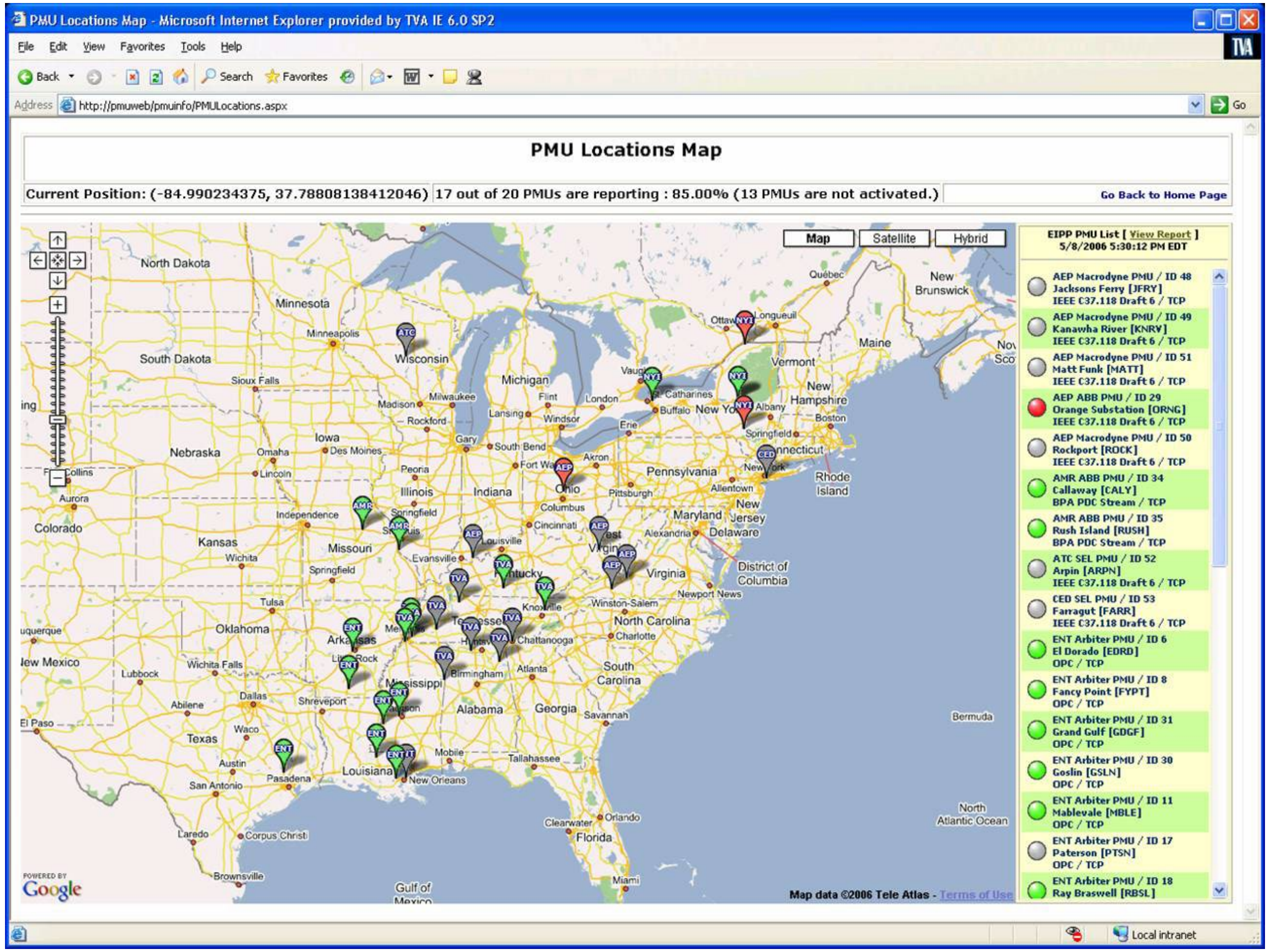
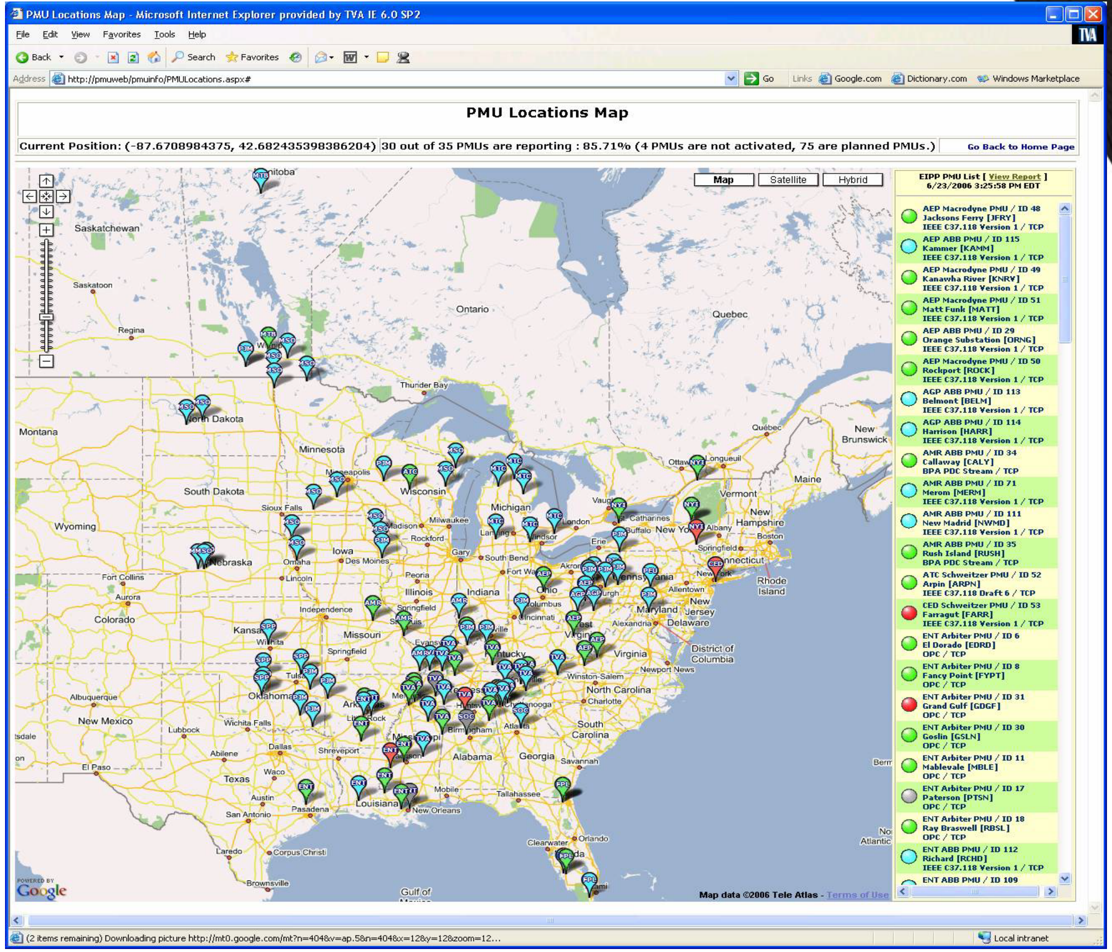
EIPP PMU Map - 2006

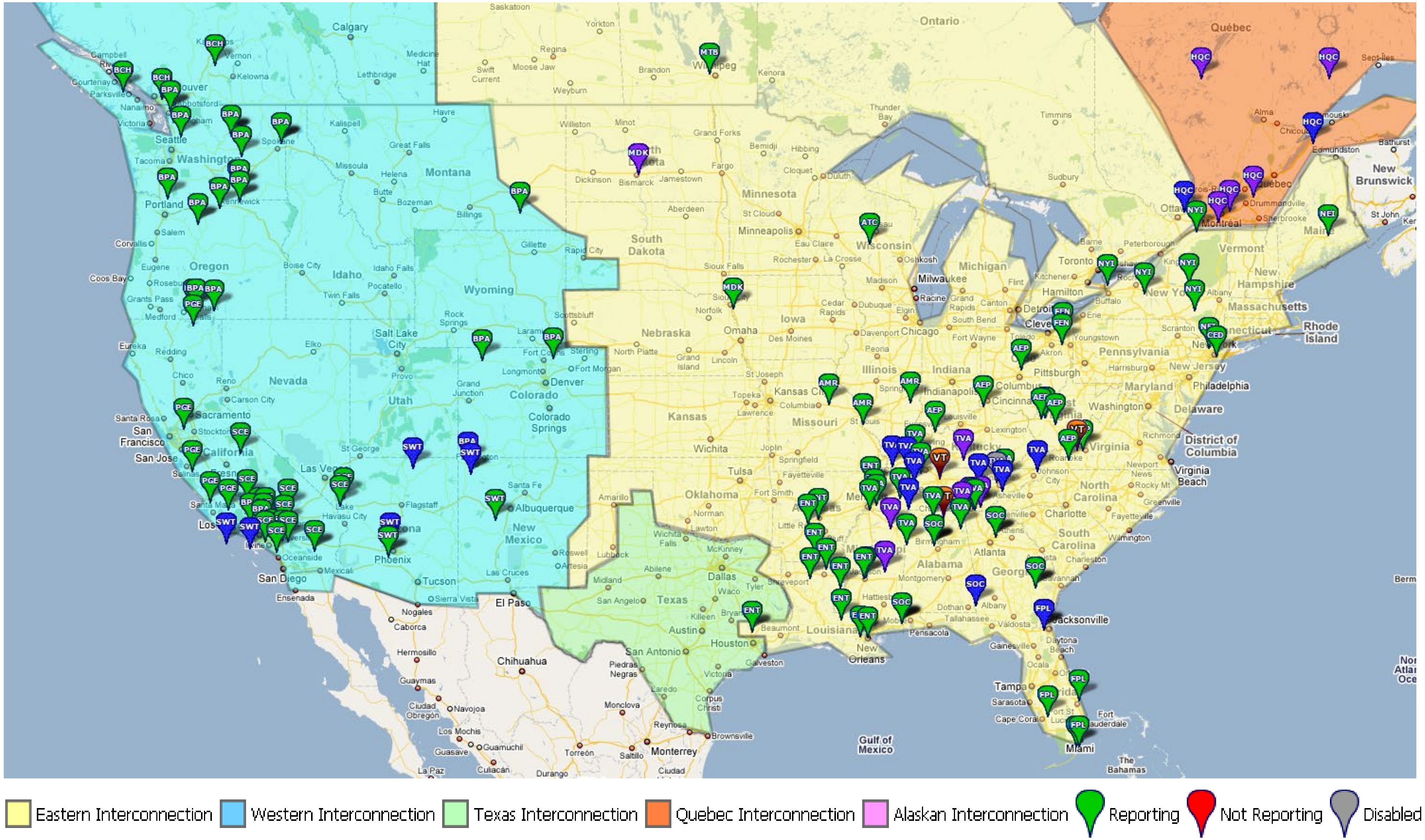


Early 2006

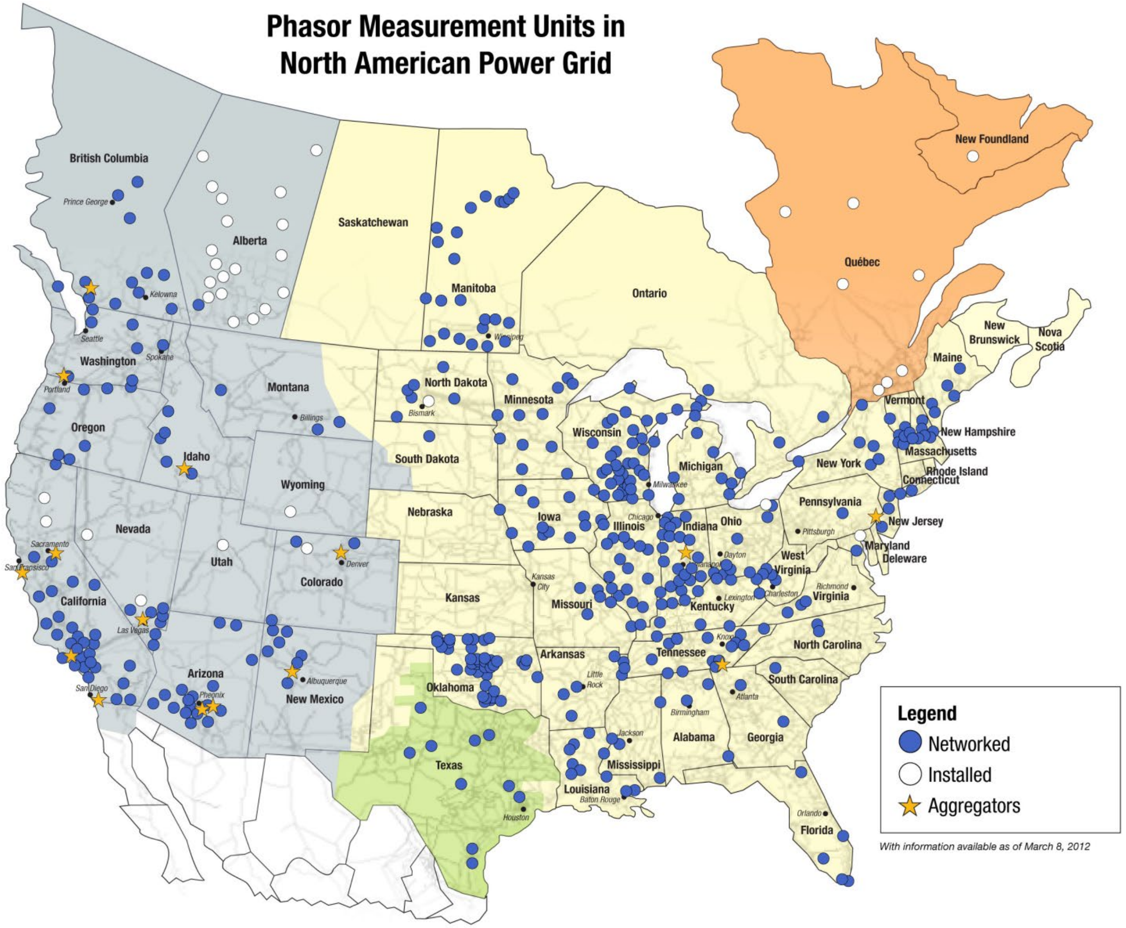


Late 2006

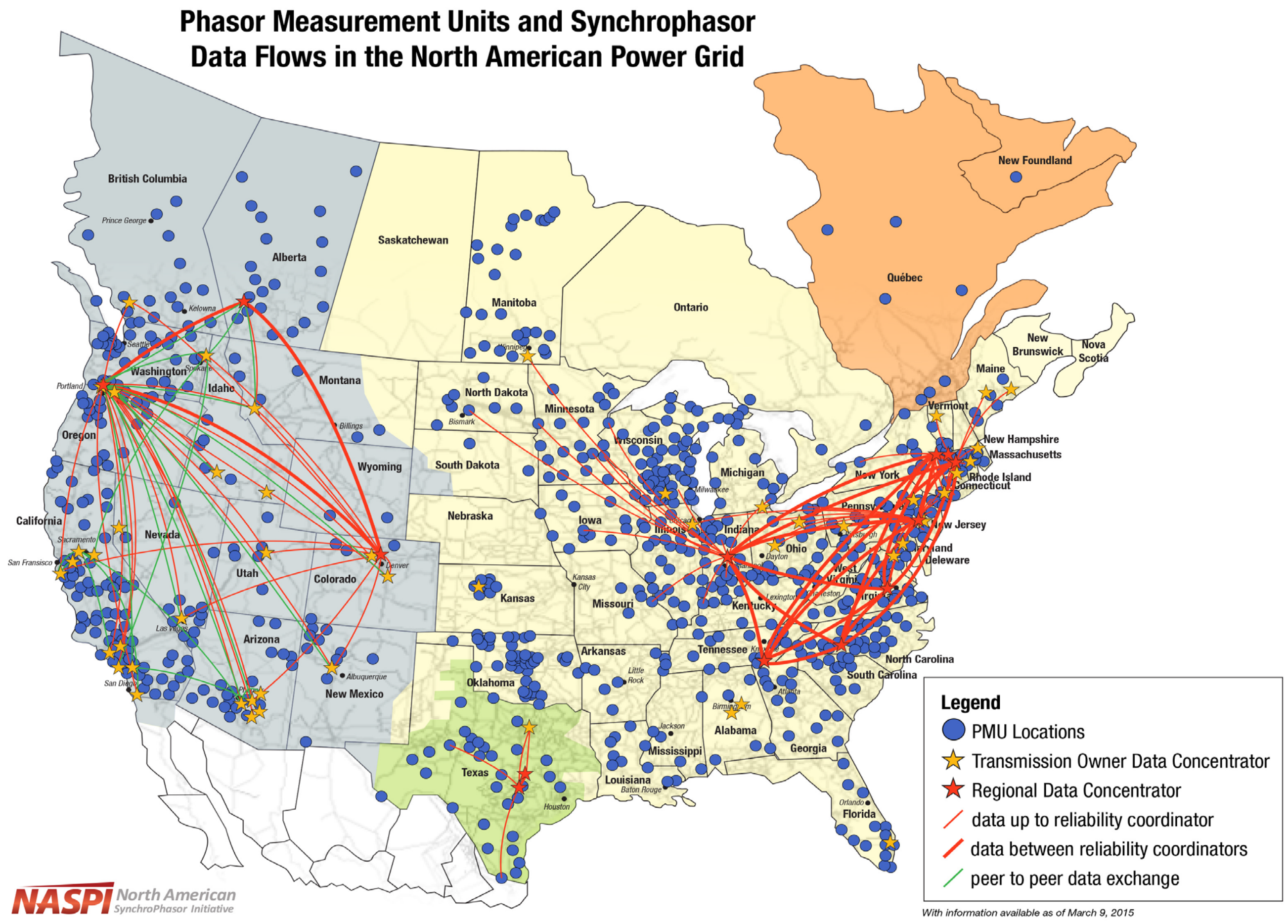
NASPI Reporting PMU Map - 2007



NASPI PMU Map - 2012



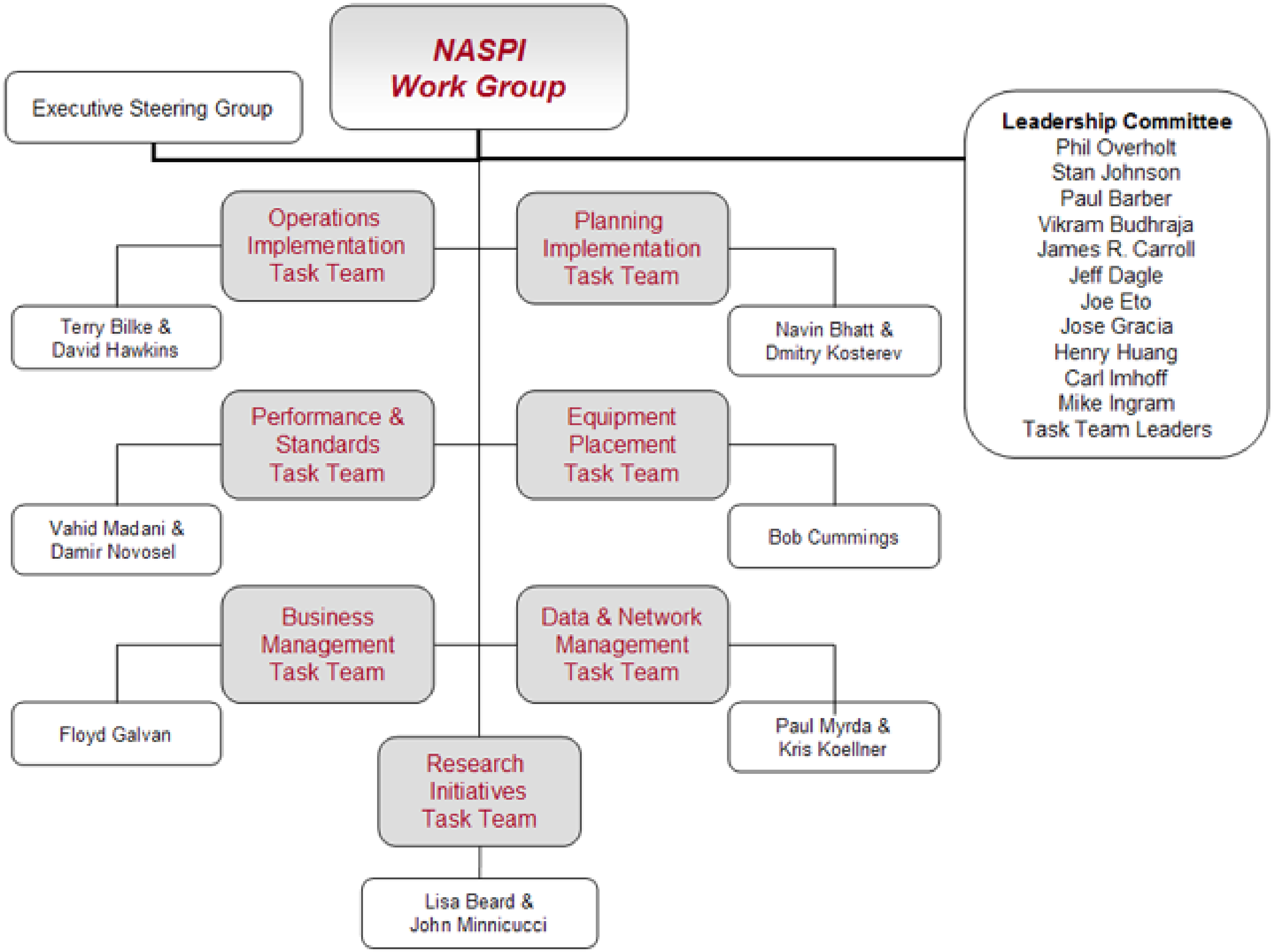
NASPI PMU Map - 2016



All PMUs displayed are connected to their local network.

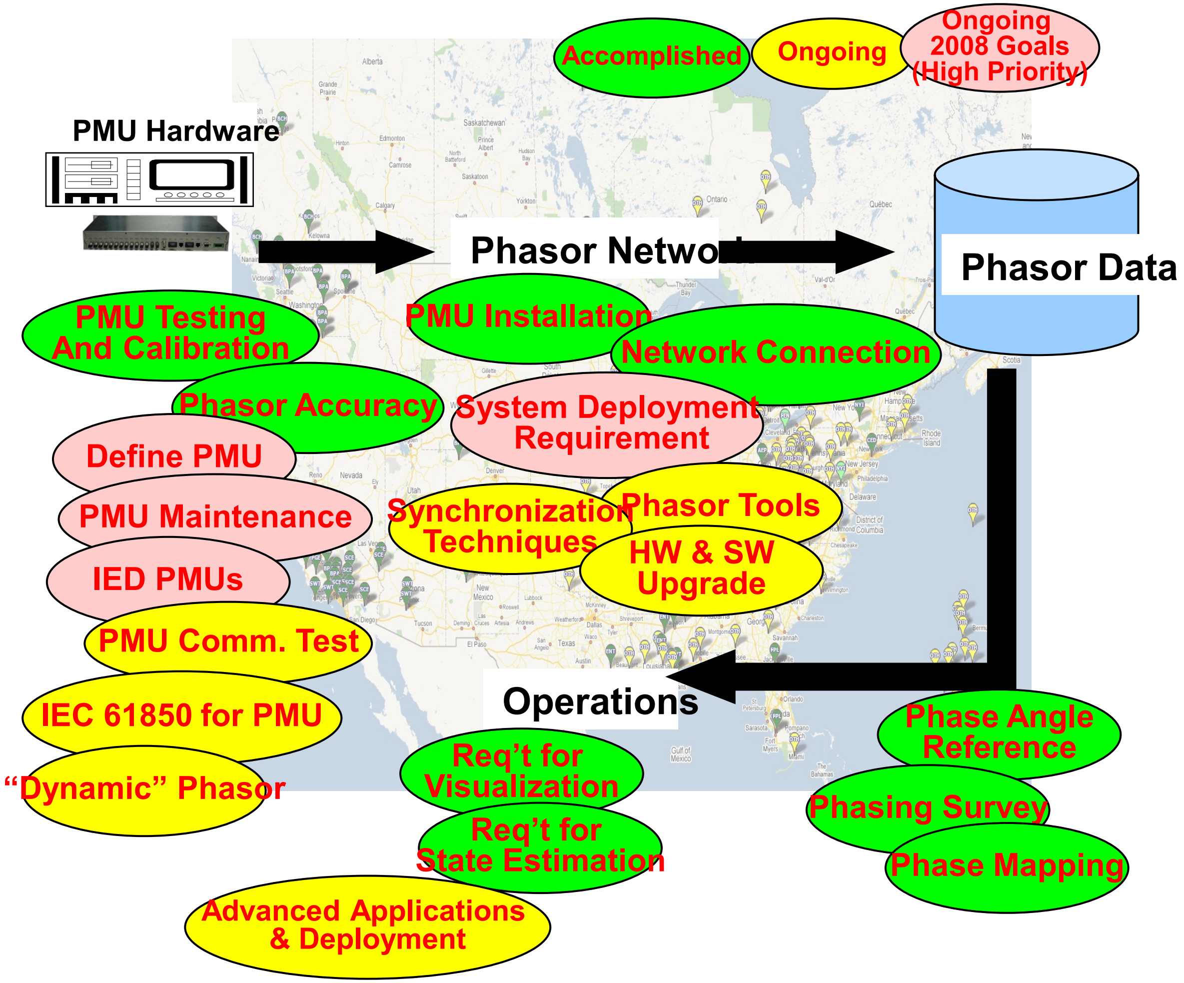
Major data paths for sharing information among operating entities are shown.

NASPI Task Teams List - 2007

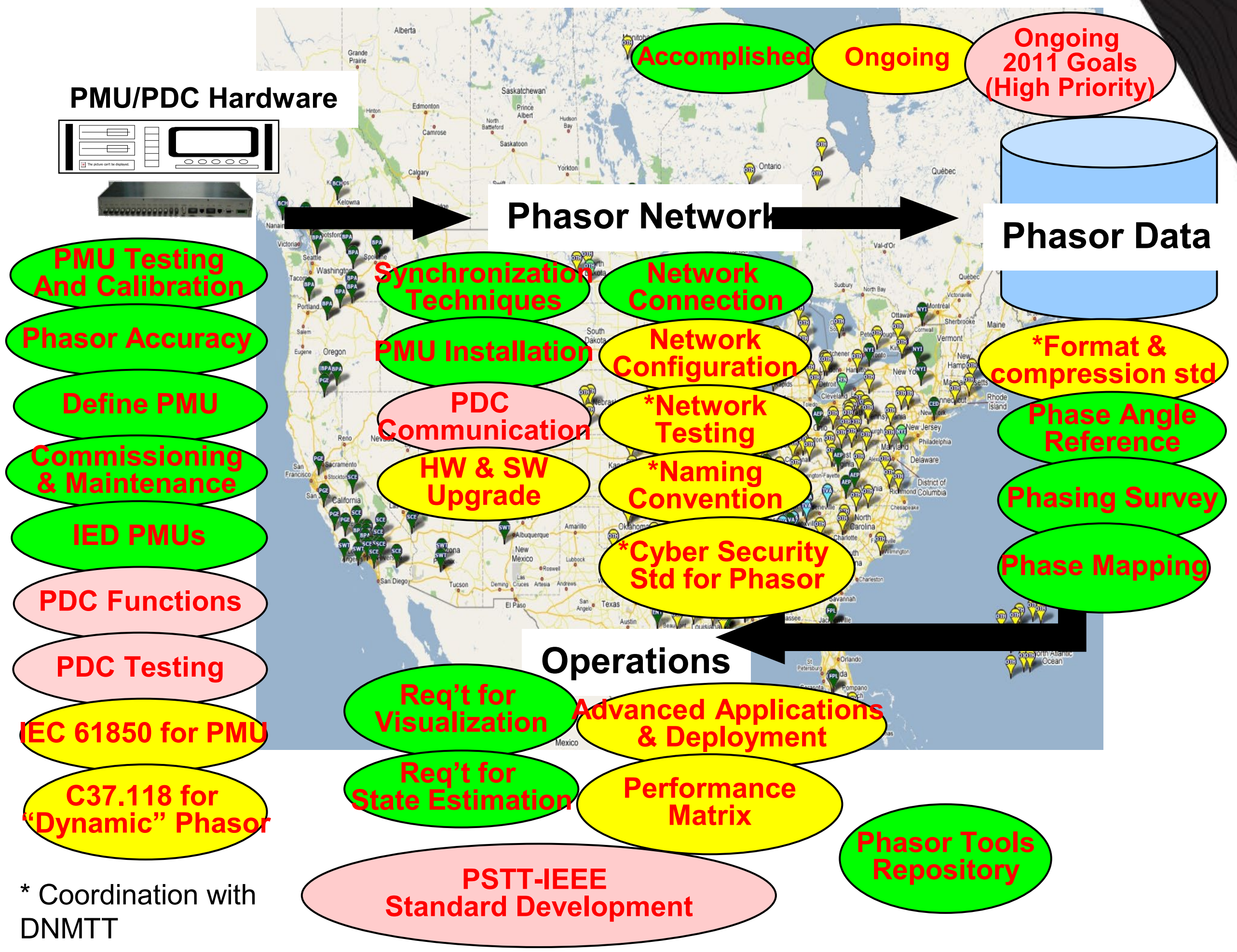


NASPI PSTT Activities and Goals

2008



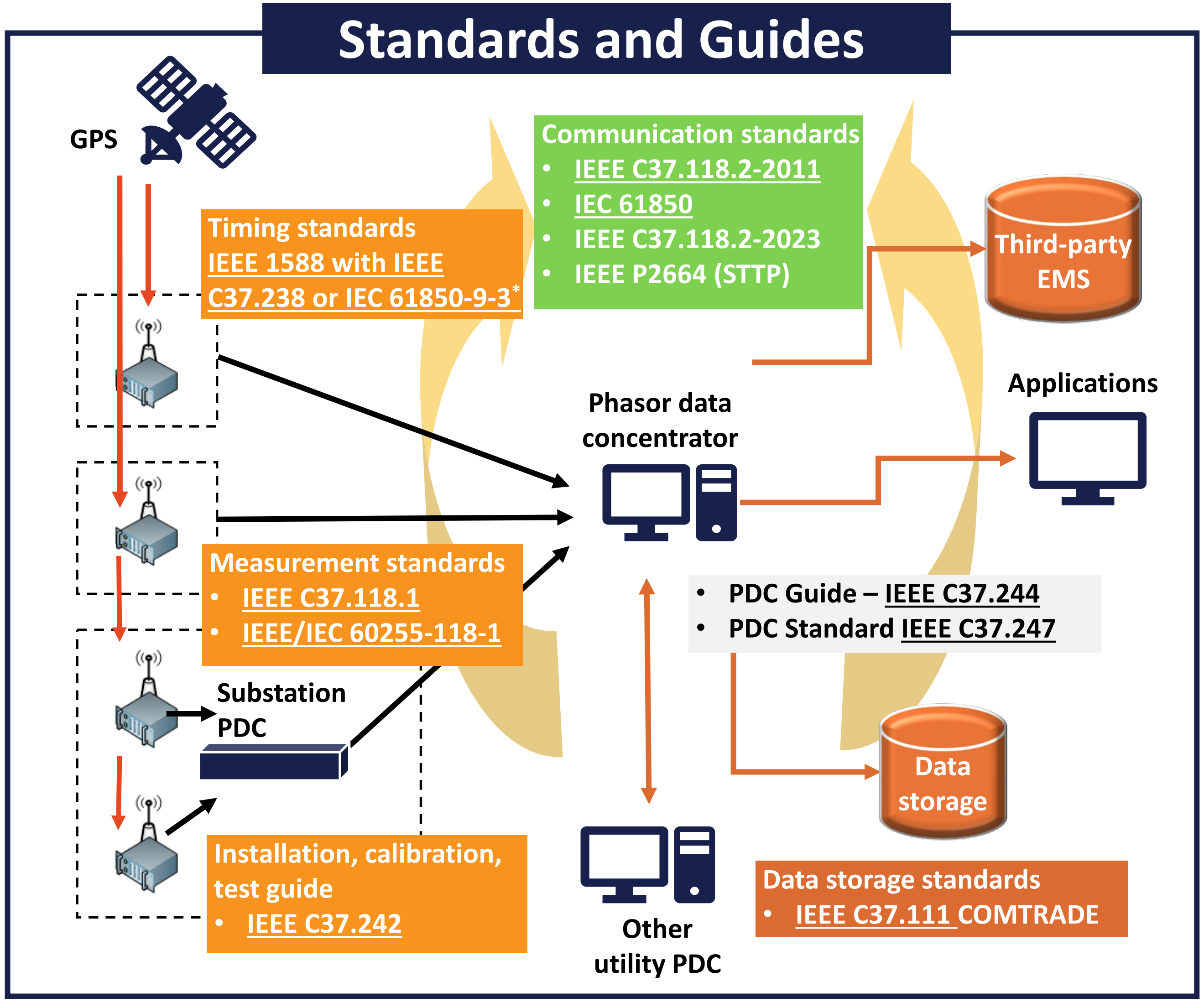
2011



* Coordination with DNMTT

NASPI/IEEE/IEC Developed Standards and Guides

Standards and Guides



Future Needs

- Beyond phasors – synchronized waves/samples/point-on-wave
- Using Data Analytics with synchronized measurements
- Addressing IBRs
- Updating existing standards and guides for new applications
- ??

NASPI Transmission PMU Roadmap 2007 - *Past* Results 16 Years Later – *Present*

Short-term
- ★ Angle/frequency monitoring (LOW)
- ★ **Post-event analysis** (including compliance monitoring) (LOW)
- ★ Voltage stability monitoring (LOW)
- ★ Thermal overload monitoring (LOW)
- ★ Improved state estimation (LOW)
- ★ Steady-state model benchmarking (LOW)
- ★ DG/IPP applications (MED)
- ★ Power system restoration (LOW)

Mid-term
- Congestion management (HI)
- ★ Dynamic model benchmarking (HI)
- ★ Planned power system separation (HI)
- ★ **State estimation** (boundary conditions) (MED)

Long-term
- ★ Linear state measurement (MED)
- ★ Real-time control (HI)
- Adaptive protection (MED)
- WA-PSS stabilization (LOW)

Synchronized measurements value:
- Necessary and critical
- Critical with added benefits
- Moderate need, added benefits
- Requires more investigation

★ Presently deployed
★ Limited deployment

Deployment challenge:
LOW MED HI

- **Developed** based on CEC and DOE PMU benefit-cost analysis project
- **Served** as a blueprint for successful transmission PMU deployment

Source: NASPI

Distribution Synchronized Measurements – *Present and Future*

DissTT 2020 Synchronized Measurements and their Applications in Distribution Systems

DOE 2021 Distribution Synchronized Measurements Roadmap

Short-term

- AG13: Advanced microgrid applications and operation
- AG11: High-accuracy fault detection and location
- AG2: Advanced monitoring of distribution grid
- AG14: Improved load shedding schemes
- AG4: Wide area visualization

Synchronized measurements:

- Provide added benefits for moderate applications
- Provide added benefits for critical applications
- Are necessary for critical applications

Mid-term

- AG6: Real-time distribution system operation
- AG5: DER integration and control
- AG12: Advanced distribution protection and control
- AG10: Improved stability management
- AG16: Technical and commercial loss reduction
- AG8: Advanced distribution system planning
- AG19: Power quality assessment and analysis
- AG1: AVVC

Long-term

- AG7: Enhanced reliability and resilience analysis
- AG15: Advanced distribution automation
- AG3: Asset management of critical infrastructure
- AG17: Monitoring & control of electric transportation infrastructure
- AG9: Distribution load, DER, and EV forecasting
- AG18: Integrated resource, T&D system planning and analysis

Deployment challenge:

LOW MED HI

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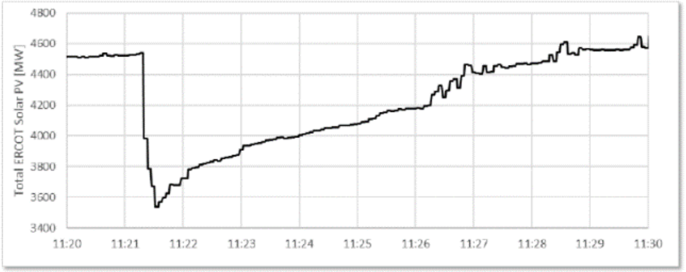
QUANTA TECHNOLOGY
OAK RIDGE National Laboratory
comed AN EXELON COMPANY
conEdison
Dominion Energy

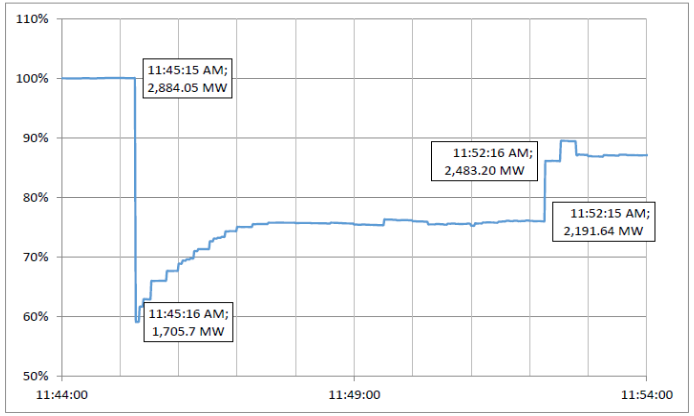
Systems with Inverter-based Resources (IBR) – *Present and Future*

Transformation from a few hundred large-scale, dispatchable generation resources to a system involving a large number of DERs located on the traditional “supply” and “demand” sides of the system, not fully visible to the operator

ERCOT
Solar resource loss
May 9, 2021



Southern California
Solar resource loss
August 2016



Loads and IBRs need to participate in coordinated control by providing network regulation and flexibility services

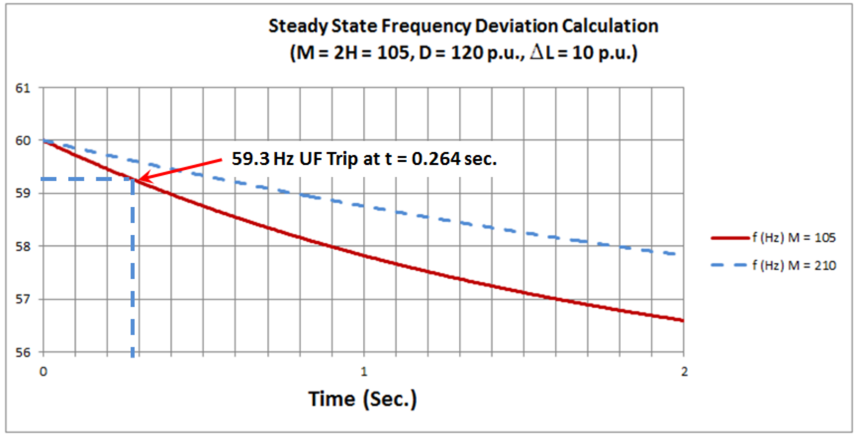
Fundamental changes in T&D planning, operation, protection, control, and monitoring

- **Need for integrated resource and T&D planning and operations**
- **Distribution networks no longer passive loads:**
  - Drastically changed daily load curve, including effects of EV charging infrastructure
  - Weather conditions have major impact on both consumption and generation
  - Circuits with very different dynamic characteristics
  - Increased significance of near real-time communications
- **Dynamic analysis requires accurate models – Digital Twin and EMT modeling**
- **Exponential growth of interconnection requests:**
  - Hosting capacity maps are becoming a requirement
  - Need for creating a headroom for future renewable requests

Technology Solutions to Address Systems with Large Penetration of IBRs – *Present and Future*

Inverter-based resources
➔ Less inertia ➔ Things happen faster!

Frequency decay for loss of 1,000 MW



Source: *IEEE/NERC report on Impact of Inverter Based Generation on Bulk Power System Dynamics and Short-Circuit Performance*

Frequency excursions:
Rate-of-change-of frequency proportional to inertia

$$\Delta P = -k_{in}\frac{df}{dt}$$

Enabling the electric grid to integrate new resources (DR and storage) and EV charging while improving the utilization of existing assets

- **Faster monitoring and controls of DERs and energy storage** addresses dynamic changes with IBRs and improving situational awareness for the safe, secure, and reliable operation of modern grids
- **Sensors and tools for situational awareness and condition assessment:**
  - Synchronized measurements
  - Power Quality and GIC monitors
  - Equipment monitoring (transformers, switchgear, etc.)
  - Drones
  - Etc.
- **Adaptive protection** for low fault currents and dynamic system changes
- **T&D power flow and market models** to handle widespread integration of DER and energy storage
- **Analysis tools and models** (i.e., weather forecasting, dynamic security assessment, electric, gas, and communication interdependencies, etc.)
- **Microgrids** to address resilience and decarbonization
- **Communications infrastructure** with the necessary speed and latency

Impact of IBRs – *Present and Future*

table 1. The IBR integration issues.

Key Consideration	System Aspects
Power ramping	• High up and down intermittent "not forecast" power ramps can affect control area performance.
Low system inertia	• High rate of change of frequency following a large loss causes resources to trip due to reduced synchronizing torques. • Underfrequency relays respond to low frequency by tripping the load. • The speed of system events is faster than the ability of protection system.
Low reserves	• Renewables operate at maximum power tracking and do not leave headroom for reserves.
Low fault current levels	• Ability of protection systems to detect faults
Low short circuit ratio (weakened grid)	• Instability in inverter controls (phase-locked loop synchronization and low-frequency oscillations) • Challenges to inverter ride through and islanding • Voltage flicker (especially in distribution feeders) • Difficulty of voltage control due to high voltage sensitivity to reactive power changes (i.e., dV/dQ) • Difficulty in energizing large power transformers
Low damping of system oscillations	• Synchronous machines have rotor dampers. • Use of grid-forming inverters and inverter control settings for mitigation
Voltage and power fluctuations	• Intermittent renewables cause fluctuations in system voltages, especially when the grid short circuit current is low. • Ensure compliance with IEEE 1453, *Recommended Practice for the Analysis of Fluctuating Installations on Power Systems*, for flicker.
Black start	• Ability to restart a system with predominantly IBRs
Scale and integration	• IBRs tend to be smaller and distributed throughout a cross section of high-voltage, medium-voltage, and low-voltage distribution systems. • Challenges for power system operators to integrate customer-owned IBRs

may/june 2023

IEEE power & energy magazine 19

Properly designed automated control and protection can exploit

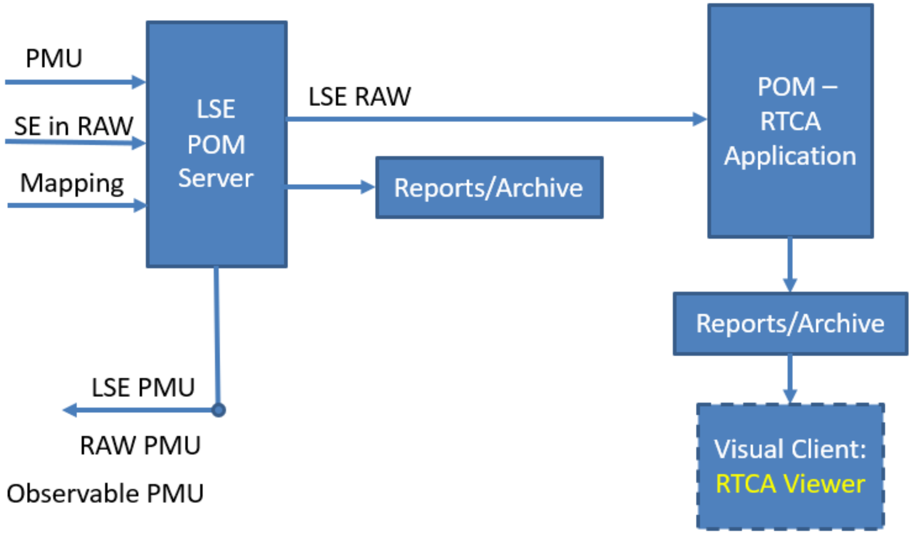
- The fast response of IBRs
- Wide Area Monitoring Protection and Control (WAMPAC) data and actions
- Improving grid reliability and resilience

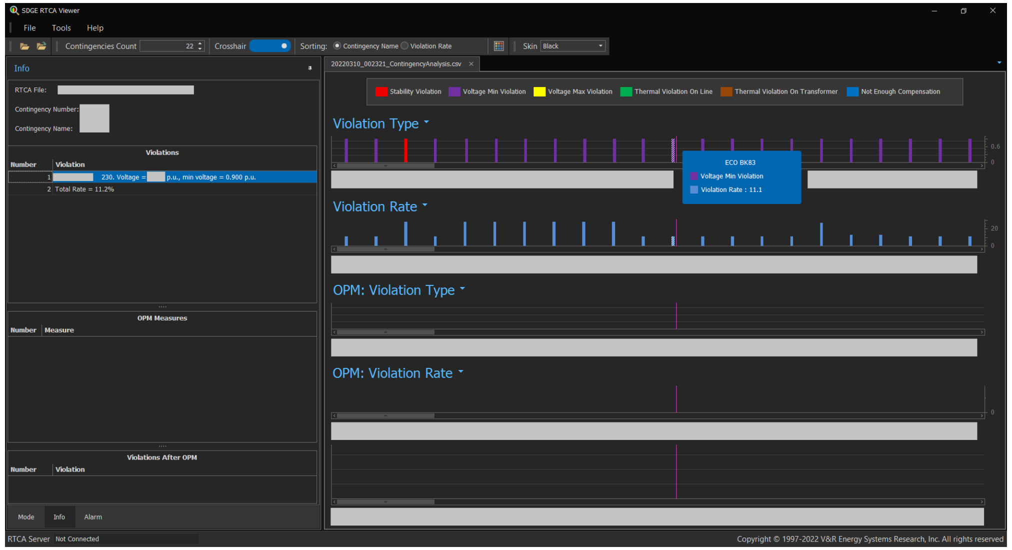
Unexpected consequences – Global blackout experiences and preventive solutions

Implementation Examples: *Present*

CAISO - Tracking overvoltages to address the drastic climate swings

SDG&E – Real-time situational awareness LSE POM Server and Contingency analysis Visual Client





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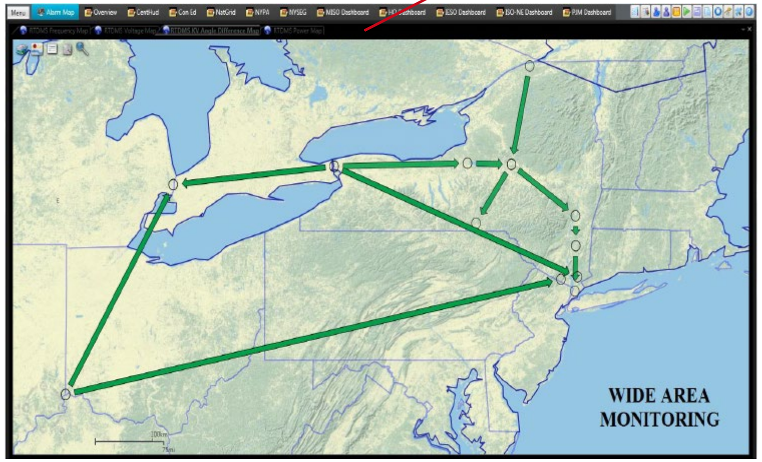
Implementation Examples: *Present*

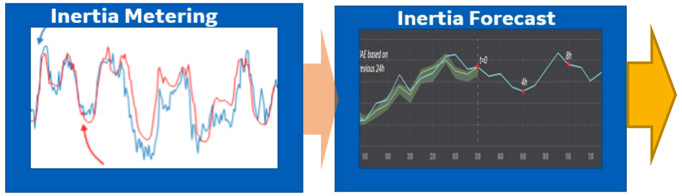


Source: http://readmedia.com/officials-celebrate-nyisos-new-power-control-center/8437753

NYISO - PMUs grouped by electrical load zones and neighboring regions to reflect expected coherent generation response

Inertia Metering & Forecasting

Control Room Operational Awareness

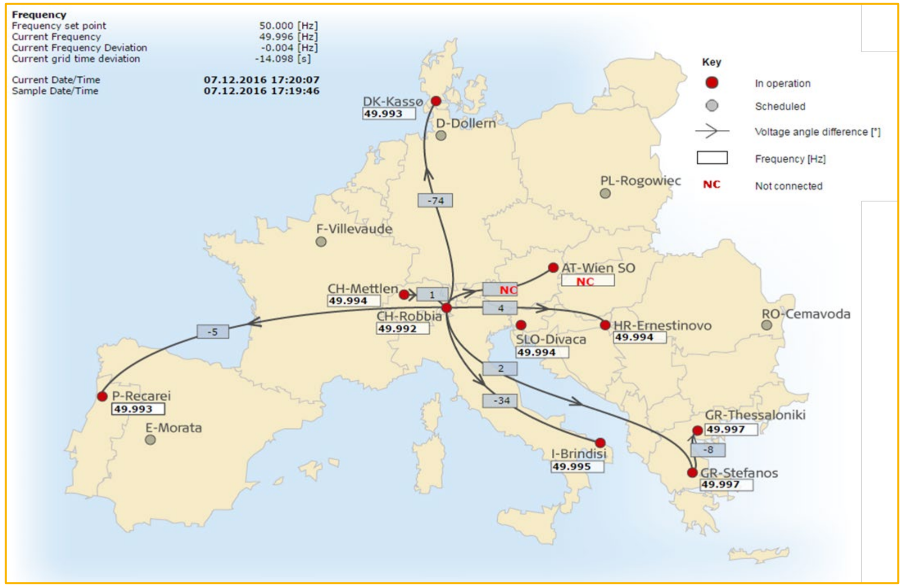


Pure WAMS sensing

Machine Learning Model from Grid Analytics

nationalgridESO

Source: GE



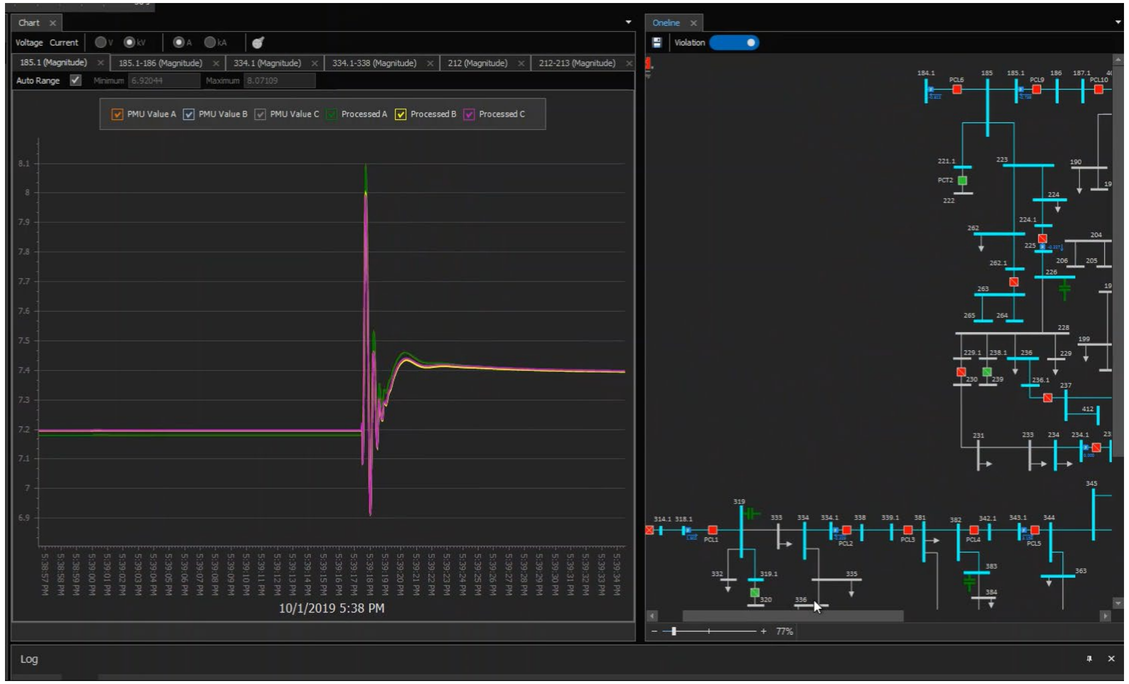
SwissGrid - Hosting a WAMS application where the power system frequencies and angle differences of grid operators from Austria (APG), Denmark (Energinet.dk), Portugal (REN), Slovenia (ELES), Croatia (HEP), Italy (TERNA) and Greece (IPTO) are monitored

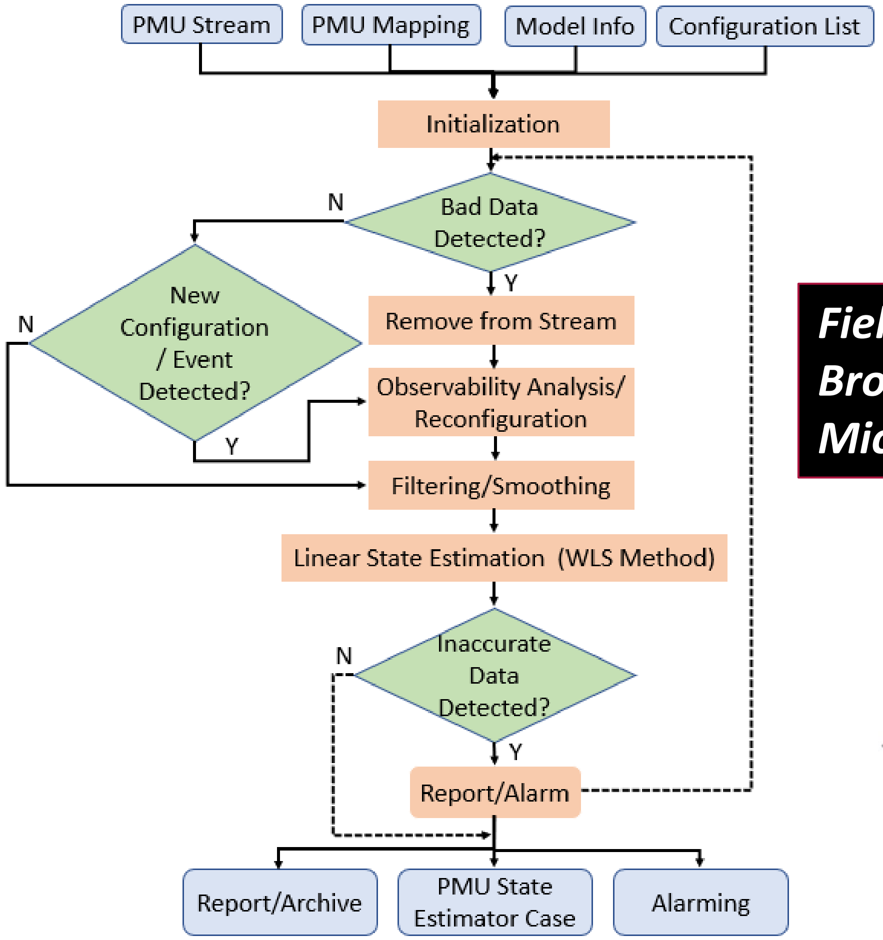
Source: https://www.swissgrid.ch/swissgrid/en/home/reliability/wam.html

Distribution Implementation Example: *Present*

Linear State Estimator for Increased Situational Awareness and Resilience

ComEd: Solves 3 phase unbalanced DLSE
Bad data detection, correction, alarming and reporting
Observability analysis
Detection of switching events (only on PMU data)
Real-time system monitoring (voltage and thermal)





Field deployment at Bronzeville Community Microgrid

ComEd
An Exelon Company

ENERGY

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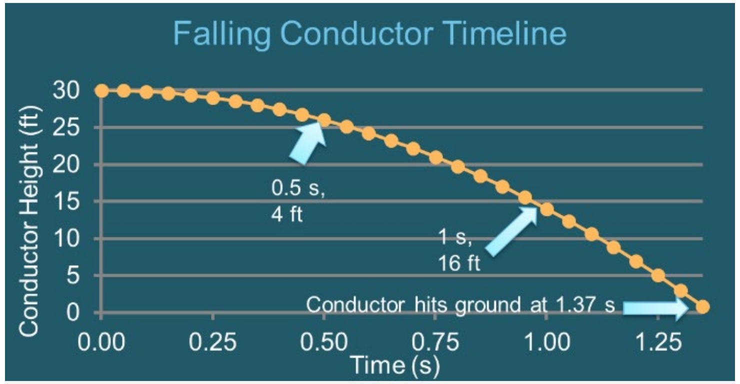
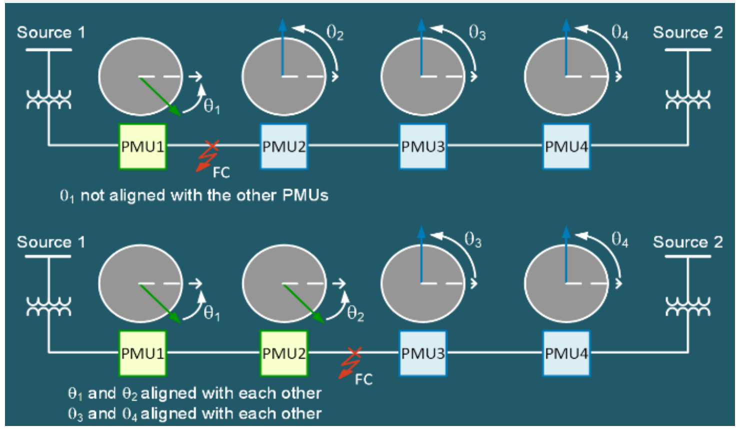
Distribution Implementation Example: *Present and Future*

Present - *Fallen Conductor Protection*





Deenergize the conductor *before* it hits the ground:

- Break isolated in 200–500 ms
- Avoids high-impedance fault arcing and fire risk
- In service since 2016
- SDG&E planning 70 circuits by 2023 and 135 by 2028 and deploying next-generation wideband Ethernet radio system using private cells

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Future

Five top-priority application groups use synchronized measurements at medium cost with high benefit:

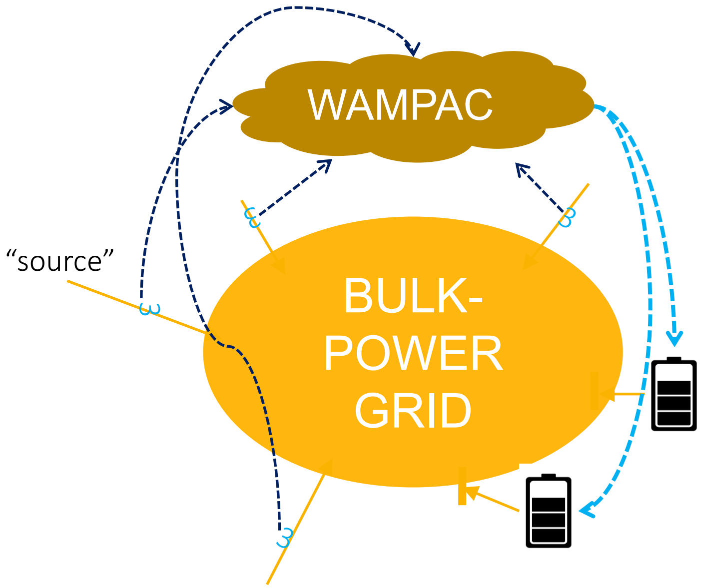
- High-accuracy fault detection and location
- Advanced microgrid applications and operation
- Advanced monitoring of distribution grid
- Improved load-shedding schemes
- Wide-area visualization

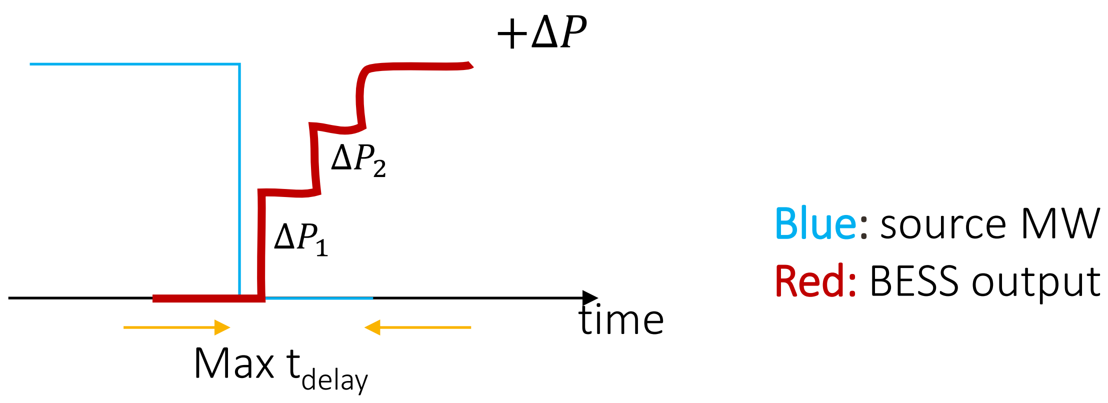
Mid-tier application groups with high benefits needing more development effort:

- Advanced distribution protection and control
- Real-time distribution system operation
- DER integration and control

WAMPAC Monitors Sources and Communicates with Battery Energy Storage System (BESS) Units – *Future*

- BESS units regularly inform WAMPAC of their capability.
- Upon detecting sudden imbalance $(-\Delta P) \Rightarrow$
  WAMPAC instructs each BESS to inject ΔP_i so that $\sum_i \Delta P_i = +\Delta P$
- Comments:
  - Max t_{delay} is due to long-distance communications and coordination of multiple devices.
  - Detects several events, but list of events is limited by WAMPAC coverage.





Distributed Sensors Offer New Options for an Evolving Grid – *Past, Present, and Future*

Inputs and Tools:

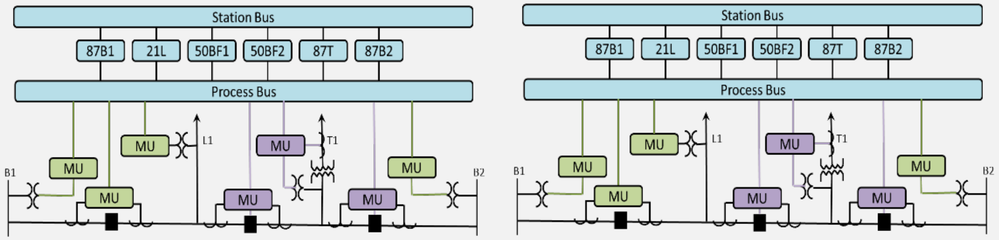
- IEDs (e.g., digital relays, digital reclosers, capacitor bank controllers)
- **Synchronized measurements**
- PQ meters
- IEC 61850 network data
- Field sensors (e.g., FCIs, line sensors)
- Smart meters and AMI headend systems
- SCADA, GIS, and Lightning data
- LIDAR/satellite imagery
- System model
- Protection settings
- Artificial Intelligence/Machine learning

Data analytics applications

Centralized data collection

Local data collection | **Local data collection**

IEC 61850 Substation | **IEC 61850 Substation**



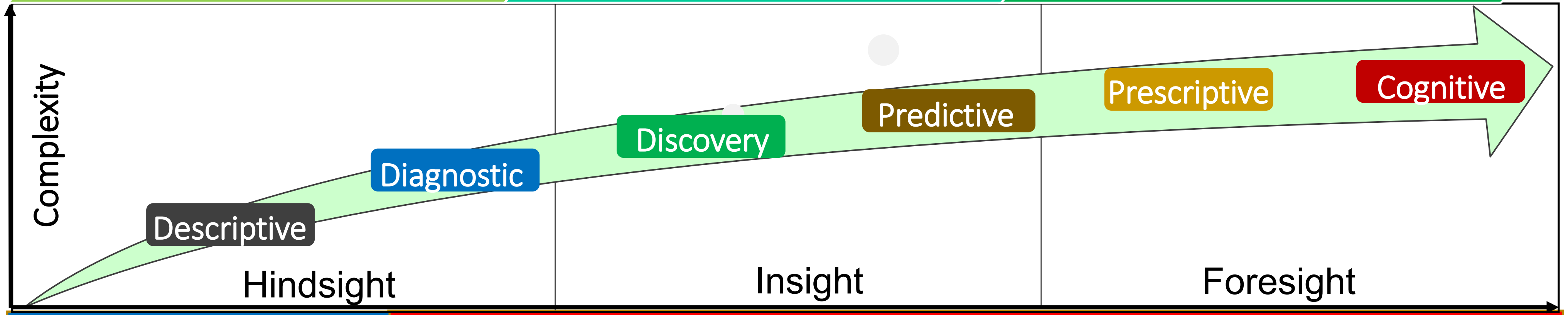
Data Analytics:

- Event analysis
- Fault location
- Grid situational awareness and modeling (T&D)
- Model and Settings validation
- 61850 network monitoring
- Compliance
- Asset monitoring, predictive maintenance
- Dynamic ratings
- Reliability and resilience indices and metrics

Marching Towards The Future

Protection &Control	Taking offline-calculations determined (re)actions	Taking adaptive (re)actions based on online assessment	Taking actions based on online predictions
Real-Time Operation	Threshold alarms, SA for slow (re)actions	Intelligent event alarms, SA for faster (re)actions	Early warnings, SA for proactive/preventive actions

Data Analytics



Other Data	Fuel Supply	+Lightning/Storm/Fire/Earthquake/Vegetation/...
		+Temp/Wind/Sunlight/Water/…
System Data	PMUs	+IEDs/DFRs/DDRs/Meters/PQMeters/Sensors/...
		+SMUs

Carbon Emission	> 90%	<70%	<30%	Net Zero

Synchronized Measurement Evolution

Past

First PMU

Analog displays

Present

- Standard features (relays, DFR, controllers, monitors)
- On major interconnections and generators
- Standard software tools included in EMS/SCADA
- Primary use for monitoring and event analysis but deployed for control
- Interoperability standards deployed
- Distribution PMUs expanding due to DER
- Improvements in communication infrastructure

Future (2030)

- Extensively deployed in Transmission
- Integrated in standard business and operational practices
- Integrated with EMS/SCADA
- Higher data rates
- Deployed in Distribution
- Distributed communications and processing architecture
- Fast control and adaptive protection

Solutions for the Energy Future

A resilient, modern electric grid is the foundation for our clean energy future, requiring renewables, energy storage, energy efficiency, and electrification.

Electricity is key for achieving societal and economic goals, such as decarbonization and growth:

- Demand for electricity increases electrification and fuel transformation
- Need for clear and balanced societal and regulatory policies

Essential factors for a resilient grid to protect against and recover from any event that would significantly impact the grid:

- Technology advancement
- Educated and diverse workforce
- Standards and sharing global best practices

Coordinated resource and T&D planning and operations for investment prioritization:

- Load, DER, and electrification forecasting
- Accurate system and equipment modeling
- Scenario planning
- Risk- and probabilistic-based investment decisions

Importance of diverse generation mix for uncertainties

Automated and Adaptive Monitoring, Protection, and Control: Synchronized Measurements

Coordinated Planning – Tools and Processes

Digital Transformation through Automation - Single Data Source

Long-Term Storage

Synthetic Gas

Small Modular Reactors

Hydrogen

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