Quadrennial Technology Review: Measuring, Modeling and Control

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Achieving a Clean Energy Future

Will pose operational challenges to the electric system…

- *The future generation resource mix is unknown*
- *The variability and uncertainty of wind and solar power require new ways to operate the power system (including the use of storage, natural gas, demand response, inter-hour scheduling)*
- *Load profiles are uncertain as on-site renewable energy resources, demand response technologies, and EVs/PEVs are introduced to distribution systems*
- *Valuation of ancillary services is evolving*
- *Changing technologies and policies, e.g. environmental legislation, will have a significant effect on future generation and transmission*
- *Boundary seams (planning, modeling, and operations) are critical for effective integration with legacy systems*

… that drives need to…

- **Dynamically optimize grid operations and resources**
  - *Multidirectional power and communication flow*
  - *Adaptability of controls and protection to changing conditions*
- **Fully integrate demand response and consumer participation into grid resource planning and operations**

Measuring, Monitoring and Controls Focus Areas

- **Measurement and Controls** – *Acquiring, sharing, and (real-time) processing of data throughout the electric system*

- **Communications and Security** – *Establishing the enabling secure, resilient information backbone*

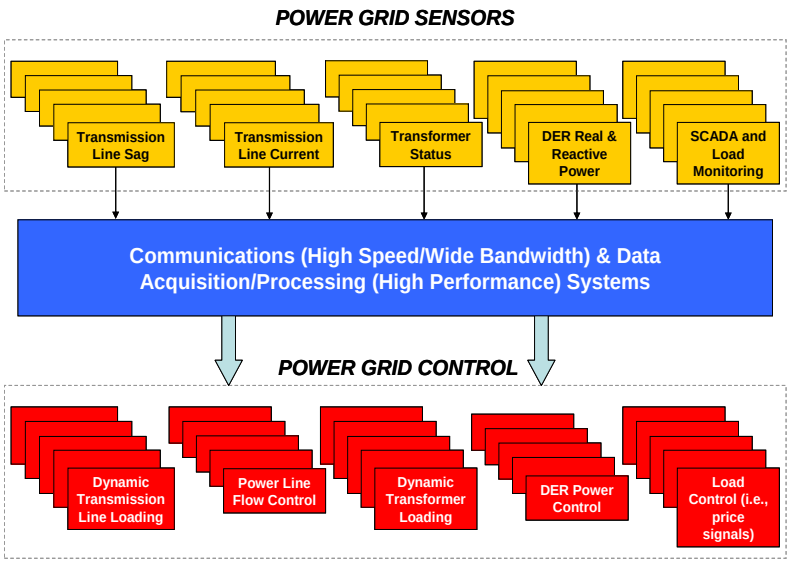
- **Modeling and Analysis** – *Facilitating system understanding (primarily off-line) to support better grid operations, planning, markets, and policy decision-making*

Depth and Breadth of Electric System Data is Growing, Offering Unprecedented Opportunities to Enhance System Flexibility through Measurement and Control

Through 2015, the Recovery Act funds will result in the deployment of:

- An additional 15.5 million smart meters on homes and commercial buildings,
- Sensors, smart switches and control devices that will help automate approximately 6,500 distribution circuits, and
- Over 800 networked phasor measurement units distributed throughout the transmission system.

However, there is still considerable time and investment that is required to fully modernize the electric grid with smart, digital systems. By the end of 2015, a small percentage of households will have enabling technology and access to variable rates; about 5% of the country's distribution circuits will have been upgraded, yet not achieve the level of automation anticipated for sophisticated, self-healing circuits that can communicate effectively with distributed energy resources (DERs) and electric vehicles (EVs).



Even at Current Levels, Benefits are Being Realized: Impact of Distribution Automation Technology

Application of sensors, smart switches and communications equipment in the distribution system will permit:

- Optimized control of voltage and reactive power (Volt/VAR) requirements resulting in **improved energy efficiency**, including an ability to undertake conservative voltage reduction (CVR)
- Real-time outage detection and system reconfiguration to **improve reliability** (resulting in the reduced frequency and duration of power outages)
- Monitoring of equipment condition, combined with **operational efficiency improvements** resulting in **lowering overall operations and maintenance costs**

PNNL Study* reports that deploying CVR technology nationwide would cut annual energy consumption by 6,500 megawatts (targeting 10 percent of nation's feeders nets 37 percent of the total benefit)

Dominion Virginia Power applied CVR at its Trabue station in Midlothian where 6,000 customers in the test area saved roughly $260,000 in energy costs, or about 2.7 percent of their overall consumption during the past year.

PPL Electric Utilities (with DOE funding) will install smart switches, reclosers and other equipment to create a self-healing network. Arizona's Public Service's self-healing grid pilot in Flaggstaff has avoided more than 300,000 customer outage minutes in eight separate events since July 2010

"Evaluation of Conservative Voltage Reduction (CVR) on a National Level [PNNL-19596]", July 2010, http://www.pnl.gov/main/publications/external/technical_reports/PNNL-19596.pdf

Understanding the Impact of AMI and Dynamic Prices on Consumer Behavior

Ten (10) statistically rigorous studies are being conducted to:

- Identify factors influencing customer acceptance of dynamic electricity rates and AMI technology
- Quantify the effect of dynamic rates on electricity consumption (peak and overall load reduction)
- Understand the relative and combined contributions of pricing, information feedback, and control technology on consumer behavior
- Provide statistically-relevant data with analysis to researchers and decision-makers

Oklahoma Gas and Electric (OG&E) is undertaking a 2 yr study with 4,600 residential and 650 small businesses to determine load reduction resulting from combinations of dynamic rates and enabling technologies

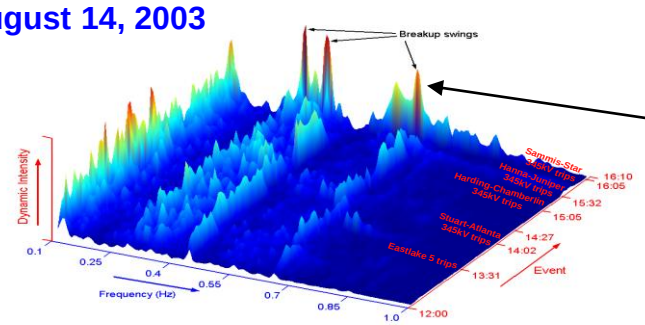
	Technology Option			
Pricing Strategy	Web Portal	In-Home Display (IHD)	Programmable Communicating Thermostat (PCT)	All Technology Options
Variable Peak Price (VPP)	Treatment 1	Treatment 2	Treatment 3	Treatment 4
TOU Critical Peak Price (CPP)	Treatment 5	Treatment 6	Treatment 7	Treatment 8
Control Group	Control Group			

OG&E expects to avoid building two 165 MW peaking units based upon achieving a 20% customer participation rate (on an opt-in basis)

Improving Wide-Area Situational Awareness through SynchroPhasor Technology

- Synchrophasors are precise grid measurements from monitors called phasor measurement units (PMUs)
- Improve power system reliability and visibility through wide area measurement and control, based on *GPS time synchronized high resolution data*
- **TODAY**: Important applications today include wide-area monitoring, control strategies for outages, and forensic analysis of grid disturbances.
- **FUTURE**: Phasor technology is expected to offer great benefit for real-time operations and power system planning, including integrating renewable and variable resources, automated controls for transmission and demand response, increasing transmission system throughput, and improving system modeling.

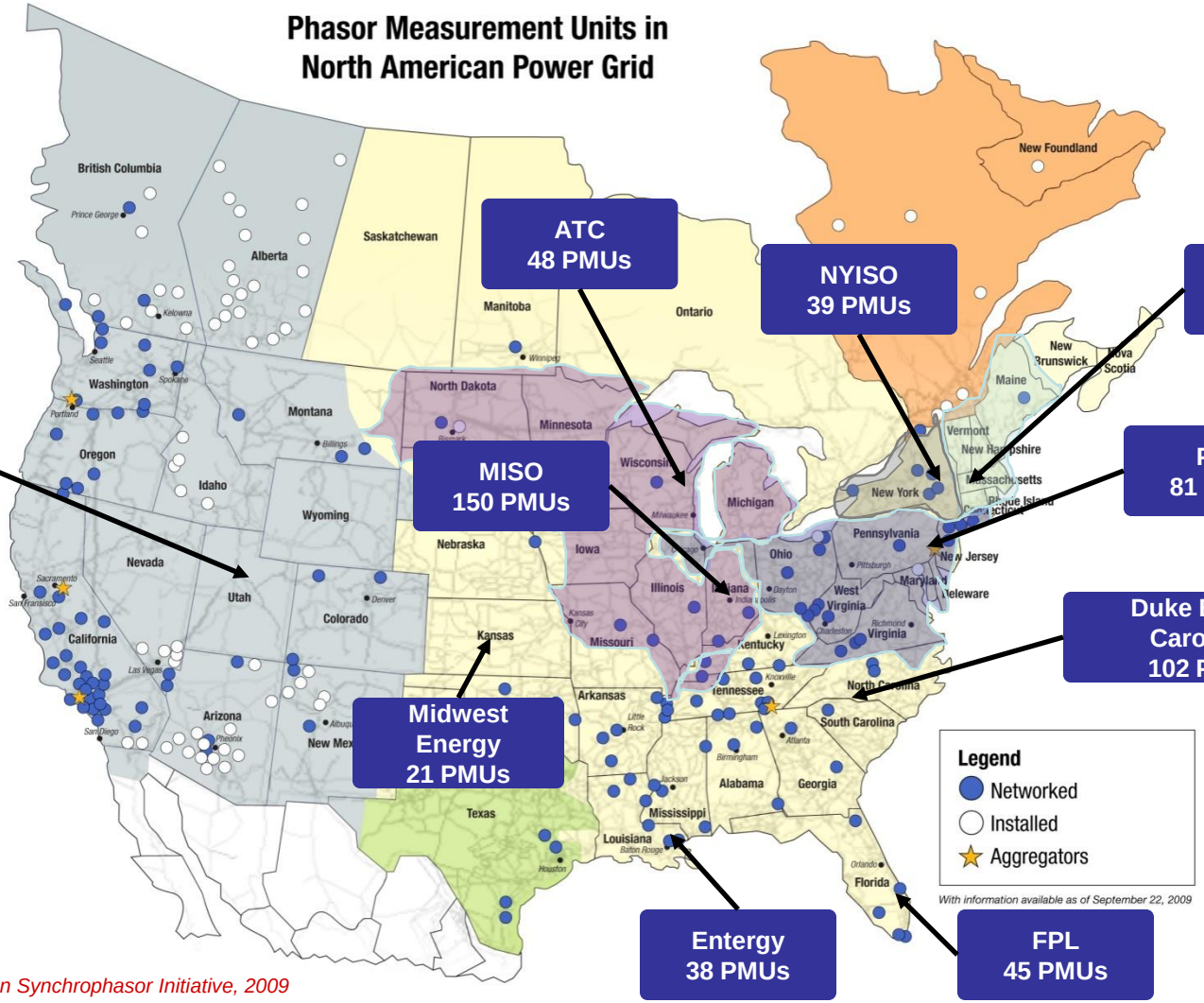
August 14, 2003



- Grid Stress – phase angle measurements
- Grid Robustness – damping status and trend
- Dangerous Oscillations – low damping
- Frequency Instability – Frequency variation across interconnection
- Voltage Instability – Low Voltage Zones
- Reliability Margin – "How far are we from the edge" – Sensitivity metrics

Sources: AEP; PNNL

Phasor Measurement Unit (PMU) Deployment



ATC
48 PMUs

NYISO
39 PMUs

ISO-NE
30 PMUs

WECC
250 PMUs

MISO
150 PMUs

PJM
81 PMUs

Duke Energy
Carolinas
102 PMUs

Midwest
Energy
21 PMUs

ARRA Total
804 PMUs

Entergy
38 PMUs

FPL
45 PMUs

Source: Map from North American Synchrophasor Initiative, 2009

Emerging Need for Real-Time Tools and Platforms that Analyze Electric System Data and Can Maintain Reliability by Balancing (Dynamically and Automatically) Demand-Side Flexibility and Supply-Side Variability

Monitoring* → *Controls

Subcategory readiness	Angle & Frequency Monitoring	Wide Area Monitoring	Disturb-ance Analysis	Inter-area Oscillation Detection and Analysis	Real-time control of Trans-mission Corridors	High precision State Estim-ation	Voltage Stability Monitoring	Determin-ation of Accurate Operating Limits	Trans-mission System Rest-oration	System Model Deriv-ation & Valid-ation	Detection of Imminent Disturbance Cascading	Real-time Control of Wide-Area Networks
Algorithm												
Hardware												
Data												
Decision support												
Demo												
Pilot study												
Utility application												
Standards												

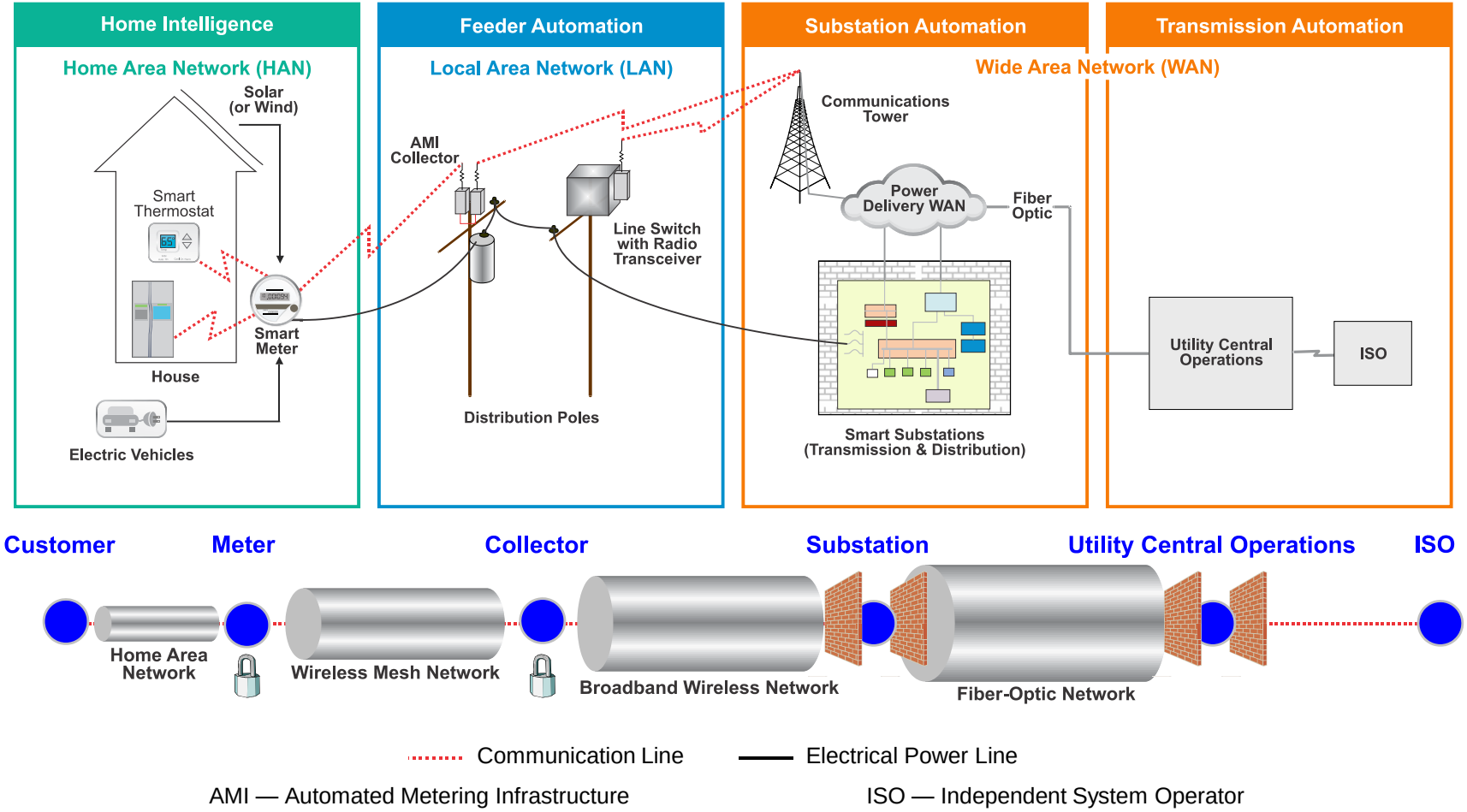
1-2 years 2-5 years >5 years

Requires Development and Pilots

Needs Moderate Development

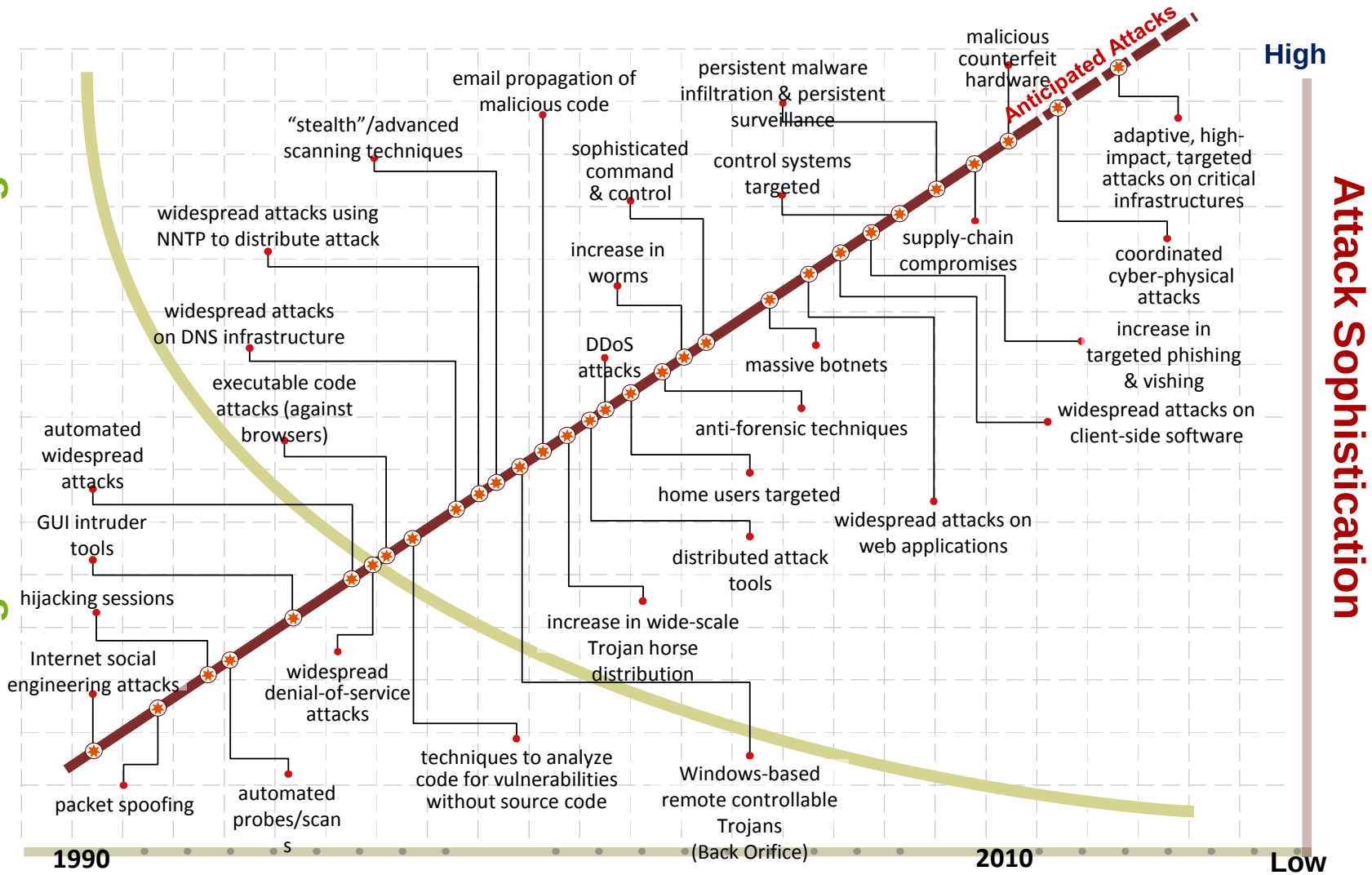
Available Now or Soon

Effective Controls Require Seamless Communications (and Data Access) across the Electric System



This chart captures a representative architecture. It is recognized that there are multiple technological options available for each vertical (Home Intelligence, Feeder, Substation and Transmission Automation) respectively. It is not the intent of this chart to represent a comprehensive depiction of ALL technologies.

Trustworthy Information Sharing is Critical: Standards, Privacy Protection and CyberSecurity



Source: CERT/Software Engineering Institute/Carnegie Mellon University

Becoming "Students of the Electric System": Modeling and Analysis Can Help System Operators to Approach the System Differently

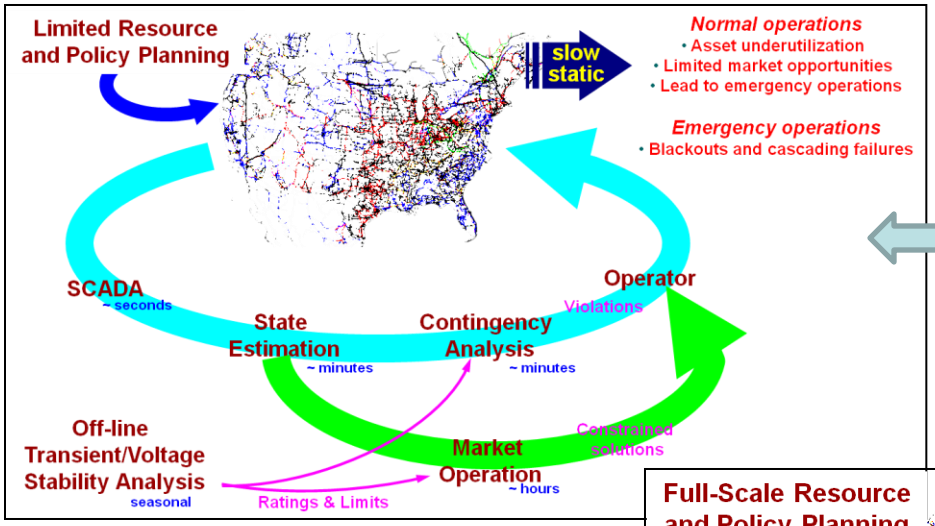
Computational, mathematical, and scientific understanding is needed to transform the tools and techniques (e.g. mathematical formulations) that underpin the planning and operation of the electric system:

- ***Accelerate Performance –*** improving grid resilience to fast time scale phenomena that drive cascading network failures and blackouts

- ***Enable Predictive Capability –*** relying on real-time measurements and improved models to represent with more fidelity the operational attributes of the electric system, enabling better prediction of system behavior and thus reducing margins and equipment redundancies needed to cover uncertainties

- ***Integrate Modeling Platforms (across the system) –*** capturing the interactions and interdependencies that will allow development (and validation) of new control techniques and technologies

Accelerating Performance and Predictive Capability

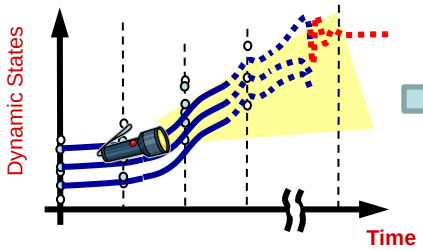


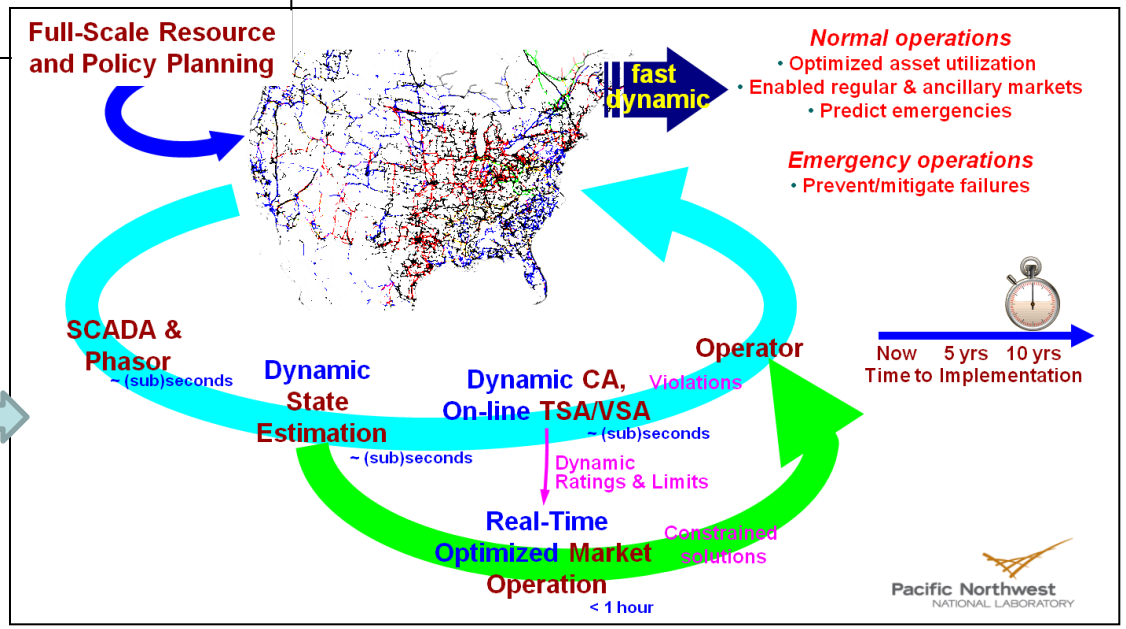
TODAY:

- Reliance on off-line analysis to set operating limits
- Operator trying to make control decisions, especially fast decisions during a disturbance, on incomplete data
- High reliance on local protection technologies to protect the grid if all else fails

Today's Power Grid Planning and Operation Paradigm

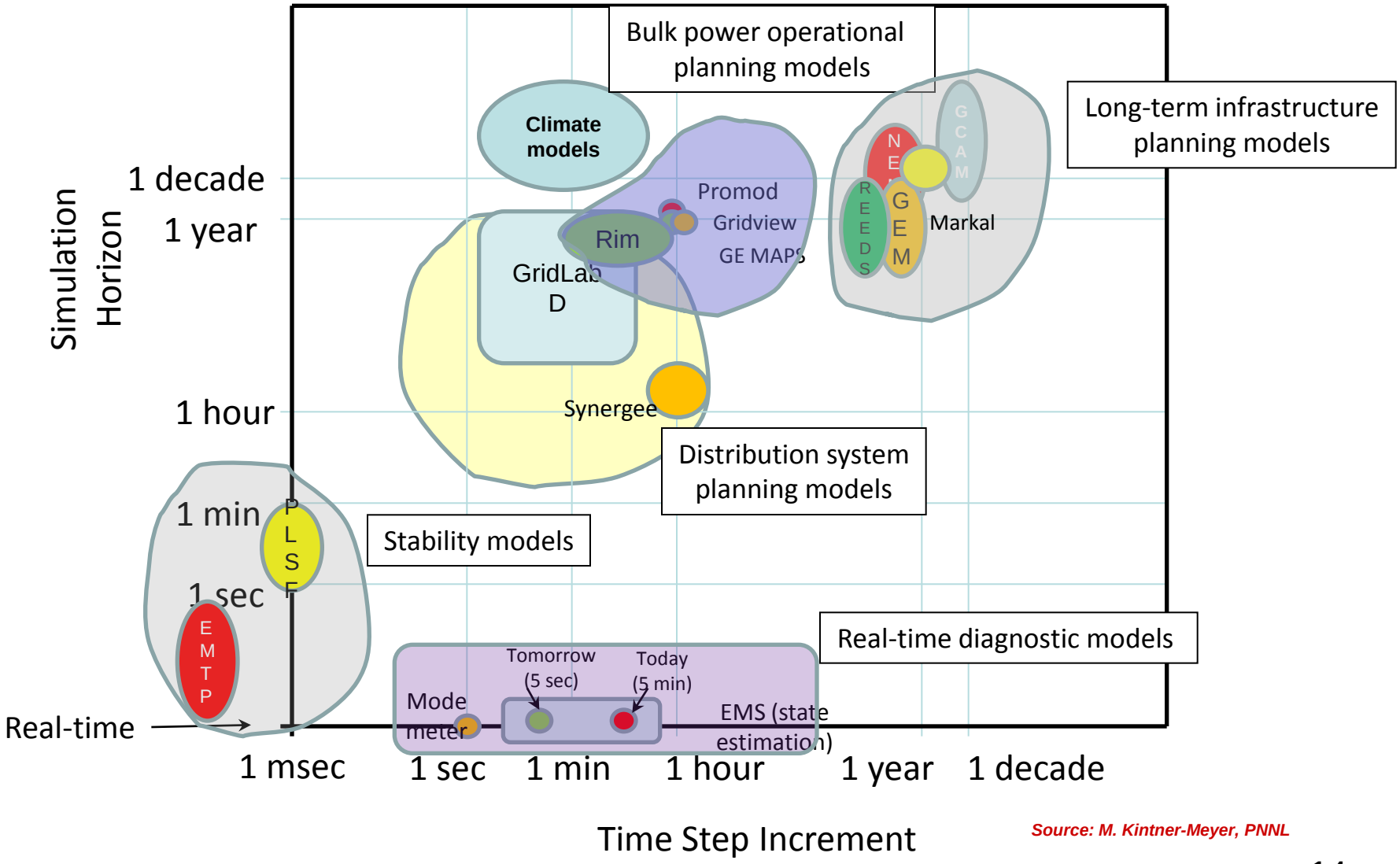
From Reactive to Predictive





Long-Term Vision for Power Grid Planning and Operations

Integrating Model Platforms

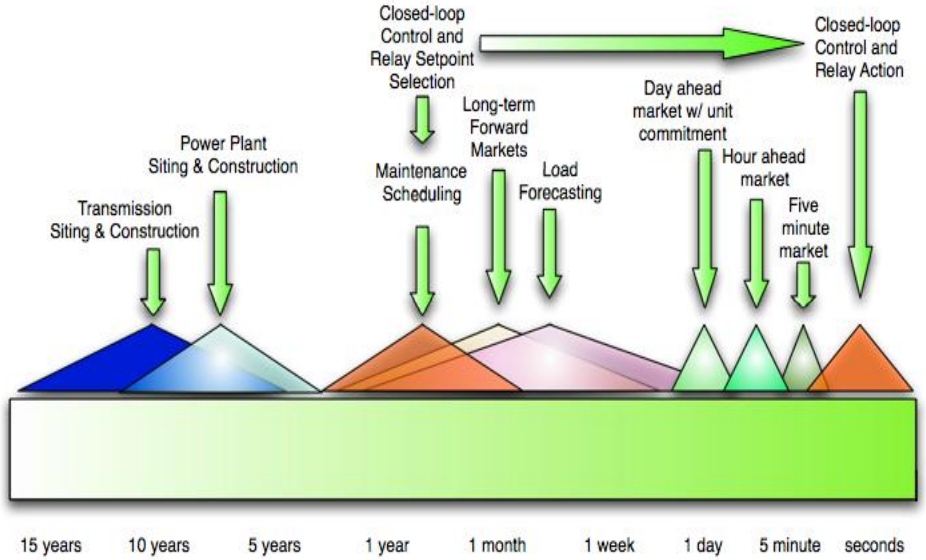


Source: M. Kintner-Meyer, PNNL

Emerging Areas of Model Research

Develop and test new approaches for operations and planning that incorporate…

- Uncertainty
  - *Wind, other generation*
  - *Load*
  - *Contingencies (discrete, low probability/high consequence)*
- Spatiotemporal dimension
  - *Storage, load shifting*
  - *Ramping constraints and costs*
  - *Unit commitment; economic dispatch*
  - *New generation and transmission infrastructure – dynamic effects*
- Environmental costs/drivers
- Infrastructure Inter-dependencies
- Pricing
  - *Co-optimize, avoiding sequential optimization (avoid proxy contraints)*
  - *Capture consumer behavior (as enhanced by smart grid technologies)*



Source: C. DeMarco, Univ. of Wisconsin-Madison