Power Grid Modeling and Data Integration

Data + Compute Convergence Summit

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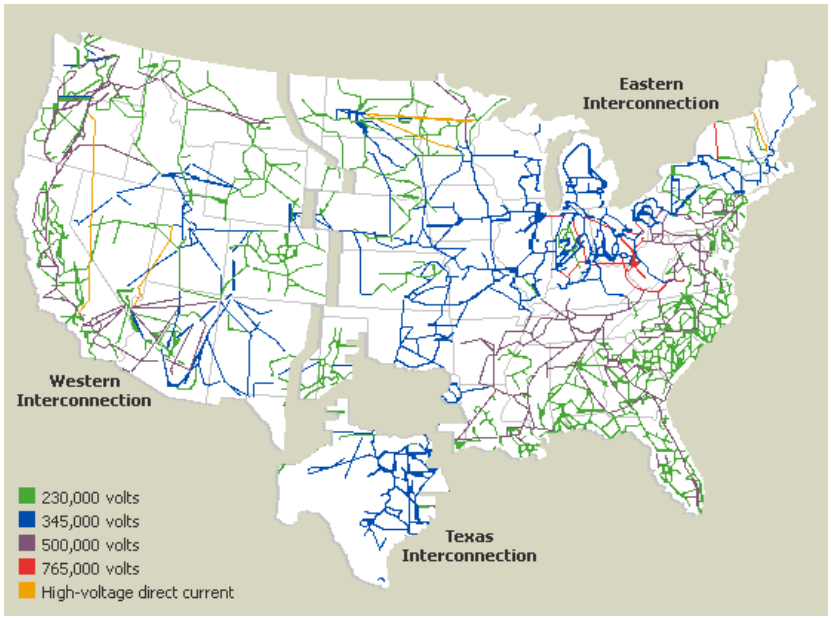
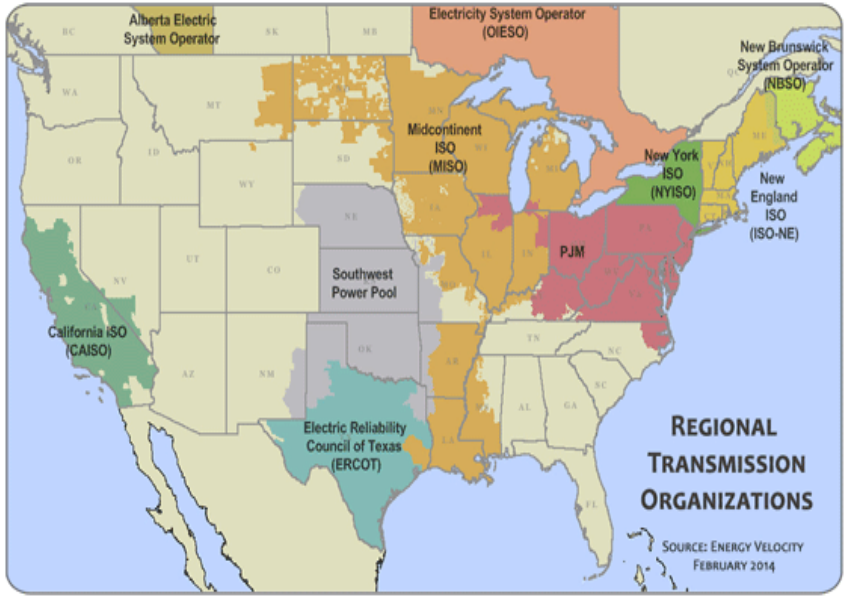
Power Grid at a glance

U.S. Power Grid Interconnections



- Three interconnections
  - Eastern (Largest)
  - Western
  - Texas

Regional Transmission Organizations



- Electricity Markets
  - Day-ahead
  - Hour ahead
  - Real-time (5 min or 15 min)

Bulk Power System Data

X Experimental data

- Almost none due to tractability
- May get some from specific equipment testing

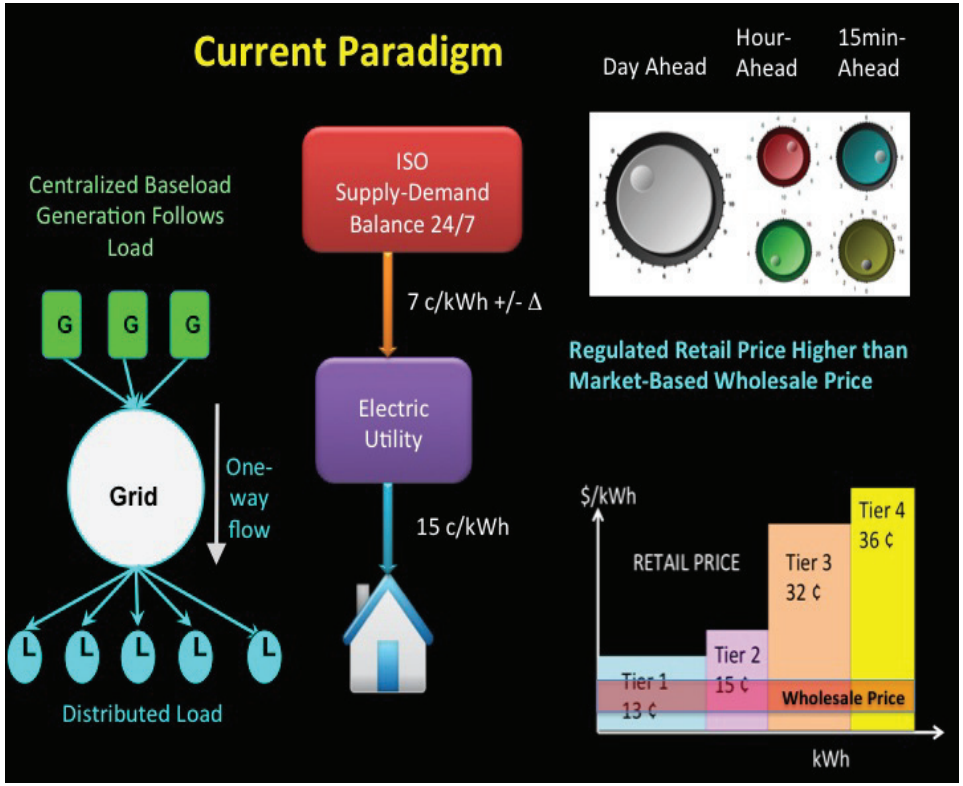
X Observed data

- System states, measurements, load/generation patterns
- Very difficult to acquire for large regions
- Data sharing : business and privacy issues

✓ Simulated data

Current operational paradigm

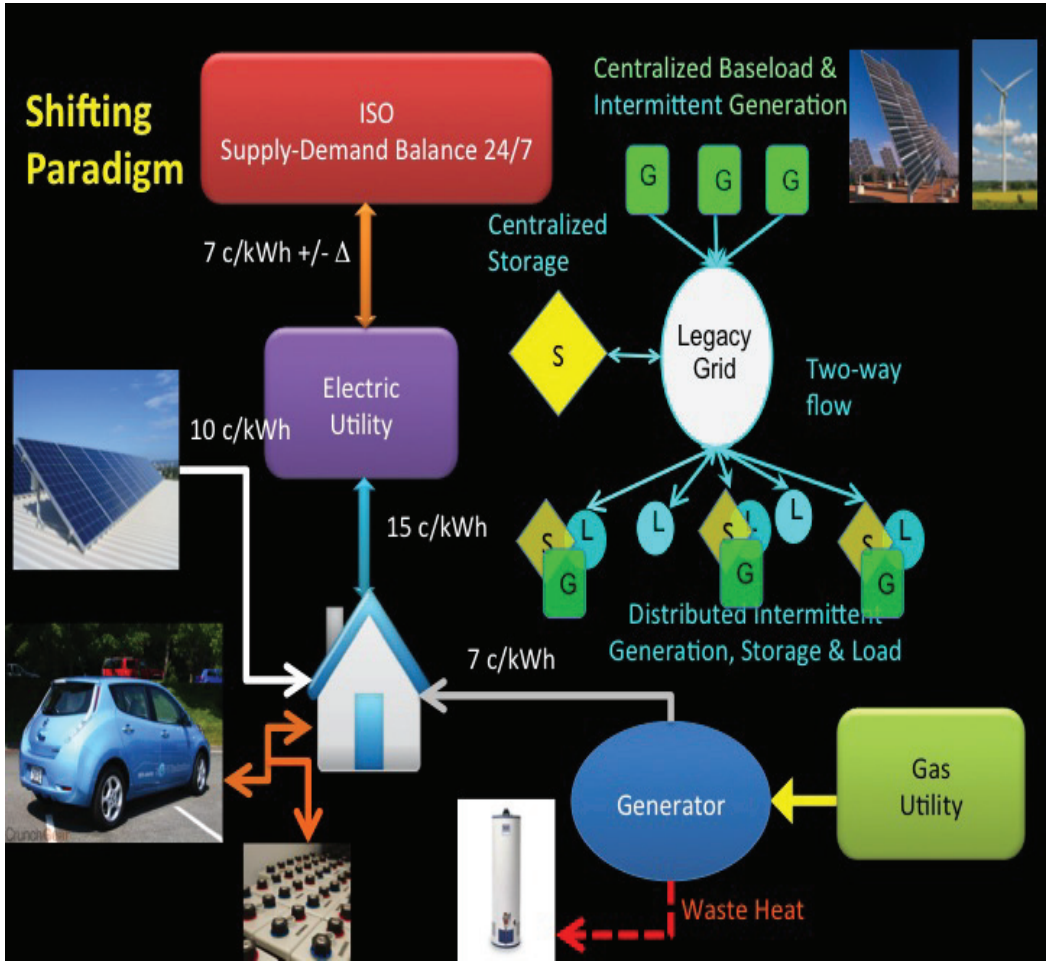
- Unidirectional flows
- Load aggregation
- Low penetration of renewables
- Bulk power generation



Source: Workshop Report on Mathematical Sciences and Research Challenges for the Next-Generation Electrical Grid

Future Operational Paradigm

- Load as a "prosumer"
- Two-way power flow
- Increased penetration of renewables
- Electric vehicles, rooftop solar PV panels, storage
- Increase in size and problem uncertainty
- Interdependency on other infrastructures
  - Gas, Water, Communication

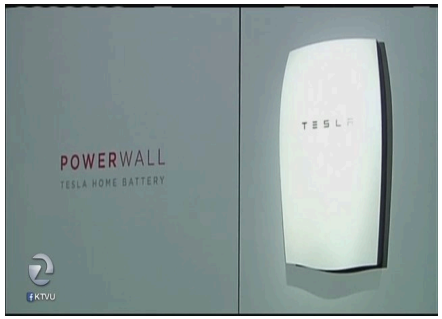


Source: Workshop Report on Mathematical Sciences and Research Challenges for the Next-Generation Electrical Grid

Emerging Data sources for simulations

Renewables

Storage

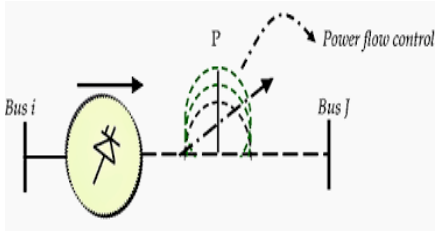


Electric Vehicles

Smart meter

Phasor Measurement Units

Power Electronics



Power flow controllers

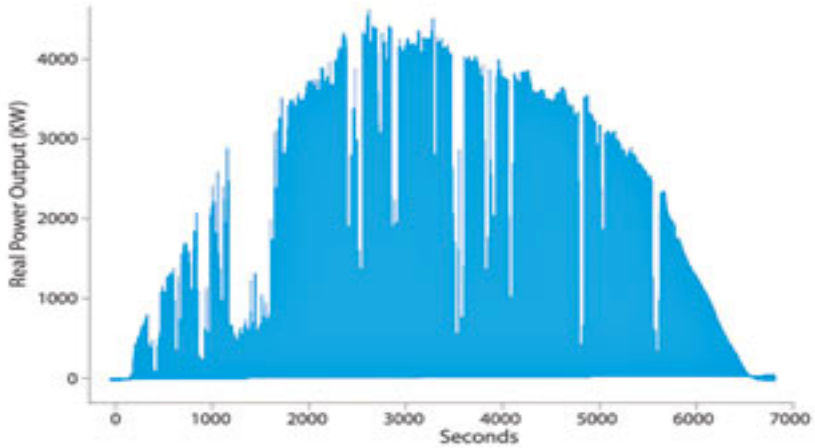
Future power system challenges

- Planning and operation with increased penetration of renewable energy (particularly solar and wind)
- Incorporating smaller generation sources and dynamic demand
- Prediction and Mitigation of Blackouts
- Handling data from increased deployment of sensors (PMUs, AMI, others)

Decision making under increased penetration of renewables

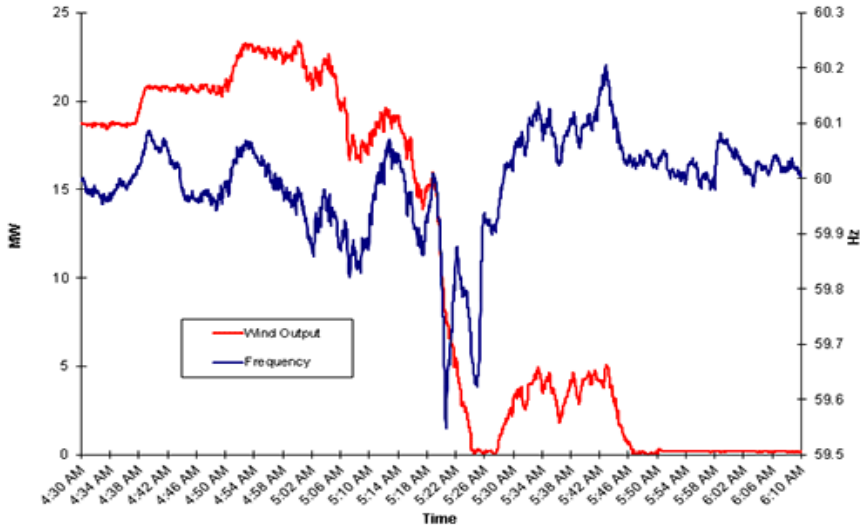
Intermittent and Variable Supply

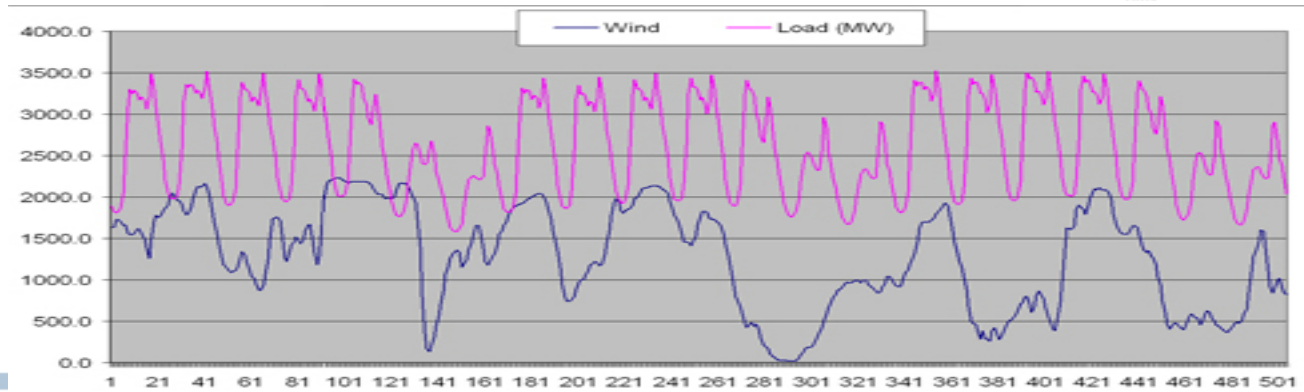
Real power output of a 4 MW PV power plant



SOURCE - EPRI

Example of wind variability and the effect on frequency





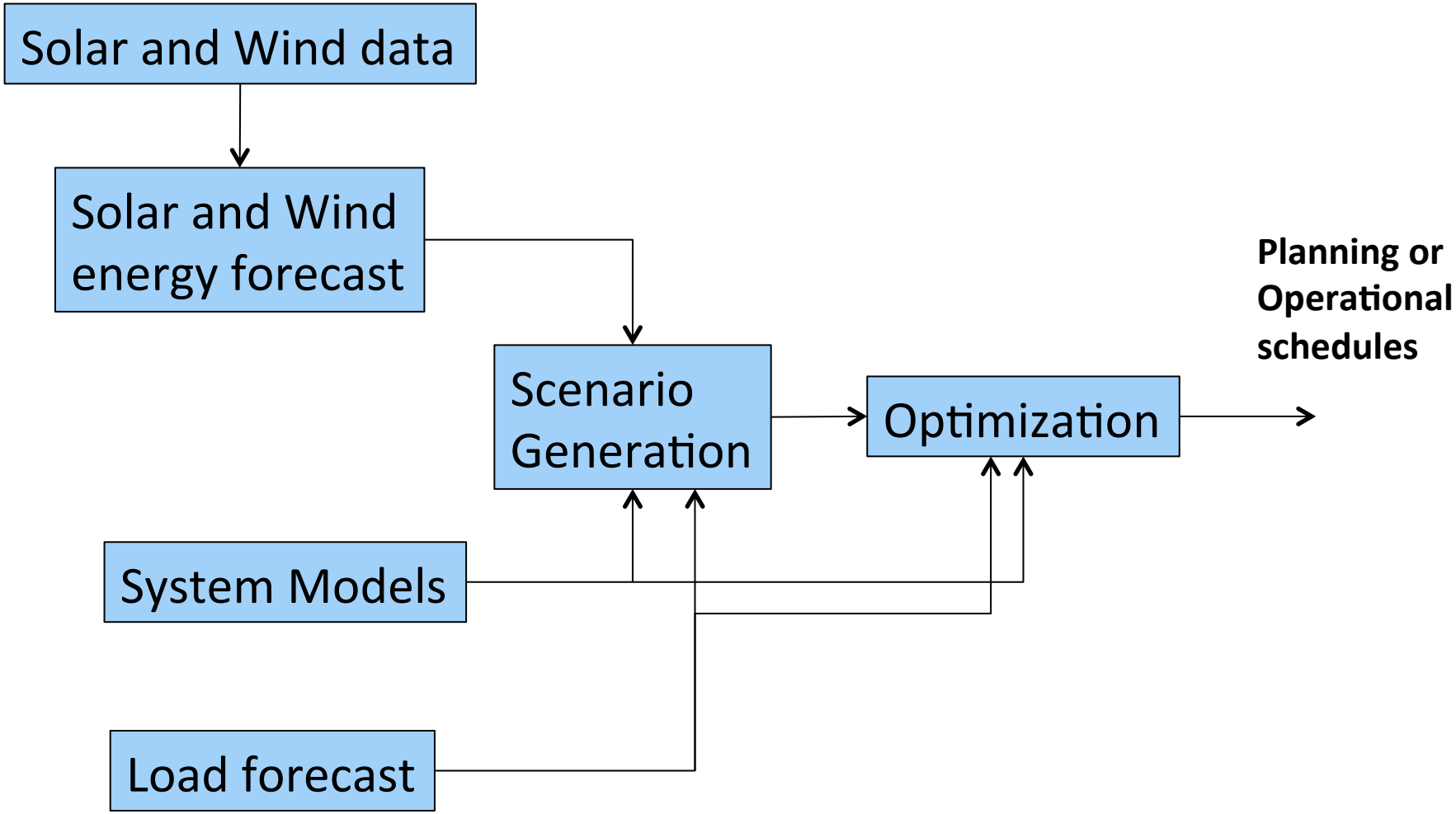
Decision making under increased penetration of renewables: Planning

- Generation and Transmission planning
  - 2 yr to 20 yrs horizon with 1 hr. decision intervals
  - Capacity value and transmission determination
  - Siting and interconnection of new units
  - Demand (Load forecast)
  - Very large mixed-integer linear (nonlinear) stochastic optimization problem (Billions of variables)

Decision making under increased penetration of renewables: Operations

- Security Constrained Unit Commitment
  - Main electricity market operation for day-ahead planning of resources
  - Large mixed-integer linear (nonlinear) stochastic optimization problem (> millions of variables)
  - Incorporate uncertainty from renewable energy sources such as solar and wind (lots of scenarios)
  - Security constraints (N-k)
  - Solution time constraints: Less than 24 hours

Decision making under increased penetration of renewables: Simulation workflow



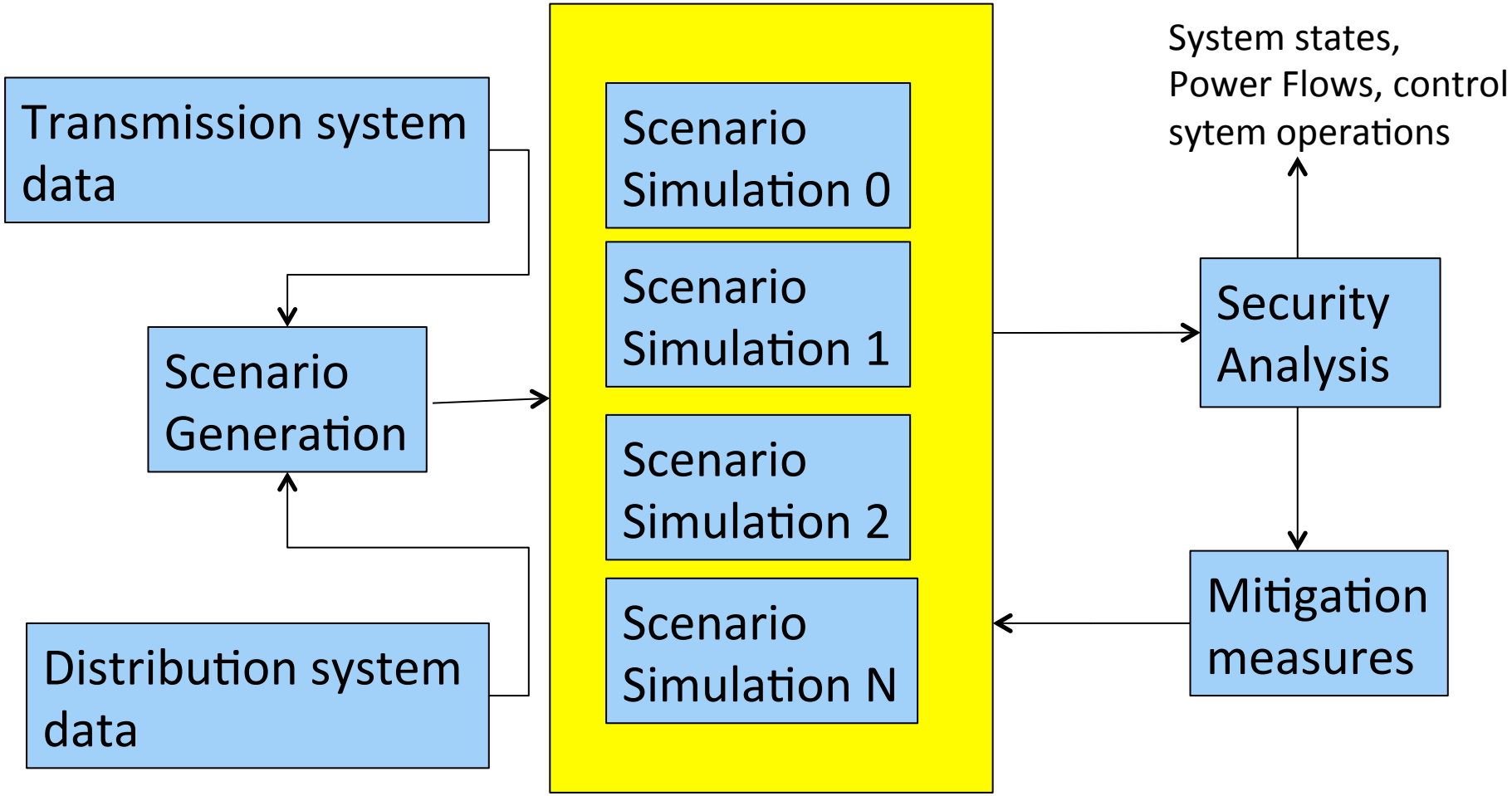
Integrated transmission and distribution analysis

- Currently, spatial separation for power grid applications
  - Transmission tools : Generation and high-voltage network
  - Distribution tools : Distribution substation to individual houses
- In Future, Active distribution system
  - Increased deployment of distributed generators (small generators, storage, roof-top solar panels, electric vehicles, others)
  - Load response

Integrated transmission and distribution

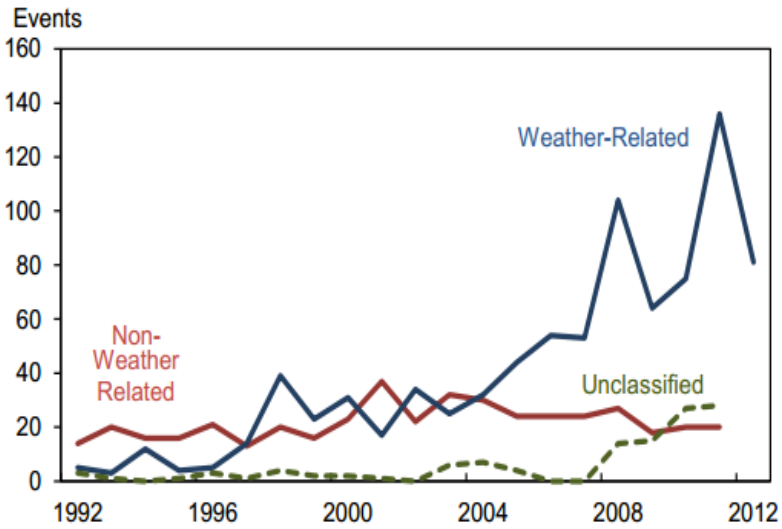
- Realizing the potential of distributed PV technology
- Understanding distribution system disturbances on transmission grid and vice-versa
- Potentially hundreds of millions of variables for a regional transmission + distribution grid steady-state (nonlinear) solution.

Integrated transmission and distribution analysis



Cascading Blackouts

August 2003 blackout

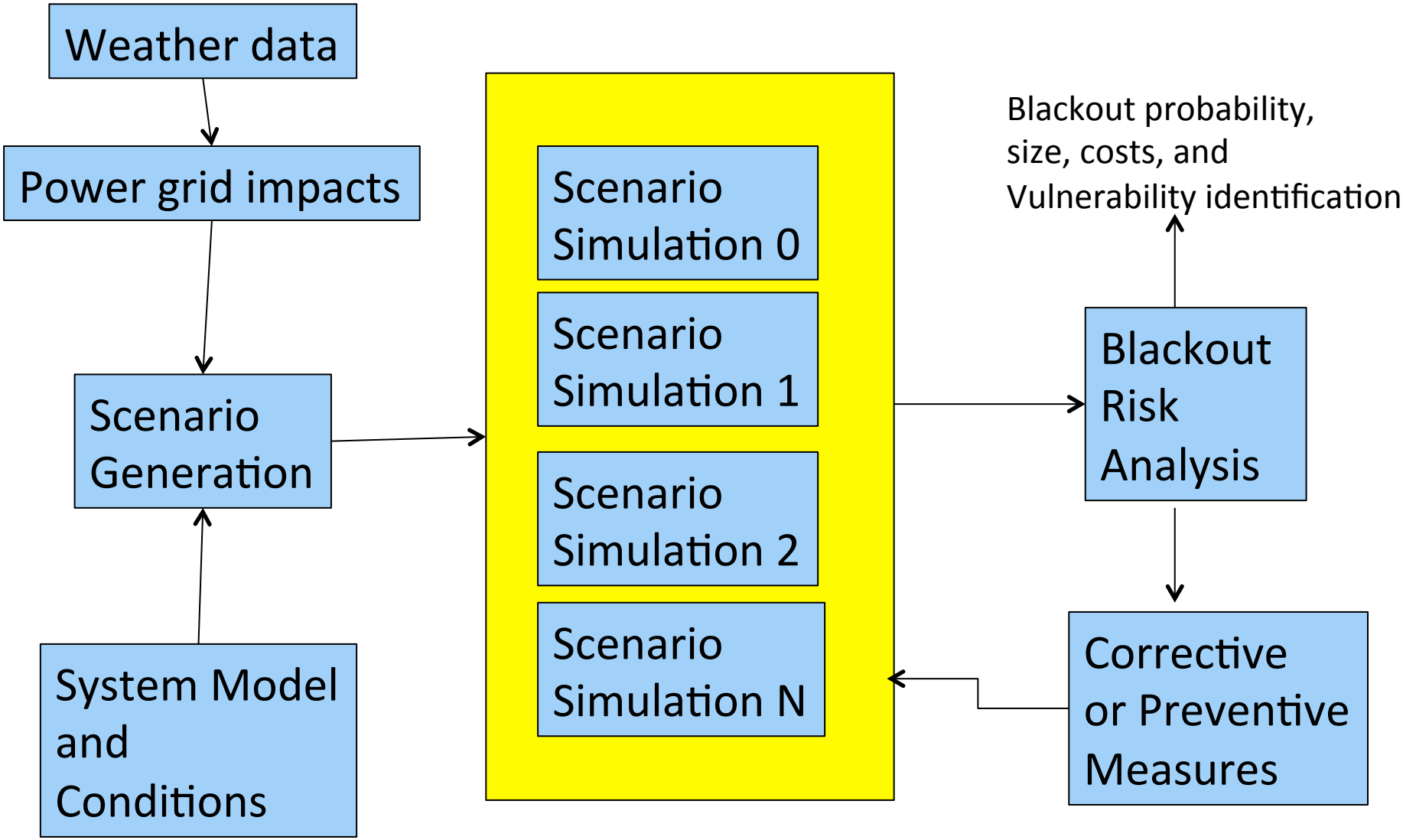


Number of blackout events on the rise

Mitigation of Cascading Blackouts

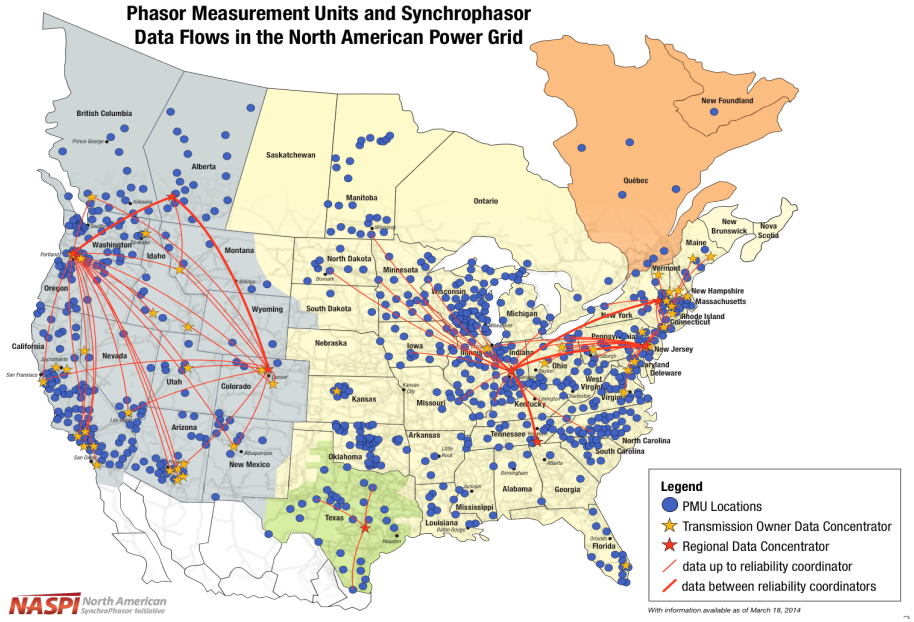
- Complex dynamic process involving solution of discontinuous differential-algebraic equations
- Key research questions:
  - Blackout propagation modes?
  - What is blackout probability in presence of bad weather? What is the size, societal costs?
  - Can a blackout be prevented if certain action is taken? Is it an optimal action?

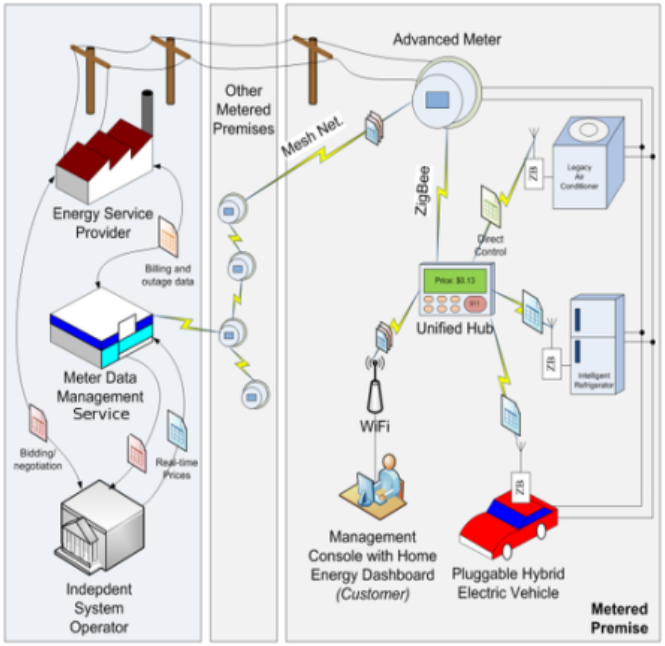
Blackout analysis workflow



Increased deployment of Sensors

Figure 1 – Data Flows from Transmission Owners to Regional Data Hubs and Between RCs





Phasor Measurement Units

- Nodal measurements are 30-60 times per second
- Over 1000 deployed currently.
- Increased deployment, including on the distribution grid

Smart Meter Infrastructure

- About 51 million deployed by 2014.
- Data rate of 15 mins – 1 hr.
- Enablers of behind-the-meter sources

Power grid sensor research questions

- Identifying system stress indicators from sensor data
- Understand correlations between heterogeneous sensor data
- Validation of models

- However…
  - Data availability issues!!!

Concluding remarks

- DOE GMLC Goals for next 10 years
  - 10% reduction in societal costs of power outages
  - 33% reduction in cost of reserve margins while maintaining reliability
  - 50% cut in the costs of wind and solar and other DG integration

Need advanced math, computing, and data science to realize future power grid potential

Date + Compute Convergence

- Bottlenecks
  - Scenario generation and interaction with simulation
  - Organizing data for analysis, data reduction
  - Fast and robust optimization solvers
  - Real-world data unavailability

Bibliography

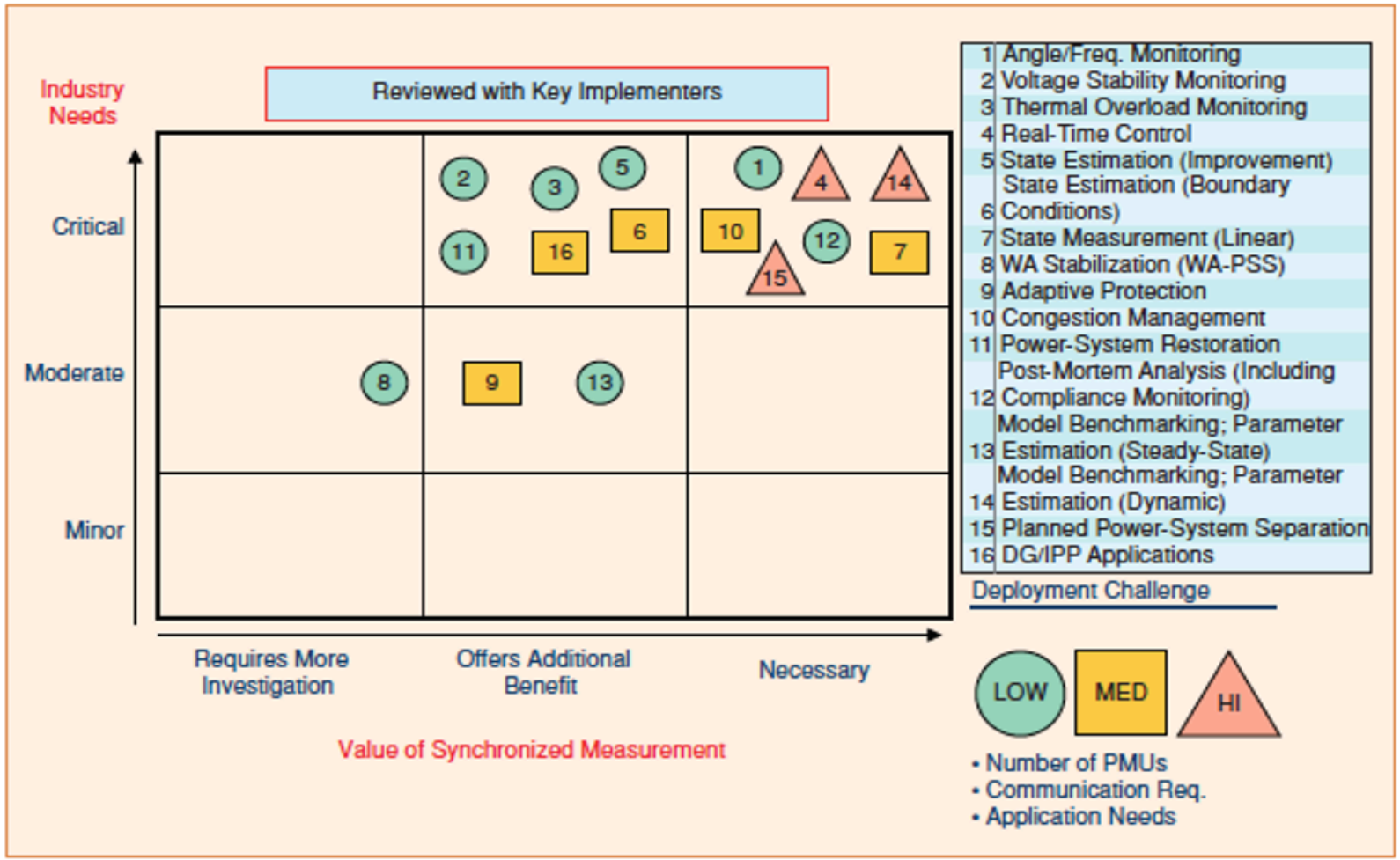
- Mathematical Sciences and Research Challenges for the Next-Generation Electrical Grid: http://www.nap.edu/21808
- 2nd Workshop on Challenges in Next-Generation Analytics for the Future Power Grid
- The future of the Electric Grid. An Interdisciplinary MIT report
- Tommorow's Electric Power System: Challenges & Opportunities
- PMUs and synchrophasor data flows in North America
- Technology Challenges in Designing the Future Grid to Enable Sustainable Energy Systems

QUESTIONS

Date + Compute Convergence

- Meaning of "convergence"
  - Solving large-scale problems involving data and computation
  - Data analytics to understand patterns, identifying anomalies.
- Benefits to Power Grid
  - Direct implication on planning, operations, and analysis.
- Bottlenecks
  - Scenario generation and interaction with simulation
  - Fast and robust stochastic optimization solvers
  - Fast and large-scale mixed integer nonlinear solvers
  - Real-world data unavailability (only through NDAs)
  - Visualization of time-varying data over large networks

Phasor Measurement Units (Industry Needs)



Source: D. Novosel. "Dawn of the Grid Synchronization – Benefits, Practical Application and Deployment Strategies for Wide Area, Monitoring, Protection, and Control

DOE GMLC Goals for next 10 years

- 10% reduction in societal costs of power outages
- 33% reduction in cost of reserve margins while maintaining reliability
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Developments in power grid

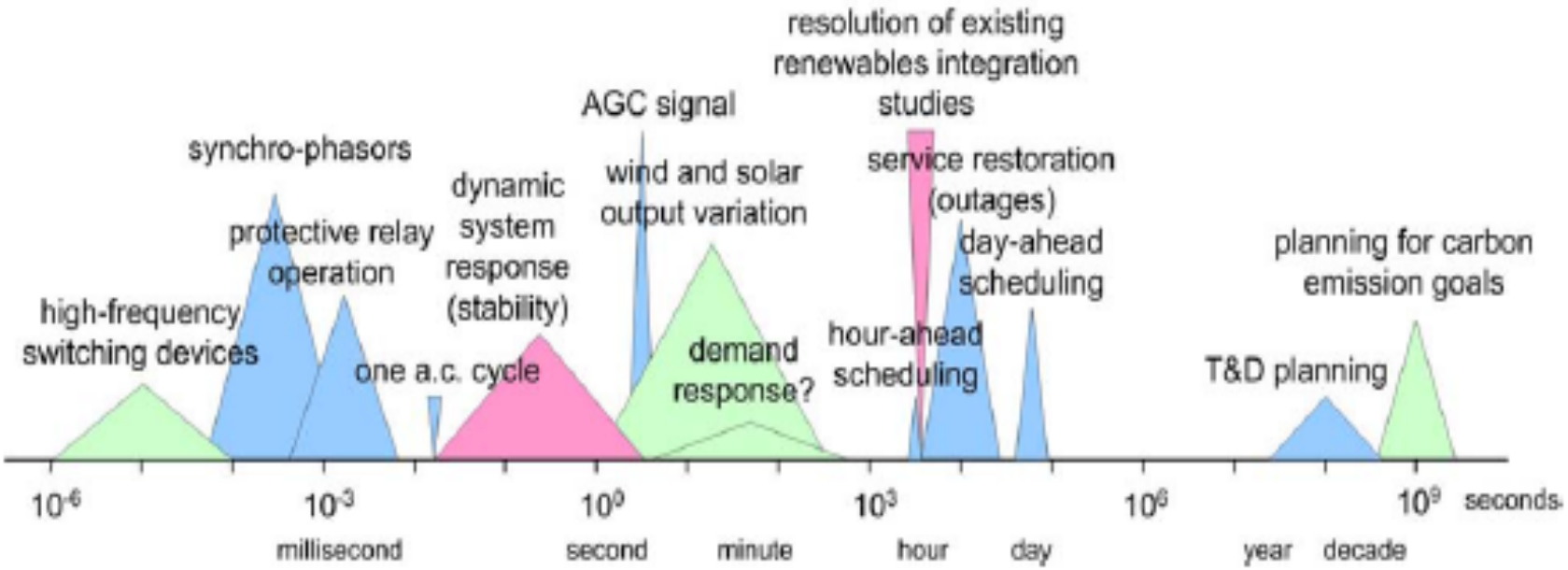
- Increased penetration of renewable energy sources
- Customer installation of distributed generation (solar rooftop panels, wind turbines, storage, electric vehicles)
- Greater system awareness (smart meters, dynamic pricing)
- High-Fidelity measurements (Phasor measurement units) for improving stability and monitoring of disturbances
- Installation of new devices (HVDC lines, Static Var compensators, and others) that require advanced tools blurring temporal boundaries.

Power system emerging data characteristics

- Heterogeneous
- Spatial/Temporal or both
- Variability and Intermittency (renewables)
- Volume
- Sources
  - Forecasts
  - Measurements
  - Models
- Constraints
  - Time-critical

Power system time-scales

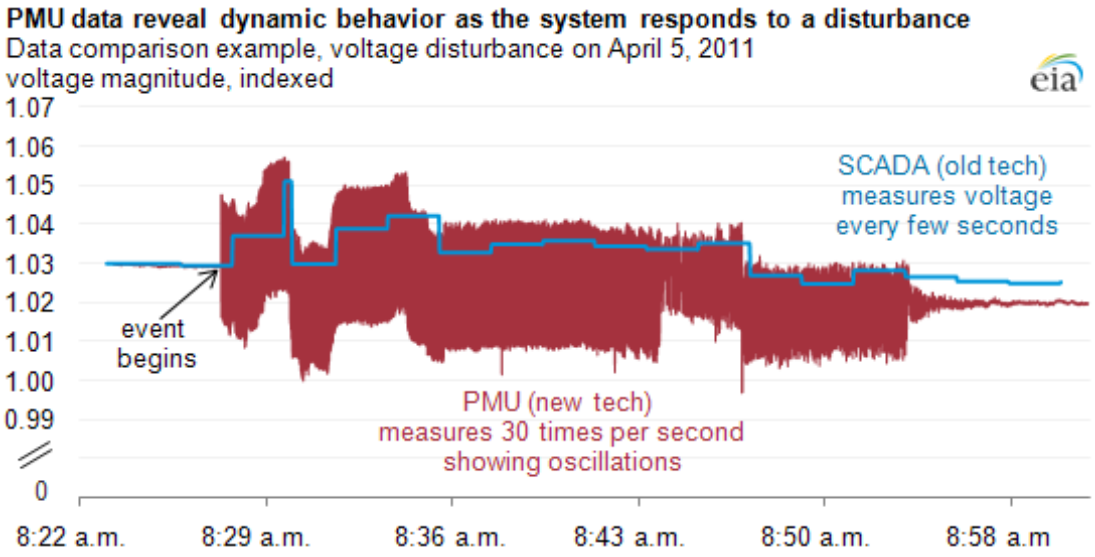
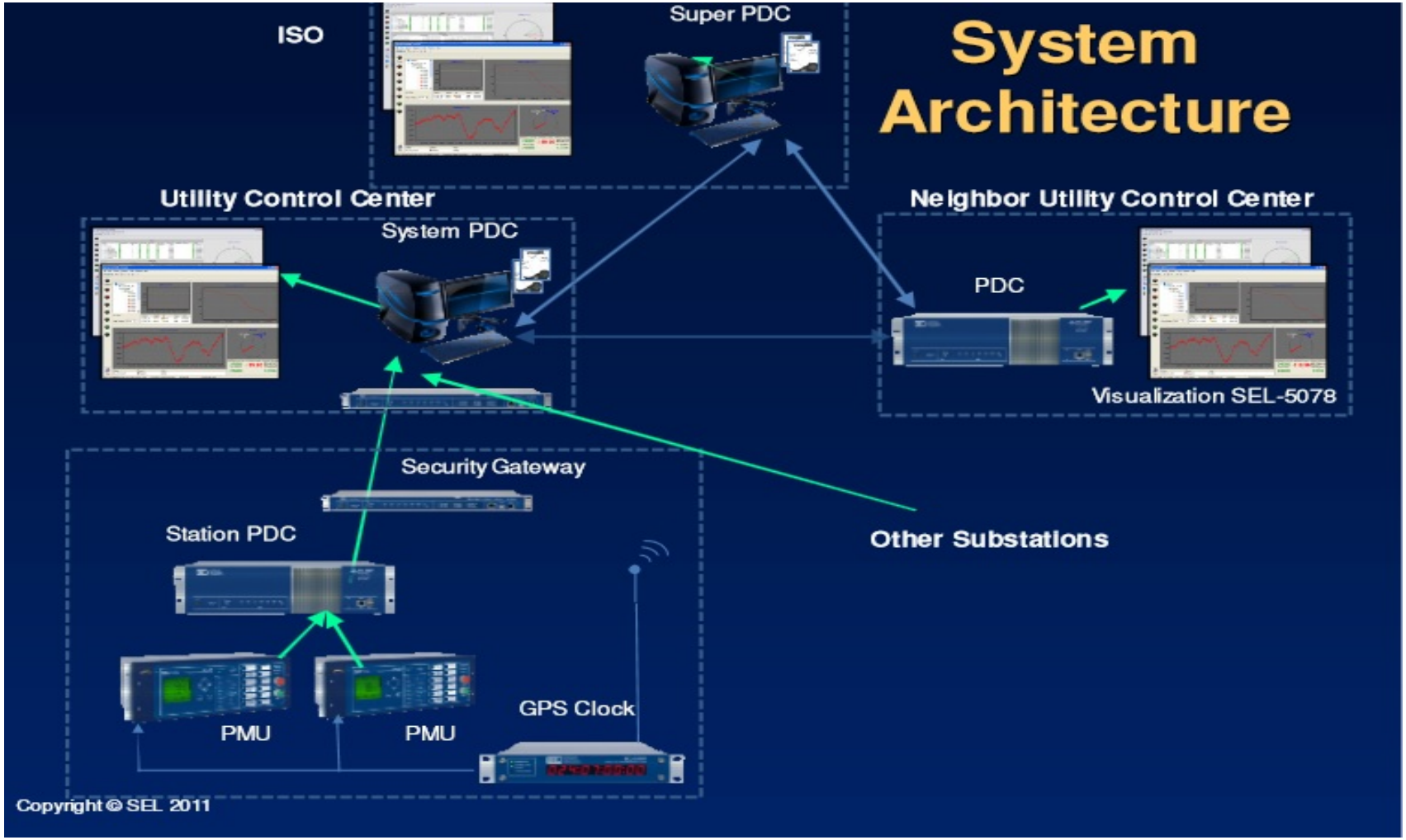
Figure 1: Time Scales for Power System Planning and Operation



- Scale separation for simulations
  - Planning versus operation (Business)
  - Steady-state versus transient (Temporal)
  - Transmission versus Distribution (Spatial)

Phasor Measurement Unit (PMUs)

- Replaces slower (SCADA) measurements
- Measure system state (voltages) at minimum 30 samples per second.
- ~ 8 GB/PMU per day @ 30 samples per second
- Need atleast one-third of nodes covered for system observability.
- Only used for post-mortem analysis (currently)



Phasor Measurement Unit: System connectivity