The Road Ahead: Autonomous Power Grid

Dr. **Vahid Madani**, PE, Fellow IEEE
President and Executive Engineer

www.GridTology.com

Workshop Theme: Time and Synchronization Across Industries

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Every crucial economic and social function depends on **resilient**, **secure**, **and reliable** operation of the power and energy infrastructure.

Energy related low carbon initiatives and Grid modernization are in full gear worldwide

Source and load control at the distribution level are quickly becoming key requirements in this evolving system

A changing environment requires a transformed grid

The immense investments in power system upgrades and deployment of advanced technology-based sensors and measurement devices

Digital Substation business case is becoming more evident / relevant, and human machine interface for managing power system assets is gaining attention

CIMON: New Space Cadet
Crew Interactive Mobile Companion

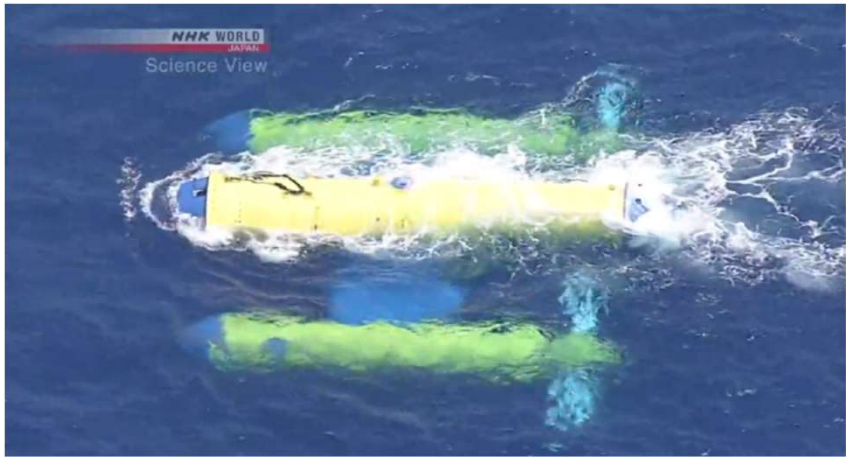
Machine Learning and Robotic Inspection for substation equipment is now in experimental testing in parts of the world.

Cognitive computing, and ability to interact with humans is within reach, due to the advancements in technologies like natural language processing and facial recognition.

Introduction (Cont'd)

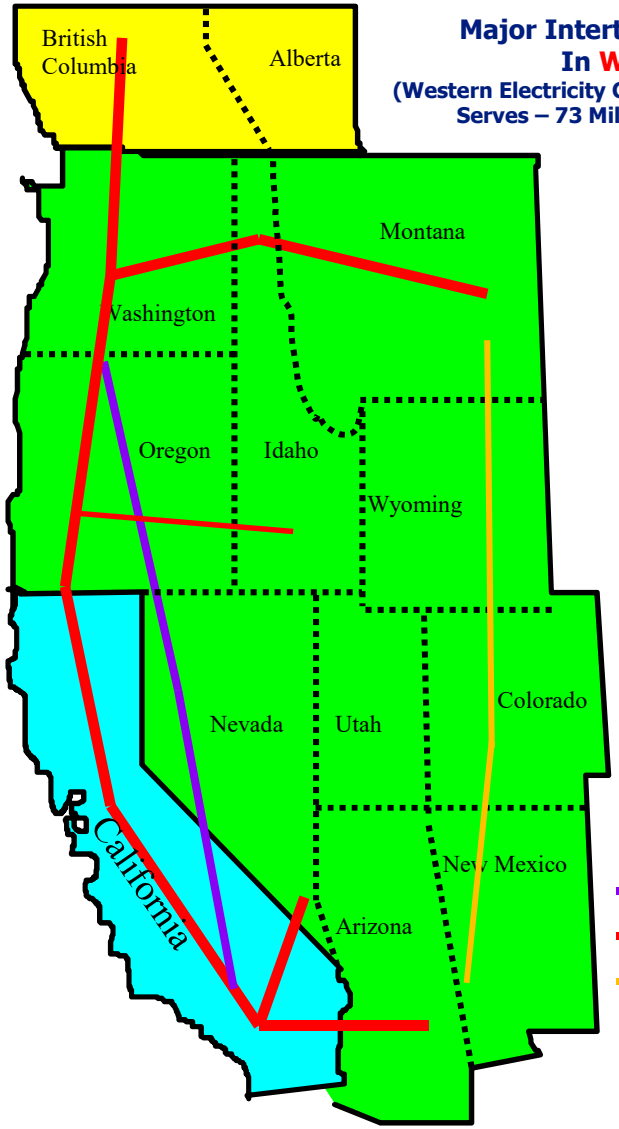
- Wireless technology has become a ubiquitous part of our daily lives
- The prospect of not being connected continuously has become unimaginable
- Use of GPS and precision timing, for synchronization of critical grid infrastructure essential
- Timing security and threat mitigation measures have become indispensable in a changing landscape
- Upcoming Global Positioning System (GPS) week number rollover will occur on April 6, 2019; an event potentially affecting satellite clocks
  - The previous week number rollover occurred August 21, 1999
- It may be worthwhile to contact vendor(s) to verify necessary precautions are in place for any critical applications, and monitor the rollover event closely

- The need for new robust and well tested solutions to leverage the investments is more acute
- Many segments or components of the grid will soon become more autonomous and responsive
- When properly implemented, advanced portfolio of timing technologies, services and solutions, enable us to build more reliable networks and systems supporting today's needs and future autonomous grid systems



50kW Marine Generating Unit, Trial Operation 2017
Source: NHK Word News

NERC Grid capacity - 1.25 Terawatt



Major Intertie Corridors
In WECC
(Western Electricity Coordinating Council)
Serves – 73 Million Population

PDCI – DC Link, 1000kV

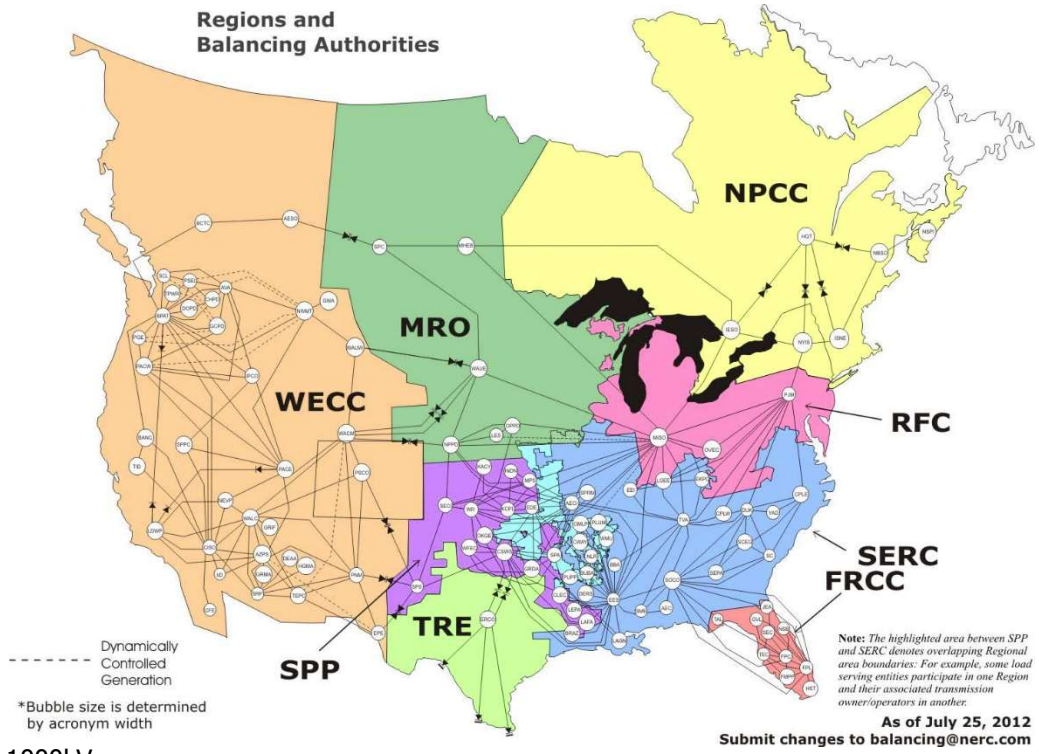
PACI – AC Corridor, 500kV

PACI – AC NE/SE, 345kV

NE / SE - North East

SE – South East

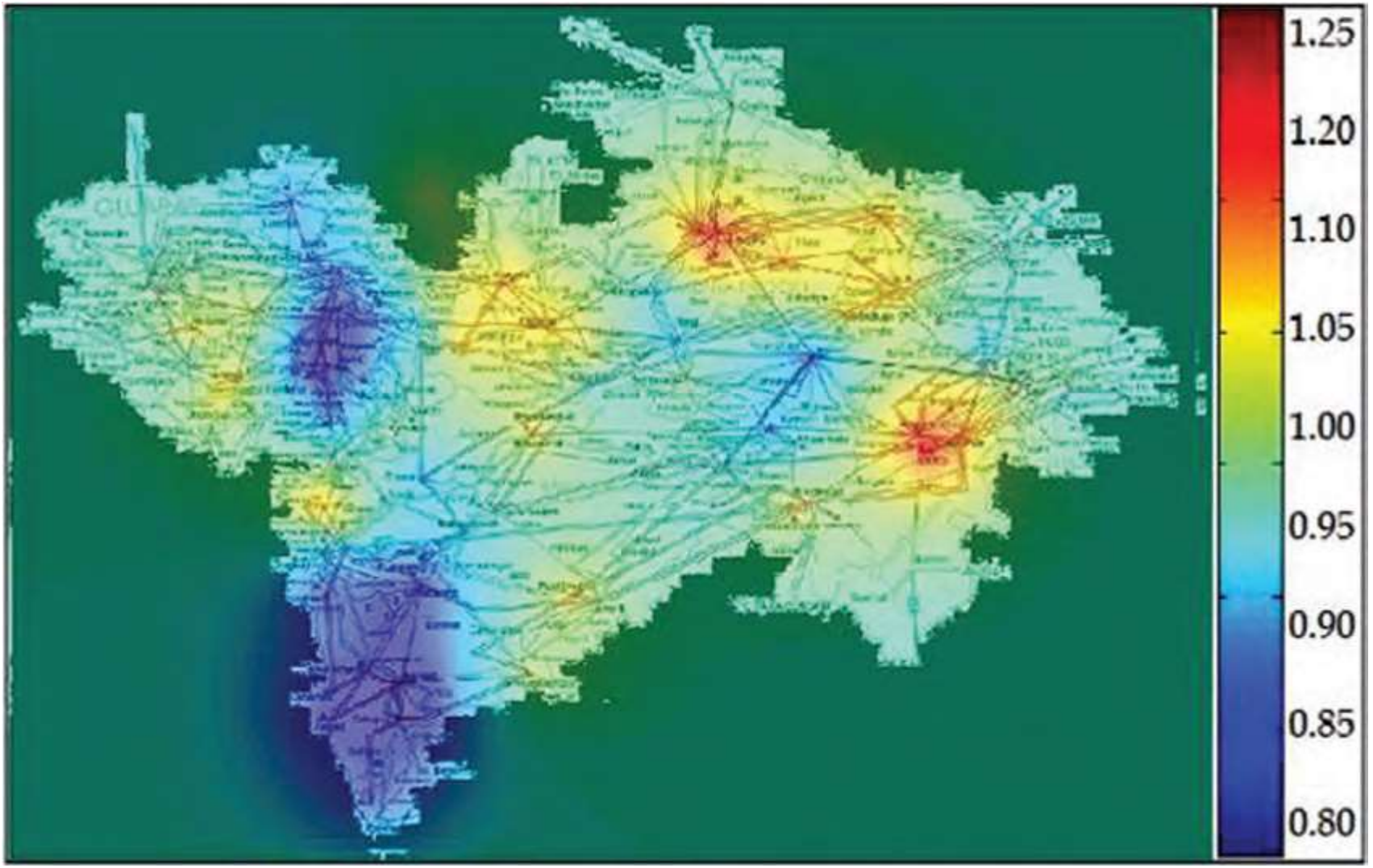
Over 100 Balancing Authorities. Overseeing the Balancing Authorities are operators called Reliability Coordinators.



Relationship between Reliability Coordinators and Balancing Authorities is similar to that between air traffic controllers and pilots.

http://www.ferc.gov/market-oversight/mkt-electric/nerc-balancing-authorities.pdf

Not Unique to North America, One Example



source: POSOCO – “Synchrophasors in India” 1800 Device

Transformation at incredible speed

Growing scarcity in flexibility

Power Industry Transformation

Wind

- Unpredictable Output
- 4,773 MW Peak – April 24, 2016
- 6,087 MW Installed Capacity

Solar Thermal / Photo Voltaic

- Semi – Predictable Output
- 9,868 MW Peak – April 21, 2017
- ≈ 10,000 MW Installed Capacity

* Simultaneous wind and solar has exceeded 13,000MW on April 23, 2017

Roof Top Solar

- Semi – Predictable Output
- Behind the meter – Residential
- 5,000+ MW Estimated Capacity

Main Drivers:

- ✓ California RPS
- ✓ GHG reduction
- ✓ Once-through-Cooled plants retirement

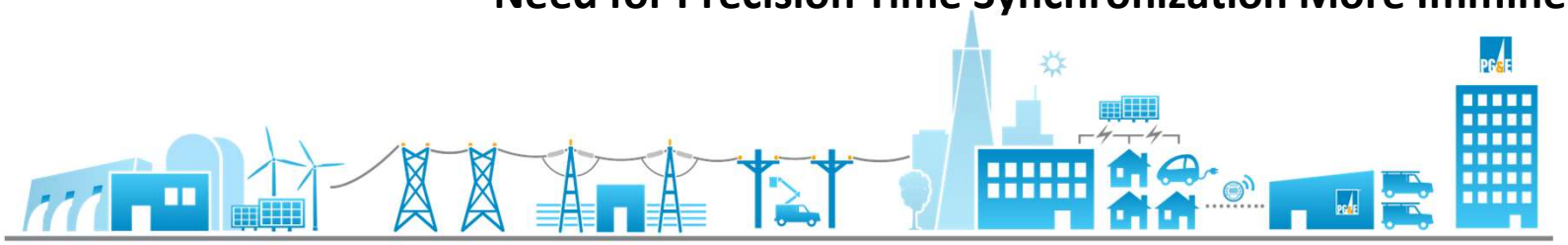
Goals:

- ✓ Higher expectation of reliability
- ✓ Higher expectation of security
- ✓ Smart Grid
- ✓ Situational awareness through Visualization

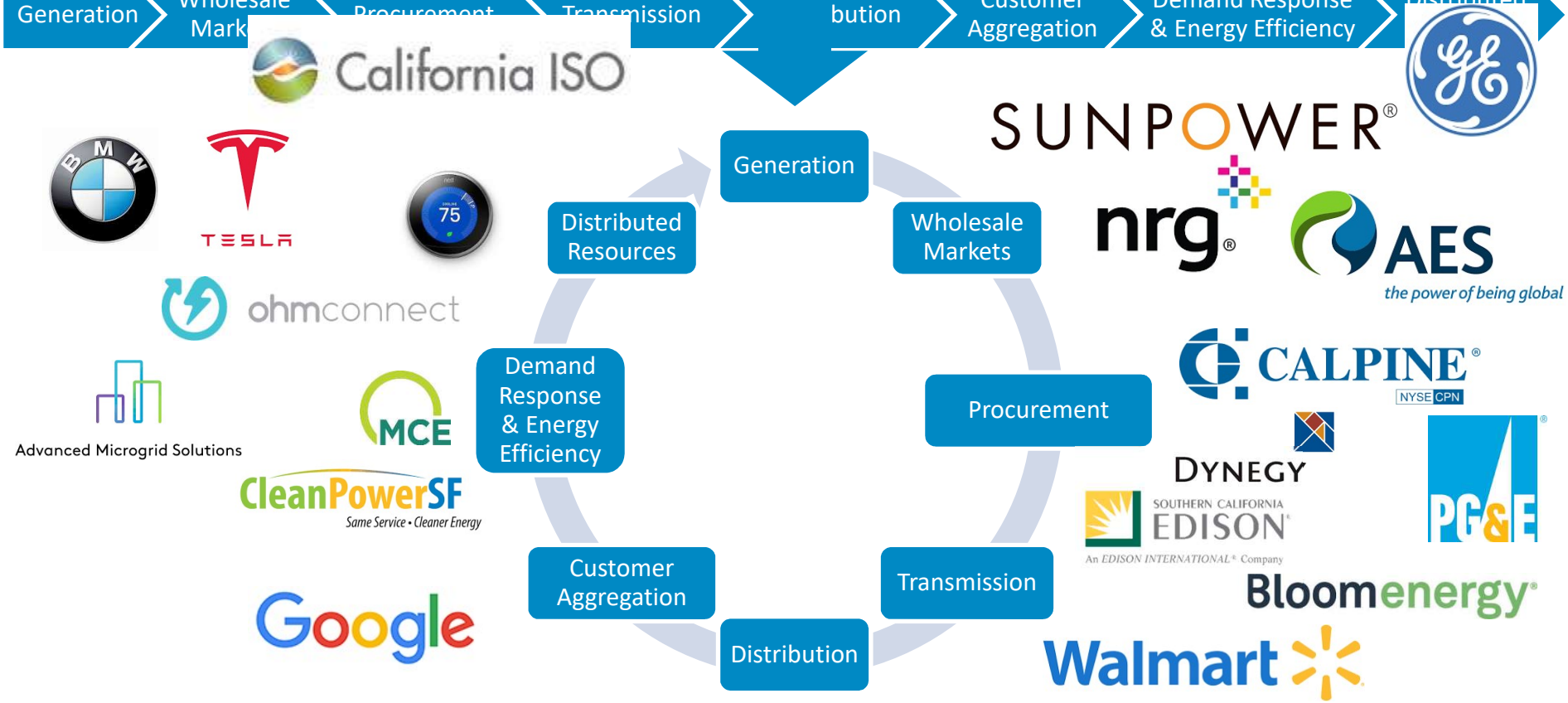
RPS – Renewables Portfolio Standard

Energy Landscape Transition; More Distributed & Dynamic

Need for Precision Time Synchronization More Imminent

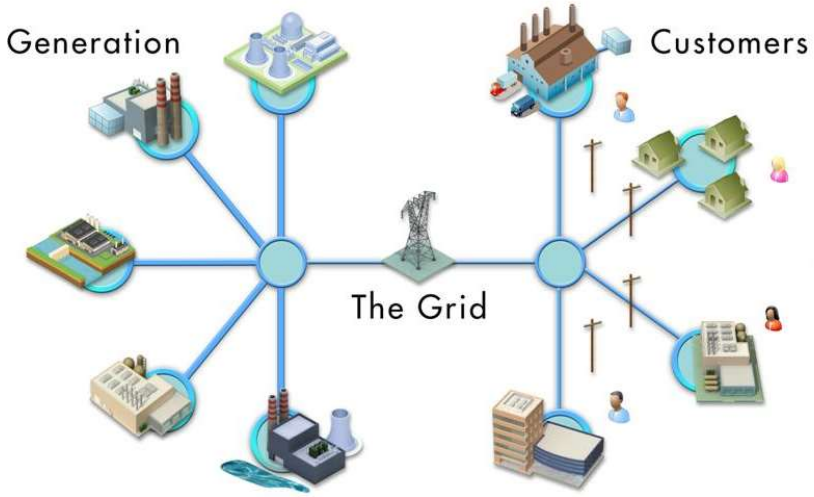


Generation | Wholesale Mark | Procurement | Transmission | bution | Customer Aggregation | Demand Response & Energy Efficiency | Distributed



The Electric Grid: Past, Present, and Future

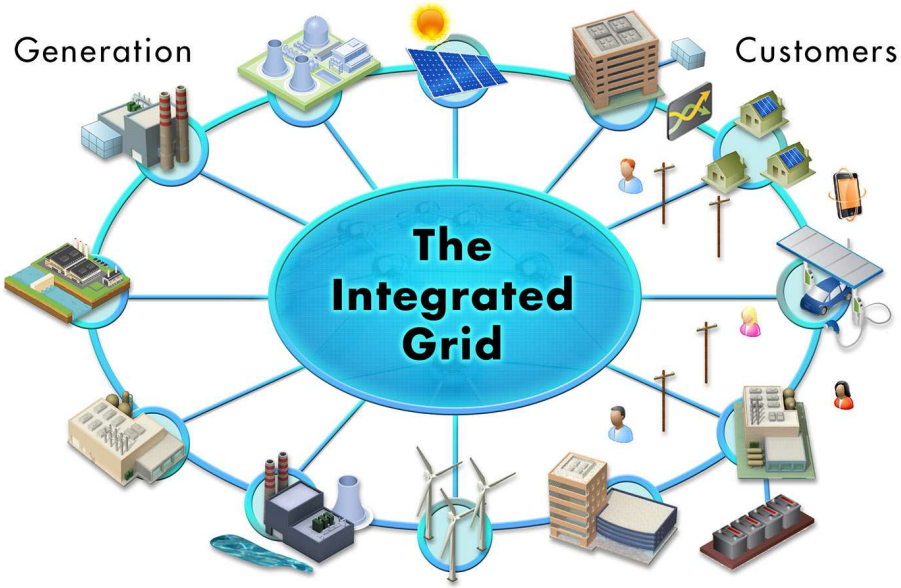
Past



Core Mission:

1. Safe
2. Reliable
3. Affordable

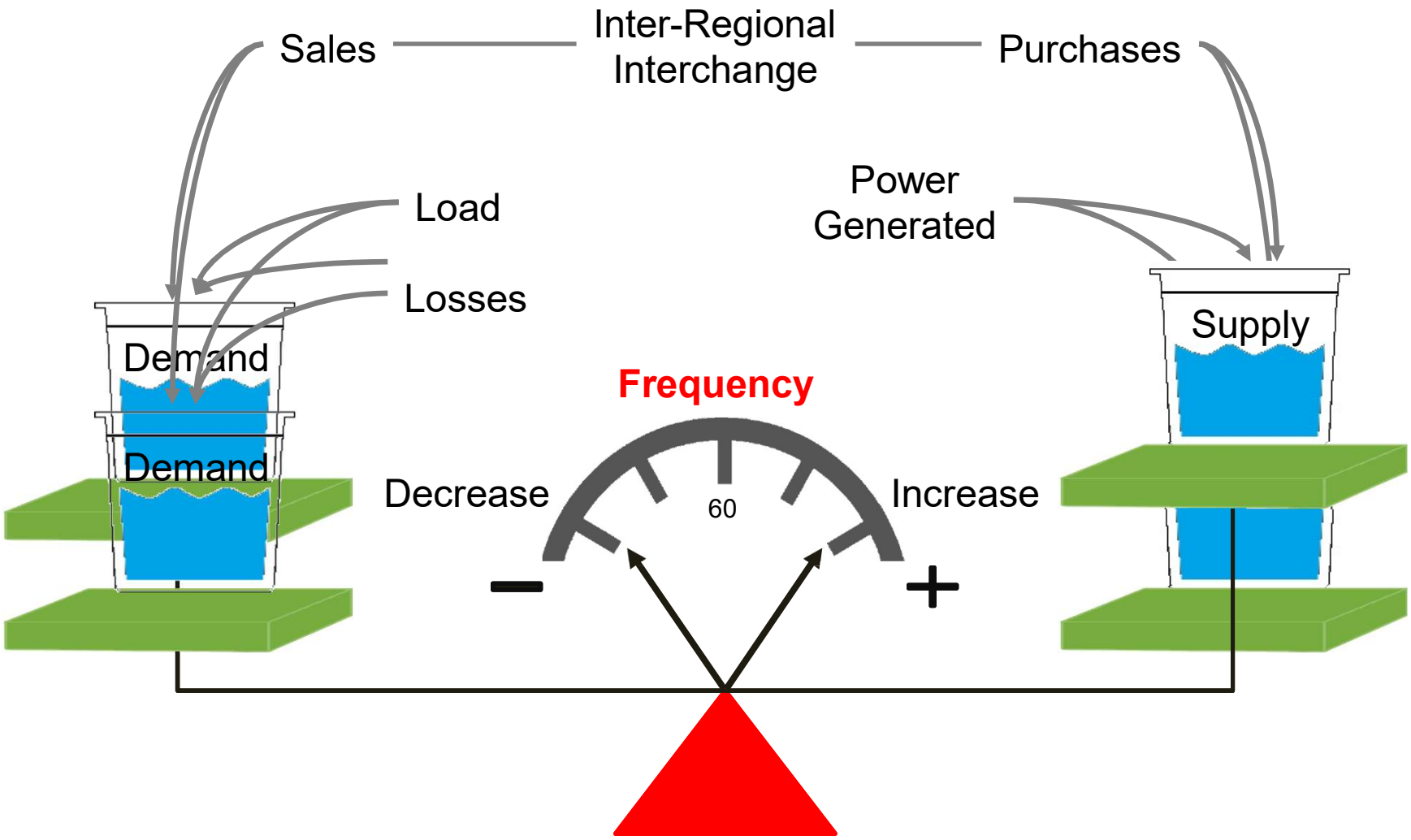
Future
Present Path



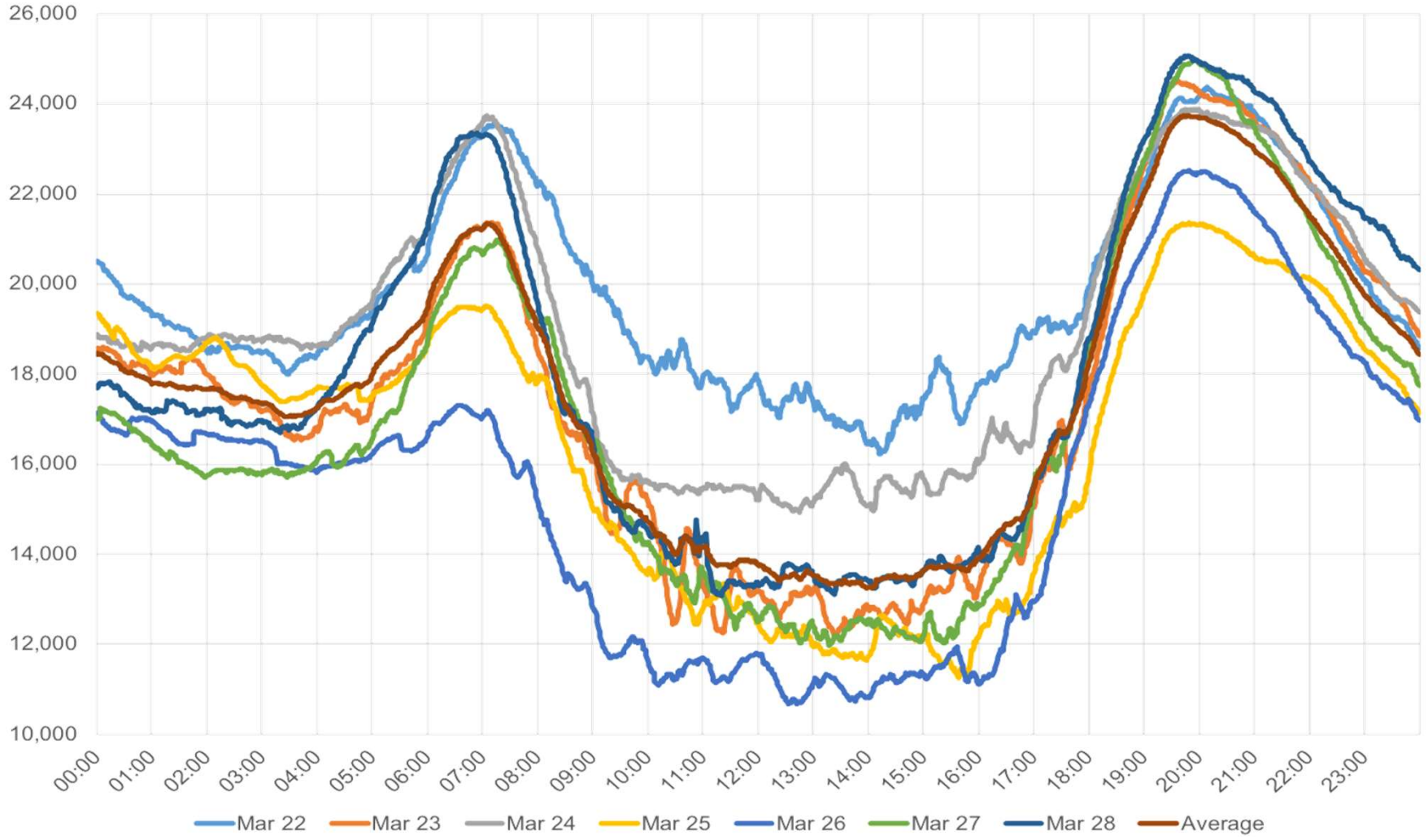
Core Mission:

1. Safe
2. Secure
3. Time and Frequency Synchronized
4. Reliable
5. Affordable
6. Environmentally Responsible
7. Integrated
8. Connected, not islanded
9. Resilient
10. Flexible

The balancing of supply and demand

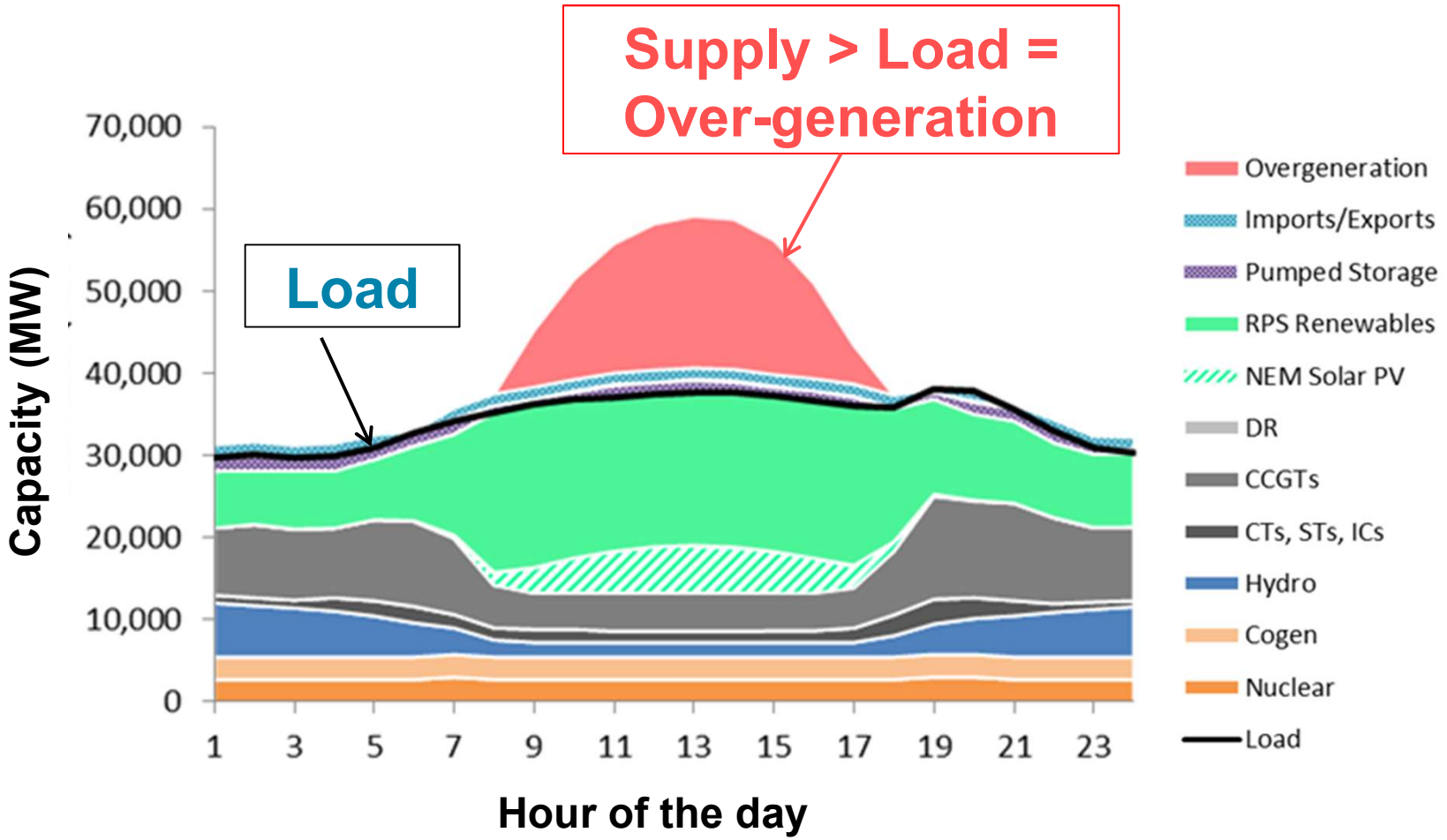


Net load varies significantly day-to-day and minute-to-minute



Over-generation

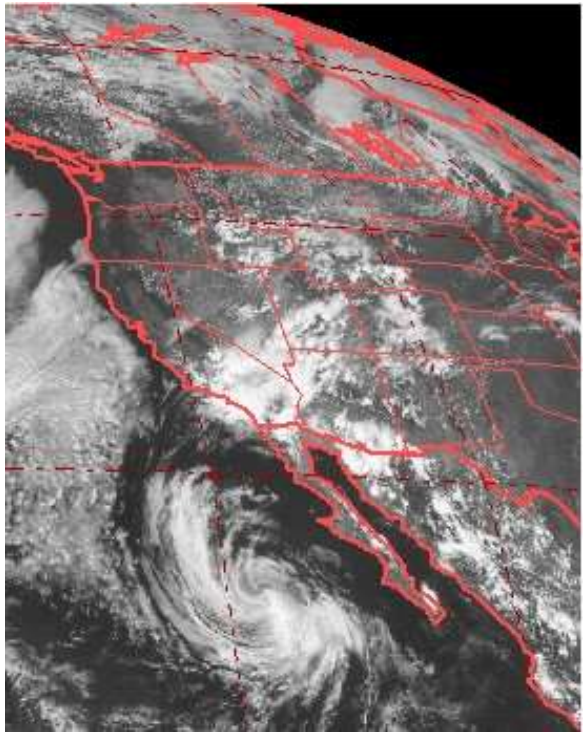
Generation mix calculated for April Day in 2030 with 50% RPS

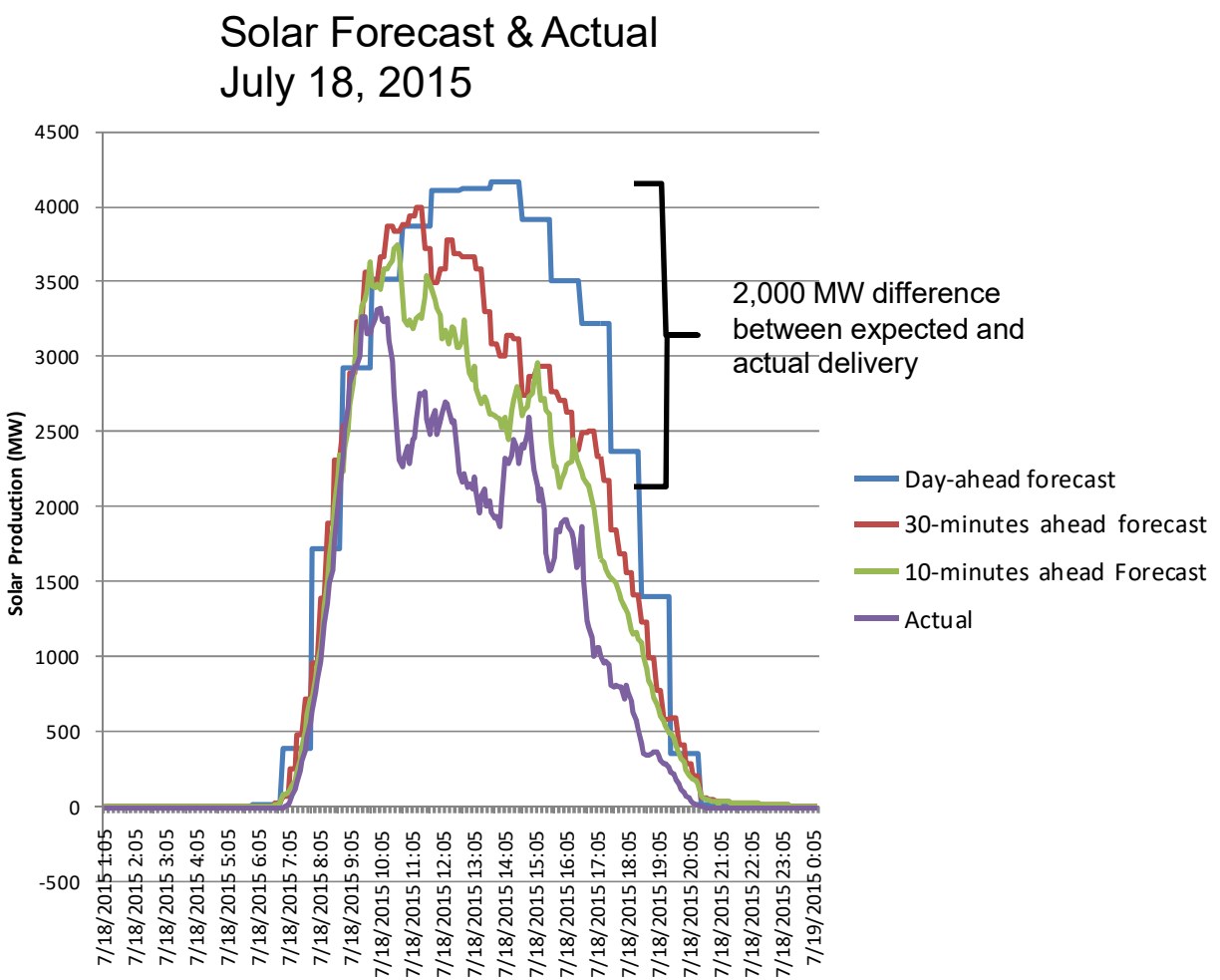


RPS – Renewable Portfolio Standard

Enhance forecasting to manage supply uncertainty

Example day with monsoonal conditions

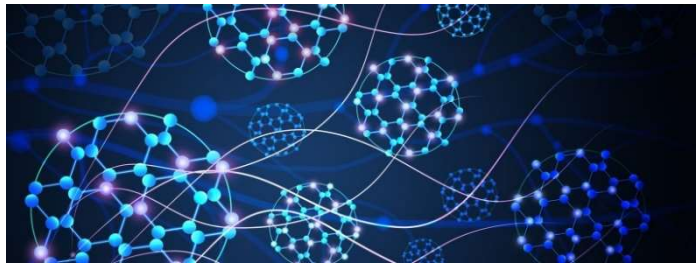




Source: California ISO

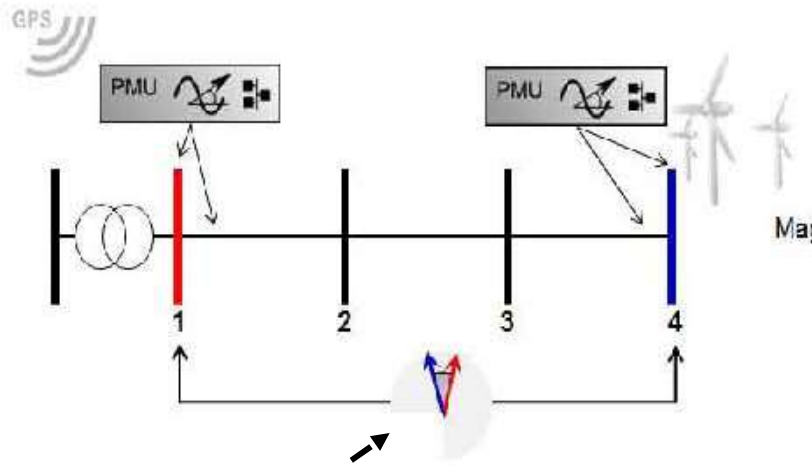
What is Synchrophasor Technology?

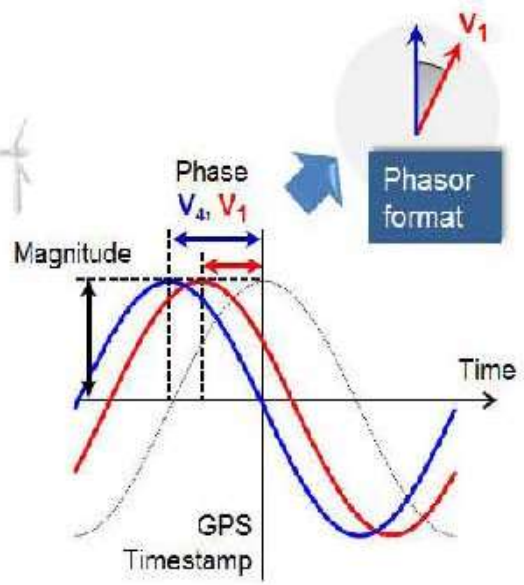
- Latest measurement technology
  - (voltages, currents, frequency, frequency rate-of-change, etc.)
- Far higher resolution scans
  - e.g. 30-240 samples/second
  - Compared to one every 4-8 seconds and no time tag
  - Improved visibility into dynamic grid conditions.
  - Early warning detection alerts
- Started with Transmission
  - Proliferating into distribution systems
- Precise GPS time stamping
  - Wide-area Situational Awareness
  - Faster Post-Event Analysis



Synchrophasors show the DNA of power system in real-time

Phasor Measurements and Synchrophasor Systems

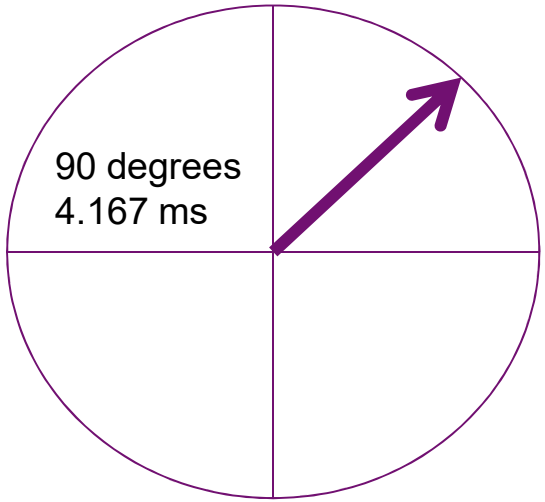




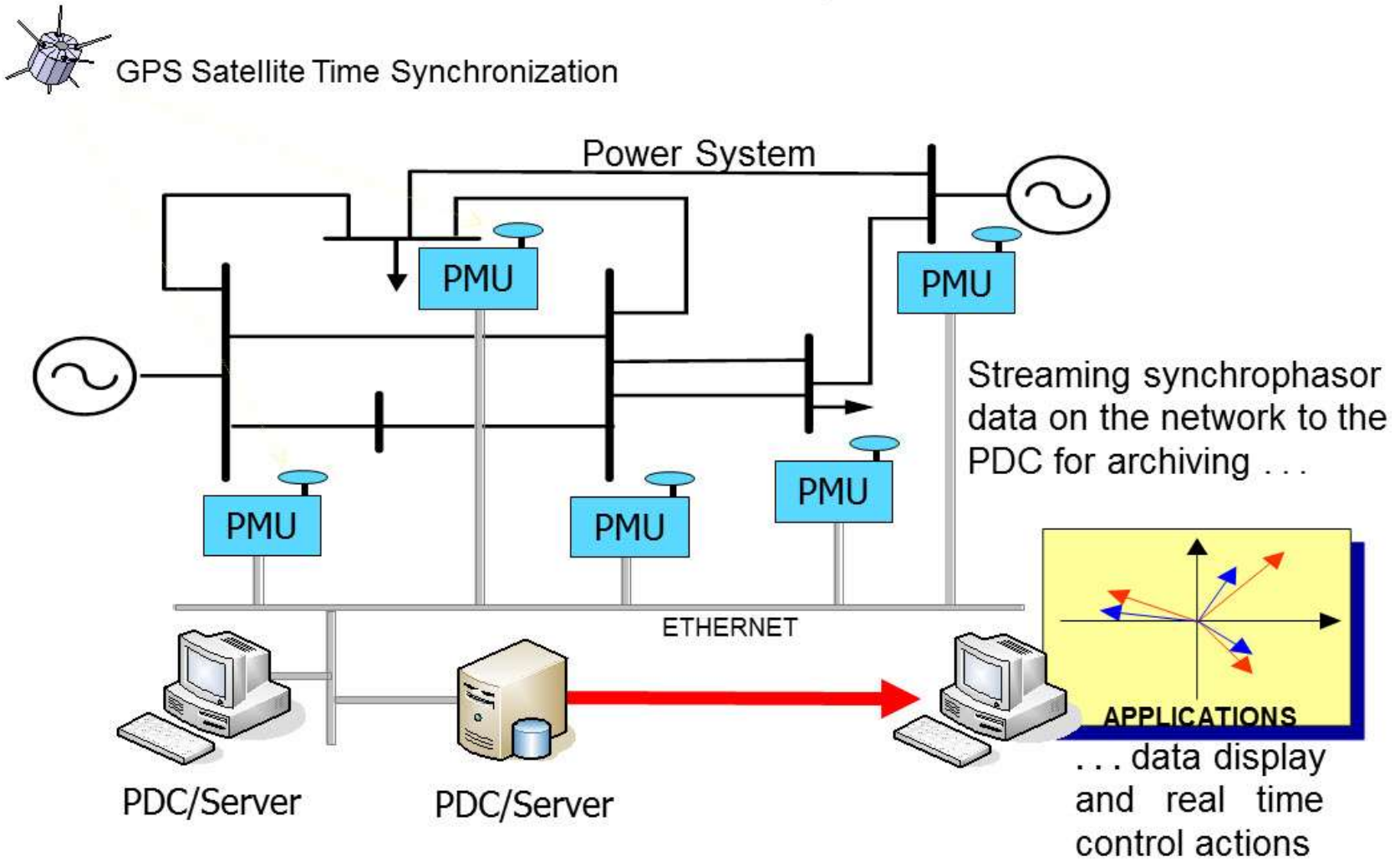
Error of 1 ms is more than 20 Degrees (1/4 of 90 degrees)

Measurements Must Have a Common Reference

60 Hz, 360 degrees

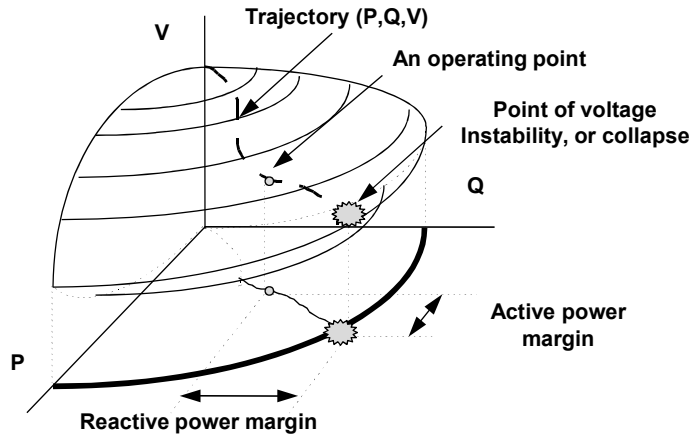


Typical Synchrophasor System



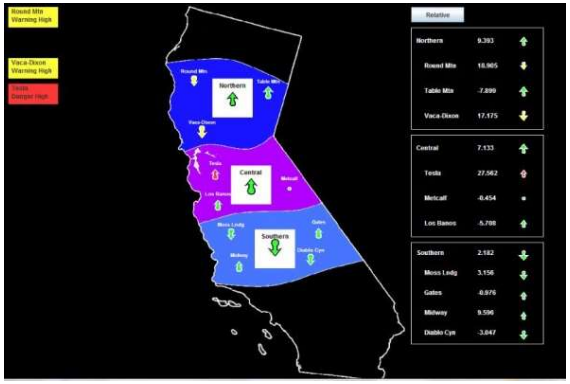
Information Semantics to Manage Complex Systems

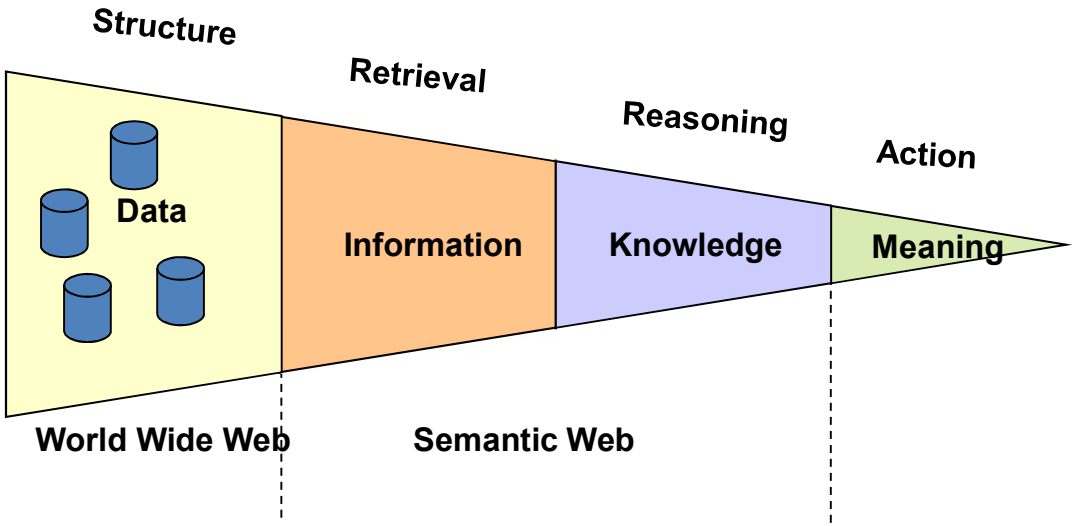
Need for Precise GPS time stamp



P-V, V-Q, and PVQ Curves - Test for Determination of Reactive Power Margin

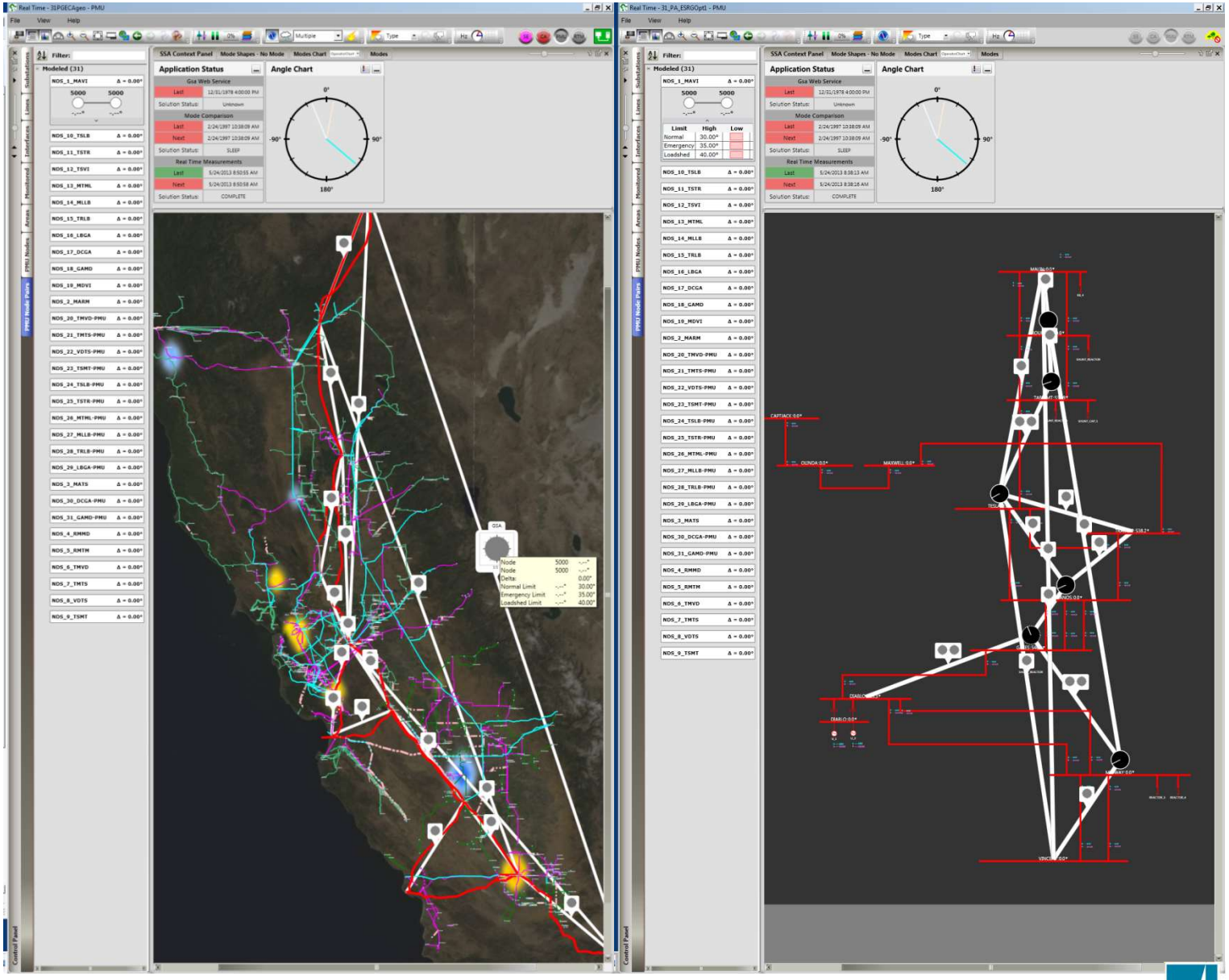
Cluster Overview



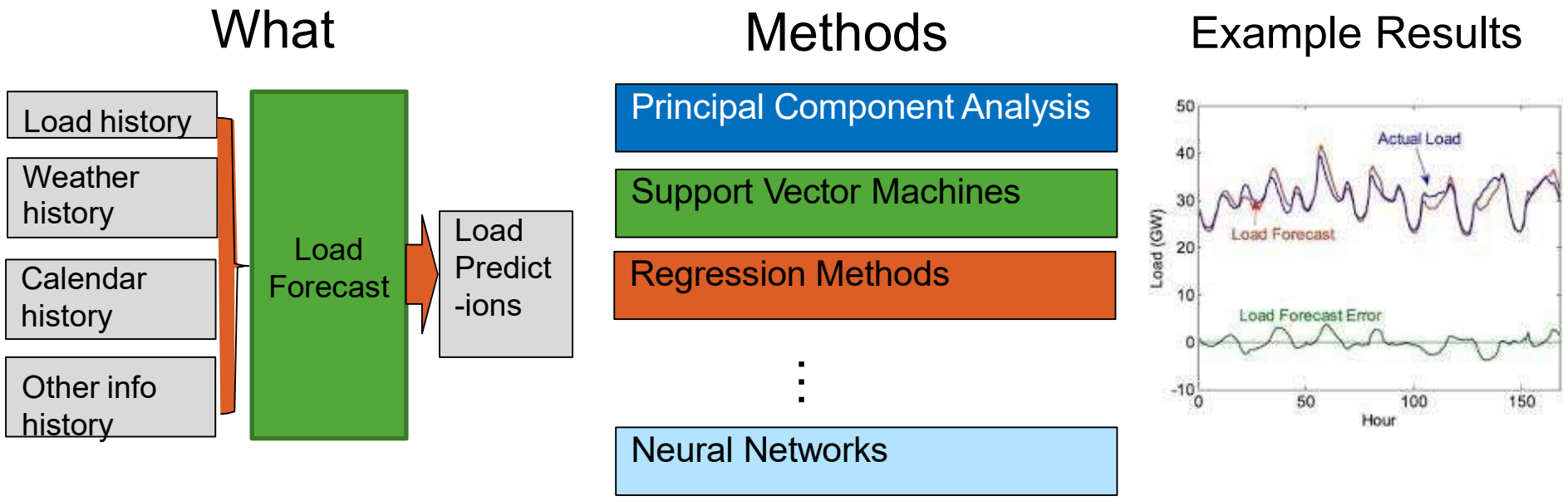


Cluster – Zoomed In

Volt/Angle data from PMU's Node Pairs and Trending



Machine Learning for Load Forecasting



Why forecasting is one successful application area?

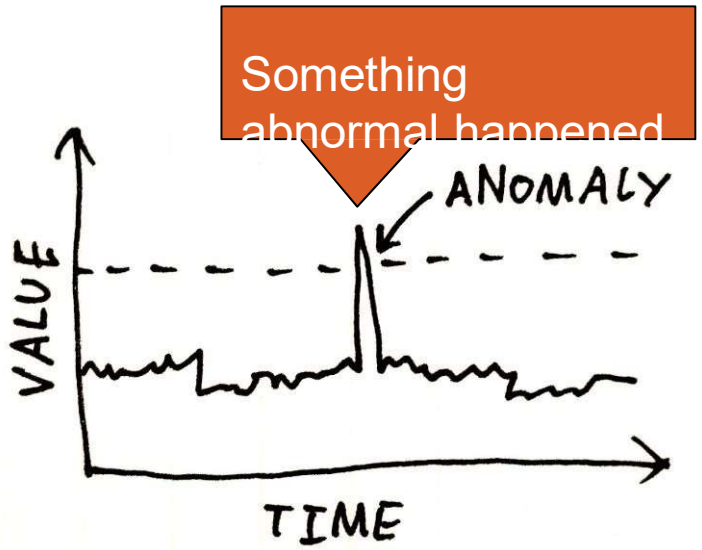
- Data completeness
- Industry need

Machine Learning

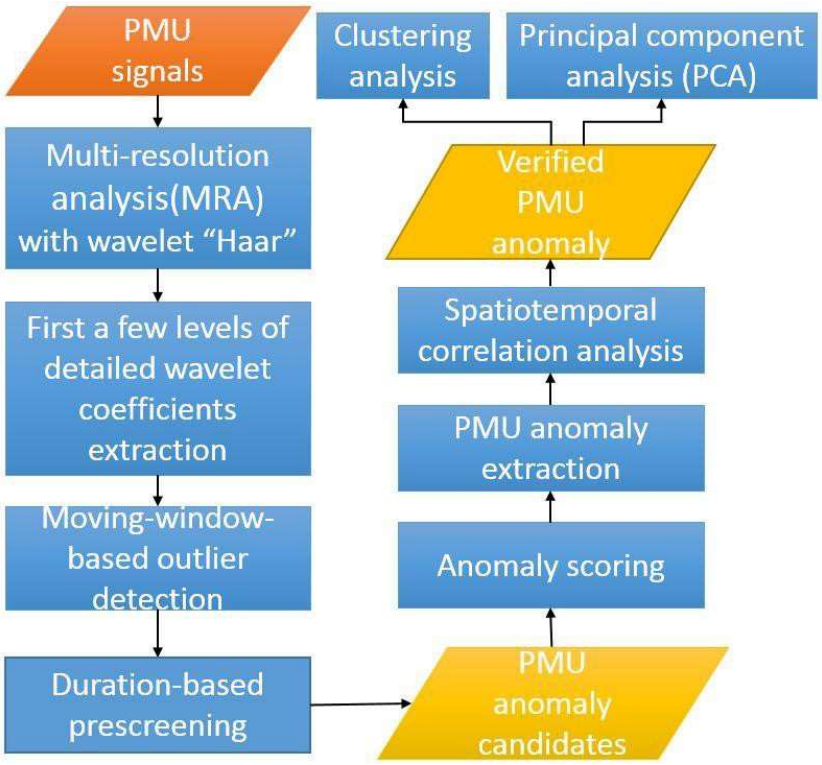
Category	Techniques	Applications
Supervised learning	Neural networks, support vector machine (SVM), decision tree (DT), ensembles (bagging, boosting, random forest)	**Regression or Prediction** (generation/load/price/ weather forecast) **Classification** (power flow security assessment, fault detection, non-intrusive load monitoring)
Unsupervised learning	Principal Component Analysis (PCA), K-means, generative adversarial networks (GANs)	Dimensionality reduction, clustering, anomaly detection, scenario generation, etc.
Reinforcement learning	Q-Learning, Deep Q-Network	Optimal control, scheduling, Parameter tuning

Anomaly Detection & Classification, Need for Precision Timing

- Objective
  - Detect and classify events using phasor measurement unit (PMU) data to improve situational awareness
- Approach



Anomaly Detection

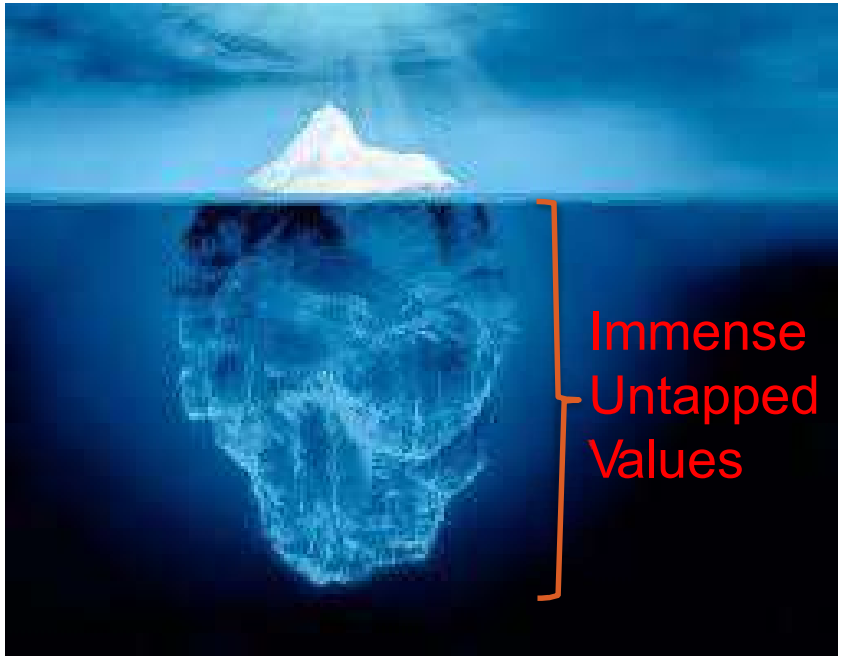


We have only seen the tip of the "big data" iceberg

Requires Precision Timing

- SCADA
- PMU
- AMI
- Sensors
- Simu. Results
- Market
- IED
- Billing
- Weather

Big data



"Machine learning is to big data as human learning is to life experience"

PMU – Phasor Measurement Unit – Measurements Synchronized to microsecond resolution or better

Benefits Harvested from Machine Learning, Power Systems

Load forecasting Short-term load forecasts are vital for utilities Machine learning could be used to forecast supply and demand in real time and optimize economic load dispatch. **UK / Google partnership estimate reduction of national energy usage by 10%**

Yield optimization With AI, power providers can optimize generation efficiency with real-time adjustments across their assets.

- GE Renewable Energy's "Digital Wind Farm" concept includes software that monitors and optimizes the turbine - **Increasing energy production by up to 20%**

Predictive maintenance Bolstered with drones for asset inspections, replacing time intensive and risky manual inspections.

- **The drones are trained using deep learning algorithms** to automatically identify defects and predict failures without interrupting operations

Demand management can be automated and made smarter with machine learning.

- **In the UK, machine learning is used to manage a portfolio of storage assets to support the grid,** with flexibility to shift demand in real time. It is estimated that machine learning could help unlock up to 6GW of demand-side flexibility during the evening peak without affecting end users

Energy theft remain huge problem in some developing countries

- In some countries, theft accounts for up to 40% of the electricity distributed. AI can be used to detect usage patterns, payment history, and other customer data that may signal irregular behavior

On the retail side

AI can unleash market forces as well as transform the user experience:

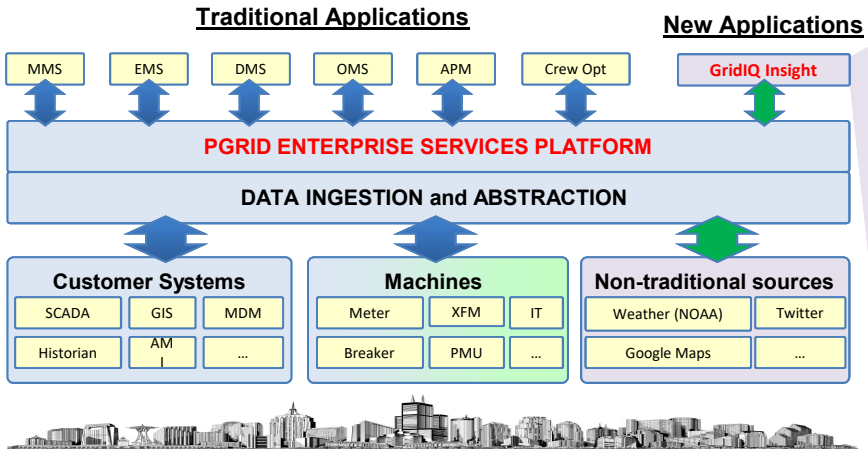
Customer insights Machine learning applications could allow utilities to craft electricity prices that maximize their margins while minimizing customer churn. **AI could be used to create individual offers and services to help utilities retain their most profitable customers**

Energy trading Prosumers are generating their own renewable energy and sending the excess back into the grid, platforms are emerging to allow peer-to-peer trading between producers and consumers. As supply and demand continuously fluctuate, AI can be used to more quickly match producers with consumers. **Netherlands**

Virtual agents will revolutionize call centers, being able to respond to consumer queries and provide instant assistance. They will be able to automatically segment consumers based on service history and provide early warning of bad debts. **The development of natural language technologies will eventually unlock the capacity to fully automate customer service**

Gaining insight from big data

Turning data into Insight



Interoperability

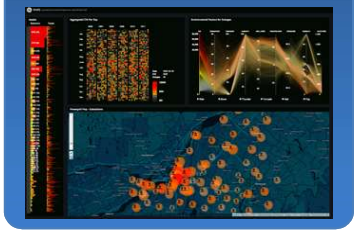
- Enterprise interoperability
- Open standard platform
- Traditional and new data sources

Applications

- New applications – complementary to conventional applications
- Big data analysis
- Cloud and premise solutions
- Open APIs – customer innovation

New applications emerging

Outage Insight



- Outage prediction
- Outage event recorder
- Planned outage optimization
- Triage analysis to optimize restoration sequence
- Optimized resource staging

Meter Insight

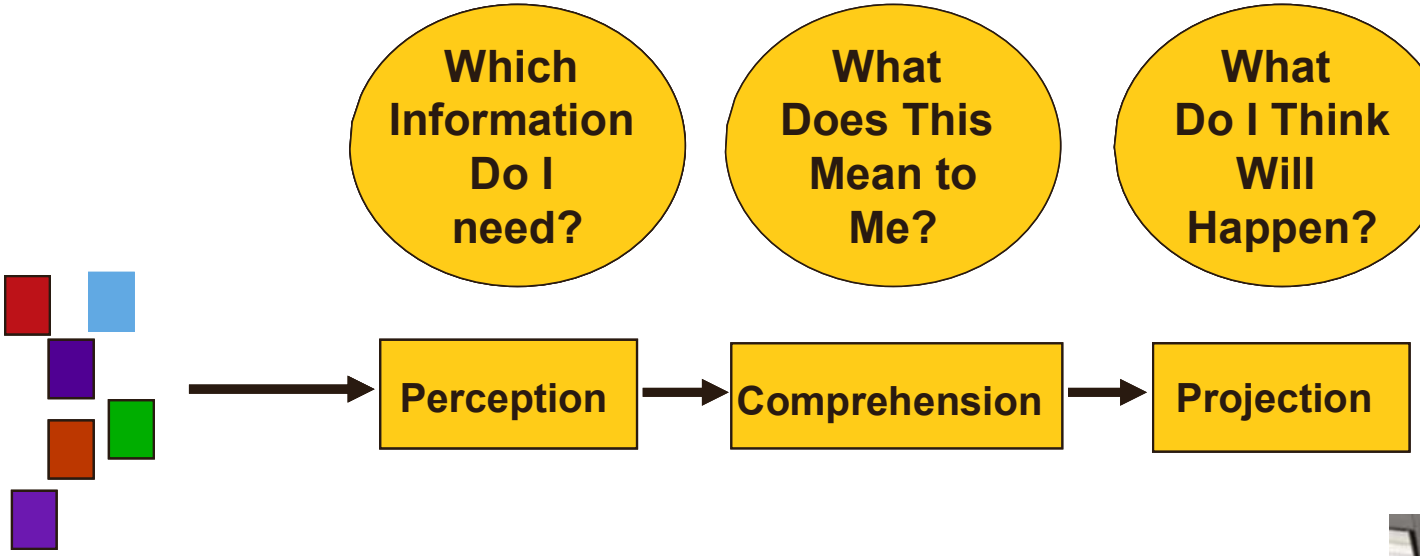
- Revenue protection – technical & non-technical loss analysis
- Health (hot sockets, fatigue)
- Power quality analysis
- Load forecast & research
- Social media integration

Reliability Insight

- Vegetation mgmt analysis
- Asset health analysis
- System health analysis
- Lifecycle analysis
- Portfolio optimization
- Dynamic Load Forecasting

A Solution to Enhance Control Center Operators' Situational Awareness …

Situation Awareness in Control Centers …



- *System frequency*
- *Voltage level*
- *Direction of flow*
- *Current temperature*

- *Violation of limit*
- *Frequency violation*
- *Organization with limiting element*

- *Projected impact on system of losing element*
- *Projected limit violations*

Autonomous System Self-managing Technologies

An autonomas system can sense its operating environment, model its behavior in that environment, and take action to change the environment or its behavior. An Autonomous system has the properties of self-configuration, self-healing, self-optimization and self-protection.

Self-managing systems deliver:

Increased Responsiveness

Adapt to dynamically changing environments

Robustness and Resiliency

Discover, diagnose, and act to prevent disruptions

Possibly redundant in mission critical Apps

Operational Efficiency

Tune resources and balance inputs to maximize use of resources

Precise Time Mechanism, Secure Information and Resources

Anticipate, detect, identify, and protect against attacks

Skilled and Trained Resources to Manage Assets and Life Cycle Process

Thank you

Stay Energized and Synchronized

Proof of Concept Facility, Time Synchronization, System Application and Real-time simulation

Pacific Gas and Electric Co.

Opportunity Example: New price patterns incentivize innovation in responsive demand and storage