Challenges and Opportunities of Applying Optimization and Analytics for Managing Modern Power Systems

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Kwok W. Cheung, Ph.D., PE, PMP, FIEEE
Director, Global Market Management Solutions
GE Grid Solutions

Outline

- Introduction
  - Industry challenges, needs and transformation
- Areas of opportunities to apply optimization and analytics
  - Wide-area management system (WAMS)
  - Energy forecasting
  - System dispatch (Demand, Distributed Energy Resources, Storage)
  - Retail market (Dynamic pricing, Distributed LMP)
- Final remarks

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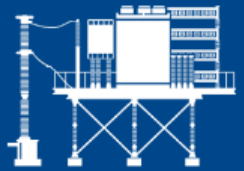
Introduction

A Key Element of Grid Solutions



Power Electronics

High Voltage DC
Flexible AC Transmission Systems
Reactive Power Compensation
Energy Storage

HV Equipment

Power Transformers
Gas Insulated Substation
Air Insulated Substation
Capacitors & Voltage Regulators

Grid Automation

Protection & Control
Substation Automation
Communications
Monitoring & Diagnostics

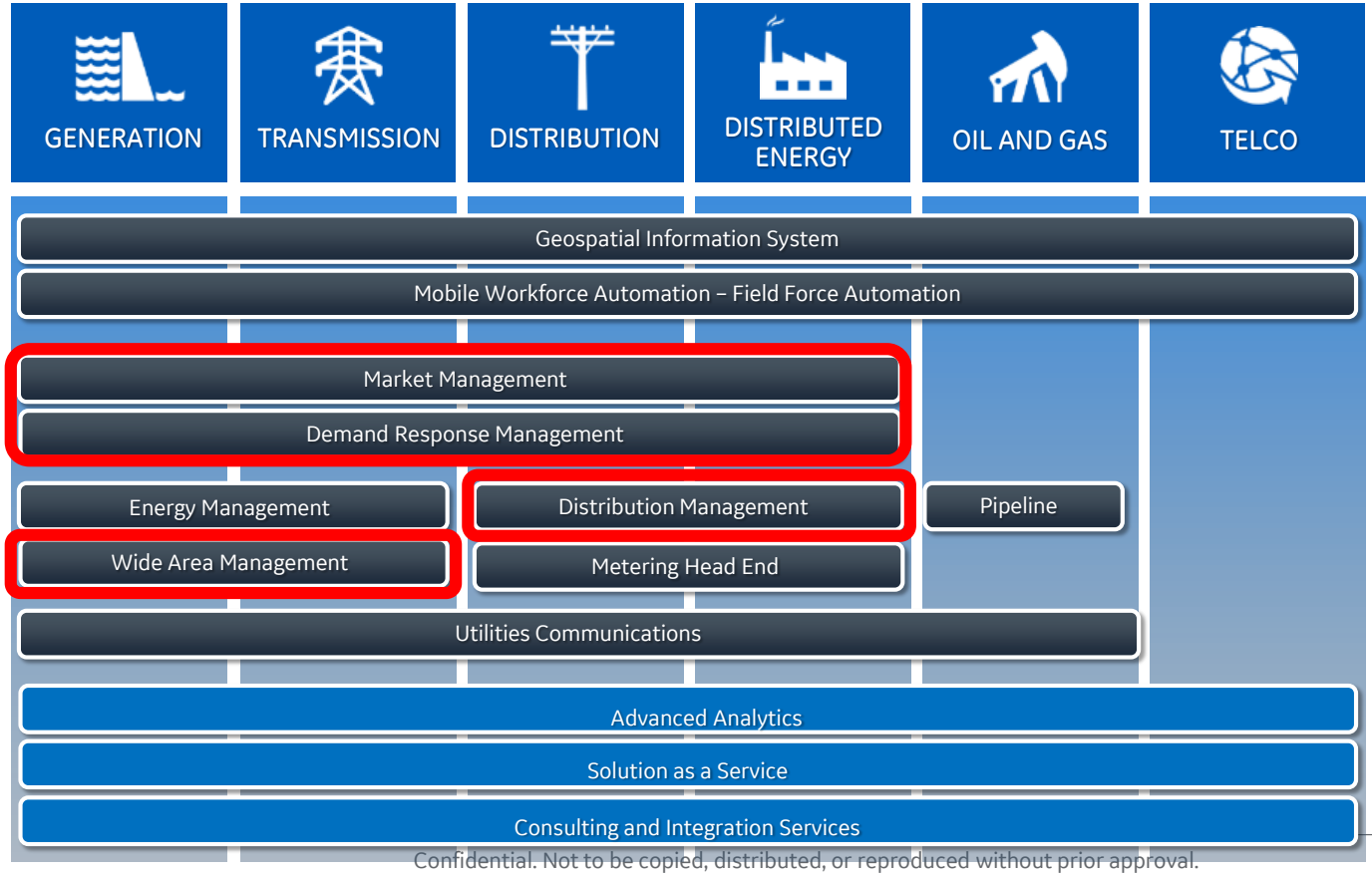
Software Solutions

Distribution & Outage Management
Energy Management
Market Management
Geospatial & Mobile Solutions
Gas & Pipeline Management

Projects & Services

Turnkey Projects & Consulting
Electric Balance of Plant
High Voltage Substations
Maintenance & Asset Management

Software Solutions



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Industry Challenges

Retiring
Workforce

Big Data
Meters, PMU, ...

Critical mission
Communication

Cyber-Security

New Electrical Equipment
(FACTS, HVDC, ...)

Sustainability
Renewable deployment & CO2 free energy
New Generation Mix

Business Model Change
New regulation

Environment
Public Safety
Storm Restoration GHG

IT Architecture & Services
Control Room

System Dynamics
Operating near to true real time limits

System Scalability
From energy cluster to large Interconnected grids

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Key Industry Needs

RELIABLE POWER

Maintain grid stability

- Improved operational decision support (Asset conditions & limits)
- Mitigate blackouts and outages impacts
- Manage aging workforce
- Outage Reduction

AFFORDABLE POWER

Improve energy efficiency

- Maximize energy flows in constrained and aging grids
- Enable end-user DERs with the energy system ("prosumers")
- Leverage information across business silos (bridging OT & IT)
- Increase operational efficiency

RENEWABLE POWER

Integrate CO2 free energy

- Enable renewable DER (wind, solar) grid connection & dispatch
- Develop back up energy asset flexibility (generation & distributed storage)
- Integrate distributed renewable, Energy Positive buildings and Electric Vehicles

Power Industry Transformation

Past, Present, Future

Classic Utility

- Vertically integrated
- Cost-based operation
- Physical infrastructure

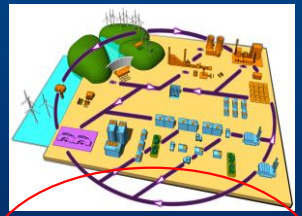
Reliable

Competition

- Open transmission access
- Genco divestiture
- Wholesale electricity market

Reliable & Affordable

Smart-Grid



- Distributed intelligence
- Service valuation
- Prosumer choices

Smart City

- Sustainability
- Resiliency
- Connectivity

Reliable, Affordable & Sustainable

1980 — 1990 — 2000 — 2010 — 2020

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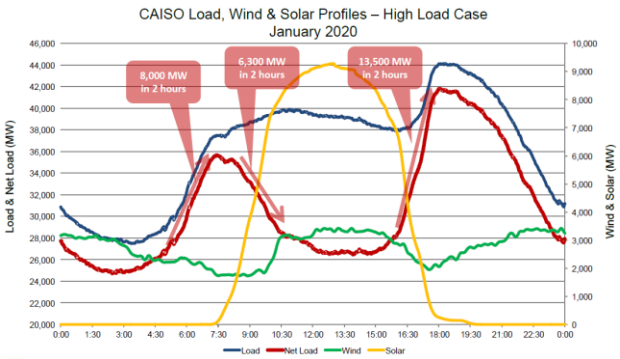
Smart Grid Challenges

- Global energy & environmental movement
  - Emphasis on low carbon energy mix and Demand Response (DR)
  - Increasing presence of renewable power
  - Increasing presence of Distributed Energy Resources (DER), storage, PHEV
- Smart Grid Transformation
  - From centralized to more decentralized generation and control architecture
  - Bi-directional flow of energy (“Prosumers”)
  - Automation of distribution management
  - Retail electricity market and gas/electricity market coordination
  - Situational awareness and grid visibility/predictability is becoming more critical
  - New applications/services based on new equipment and more active network
  - Optimization: larger footprint and deeper in the T&D hierarchy
  - Operational challenges: Uncertainty management
- Unrelenting complexity in business & technical decision process
  - Smart devices/resources with distributed intelligence
  - Coordinated decision making
  - Big Data



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Four V's of Big Data for Smart Grid

Volume (Scale of data)

- Technological advances (PMU, AMI, Smart Inverter)
- New and more devices (Smart appliances)
- IIoT

Velocity (Speed of data)

- Analysis of streaming data from IED, PMU
- Real-time control and decision-making

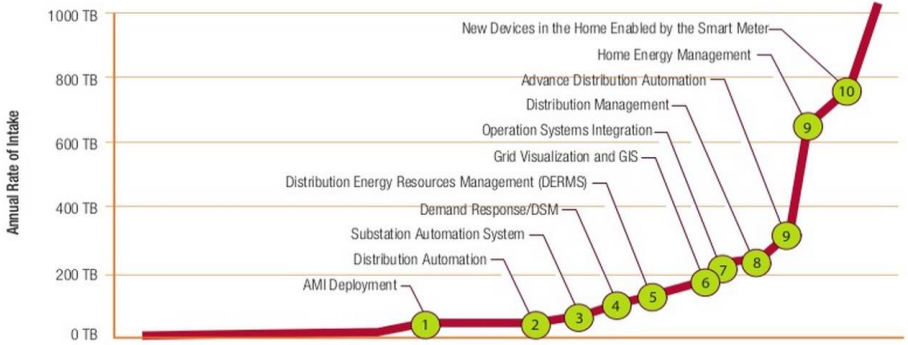
Variety (Forms of data)

- Handling of all forms of structured and unstructured data (video, social media)
- Many different types of data repositories

Veracity (Uncertainty of data)

- Data cleansing/conditioning (data quality)
- Confidence measure (e.g. forecasting)
- Optimization application robustness

Source: SAP



Source: EPRI Intelligrid Via Lockheed Martin Presentation, "Solving Big Data Challenges US Electric Utility Industry", July 2014

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A Continually Transforming Landscape

GENERATION	TRANSMISSION	DISTRIBUTION	DISTRIBUTED ENERGY	OIL AND GAS	TELCO
Market Drivers					
• Renewable massive deployment • Energy storage deployment • Aggregator and Demand Response player • New market places and Regulation change	• Interconnected networks and coordination • WAMS Stability & Protection control • VAR Control, Look ahead • Dynamic line rating • AC and DC network • CIM model • Cyber security	• DA centralized (FLISR) • Distributed Energy • Voltage optimization • Operation Efficiency from Analytics • Network digitalization with connected objects	• Local generation (PV) • Multi shape grids : feeder, microgrid, homegrid, picogrid • Metering • Energy efficiency • Demand response • Local market place	• Gas pipeline expansion as gas extraction sites move • Pipe capacity • Oil / Gas market price +/- • Physical and Cyber security • PHMSA Standard	• Technology (MPLS, 4G 5G ...) • Regulatory service covering and quality • WAC and Distribution automation • IT / OT convergence

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Areas of opportunities to apply optimization and analytics

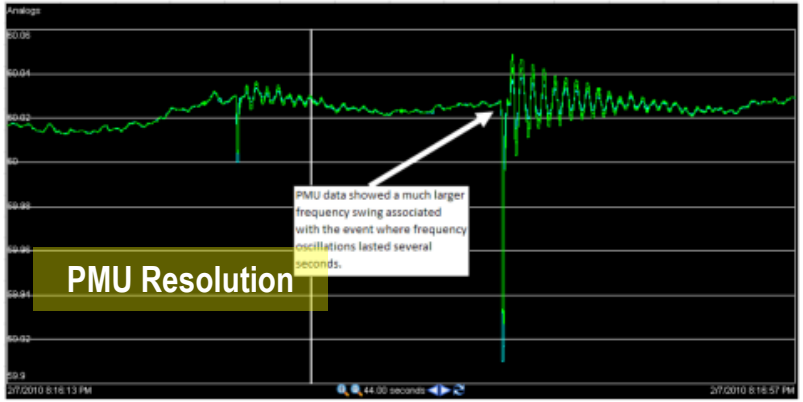
Wide Area Management System

What is SynchroPhasor Technology?

Phasor Measurement Units (PMUs)

- Next generation measurement technology (voltages, currents, frequency, rate-of-change of frequency, etc)
- Higher resolution scans (e.g. 30 or 60 samples/second)
  - *Improved visibility into dynamic grid conditions.*
  - *Early warning detection alerts*
- Precise GPS time stamping
  - *Wide-area Situational Awareness*
  - *Faster Post-Event Analysis*

"MRI quality visibility of power system compared to x-ray quality visibility of SCADA" – *Terry Boston (PJM)*



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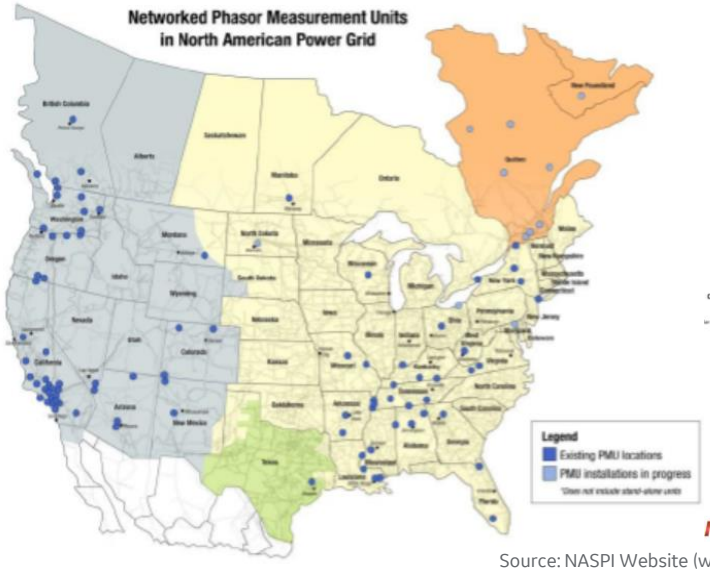
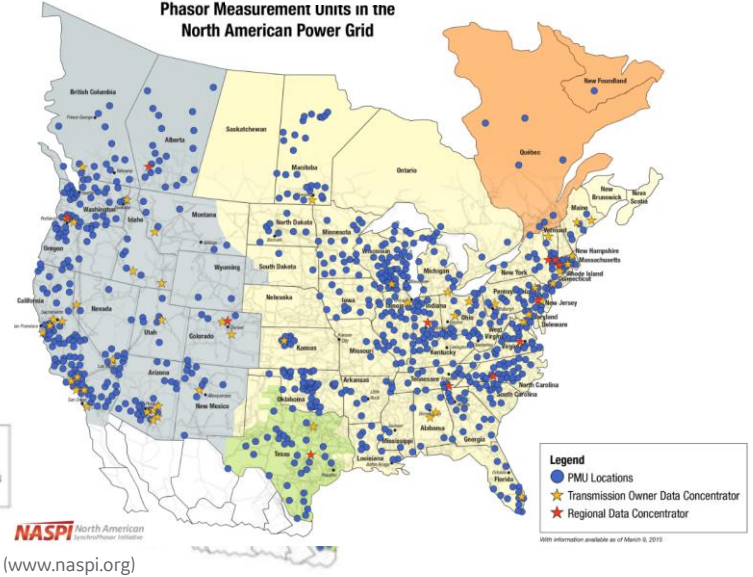
Synchrophasor Deployment in North America

Changing Landscape





Source: NASPI Website (www.naspi.org)

- Approx. 200 PMUs in 2007
- Most R&D grade deployments

- Over 1700 PMU deployed by 2014
- Production grade & redundant networks

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WAMS : Control Room Operations

Transitioning from traditional "steady-state" view to enhanced "dynamic" situational awareness.

The Next Generation Energy Management System!

EMS
MODEL-BASED ANALYSIS

WAMS
MEASUREMENT-BASED ANALYSIS

Other EMS Applications

- SCADA & Alarms
- State Estimator
- Small Signal Stability
- Transient & Voltage Stability
- Island Management

New Applications

- WAMS Alarms
- State Measurement
- Oscillation Monitoring
- Stability Monitoring & Control
- Island Detection, Resync, & Blackstart

Control Center - PDC

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Synchrophasor Applications in the Control Room

e-terra*phasorpoint*

Leveraging time-synchronized and high fidelity PMU measurements in Operations

PDC

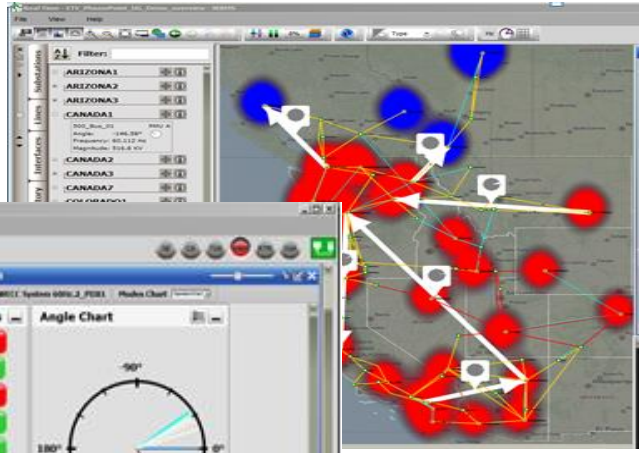
- C37.118/2005/2011/2014 compliant
- Exterme performance (5000 PMUs)
- Multiple inputs/outputs

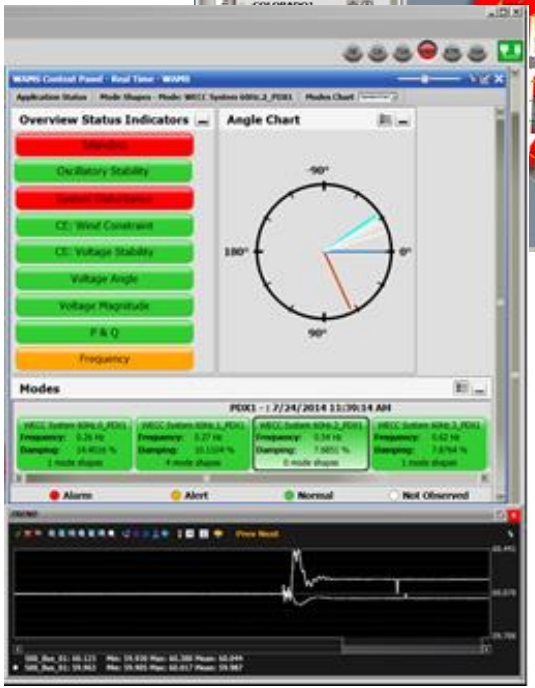
Historian

- High Resolution Rolling Buffer / Triggered Storage
- Low Resolution Rolling Buffer
- Optimized data storage technology

Applications

- Full Oscillation Monitoring (0.002 Hz to 46 Hz)
- Oscillation Source Location
- Islanding Detection
- System Disturbance Detection and Characterization





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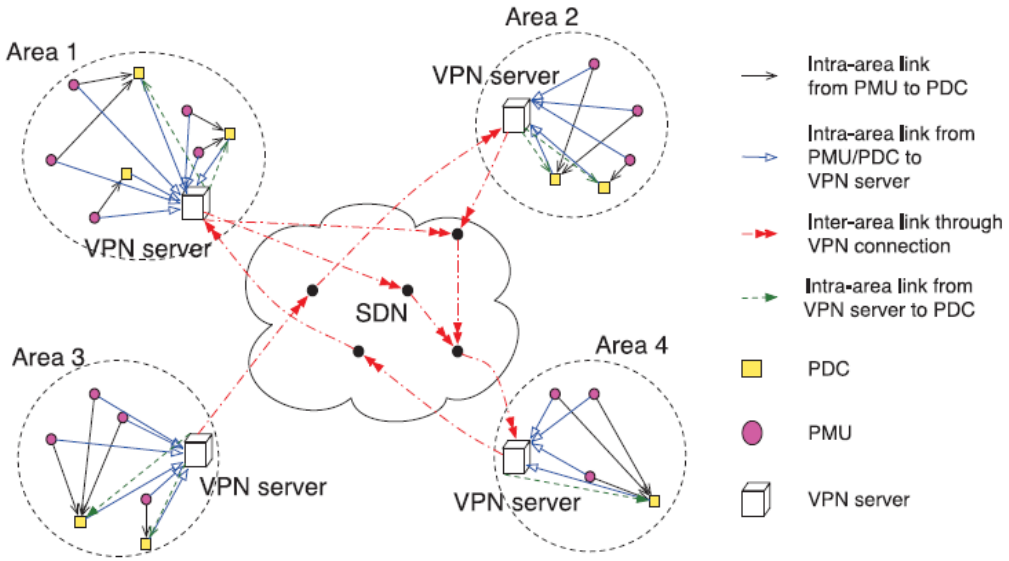
Challenges and Opportunities for WAMS

- The number of PMU's scale up to the thousands in North America and other parts of the world (e.g. India).
- Current state-of-the-art centralized communication and information processing architecture of WAMS is not sufficient.
- Decentralized WAMS architecture (NASPI) is coming but not much progress on decentralized algorithmic applications.



S. Nabavi, C. J. Zhang, Aranya Chakrabortty, "Distributed Optimization Algorithms for Wide-Area Oscillation Monitoring in Power Systems Using Interregional PMU-PDC Architecture", *IEEE Transactions of Power Systems*, Vol. 6, No. 5, pp.2529-2538, September 2015.

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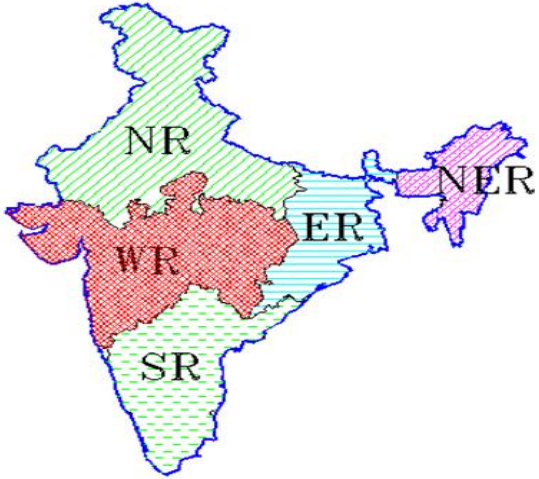
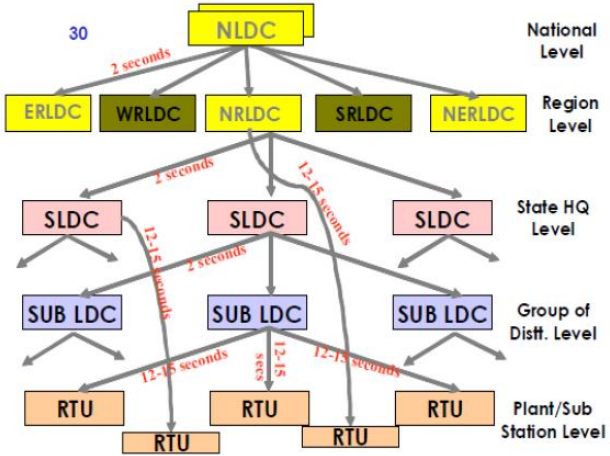
PowerGrid India - URTDSM

Unified **R**eal **T**ime **D**ynamic **S**tate **M**easurement



- Complete observability of the Indian Power system in real time
- **World Largest WAMS dynamic monitoring system serving a billion people.**

Current SCADA measurement hierarchy



- **33 PDCs: 26 States; 5 Regions; 2 National Control Centers**
- **359 Substations with 3,400 PMUs sending 25 samples per second**
- **Over 25,000 synchrophasors (positive sequence, 3 phases, voltage and current, MW and MVAR)**
- **1 Year of long term data: 0.5 Peta Bytes**

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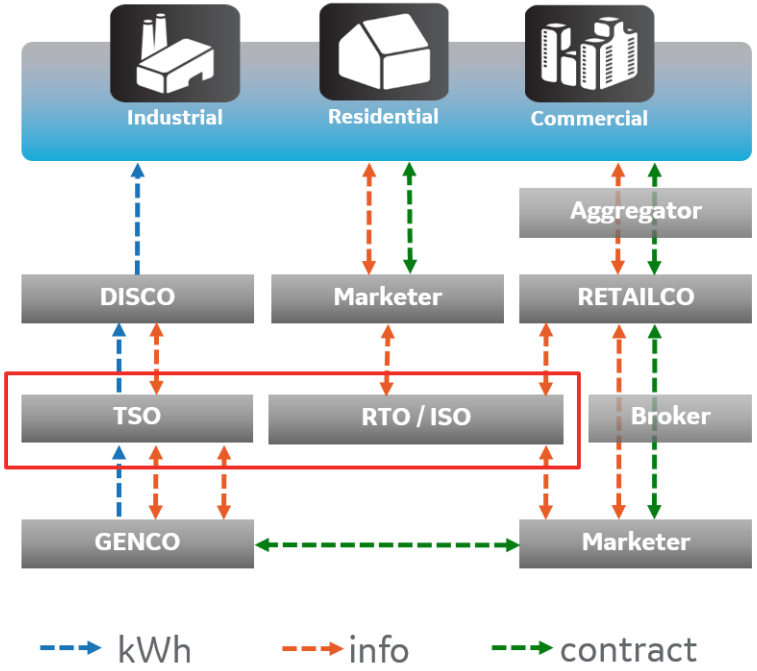
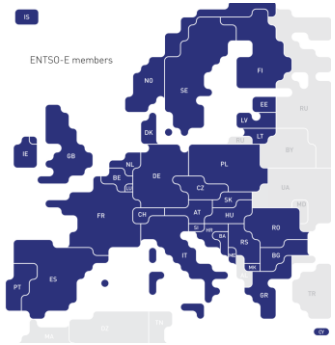
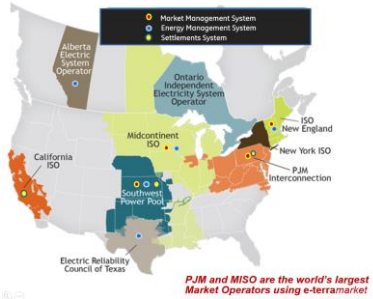
Wholesale Electricity Markets: Energy Forecasting and System Dispatch

Major Electricity Market Models

- European (ENTSO-E) Model
- US Model







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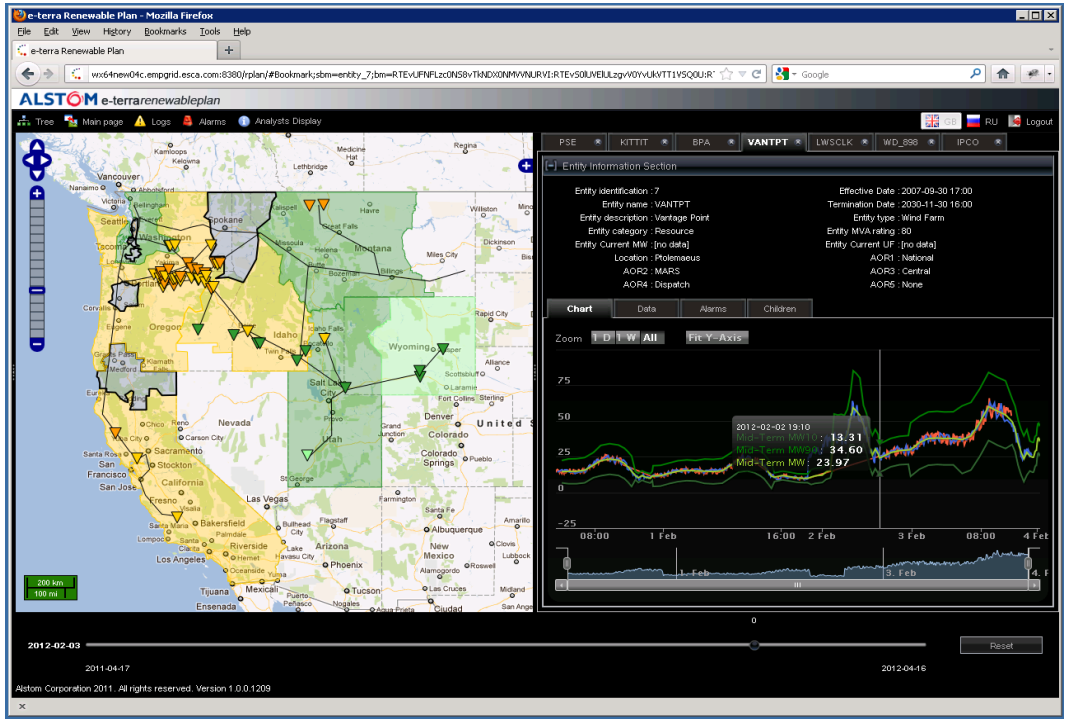
Energy Forecasting

- Types of Energy Forecasting
  - Renewable power
  - Net load
  - Net interchange
  - Dynamic line ratings
- Forecasting Techniques
  - Physical approach
  - Statistical approach
- Situation Awareness
  - Forward-looking view
  - Alarming of abrupt ramping event
  - GIS-based system
  - Drill down capability



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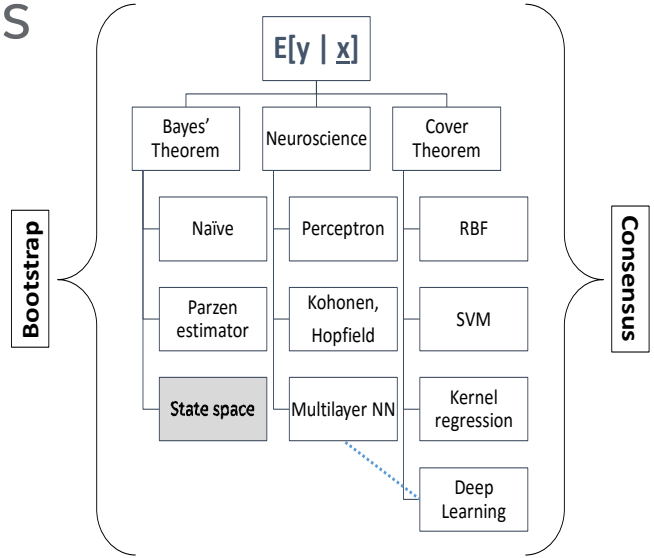
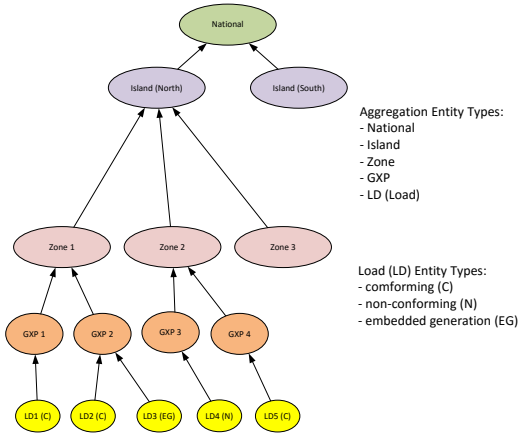
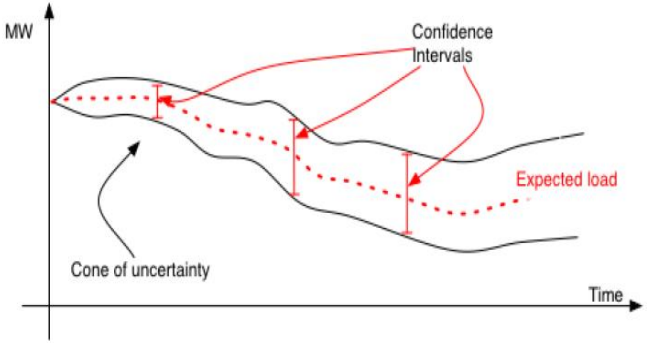
Forecasting Application Requirements

- Forecast with better accuracy
  - Advanced machine learning techniques
- Forecast with confidence Intervals
  - Model of uncertainty (Confidence Intervals)
- Forecasts for multiple hierarchical levels (T&D)







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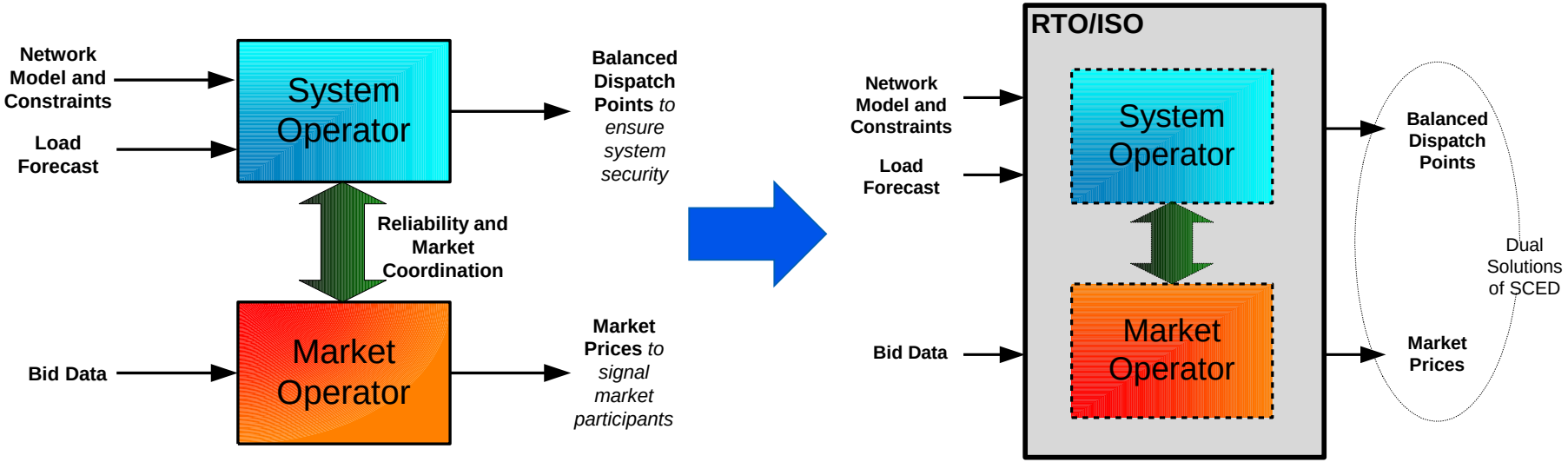
US Market Design

Optimization-based Integrated Approach



Consistent dispatch signals and price signals based on

- *Security constrained economic dispatch (SCED)*
- *Locational Marginal Pricing (LMP)*

Joe H. Chow, Robert deMello, Kwok W. Cheung, "Electricity Market Design: An Integrated Approach to Reliability Assurance"", *Invited Paper, IEEE Proceeding (Special Issue on Power Technology & Policy: Forty Years after the 1965 Blackout), vol.93, no. 11, pp.1956-1969, November 2005.*

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System Dispatch Evolution

Classical Dispatch (70's – mid 90's)

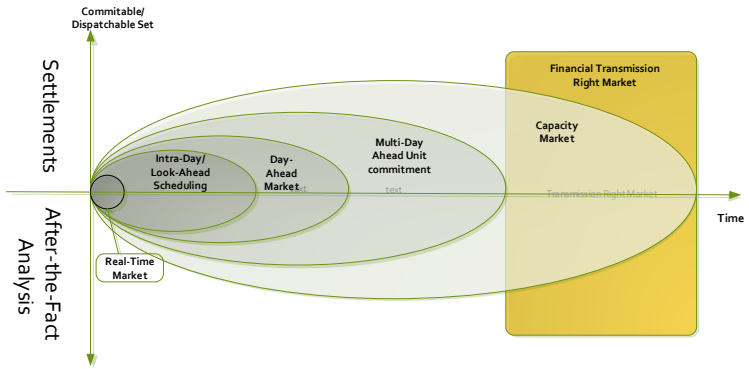
- Unit Commitment Scheduling, Economic Dispatch, AGC
- Grid security, scheduling, dispatch are Independent tasks

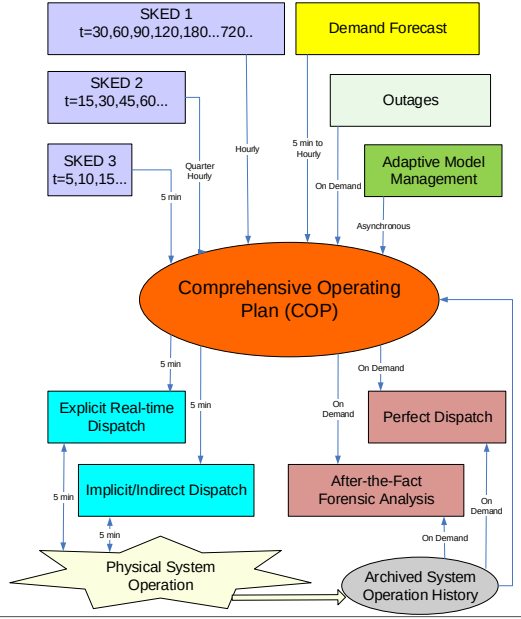
Market-Based Dispatch (mid 90's – 2009)

- UC/ED with explicit transmission security constraints
- Formal Day-Ahead and Real-time tasks
- Pricing - Dual of the MW signal
- Transparency & consistency
- Large-scale system dispatch

Smart Dispatch (2009 and beyond)

- Dispatch with explicit forward vision
- Dispatch with intelligence (e.g. parameter adaptation)
- Decentralized, hierarchical, implicit dispatch
- Improve system resiliency against uncertainties (e.g. DER, Wind, DR)
- Mitigate root-causes for dispatch deficiencies
- Process re-engineering for business/economic analysis





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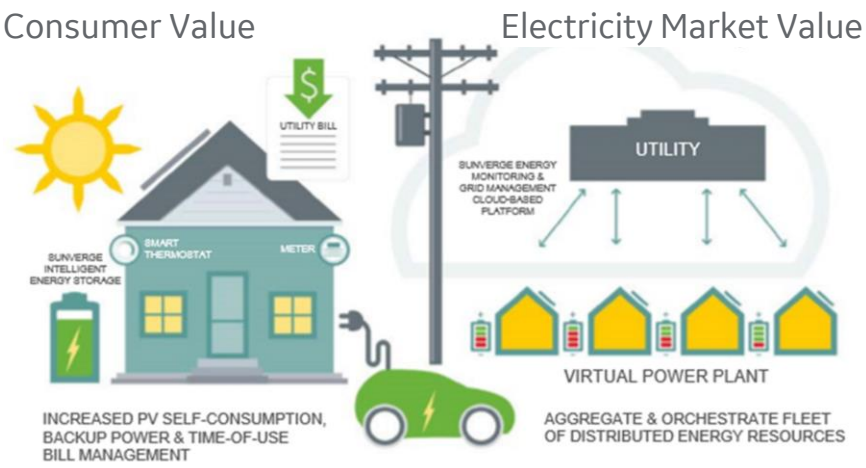
US FERC NOPR on Energy Storage and DER Aggregation

- Storage and DERS have received significant attention from FERC in the past few years.
- On November 17, 2016 FERC issued a NOPR aimed at allowing energy storage resources and all categories of aggregated DERs to more fully participate in electricity markets.
- FERC has also sought information on storage interconnection issues and the ability of storage resources to serve as transmission assets and deliver multiple services.
- CAISO submitted and FERC accepted market rules allowing for aggregated DERs to participate in CAISO's markets.



Coupling of Consumer Value and Electricity Market Values via VPP

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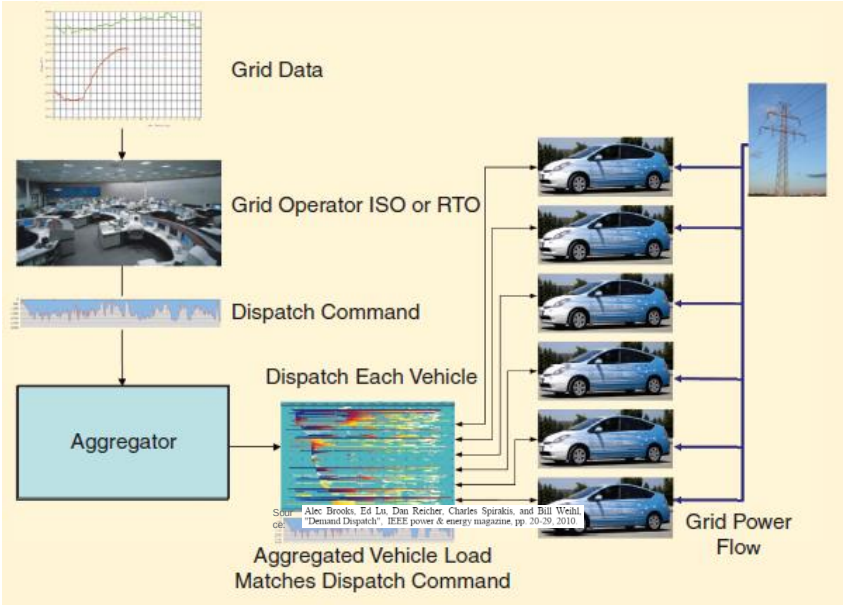
Demand Dispatch

- AMI technology such as high-speed, two-way communication enhances the ability of system operators to integrate new forms of demand response or “demand dispatch” into normal system operations during any hour rather than just peak demand periods.
- Market-based demand response vs. market-reactive demand response
- Deep demand-side management
- Roles of DR
  - **Energy** resource – dispatch for economic reasons
  - **Capacity** resource – resource adequacy
  - **Ancillary services** resource – dispatch for reliability
- DR Services
  - Load shifting, absorption of excess generation
  - Dispatchable quick start
  - Regulation, fast ramping, frequency response



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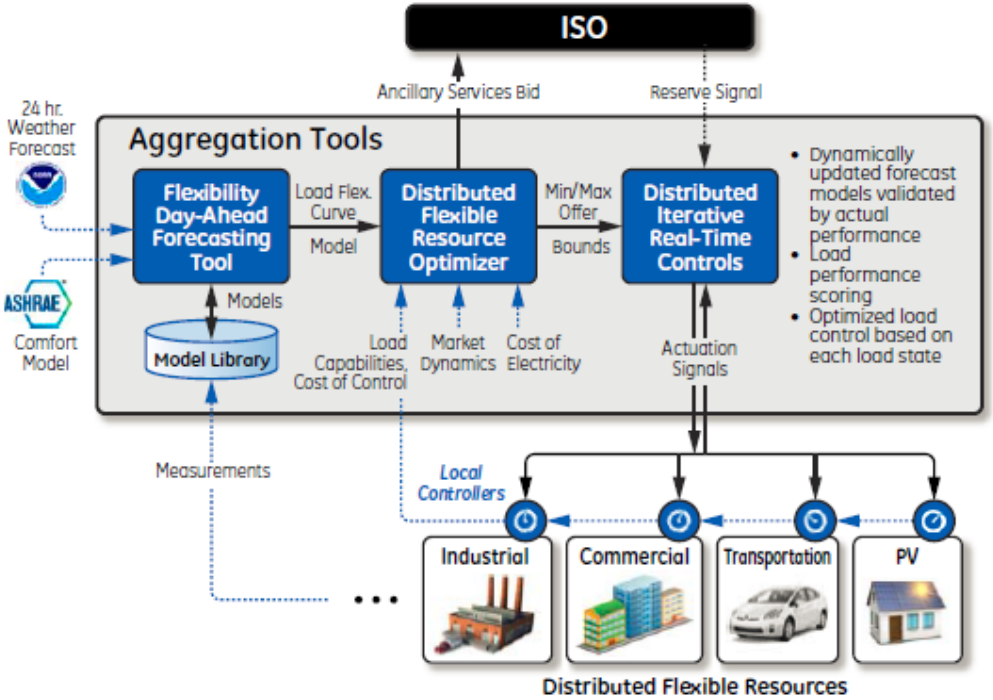
Distributed Flexible Resource Dispatch



Aggregation of DRs and DERs is the key for grid integration.

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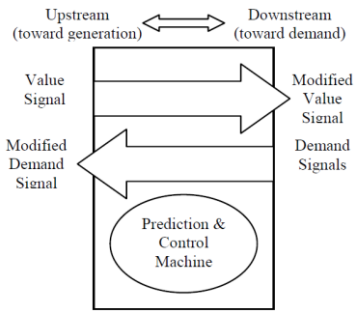
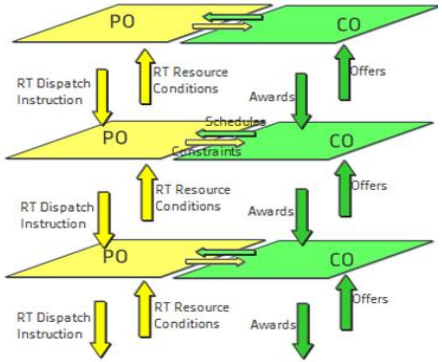
Retail Markets with Dynamic Pricing

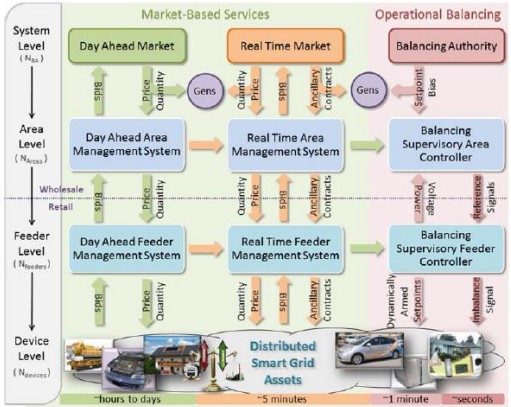
Transactive Control and Coordination (TC2)

Uses economic or market-like constructs to manage generation, consumption, & flow of electric power including reliability constraints by coordinating assets from generation to end use with precision.

- Uses local conditions and global information to make local control decisions at points (nodes) where the flow of power can be affected.
- Nodes indicate their response to the network via transactive incentive and feedback signals (TIS/TFS)
- TC2 is flexible and efficient design allowing deployment at all levels of the energy hierarchy.







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Emerging Retail Markets

How will new business models evolve to value and incent sustainable DER growth?

How can DER go beyond Net Energy Metering?

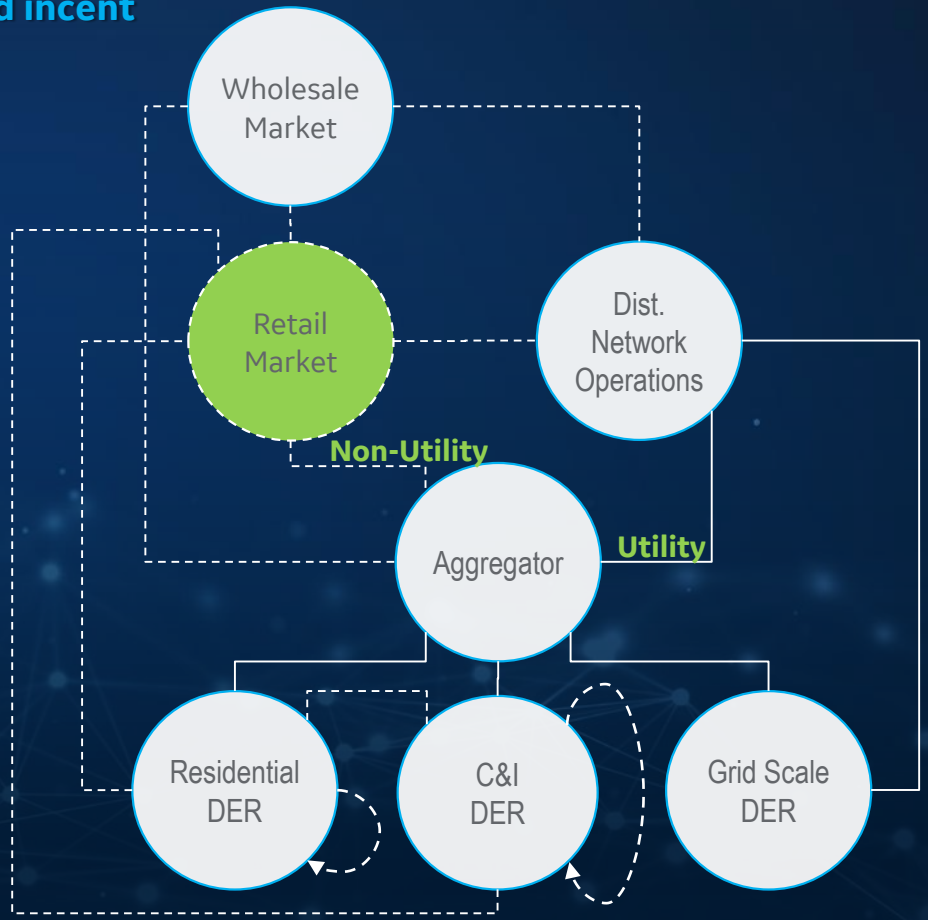
- dLMP (vary by time and location)
- Providing essential reliability services
  - Volt/var support
  - Fast frequency response (FFR)
  - Regulation reserves

How wlll retail markets coordinate with the wholesale markets?

- Interfacing between ISO and DSO (MMS/EMS/DMS)

How will retail markets be formed?

- Distribution system operator (DSO)
- Aggregator vs. Local Utility
- Peer-to-peer



Final remarks

Final Remarks

- The path of evolution of the power industry is reviewed and the challenges of grid modernization with high penetration of renewable energy resources are discussed.
- The current state-of-the-art centralized communication and information processing architecture will no longer be sustainable for IIoT and smart grid.
- There are many opportunities of applying advanced optimization and data science techniques in modernizing the electric transmission and distribution grid.
- Retail markets with dynamic pricing could be one of the mechanisms to incent sustainable growth of DERs.

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Kwok W. Cheung
kwok.cheung@ge.com

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