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

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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
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

- Geospatial Information System
- Mobile Workforce Automation – Field Force Automation
- Market Management
- Demand Response Management
- Energy Management
- Distribution Management
- Wide Area Management
- Metering Head End
- Utilities Communications
- Advanced Analytics
- Solution as a Service
- Consulting and Integration Services
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
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

1980

Competition
- Open transmission access
- Genco divestiture
- Wholesale electricity market

1990

Smart-Grid
- Distributed intelligence
- Service valuation
- Prosumer choices

2000

Reliable & Affordable

2010

Smart City
- Sustainability
- Resiliency
- Connectivity

2020

Reliable, Affordable & Sustainable

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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
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
## A Continually Transforming Landscape

<table>
<thead>
<tr>
<th>Generation</th>
<th>Transmission</th>
<th>Distribution</th>
<th>Distributed Energy</th>
<th>Oil and Gas</th>
<th>Telco</th>
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<tbody>
<tr>
<td>• Renewable massive deployment</td>
<td>• Interconnected networks and coordination</td>
<td>• DA centralized (FLISR)</td>
<td>• Local generation (PV)</td>
<td>• Technology (MPLS, 4G 5G …)</td>
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<td>• Distributed Energy</td>
<td>• Gas pipeline expansion as gas extraction sites move</td>
<td>• Regulatory service covering and quality</td>
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<td>• Aggregator and Demand Response player</td>
<td>• VAR Control, Look ahead</td>
<td>• Voltage optimization</td>
<td>• Pipe capacity</td>
<td>• WAC and Distribution automation</td>
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<td>• New market places and Regulation change</td>
<td>• Dynamic line rating</td>
<td>• Operation Efficiency from Analytics</td>
<td>• Oil / Gas market price +/-</td>
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### Market Drivers

- 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)
- 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
Areas of opportunities to apply optimization and analytics
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)
Synchrophasor Deployment in North America

Changing Landscape

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

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

Source: NASPI Website (www.naspi.org)
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
Synchrophasor Applications in the Control Room

Leveraging time-synchronized and high fidelity PMU measurements in Operations

### PDC
- Extreme 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
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.

PowerGrid India - URTDSM
Unified Real Time Dynamic State Measurement

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

- 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

Current SCADA measurement hierarchy
Wholesale Electricity Markets: Energy Forecasting and System Dispatch
Major Electricity Market Models

- European (ENTSO-E) Model
- US Model
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
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)
US Market Design
Optimization-based Integrated Approach

Consistent dispatch signals and price signals based on
- Security constrained economic dispatch (SCED)
- Locational Marginal Pricing (LMP)

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
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**
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
Distributed Flexible Resource Dispatch

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