BIG DATA to Big INFORMATION
Optimizing Transactive Controls in Hybrid Power Grids

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Panel: Using Smart Grid Data to Improve Planning, Analytics, and Operation of the US Capital region T&D Systems
IEEE PES General Meeting
National Harbor, MD
July 29, 2014
What is Big Data?

“Big data refers to things one can do at a large scale that cannot be done at a smaller one, to extract new insights or create new forms of value, in ways that change markets, organizations, the relationship between citizens and governments and more.”

Big Data is the *Old, New and Future* Normal

*Today we create approximately 5 exabytes every two days*

1 exabyte = 1, 000 000 000 000 000 000
Big Data Everywhere

Companies in all sectors have at least 100 terabytes of stored data in the United States; many have more than 1 petabyte

<table>
<thead>
<tr>
<th>Sector</th>
<th>Stored data in the United States, 2009</th>
<th>Number of firms with &gt;1,000 employees</th>
<th>Stored data per firm (&gt;1,000 employees), 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discrete manufacturing³</td>
<td>966 petabytes</td>
<td>1,000</td>
<td>967 terabytes</td>
</tr>
<tr>
<td>Government</td>
<td>848</td>
<td>647</td>
<td>1,312</td>
</tr>
<tr>
<td>Communications and media</td>
<td>715</td>
<td>399</td>
<td>1,792</td>
</tr>
<tr>
<td>Process manufacturing³</td>
<td>694</td>
<td>835</td>
<td>831²</td>
</tr>
<tr>
<td>Banking</td>
<td>619</td>
<td>321</td>
<td>1,931</td>
</tr>
<tr>
<td>Health care providers³</td>
<td>434</td>
<td>1,172</td>
<td>370</td>
</tr>
<tr>
<td>Securities and investment services</td>
<td>429</td>
<td>111</td>
<td>3,866</td>
</tr>
<tr>
<td>Professional services</td>
<td>411</td>
<td>522</td>
<td>278</td>
</tr>
<tr>
<td>Retail</td>
<td>364</td>
<td>843</td>
<td>697</td>
</tr>
<tr>
<td>Education</td>
<td>269</td>
<td>280</td>
<td>319</td>
</tr>
<tr>
<td>Insurance</td>
<td>243</td>
<td>283</td>
<td>870</td>
</tr>
<tr>
<td>Transportation</td>
<td>227</td>
<td>376</td>
<td>801</td>
</tr>
<tr>
<td>Wholesale</td>
<td>202</td>
<td>129</td>
<td>636</td>
</tr>
<tr>
<td>Utilities</td>
<td>194</td>
<td>140</td>
<td>1,507</td>
</tr>
<tr>
<td>Resource industries</td>
<td>116</td>
<td>708</td>
<td>825</td>
</tr>
<tr>
<td>Consumer &amp; recreational services</td>
<td>106</td>
<td>222</td>
<td>150</td>
</tr>
<tr>
<td>Construction</td>
<td>51</td>
<td></td>
<td>231</td>
</tr>
</tbody>
</table>

1 Storage data by sector derived from IDC.
2 Firm data split into sectors, when needed, using employment
3 The particularly large number of firms in manufacturing and health care provider sectors make the available storage per company much smaller.


Adapted from Big Data: The next Frontier for Innovation, Competition, and Productivity. McKinsey Global Institute, May 2011
Devices connected to the Web:

- 1970 = 13
- 1980 = 188
- 1990 = 313,000
- 2000 = 93,000,000
- 2010 = 5,000,000,000
- 2020 = 31,000,000,000

Source: Intel; Adapted from Presentation by Chris Geer, NIST
Overview of the Electric System

Basic Structure of the Electric System

More than 100 years Old – But Not Much has Changed in the Physics … Not Until Now

Color Key:
Blue: Transmission
Green: Distribution
Black: Generation

Generating Station
Generator Step Up Transformer
Transmission Line 500, 345, 230, and 138 kV
Substation Step-Down Transformer
Transmission Customer 138kV or 230kV
Subtransmission Customer 26kV and 69kV
Primary Customer 13kV and 4 kV
Secondary Customer 120V and 240V
Smarter Grids: when energy meets information...
Our New Hybrid Reality

“A permanently evolving electrical network, with a real-time, two-way flow of energy and information, between power generation, grid operator, and end users. It is capable of integrating all traditional and new players: renewable generation units (wind, solar, etc.), electrical vehicles, electrical storage, or even entire smart cities”.

Smarter electricity systems (Source: IEA Smart Grid roadmap 2010)
Data determine the information which drives transactions

Signal Processing and Local Automation

<table>
<thead>
<tr>
<th>Field level</th>
<th>PMU</th>
<th>IED</th>
<th>Line sensor</th>
<th>DA</th>
<th>DG</th>
<th>CMU</th>
<th>Meter</th>
<th>HAN</th>
<th>Weather</th>
<th>Files</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qty</td>
<td>1k</td>
<td>100k</td>
<td>10k</td>
<td>10k</td>
<td>100k</td>
<td>10k</td>
<td>100M</td>
<td>100M</td>
<td>100k</td>
<td>100Tb</td>
</tr>
<tr>
<td>Time Resolution</td>
<td>1ms</td>
<td>100ms</td>
<td>10k</td>
<td>10ms</td>
<td>1s</td>
<td>10min</td>
<td>100M</td>
<td>100M</td>
<td>100k</td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>V I Ph Hz</td>
<td>V I Hz</td>
<td>10k</td>
<td>Sw</td>
<td>MW MVA</td>
<td>T°, Qual</td>
<td>1min to 15min</td>
<td>V I ph Hz History</td>
<td>100M</td>
<td>100k</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Others photos, videos, labs analysis, site inspections, etc.</td>
<td></td>
</tr>
</tbody>
</table>
Data to Information to … to Wisdom

Data (Symbols) → Information (W,W,W) → Knowledge (How) → Understanding (Why) → Wisdom

Connectedness → Relationships → Patterns → Principles → Evaluated

Graphic Original Illustration: Courtesy of Dr. Richard Candy, Eskom South Africa

Russell L. Ackoff
Value Creation and Delivery

Monetizing the Value of Control Actions

• Value of the grid services to end-users
• Value of the grid services to assets (e.g. DER, FACTS, HVDC, microgrids)
• Value of assets to the grid
• Value of the grid to utilities
• Value of the grid to investors
• Value of the grid to society
We Use *Controls - Signals and Actions* - to Enhance Performance Metrics and Maximize Value Across the Grid

- Efficiency
- Reliability
- Sustainability
- Flexibility
- Resilience
- Security
- Safety
<table>
<thead>
<tr>
<th>Use</th>
<th>Minimum duration of output energy (continuous)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Short (&lt; 2 min)</td>
</tr>
<tr>
<td>Balancing Authority &amp; Market Operations</td>
<td>① Provide spin / non-spin</td>
</tr>
<tr>
<td></td>
<td>② Provide ramping</td>
</tr>
<tr>
<td>Transmission Operations</td>
<td>⑥ Shift energy</td>
</tr>
<tr>
<td></td>
<td>⑨ Provide in-basin generation</td>
</tr>
<tr>
<td>Distribution Operations</td>
<td>⑪ Smooth intermittent resource output</td>
</tr>
<tr>
<td></td>
<td>⑫ Improve short-duration performance</td>
</tr>
<tr>
<td></td>
<td>⑬ Provide system inertia</td>
</tr>
<tr>
<td>Customer</td>
<td>⑭ Improve power quality</td>
</tr>
<tr>
<td></td>
<td>⑯ Integrate intermittent distributed generation</td>
</tr>
<tr>
<td>Energy Services</td>
<td>⑰ Carbon/Operational Optimization</td>
</tr>
<tr>
<td></td>
<td>⑲ Performance Contract Risk Mitigation</td>
</tr>
</tbody>
</table>

Source: SCE, Adapted by Newport Consulting

Courtesy of Paul De Martini, Newport Consulting Group LLC
Determinants of Control Design and Optimization

- Physics
- Operation
- Economics / Markets
- Information

Control
What is Transactive Energy/Control?

The technique for managing the generation, consumption or flow of electric power within an electric power system through the use of economic or market based constructs while considering grid reliability constraints – GWAC 1st Transactive Workshop 2012

“The term “transactive energy” is used here to refer to techniques for managing the generation, consumption or flow of electric power within an electric power system through the use of economic or market based constructs while considering grid reliability constraints. The term “transactive” comes from considering that decisions are made based on a value. These decisions may be analogous to or literally economic transactions.” – recent IBM Workshop

“A set of economic and control mechanisms that allow the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter” – most recent GWAC discussion September 2013

“The ability to interact with every device that connects to the grid using price signals as a basis for monetizing responses.” – NIST Smart Grid Advisory Committee Report
Transactive Control - Every Action Counts

What is it?

- Transactive control is a distributed method for coordinating responsive grid assets wherever they may reside in the power system.

Incentive, feedback, and feed-forward signals

- The incentive signal sends a synthetic cost forecast to electricity assets
- The feedback signal sends a consumption pattern in response to the incentive.

Source: Adapted from presentation by Dr. Ronald Melton, Pacific Northwest National Laboratory
Two-Way, Hierarchical, Transactive Architecture Localizes and Balances Values & Prices

Information for each layer of value signal is entirely local

Honoring natural domains keeps the smart grid simple:
- protocols/standards are mostly quantity, cost, and time ("KISS")
- honoring “need-to-know” enhances cyber security

Source: Presentation by Rob Pratt, PNNL
Existing and new flexibility needs can be met by a range of resources in the electricity system – facilitated by power system markets, operation and hardware.

Source: Figure Adapted from Harnessing Variable Renewables, International Energy Agency
Enhanced T&D Grid Ops using DER Flexibility Services
Synchrophasors: The New Heartbeat of the Grid!

Enabling Intelligent Decentralized Grid Monitoring & Control

- Root Cause Analysis
- Modelling
- Post-Event
- Offline Analysis
- Generator & ISO Compliance
- Dynamic Security Assessment
- State Estimation Contingency Analysis
- EMS
- Synchrophasor Analytics
- Local Controls
- New Smart Grid Applications
- Distribution
- Wide Area Controls
- Demand Response
- DMS
- Distributed Generation
µPMU Measurements Potential Applications

Holistic Approach to Big Data Analytics

A functional transverse layer that pulls data from all sources and generate value to each domain.

UMDM is a facility to integrate real time data, meter data, financial data, and analytics to bring value to Network Operations, Network Planning, Customer Services and Company Efficiency.
Transactive Controls and Predictive Analytics for Managing Uncertainty in Hybrid Grids

Coping with Uncertainty
- Increasing Variability
- Data Uncertainty
- Comprehension Uncertainty
- Projection Uncertainty
- Decision Uncertainty
Predictive Operations Capability in Control Rooms

- Reduces the impact of variability and uncertainty on real-time decision making in the control room
- Create new value grid services, e.g. improve asset utilization
Advanced Analytics for Big Information
Transition from Deterministic to Probabilistic Paradigms

Stochastic Commitment and Dispatch
Probabilistic Reliability Criteria
Data Driven System Model
Deep Dive Tail Event Analysis
Simulation of Blackouts
Predictive Congestion
Preventive Redispatch

Benefits
- Understanding & Prediction of System Behavior
- Actionable Information
- Super Fast Simulations
- Better Utilization of Transmission
- Better/Modal Control
- More Effective Integration of Renewables
- Accurate Security Margin Quantification
- Effective Integration of Renewables
- Actionable Information

How to Stochastic Machine?
- Probabilistic System Models & Analytics
- Uncertainty Quantification Including All Sources
- Statistical System Model
- HPC Framework
- Transmission Tool
- Statistical Control
- Stochastic Dynamics
- Statistical Linearization
- Risk-based Limits
- Principal Components
- Probabilistic Stressing

Conclusions

• Harness data and advanced analytics that produce information to extract new insights, and create new value streams.

• Use value-based controls for enhanced grid performance and allocation of maximal benefits from services along the electricity value chain.
Thank You

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