Smart Uses of Data in Smart Grids

Mladen Kezunovic
Texas A&M University, USA

Keynote Lecture
ISGCE 2013
Jeju Island, Korea
July 8, 2013
Outline

• Background
• Data Properties
• Translational Knowledge
• Implementation
• Q/A
BACKGROUND

Intelligent Grid Technology Hype Cycle

Visibility
- Advanced Distribution Management Systems
- Home-Area Network
- Distributed Generation
- Consumer Energy Storage
- Plug-In Hybrid Electric Vehicle
- Business Process Management for Energy
- Smart Appliances
- Web 2.0 for Utilities
- Phasor Measurement Units

Controllability
- Provider Energy Storage
- Combined Heat and Power
- Customer Gateways
- CIM-Driven Integration Standards
- Advanced Metering Infrastructure Residential/Domestic
- Active RFID for Utilities
- Demand Response
- Passive RFID for Utilities
- Broadband Over Power Lines
- Intelligent Electronic Devices
- Process Data Historians
- RF Networks for Utility Field Applications
- Advanced Metering LC&I

Observability
- Advanced Distribution Protection and Restoration Devices
- Broadband Over Power Lines
- Demand Response
- Advanced Distribution Management Systems
- Home-Area Network
- Distributed Generation
- Consumer Energy Storage
- Plug-In Hybrid Electric Vehicle
- Business Process Management for Energy
- Smart Appliances
- Web 2.0 for Utilities
- Phasor Measurement Units

Years to mainstream adoption:
- less than 2 years
- 2 to 5 years
- 5 to 10 years
- more than 10 years
- obsolete before plateau

As of June 2008
The business value of data
Integrative view

Integrating smart, wise, intelligent, future, modern, perfect, empowered
10 IT technologies in 2013

- Mobile devices
- Mobile Apps and HTML5
- Personal Cloud
- The Internet of Things
- Hybrid IT and Cloud Computing
- Strategic Big Data
- Actionable Analytics
- Mainstream In-Memory Computing (IMC)
- Integrated Ecosystems
- Enterprise App Stores
DATA PROPERTIES


Future Electricity Grid
Grid Events
Operating States
Temporal and Spatial Aspects
Data Types
Grid Events

Power System States
- Steady State
- Transients
- Dynamics

Contacts Switching Causing Changes
- Circuit Breaker Switching
- Auto-reclosing Sequence
- Switching by Various Controllers (FACT, etc.)

Models Reflecting Various States
- Power flow and State estimation
- Short circuit calculation
- Time domain EMTP
- Stability (transient, voltage, small signal, etc.)
System and Market Operating States

<table>
<thead>
<tr>
<th>Type</th>
<th>Configuration</th>
<th>Market Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>All MPs active</td>
<td>Within Limits</td>
</tr>
<tr>
<td></td>
<td>Complete config.</td>
<td></td>
</tr>
<tr>
<td>Emergency</td>
<td>All MPs active</td>
<td>Parameter(s) violate the limits</td>
</tr>
<tr>
<td></td>
<td>Complete config.</td>
<td></td>
</tr>
<tr>
<td>Restorative</td>
<td>Structure incomplete</td>
<td>Within limits</td>
</tr>
</tbody>
</table>

*MPs (Market Participants) include generator companies, transmission owners, load serving entities and other non-asset owners such as energy traders.*
Time and space

Local events sensed by substation equipment
- Faults
- Changes in switching state
- Out of step (between equivalents)

Correlating space and time matters

Models to data match

Global events sensed by wide-area measurement system
- Stability (various types)
- Frequency and voltage
- Cascading events

Models to data match
Temporal Issues

- GPS receiver
- Local Clock
- Two line ends
- Local/Central time stamp

- PMU
- DPR
- FL
- RTU

Phasor Measurements
Relaying
Fault Location
State Estimation

10^-6 s
10^-3 s
10^-1 s
10^0 s

Time Scale

IED

Inputs
Outputs

Signal Measurement
Synchronous
Scanning

Signal Representation
Waveform
Phasor
Temporal Issues

Data with different time perspectives

Past
Historical Data

Present
Real-time Data

Future
Planning Data
Temporal Issues

Difference between time correlation

**Scanning (relative)**

Analog Inputs → MUX → A/D → Sampling Clock

**Synchronous Sampling**

Analog Inputs → S/H → MUX → A/D → Sampling Clock

**Time Stamping (absolute)**

Analog Inputs → S/H → MUX → A/D → LOCAL CLOCK → 1PPS → GPS CLOCK RECEIVER

PROCESSOR + MEMORY → TIME CODE
Temporal Issues

Phasors in Relaying (triggered sampling)

Measurements through moving data window

Relay calculated phasors

Compare with settings

Phasors in Monitoring (continuous sampling)
Spatial Issues

Uses of data: driven by applications

Data Sources

- SCADA (operational data)
- PMUs (synchronized phasors)
- IEDs (non-operational data)

Applications

- Intelligent Alarm Processor
- Optimized Fault Location
- Cascading Analysis

Data Formats:

- IEDs data format
- PMUs data format
- Other data format
- COMTRADE data format
- Synchro-phasor data format
- Synchro-sampling data format
- Naming Convention
Spatial Issues

Local (substation-wide)

Broad (system-wide)

United States transmission grid
Source: FEMA
Spatial issues (System wide)

Inter-station

Intra-station

General Communications (IP-based schemes)
Spatial issues (local)

Layout of typical substation equipment

LEVEL I
CENTRALIZED LOCATION

LEVEL II
SUBSTATION

LEVEL III
SWITCHYARD INTERFACE

CFL  MS  PE  EMS
LMS  IS  RC  SC
FL  DFR  CBM  DPR  PMU  RTU  SOE
A  S  A  S  A  S  A  S  A  S  A  S  A  S  A

Non operational data  Situational awareness data  Operational data
Markets

Oil and Electricity Monthly Average Price

- IPEX baseload (euro/MWh)
- Brent (euro/bbl)
- WTI (euro/bbl)
GIS and GPS

- Satellite Data
- Other Digital Data
- Aerial Photographs
- Digital Maps
- Tabular Information
- New Information
Weather

Lightning (blue dots) on 19/10/2012, 60min prior to 21:20:00 UT

Contact University of Washington for Copyright Info
TRANSLATIONAL KNOWLEDGE

<table>
<thead>
<tr>
<th>Application</th>
<th>Temporal</th>
<th>Spatial</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal Fault Location</td>
<td>Synchronized or unsynchronized phasor or sample vector</td>
<td>Local and system-wide</td>
<td>Power System Network for short circuit study</td>
</tr>
<tr>
<td>Intelligent Alarm Processing</td>
<td>Synchronized or unsynchronized phasors</td>
<td>Substation and system-wide</td>
<td>Petri-Net Logic for cause-effect representation</td>
</tr>
<tr>
<td>Inherently Adaptive Fault Detection and Classification</td>
<td>Synchronized sample vector</td>
<td>Local</td>
<td>Power system model for training pattern clustering</td>
</tr>
</tbody>
</table>
Fault Location

- Phasor based Methods
  
  *Use fundamental frequency component of the signal and lumped parameter model*

- Time-domain based Methods
  
  *Use transient components of the signal and lumped or distributed parameter model*

- Traveling wave based Methods
  
  *Use correlation between the forward and backward travelling waves along a line or direct detection of the arrival time*

  - Single end
  - Double end
  - Synchronized
  - Unsynchronized
  - Phasors
  - Samples
Big Data and Analytics

Big Data Landscape

Vertical Apps
- bloomreach
- myriss

Ad/Media Apps
- rocketfuel
- collective ID

Business Intelligence
- Oracle
- Hviezion
- Business Objects

Analytics and Visualization
- Tableau
- QlikView
- Palantir

Data as a Service
- factual
- SNIP

Analytics Infrastructure
- Hortonworks
- Vertica MAPEER

Operational Infrastructure
- Couchbase
- 10gen
- Teradata

Structured Databases
- Oracle
- MySQL

Technologies
- hadoop
- Cassandra

Copyright © 2012 Dave Feinleib
dave@vcdave.com
blogs.forbes.com/davefeinleib
IMPLEMENTATION

Cyber-Physical security
Privacy
Standardization
Testing and certification

Cyber security
The role of standards
Interoperability

- **Layer 1: Basic Connectivity**
- **Layer 2: Network Interoperability**
- **Layer 3: Syntactic Interoperability**
- **Layer 4: Semantic Understanding**
- **Layer 5: Business Context**
- **Layer 6: Business Procedures**
- **Layer 7: Business Objectives**
- **Layer 8: Economic/Regulatory Policy**

- **Technical (Syntax)**
- **Informational (Semantics)**
- **Organizational (Pragmatics)**

Copyright 2013  Texas A&M Engineering Experiment Station
Standards Landscape for synchrophasors

Timing Standards:
- GPS L1
- IRIG 200-04
- IEEE 1588 PTP
- C37.238 Profile

Other Standards:
- IEC 61850
- NISTIR 7628
- IEC 62351
- IEEE 1815-2012

PMU Standards:
- IEEE C37.118.1
- IEEE C37.242

Communication Standards:
- IEEE C37.118.2
- IEC 61850-90-5
- ICCP

Data Management:
- IEEE C37.111 COMTRADE
- PSRC H8 Schema
- IEEE C37.232
- IEEE C37.239
- IEC 61970

Network

Application

Substation
Procedure: how to test?

<table>
<thead>
<tr>
<th>PMC</th>
<th>Class</th>
<th>Dynamic State Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Measurement Bandwidth</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TV</td>
</tr>
<tr>
<td>A</td>
<td>P</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>S</td>
</tr>
<tr>
<td>A-1</td>
<td>P</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>S</td>
</tr>
<tr>
<td>B</td>
<td>P</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>F</td>
</tr>
<tr>
<td>C</td>
<td>P</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>S</td>
</tr>
<tr>
<td>D</td>
<td>P</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>S</td>
</tr>
<tr>
<td>E</td>
<td>P</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>F</td>
</tr>
<tr>
<td>F</td>
<td>P</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>F</td>
</tr>
<tr>
<td>G</td>
<td>P</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>S</td>
</tr>
<tr>
<td>H</td>
<td>P</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>S</td>
</tr>
</tbody>
</table>

Caption: Why Testing and Certification Matters

Image: Smart Grid Center

Copyright 2013 Texas A&M Engineering Experiment Station
Why T&C Matters

Process: how to certify?

<table>
<thead>
<tr>
<th></th>
<th>PMU A</th>
<th>PMU A*</th>
<th>PMU B</th>
<th>PMU C</th>
<th>PMU D</th>
<th>PMU E</th>
<th>PMU F</th>
<th>PMU G</th>
<th>PMU H</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDC A</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>PDC B**</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>N</td>
<td>S</td>
</tr>
<tr>
<td>PDC C***</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
</tr>
</tbody>
</table>
Smart grid center: http://smartgridcenter.tamu.edu/sgc/

EV-TEC: http://ev-tec.org

PSerc: http://www.pserc.org

ARPA-E: http://smartgridcenter.tamu.edu/ratc/

Smart Energy Campus Initiative: http://smartgridcenter.tamu.edu/seci/
Together - building a prosperous future where energy is clean, abundant, reliable, safe, secure and affordable
Thank you!

Mladen Kezunovic
Dept. of Electrical and Computer Engineering,
Texas A&M University
College Station, U.S.A.
kezunov@ece.tamu.edu
http://smartgridcenter.tamu.edu/pscp_kezunovic/