BIG DATA ANALYTICS FOR ELECTRIC POWER GRID OPERATIONS

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Agenda

- Big Data in the Energy Industry
- Solution Architecture/Approach for Managing Big Data Analytics
- Synchrophasor Data Analytics for Real Time Grid Operations
- Synchrophasor Data Analytics for Offline Engineering Analysis
- Conclusions
Big Data in the Energy Industry

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>
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</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>10M</td>
<td>100M</td>
<td>100k</td>
<td>100Tb</td>
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<tr>
<td>Time Resolution</td>
<td>1ms</td>
<td>100ms</td>
<td>10k</td>
<td>10ms</td>
<td>1s</td>
<td>10min</td>
<td>1min to 15min</td>
<td>100M</td>
<td>100k</td>
<td>100k</td>
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<tr>
<td>Type</td>
<td>V I Ph Hz</td>
<td>V I Hz</td>
<td>V I Hz</td>
<td>10k</td>
<td>5W</td>
<td>MW MVA</td>
<td>T°, Qual</td>
<td>100M</td>
<td>100k</td>
<td>Others photos, videos, labs analysis, site reports, trend data</td>
</tr>
</tbody>
</table>

Real Time Data Management

Comm (AMI, Tcom)

Scada PDC MDM

Grid Operations

Business Operations

Customer Engagement

Transaction Data Management

Scada PDC MDM

Real Time Data Management

Comm (AMI, Tcom)
Big-Data Grid Analytics
Measurement to Information value-chain

Data acquisition → Storage → Algorithmic → Application

EMS/DMS/MMS

ODM
Near-real Time
Billion+ Points
NOSQL

eterraAnalytics
Time-series optimized
Calculation flexibility
Formula transparency
Results auditability
Horizontal scalability

Existing NMS Apps

New Grid Analytics

Partner/Customer/Competitor Systems
Itron
ESRI
OSI
SAP
Pi
ABB
Siemens
Oracle
Banner
Echelon

Partner/Customer Apps
Synchrophasor Deployment in North America

Changing Landscape

Approx. 200 PMUs in 2007

Over 1200 PMU deployed by 2012
(over 10TB/Month of “raw” PMU data)

Source: NASPI Website (www.naspi.org)
Approaches for Processing Big Data

- **Temporal Processing** *(compression)* – Pre-calculated analytics *(results archived).*

- **Spatial Processing** – Distributed Analytics *(at substation & control center)*
Data Analytics – Modes of Operation

**REAL-TIME**

- Centrally administered (modeled & configured). No end-user intervention.
- Continually processed using a *Time-Window* of data at periodic update rates.
- View-only mode to review the results.
- Analysis results may be archived.
- Examples: Oscillatory Stability Monitoring.

**OFFLINE (AFTER-THE-FACT)**

- Typically ‘data mining’ analytics that “walk-through” large volumes of historical data in smaller chunks (i.e. batch processing).
- May require initial metadata from end-user.
- Results are presented once the entire processing is complete.
- Examples: Baselining.

**CONTINUOUS (Push)**

- End-user or event triggered.
- Little to none end-user intervention.
- Single real-time view of the results.
- Results are made available as soon as they are generated.
- Examples: Event capture and reporting.

**ON DEMAND (Pull)**

- Locally processed by the end-user.
- Fully interactive end-user experience; close feedback between data-analytics-UI.
- Results are locally archived & presented to the end-user.
- Examples: Post-Event Analysis.
Examples of Real-Time Data Analytics

WAMS IN OPERATIONS

- System Disturbance Characterization
- Oscillatory Stability Monitoring
- Islanding and Resynchronization
- Angle-based Grid Management
System Disturbance Characterization

Concept: Illustration of Angle Movement in Response to a Disturbance

- Angle ($\delta$) and Speed ($\omega$) can't change instantaneously at a generator.
- $\delta$ & $\omega$ near a generator influenced by generator angle.
- $\delta$ & $\omega$ move more rapidly near the disturbance than far away.
- Disturbance appears to propagate as a kind of “wave.”
System Disturbance Characterization

Example

“Typical” Disturbance

Freq (& angle) moves first close to disturbance
System Disturbance Characterization

Example of “Typical” Disturbance (Load Loss)

Electromechanical oscillations

Inertial response (f)

Angle difference
1) Detect disturbance
2) Locate trigger point
3) Detect event type
4) Estimate impact
Oscillatory Stability Monitoring

Mode Alarming: 3 min window, 5 sec update, for alarms
Mode Trending: 20-180 min window, 20 sec update, for analysis
Operational Displays

In the Mode Selector Tabs the Frequency and Damping of the poorest damped PDX result is shown (5 seconds update rate).
Oscillation Source Location

Concept: Oscillation Phase Relations for a Single Machine

- P and δ lag ω by about 90°, determined by damping.
  E.g. damping ratio 20%, angle lags 90°+12° and power lag speed by 90°-12°
- Power (P) in phase with speed (ω) produces positive damping.
- Power out of phase with speed produces negative damping.
Oscillation Source Location (0.005 – 4.0Hz)

**Concept**

Uses Oscillation **Phase** as identification of largest contributions to oscillation. Define largest group contribution, then finds closest PMU to largest contribution in group.

**Benefits**

- **Targeted action** - on-line or planning
- Applicable to interconnection. Defines if problem in own control area.
- Supports **operational process** to manage unexpected behaviour
- Supports **control tuning process**

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### Full Oscillation Range

#### Concepts

- **4-46Hz:** Sub-Synchronous Oscillations (SSO) from series capacitors, torsional modes, control interaction, etc. to identify precursors.

- **0.005-0.1Hz:** Manage governor-frequency control stability risk by oscillation detection & angle-based

#### Benefits

- **SSO Early warning**
  - Avoid network tripping
  - Natural frequencies for model tuning and scenario selection

- **Assess system tests of control tuning and control tuning effect**

- **Identify & correct plant malfunction or misconfiguration quickly**

<table>
<thead>
<tr>
<th>Governor Control</th>
<th>Electromech &amp; V. Control</th>
<th>Sub-Synch Osc</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.005 – 0.1Hz</td>
<td>0.1 – 4Hz</td>
<td>4 – 46Hz</td>
</tr>
</tbody>
</table>

- **Detection & early warning**
- **Source Location** for identifying contributions (unique Alstom)
- **Geographic View** presents participation and contributions
- **Analysis** information for scenario selection, problem location, modelling
Benefits of Hybrid Approaches

Angle-based Grid Stability Management

Dynamic/Static Limit

Correct

Predict

Angle Monitoring
Real-Time Monitoring

WAMS-based Information

Real-time alerts on large angle differences.

Predicting post-contingency angle changes.

Recommendations on corrective actions (based-on network sensitivities)

**NOTE:** Limits may be (1) Static (i.e. offline) OR (2) Dynamic (i.e. based on Real-Time Dynamic Security Assessment)
Prediction

Topology-based Line Outage Distribution Factors


2. Post-Contingency Angle Difference Values
Corrective Actions

Topology-based Network Sensitivities (i.e. efficacy in relieving grid stress)

1. Angle Difference Pairs
2. Generator sensitivities (in MW) to reduce angle difference values.
Examples of Offline Data Analytics

WAMS IN OFFLINE PLANNING

- Model Validation (*Ringdown Analysis*)
- Dynamic Performance Baseline/PSS Tuning
- Compliance Monitoring
Offline Engineering

Leveraging time-synchronized and high fidelity PMU measurements in Operations Planning

**Post Event Analysis**
- Quicker post-mortem analysis.
- Sequence of events & root cause analysis.

**Dynamic Model Validation**
- Dynamic model verification.
- Generator model calibration.
- CT/PT calibration.
- Load characterization.

**Baselining**
- Assess dynamic performance of the grid.
- Steady-state angular separation.
- System disturbance impact measures.

**Compliance Monitoring**
- Primary frequency (governing) response.
- Power System Stabilizer (PSS) tuning.
- Sub-synchronous resonance.

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**Synchrophasor benefits for Post-Event Analysis**

Phasor data are also valuable for investigation of grid disturbances, improving both the speed and quality of analysis.

In the case of the 2007 Florida blackout, NERC investigators used phasor data to create the sequence of events and determine the cause of the blackout in only two days; in contrast, lacking high-speed, time-synchronized disturbance data it took many engineer years of labor to compile a correct sequence of events for the 2003 blackout in the Northeast U.S. and Ontario.

*NERC RAPIR Report, 2010.*
Model Validation – Comparison Modes Between PMU data and Simulation Data

Selected exactly same time period on both PMU measured power and simulated power. Original signals (in solid lines) and reconstructed signals (in dash lines).

Both PMU measured and simulated power contain 0.72Hz Mode.
Both PMU measured and simulated power contain 1.10Hz Mode

Selected exactly *same* time period on both PMU measured power and simulated

Original signals (in solid lines) and reconstructed signals (in dash lines)

Simulation data shows negative damping ratio!
Dynamic Performance Baselining

Number of occurrences of a mode.

Recommended sub-bands

Analysis filters
AVR, PSS and Governor Tuning

1. Observe
2. Model
3. PSS Design
4. Testing & Commissioning
5. Operation

PhasorPoint Oscillatory Stability Management:
- Wide area real-time damping visualization and alarms
- Dynamics baselining & trending
- Wide area event analysis
Alstom’s e-terra analytics
Flexible engine for complex, highly-scalable time based analytics

- Time-Series Optimized
- Calculation Flexibility
- Formula Transparency
- Results Auditability
- Data Version Control
- Source Integration
- Business Process Automation
- Horizontal Scalability
Closing Remarks

• Big data management/analytics require a holistic approach across multiple data sources serving different stakeholders.

• Synchrophasors are increasingly becoming a part of ‘Big Data’ within the energy industry (*next generation SCADA*)

• Approaches to handling big data include:
  − *Temporal processing (compression)* – i.e. pre-calculated results/stats.
  − *Spatially distributed processing* – i.e. processing at the meter/substation/control center levels.

• Big data analytics operate in different modes including real-time, offline, continuous (automated), and on-demand.
  → *Flexible/versatile platform to meet use cases.*