Using Big Analog Data™ and the Industrial Internet to Improve Operations at Duke Energy

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Duke Energy - Maintenance & Diagnostics
Duke Energy at a Glance

Fossil/Hydro Operations (FHO) – Power Generation

- 42 GW Regulated Fossil/Hydro Generation
  - Coal, Combined Cycle, Combustion Turbine, Hydro, Pumped Storage
- 92 Plants/Sites (324 Units)
  - Carolinas – NC, SC (57 sites/ 202 units, 24 GW)
  - Florida (16/ 62, 9 GW)
  - Midwest – IN, OH, KY (19/ 60, 9 GW)
- ~3,800 Employees, ~1,600 Contractors
- Largest Utility in the United States
What we do...

7.3 million retail electric customers on the demand-side of the market (Load)

Provide electric power supply to instantaneously match the load demand by typically...

- Converting the chemical energy of combustible fuels (coal, natural gas, oil) to mechanical energy (steam-driven or combustion air-driven turbines) to electrical energy (large electric generators)
- Converting the mechanical energy of water (dams and hydro turbines) to electrical energy (large electric generators)

**EXTENSIVE** amount of machinery and infrastructure involved in electric power generation
Fleet/Plant Operations

Load demand forecasts and dispatch hierarchies

Low-cost, higher efficiency units dispatched first

Cost to generate MWs, cost to transmit MWs
  • Fuel = major contributor

Puts a significant emphasis on both cost and reliability

Will most cost-effective units be capable of running?

Equipment failures = detrimental

Fleet/Plant Maintenance

- Is performed either online while the unit is running, or as part of outages while the unit is offline
- Offline maintenance is either planned or unplanned (forced)
- Maintenance to major, critical assets almost always requires offline maintenance
- Unplanned offline maintenance can be very costly, and very undesirable
Advancements in Maintenance to Improve O&M

Looking for an optimized mix:
1. Reactive (run-to-failure)
2. Preventive (PM) (time-based)
3. Predictive (PdM) (condition-based)
4. Proactive (combination of 1, 2 and 3 + root cause failure analysis)
“Optimizing Maintenance”

“Preventive” = Conservative

- Traditional Preventive Maintenance requires extensive manual actions.
- Cost-prohibitive in terms of labor and resource requirements for acquisition and analysis of data.

“Reactive” = Run-to-Failure

- Reactive Maintenance addresses problems when they interrupt business.
- Cost-prohibitive in terms of significant opportunity costs.

June 26, 2015
Shifting the Paradigm

- Leverage advancements in technology along with cost-effectiveness of technology
- Drive the “Optimum” down and left
- More cost effective data acquisition and analysis methods

<table>
<thead>
<tr>
<th>“Conservative Strategy”</th>
<th>“Intelligent Strategy”</th>
<th>“Reactive Strategy”</th>
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</table>

- Preventive Costs
- Reactive Costs

June 26, 2015
Advancing Fleet/Plant O&M via Technology

Improve Condition-Based Maintenance (CBM) Concept Using Technology: “SmartGen”

Implement a system that enables remote, automated monitoring and diagnostics of plant equipment
Typical M&D Process… what does that look like?

Current State Monitoring & Diagnostics

Diagnostics…
Adding the “Smart” to Monitoring & Diagnostics

SmartGen Sensor System
- Vibration
- Temperature
- Oil Level
- Oil Dielectrics (quality)

M&D Center
- Detect a step change in vibration
- Trend reaches alarmable level; initiates troubleshooting/diagnostic process

Automated Diagnosis
- System performs assessment of spectrum vibration
- Recognizes a pulsing phenomenon of 2x (120Hz) frequency – electrical
- System queries motor amps in PI
- Recognizes pulsating amps coincidental with 2x – confirmed electrical issue
- System queries past maintenance history
- Identifies previous equipment performance with similar “symptoms”

Diagnosis: Clogged Intake Screens
Action: Specialist review and validate/refute auto-diagnosis
If validated, Create a WO/JR to clean screens at convenient time
Benefit: Quick response with determination of criticality
Save time and effort of data collection
“That’s impossible... or impossibly complex...”

**SmartGen/SmartM&D requires:**

- Instrumentation and sensors
- Data collection, management, integration, and presentation
- Advanced analytics and diagnostic modeling
- Interoperability and communications of systems, applications, and devices
- Network performance and security requirements
Instrumentation and Sensors

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<thead>
<tr>
<th>Type I</th>
<th>Type II</th>
<th>Type III</th>
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<tbody>
<tr>
<td>“The Usuals”</td>
<td>• Process Variables</td>
<td>“The Improvements”</td>
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<td>• Temps</td>
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Wireless
# SmartGen Instrumentation, Sensors, and Data Generation

## SENSORS

<table>
<thead>
<tr>
<th>Embedded Turbine Monitoring System</th>
<th>NI cRIO Monitoring Node</th>
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<tr>
<td>Vibration Sensors</td>
<td>Turbine Monitoring Systems</td>
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<tr>
<td>3rd Party Systems</td>
<td>Configuration (A/D conversion)</td>
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<tr>
<td>Sensors</td>
<td>Data Capture</td>
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<tr>
<td>Vibration</td>
<td>Computation</td>
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<tr>
<td>Temperature</td>
<td>Forward Data</td>
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<tr>
<td>Pressure</td>
<td>H₂ and NH₃ Leak Detection</td>
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<tr>
<td>Flow</td>
<td>Oil Levels</td>
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<tr>
<td>Position/Displacement</td>
<td>Particle Counts</td>
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<tr>
<td>Oil Quality</td>
<td>Oil Dielectrics</td>
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<tr>
<td>Ultrasound</td>
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<td>Infrared Thermography</td>
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<td>Power/Current</td>
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<td>Leak Detection</td>
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<td>Dissolved Gas Analysis</td>
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<td>Electromagnetic Interference</td>
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<td>Partial Discharge</td>
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<td>Optics</td>
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<td>Acoustic</td>
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## Balance of Plant Systems

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<th>Configuration (A/D conversion)</th>
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<td>Computation</td>
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<td>Forward Data</td>
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| Data Acquisition Systems, Wireless Access Points, Routers, etc |
| H₂ and NH₃ Leak Detection |
| Oil Levels |
| Particle Counts |
| Oil Dielectrics |

### Monitoring Node

- Accelerometers, Proximity Probes

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*June 26, 2015*
<table>
<thead>
<tr>
<th>Condition Assessment</th>
<th>Personnel</th>
<th>Data Source</th>
<th>Data Type</th>
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</thead>
<tbody>
<tr>
<td>Visual Inspections</td>
<td>Operations, Engineers, etc.</td>
<td>Operator Logbooks, CMMS, etc.</td>
<td>Text, Checklists, etc.</td>
</tr>
<tr>
<td>Vibration Analysis</td>
<td>PdM Technician, Engineer</td>
<td>RBMWare, Spreadsheets</td>
<td>Numerical Arrays, Text</td>
</tr>
<tr>
<td>Lubrication Analysis</td>
<td>PdM Technician, Chemists</td>
<td>Spreadsheets</td>
<td>Numerical Arrays</td>
</tr>
<tr>
<td>IRT Assessment</td>
<td>PdM Technician</td>
<td>FLIR software database</td>
<td>Numerical Arrays, Text</td>
</tr>
</tbody>
</table>
Data Collection, Management, Integration, and Presentation
Data Collection, Management, Integration, and Presentation
Data Collection, Management, Integration, and Presentation

- Addition of new instrumentation/sensors = **MORE DATA**
- Transitioning route-based collection to online collection = **MORE DATA**
- Standardized systems/processes needed to ensure...
• Significant amount of new data generation (potentially 100s of GB/week)
• Better integration... both “vertically” and “horizontally”
SmartGen Data Visualization and Presentation

Presentation of data to technical users and management in improved ways:

- Better Visual Representation of Phenomena
- Integrated Displays of Related Data
Advanced Analytics and Diagnostic Modeling

• Adding the “Smart” to SmartM&D
• **NOT** intended to replace the human element
• Intended to **LEVERAGE** the human element
• Symptoms-based troubleshooting
  • What indicators exist?
  • What other data/information would substantiate those indicators?
  • Where is that additional data information?
Remote Monitoring & Diagnostics (M&D) center enters the picture...

- Advanced Pattern Recognition (APR) model revealed that vibration was actually high in both X and Y directions
- SME support was contacted for further review

Generator SME confirmed...

- indications of partial coil shorts not there previously
- rotor is more susceptible to bowing if there are shorts on these coils
- appears that the insulation structure from turn-to-turn on generator field has degraded
- may indeed be a contributor to the increase in vibration seen.

Raw data observable at the station...

- showed overall vibration increase on one prox probe in Y-direction
- vibration in the X-direction remains relatively unchanged
- not overly concerned by a 0.5 mil increase
- initially it was thought that the sensor may be bad
Interoperability and Communication of Systems, Applications, and Devices
Network Performance and Security

• Typical Machine’s High Speed Sensors
  – 2 Accelerometers
  – 2 Proximity Probes
  – 1 Tachometer

• Speed 51.2 KS/s
• Each sample is 32 bits/4bytes
• ~200 Kbytes per second per channel
• ~1 Mbyte per second

• Adding access points:
  • 1000s of new data collection points
  • Additional Routers, WAPs, etc.

605GB of data EACH WEEK!!!
### FUTURE STATE: The Smart, Connected Plant/Fleet – Intelligent Assets

<table>
<thead>
<tr>
<th>PLANT ASSETS</th>
<th>SMART PLANT ASSETS</th>
<th>SMART, CONNECTED PLANT ASSETS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical components e.g. combustion turbines, steam turbines, generators, turbines, pumps, motors etc.</td>
<td>Sensors, microprocessors, data acquisition, data storage, controls, software, embedded operating system, enhanced user interface etc.</td>
<td>Ports, antennae, protocols enabling wired / wireless connections with plant asset: one-to-one, one-to-many, many-to-many.</td>
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</tbody>
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#### Autonomous Capability

<table>
<thead>
<tr>
<th>Monitoring</th>
<th>Optimization</th>
<th>Control</th>
</tr>
</thead>
</table>
| Sensors and external data sources enable comprehensive monitoring of asset:  
• Condition  
• Operational performance  
• Asset usage  
• External environment | Embedded software (asset or asset cloud) enables:  
• Localized control of asset functions  
• Customizable operation according to operating conditions | Monitoring and control capabilities enable algorithms that optimize asset operation and use in order to:  
• Enhance asset performance  
• Allow real-time predictive diagnostics and repair  
• Ability to benchmark with other assets on network |

Combining monitoring, control and optimization allows:  
• Self diagnosis and service  
• Autonomous asset operation  
• Self-coordination of operation with other assets and systems