# Lessons Learned in Fleetwide Asset Monitoring of Gas Turbines and Supporting Equipment in Power Generation Applications

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## ABSTRACT

Condition monitoring remains an important technology for equipment life cycle management. Historically, online condition monitoring systems are installed only on the most critical assets within a power plant, process plant, or manufacturing facility. Less critical equipment, while vital to operation of the plant, are only monitored or tested periodically using manual route based technologies. This historical practice leaves equipment specialists with a small amount of time for analysis of collected sensory data (vibration, temperature, oil, power, etc.) as they spend the vast majority of working hours collecting equipment sensory data. Fortunately, data acquisition technology has evolved, making it possible to transform standard and advanced machinery measurements from manual collections to online collections, increasing time for specialists to analyze, and yielding opportunities for automated diagnostics and prognostics. By taking advantage of automation, the ability of equipment owners and operators to lower life cycle costs and increase reliability of plant equipment is greatly improved.

The transition from manual route based measurements to a fleetwide surveillance program touches many elements from sensors to networked data acquisition nodes to servers to historians and predictive technologies. Within power generation plants, installation costs, information technology strategies, and long term vision come together to create higher machine reliability at lower operational cost and new automation in performance monitoring, diagnostics, and advisory generation. With automation, comes increased sensory data from pumps and turbines that require new tools for data management, data mining, and data transformation into actionable information. A case study reviews the open and extensible data architecture of a fleetwide monitoring system deployed, the ongoing efforts, and current benefits delivered to the power generation industry participants.

## 1. MOTIVATION FOR FLEETWIDE MONITORING

Fleetwide Monitoring (FWM) is the implementation of applications for monitoring, maintaining and optimizing generation (and other) assets from a centralized location (Hussey, 2010). Fundamentally, FWM involves monitoring assets within a fleet of assets to detect operational and equipment problems earlier enough to mitigate damage, manage risk, identify performance problems, and manage business and market conditions or risks. A key part of FWM involves the use of advanced online monitoring technologies developed in the 1990s and 2000s and first applied in aerospace, transportation, and petrochemical applications. The goal of FWM is intelligent top-down approach to plant maintenance and scheduling. The goal is accomplished by the move toward centralized monitoring and diagnostic centers, the integration of advanced monitoring applications, and continued use of existing monitoring and maintenance technologies. The efforts supporting the goal will be facilitated by emerging standards supporting interoperability of equipment and technologies from multiple vendors.

### 1.1. Aging and New Power Plants

The power generation industry is undergoing a transition from traditional power using Nuclear and Coal to more efficient gas turbine combined cycle technologies (EIA, 2011). The United States Power Industry has relied on Nuclear and Coal based power generation for the majority of base load demand for many years, Figure 1. As of March 2011, 51% of all generating capacity is over 30 years old (Cook, 2013).

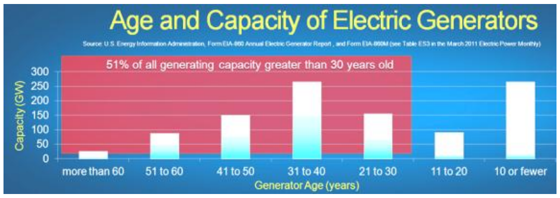

Figure 1. Age and capacity of electric generators.

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To keep these older generation assets producing power, additional maintenance is required. Adding to the maintenance challenges in power generation, the majority of new assets brought online in the last 20 years are natural gas based, Figure 2. Combustion turbine and combined cycle power generation plants are more economical to operate, given the lower price in natural gas. However, natural gas plants incorporate newer technology that is more complex and often more costly to repair. As a result of older power plants aging, and newer plants being more complex, a growing need for FWM coupled with automated diagnostics and prognostics is needed.

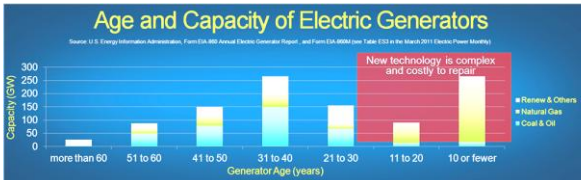

Figure 2. Newer power plants are natural gas plants.

### 1.2. Change in Operational Patterns Underscore Reliability Needs

Base load demand is now predominately provided by combined cycle gas turbine and steam turbine operations. Larger coal plants are now used to meet peak demand and smaller coal plants are being decommissioned. The result of this operational change is the combined cycle plants have higher reliability and availability demands. Further, the operating coal plants are experiencing reliability challenges as they operate differently than their design, that is they cycle on and off as compared to continuous operation.

As a result of these increasing reliability demands, the executive teams at power generation plants are challenged to leverage new technologies to address increasing reliability demands and workforce optimization. These power generation companies are collaborating with the Electrical Power Research Institute (EPRI) to address reliability needs from an industry perspective.

### 1.3. The Change from Manual Data Collection to Automatic Surveillance

A core objective of FWM is to greatly reduce the time equipment specialists spend collecting condition indicating sensory data, and as a result to increase the amount of time specialists spend analyzing sensor data and results from automated analysis, Figure 3. This change from manual sensory data collection is intended to result in improved consistency in diagnostics thru automation and standardization. Other improvements include better fusion of technology exam sensory data with process data. The end result is expected to be a more integrated monitoring and diagnostics center with improved visualization, enabling engineering and specialist workforces to perform higher value tasks.

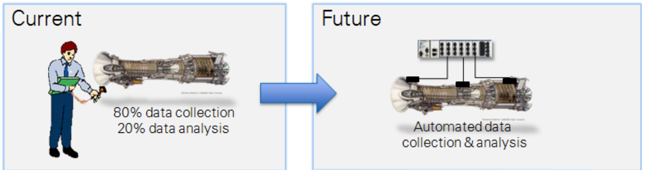

Figure 3. Workforce optimization thru online monitoring.

In comparison to manual route based data collection, Figure 4, online monitoring systems overcome several disadvantages. The first overcome disadvantage of manual route based sensory data collection is sparse data collection schedules. With manual route based exams, specialists visit the machines on schedules perhaps just once per month or once per quarter. These schedules may be interrupted by unplanned higher priority needs of the plant. In a large power generation enterprise, for example, staff and time is needed for nearly 60,000 manual exams per month. A second overcome disadvantage is equipment availability for an exam. The equipment may not be in operation during the specialist physical visit.

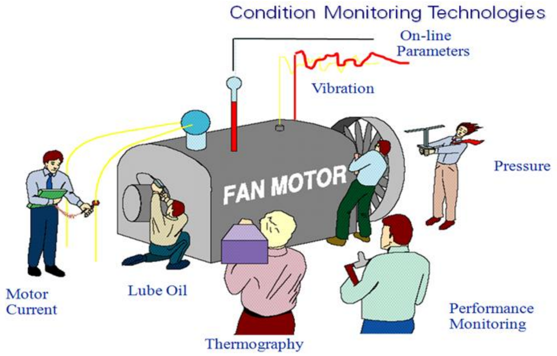

Figure 4. Manual technology exam measurements.

Third, there is a high probability of missing an event, as the symptom of degradation may not adequately show itself during the periodic visit. Fourth, when the technical exam sensor data is collected, it often remains on the specialist's computer, until such time as the specialist determines it is important to report during a face to face meeting. In other words, an individual's limited view of the overall equipment may prevent data from being reported at a face to face meeting. And perhaps most importantly, over 60% of specialist manpower is used to collect sensory data, with limited time left for analyzing and reporting equipment health.

The goal of intelligent top-down approach to plant maintenance and scheduling is met by the implementation of centralized monitoring and diagnostics centers. These centers require continuous updates of equipment performance and condition. To reach the goal then, the technology exams that are now performed manually will become automatic and online.

## 2. FLEETWIDE ASSET MONITORING SYSTEMS ARCHITECTURE

There are several aspects to the implementation of an online fleetwide asset monitoring systems. These include field communications, measurement coverage, data management, installation costs, and interoperability. Field communications is imperative to FWM as it allows data acquisition systems to report equipment conditions in real-time. The data acquisition systems also must cover all of the traditional condition and performance monitoring technologies, as well as allow for new advanced monitoring technologies. With the addition of FWM, terabytes of sensory data become available. Tools to manage the data, extract information, and guide diagnostics and prognostics applications are paramount. With careful planning, selection of sensors and server technology, the installation costs of FWM applications can be mitigated. Since a FWM system has many components, interoperability of components from different vendors brings flexibility to integrate existing systems with new technologies.

### 2.1. Field Communications

Many plants are deploying wireless communications networks within the physical plant. These networks allow plant personnel to access documentation, email, and task related applications using portable computing technology such as tablet computers. This business communications network is convenient for implementation of an online monitoring system.

To implement a FWM system, automatic data collection nodes, capable of measuring sensors from multiple technologies, are added to the business computer communications network, whether this is wired or wireless, Figure 5. By placing the data acquisition systems on the business computer network, the data acquisition systems avoid interfering with control systems, and face less interference evaluation. Figure 6 shows a sample data acquisition system including data acquisition hardware, power supplies, fuses, and communication equipment.

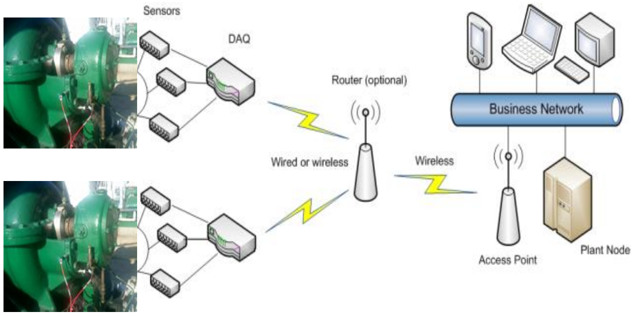

Figure 5. Data acquisition system on the business network.

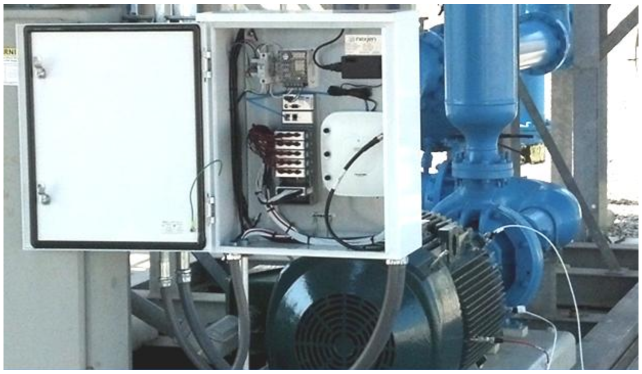

Figure 6. Sample data acquisition hardware cabinet.

### 2.2. Flexibility of Measurements

Measurement technologies for condition monitoring are prescribed in standards including the ISO 17359 condition monitoring standard (ISO, 2003). Measurements mentioned in the standard include temperature, pressure, flow, current, voltage, vibration, acoustic emissions, oil, and speed. Data acquisition systems must be able to digitize these physical phenomenons from a variety of sensors both those making dynamic and static measurements. Dynamic measurements are of physical phenomenon that changes rapidly such as vibration, motor currents, and pressure. Static measurements include oil, temperature, flow, and loads. Dynamic measurements may utilize analog to digital sampling rates in the 10’s of thousands of measurements per second. These systems are designed to continuously monitor sensors, in order to overcome the problem of missing an equipment degradation indication.

### 2.3. Data Management at the Data Acquisition Level

A challenge in FWM, is managing the large amount of data being acquired. For example, just monitoring two critical feed water pump shafts with two bearings can produce over one terabyte of data per week with continuous sampling. To overcome this sensory data deluge, the continuous monitoring data acquisition systems must be designed to record and transfer sensory data on an event bases, Figure 7.

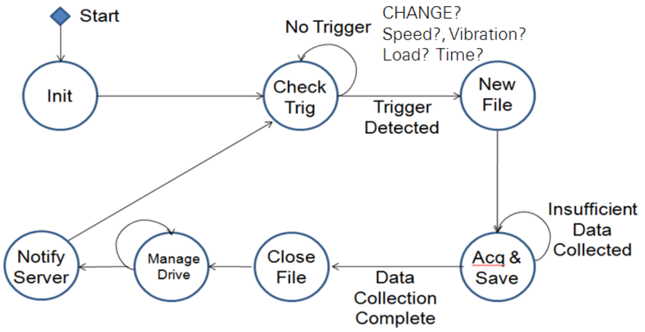

Figure 7. Data acquisition system software diagram.

To determine when a sensory data recording event has occurred, these networked systems must be both data acquisition and analysis network nodes (DAAN). Several FWM hardware vendors now offer an embedded architecture that implements embedded analysis for data reduction, Figure 7. This evolution has occurred as more online hardware has deployed, and end user and information technology (IT) feedback has been gathered. With this architecture, data is filtered at the DAAN, producing only sensory data with new information.

Both dynamic and static measurements are made with their time stamps synchronized. Some sensory values may come from communications to local control systems. As the sensory values arrive in memory, the DAAN analyzes the time stamps and values of sensory measurements to determine an event based trigger. With a trigger identified, sensory time waveform data is recorded to local on-board storage and placed in an out box directory for later transfer onto the network. The format of the time waveform recording is an open format such as the National Instruments TDMS format, UFF58 binary, or some other format that is documented and facilitates interoperability between vendors.

It should be noted that the DAAN, when recording data to its local disk, has provided metadata including equipment hierarchy, sensor calibration information, sensor location, time stamps, and other pertinent information to facilitate data search, off-line analysis, and peer to peer comparisons. The equipment and sensor location hierarchy should follow an information model commonly used in industry. This allows for interoperability of Data Acquisition systems and for downstream prognostics applications (Monnin et all, 2011) For condition monitoring there is not a formal standard, yet some good examples to build from. These include OSA-CBM, the IEC 61970 Common Information Model (CIM), and ISA-95 equipment model.

In a FWM application, 100's of DAANs may be added to the business or maintenance network. These DAANs themselves then need to be managed. A server class computer, also residing on the business network, is responsible for managing the DAANs, noting the health of sensors and data acquisition hardware as well as retrieving sensory data recordings from them, Figure 8.

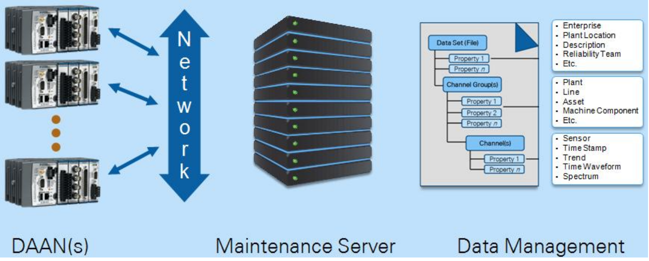

Figure 8. Data acquisition node, network, and server.

The server tasks include discovery of monitoring devices, insuring correct configuration of the monitoring devices, managing network and communications security, and monitoring the health of the DAAN as well as the attached sensors. These tasks are performed using both standard and proprietary vendor specific communications protocols to detect, configure, manage, and retrieve data from the DAANs.

## 2.4. Data Management at the Maintenance Server

The maintenance server has the responsibility of hosting specialist visualization and analysis software. With these tools, vibration analysts in particular can retrieve vibration time waveforms to perform comprehensive visual and comparative analytics within a single rotating machine and components or across machine peers. The maintenance server also has the responsibility of transferring condition indications to the plant historian where DAAN collected condition indicators are later correlated with process and operations data, Figure 9.

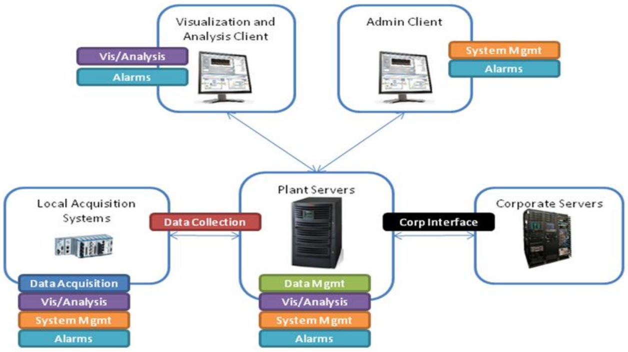

Figure 9. High level architecture of monitoring system.

Analysis of sensory data from the DAANs, and supporting control systems occurs in multiple locations, and ranges from threshold alarms, to advanced signal processing of time waveforms, to automated diagnostics, and health prediction, Figure 10. To optimize the overall process of tracking equipment health, reliability, and availability; a distributed analytical architecture provides both advanced calculations capabilities and data fusion opportunities. By distributing analytics amongst the DAAN, Maintenance Server, and Enterprise Historians; the amount of raw sensory data is reduced by conversion to key condition indicators, and threshold alarms

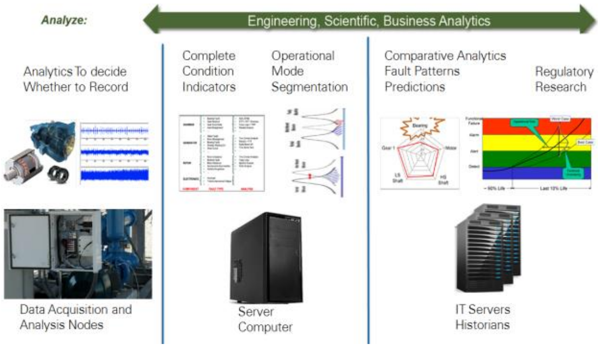

Figure 10. Data management and analytics architecture.

With sensory data and condition indicators available from multiple assets, automation of diagnostics and prognostics becomes possible. Since the entire event driven sensory data is labeled with equipment hierarchy metadata, similarity analysis with similar equipment, is now possible. When comparisons to fault signatures, operational states, and peer equipment are made; the sensory data is managed and reduced to actionable information.

### 2.5. Managing Installation Costs

By comparison to traditional condition monitoring technology, the costs of data acquisition equipment, sensors, networking equipment and server computers can add up quickly. However, with the advent of multi-mode sensors, proliferation of sensory data acquisition technologies, the industrial adoption of wireless networks, and the lowering cost of computer technologies; the industry has an opportunity to install FWM systems at lower costs than previously available.

Vibration sensors for example are now available from industrial suppliers with both temperature and vibration in a single sensor. These same vendors also offer tri-axial sensors (three directional vibration sensors in one) in industrial grade packaging. These multi-mode sensors reduce cabling and conduit equipment and labor costs.

Data acquisition systems are available from a number of vendors, and the market these vendors participate in is growing as a result of global drive to automate sensory data collection in a broad base of fields. This market trend is driving down the costs of data acquisition equipment. Further, many data acquisition systems offer the ability to monitor multiple sensing technologies from multiple assets or machines in a single device. These data acquisition systems also include the ability to filter data, only recording sensory data periodically and on event, thereby reducing the cost of data analytics and storage.

Wireless technologies are quickly being adopted in many fields. These include industrial networking supporting business network applications in the field, as well as wireless data acquisition and sensory technologies. This adoption is expanding the offerings from a larger number of vendors, as well as best practices and services for installing and managing wireless networks. With a larger field of wireless technology suppliers and practitioners, the cost of the wireless infrastructure is lowering while the reliability is improving.

Finally, the cost of computer server technology needed to host maintenance server applications is quickly reducing, while improving information technology management tools. These trends lower both the cost of hardware, and also the installation and maintenance costs of the computing infrastructure.

Coupling with the lower cost of components, careful planning to sequence installation activities will also help lower installation costs. For example, have multiple machines of a similar type instrumented at the same time will breed economies of scale. If possible, specifying the FWM technologies be installed at the initial construction of the plant or unit can have nearly a seven times reduction in installation costs.

### 2.6. Interoperability

The power generation community, with the support of EPRI continues to strive to open interoperable systems. EPRI promotes evolution of equipment models, data storage formats, and hardware data acquisition technology that strive towards interoperability between vendors. This effort is illustrated in the EPRI Fleetwide Monitoring for Condition Assessment publication (Shankar, 2006)

### 2.7. Systems Architecture Summary

In summary, the networked automatic sensory data collection system performs many tasks. The system resides on a business network, to reduce interference with operations. The DAANs have built in analytics and intelligence to determine when to record sensory data and to determine its own operational status and health. The server computer managing the network aggregates sensory data from all DAANs, publishes condition indicators to a plant historian, and provides search, retrieval, and analytics of collected data recordings.

Technology costs from the sensor, to the DAAN, to the server computing technology are advancing with cost benefits, ease of installation and operation improvements, and greater computer power to automate diagnostics and health prediction functions. These technology trends, coupled with proven online monitoring systems architectures, yield a new opportunity for online fleetwide monitoring.

## 3. AUTOMATING ALERTS, DIAGNOSTICS, AND PROGNOSTICS

Once the DAAN's are installed on selected equipment, it is possible to aggregate sensory data (at the maintenance server) and to implement exception reporting, also known as anomaly detection. When any asset is instrumented with degradation indicating sensors, it is possible to build thresh-holding alarms (warning, alert, and danger level alarms) based on either industry standards per equipment class, or based on statistical deviation from established norms. For example, it is recommended practice to monitor all sensors, and results of calculations from sensor values (condition indicators) to create a baseline of normal operation. By using the baseline, it is possible to set threshold alarms on individual sensor values or condition indicators at intervals of standard deviation from expected normal values (ISO 2003).

This practice of using standard deviation alarms or equipment class standards can be referred to as thresh-holding predictive maintenance. With thresh-holding and trending alarms, the trended rate of change becomes an indication of future performance or health of a machine and also a prediction of maintenance needs.

A more advanced approach is to utilize a combination of trends, a combination of sensory values and condition indicators, which together form a pattern of normal or abnormal operation. These patterns can then be used to track actual pattern movement with expected patterns allowing the difference or residual to indicate the "error" or health degradation (CCJ, 2014). The patterns can be defined with one piece of equipment, and then used as a fault signature for other pieces of equipment with similar components and function. What is learned from one pump can be applied to similar pumps in similar operating conditions. There are several such anomaly detection, or advanced pattern recognition products on the market which accomplish this specific task. Examples include Instep PRiSM™ and General Electric's SmartSignal™ trend analysis applications. These products are popular in the power generation and petrochemical industries.

## 4. CASE STUDIES

### 4.1. Attributes of a Successful Fleetwide Monitoring Program

There are many case studies in the field of condition monitoring; some are fleetwide monitoring case studies. In successful cases, the selection of assets, monitoring technology, repeatable test conditions, and defined exception reporting are key aspects of a successful condition monitoring program. In fact, the most successful programs implement best practices such as those described in the ISO 17359 standard (ISO, 2003). In addition, there must be organizational buy-in to the condition monitoring program. This buy-in is best undertaken at the management level, where reporting of activities and program impact are expressed in economic terms.

In its Fleetwide Monitoring for Equipment Condition Assessment report (Shankar, 2006), the Electrical Power Research Institute (EPRI) calls out five primary challenges to fleetwide monitoring (FWM). The first challenge is standardization: in equipment evaluation technologies, terminology of equipment and sensing types, and company maintenance procedures. The second is identifying a cost justification that can be used to obtain management "buy-in", or formal acceptance to invest in fleetwide monitoring. Thirdly, there exists a challenge to build visibility across the organization and to promote best practices, centralization of management and monitoring. Centralization fosters collaborative efforts across company organizations and identification of best practices and technologies. A fourth, and perhaps most important challenge, is alarm management. In particular, a mechanism to validate alarms prior to planning a response is critical in building confidence in the program. The fifth challenge is the integration of multiple monitoring technologies, to obtain the benefits of each and to create a holistic view of monitored equipment.

To address these challenges, EPRI is working with its member power generation companies to document best practices and specific cases. As an example, there is a specific EPRI project focused on cost benefit analysis. Within the project cost benefits are categorized as direct benefits and indirect benefits. Direct benefits include the reduction in time and expense necessary to maintain equipment. This benefit arises by using improved knowledge and understanding of equipment health. Indirect benefits result from avoiding a reduced power event or unscheduled downtime. The indirect benefits include the cost avoidance of significant equipment damage.

### 4.2. Southern Company's First Plant

Southern Company embarked on their fleetwide monitoring program in the late 2000's with the adoption of several EPRI recommendations and products (Hussey, 2010). Southern Company operates over 280 power generation units at 73 power plants including gas turbine, combined cycle, steam (coal), hydro and solar, Figure 11. While meeting the specific business model and company culture, Southern Company implemented the first phase of their fleetwide monitoring and diagnostics (M&D) center, beginning in 2007.

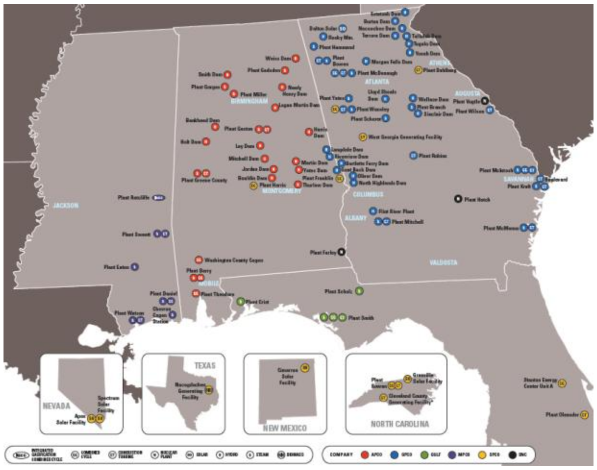

Figure 11: Southern Company power generation map.

There are five core goals of the Southern Company M&D center. First, is to establish a higher frequency monitoring program with sensory and condition indicating data arriving in minutes as opposed to once per week or longer. This first goal required the addition of continuous monitoring equipment as described earlier in this paper. The second goal is for the selected equipment to be monitored around the clock. The third goal is to mitigate the loss (through retirement) of experienced resources. By centralizing the M&D center, knowledge from experienced resources can be captured in various "best practices" documentation. A fourth component of the M&D center is a multidisciplinary focus including operations, maintenance, instrumentation and engineering. Fifth, and finally, a core goal is to establish a partnership with operations in order to eliminate any animosity that may arise from the new oversight the M&D center would have with the equipment under operations control.

Initially, just one plant was monitored for 1.5 years to document results and to provide guidance for future condition monitoring programs. Online condition monitoring hardware and FWM applications were added to critical steam turbine and gas turbine generators. The benefit to cost ratio was estimated to be a 4:1 and three additional plants were added to the centralized M&D center pilot. In 2010, management authorized expansion of the fleetwide monitoring program to 17 plants or about 1/3 of the entire fleet. Subsequent to this roll-out of turbine generator FWM applications, Southern company has begun to take advantage of lower cost sensing and data acquisition hardware, following developing recommended EPRI requirements. This allows Southern company to extend its FWM program to balance of plant equipment.

Several lessons are taken from Southern Company's experiences. The first is to start slowly. There are a number of complexities in change and management aspects of a fleetwide program. It is recommended to start small, perhaps at a single plant and even specific issues of a specific equipment type. Goals should be set with respect to the issues and equipment reliability measures. From these goals, the appropriate applications technology can be selected with the best promise of meeting the goals.

The second lesson from Southern Company is to get executive "buy-in". Executive support is very important in both the establishment and on-going improvements to the M&D center.

A third lesson is to select participating staff with multi-disciplinary skills. These skills include operations, instrumentation, controls, engineering and maintenance experience and training. With multi-disciplinary skills, team members are more easily able to engage and interact with other business and functional units within the enterprise.

The fourth lesson arising from Southern Company's M&D efforts is to invest in a proven information technology (IT) infrastructure to manage both data and knowledge obtained during the growth of Southern's FWM program. This infrastructure includes intelligent data acquisition, networking, and server hardware and software. According to Southern Company, the level of sophistication of smart trending (pattern recognition software) and data acquisition equipment maps to the success of an online condition and performance monitoring program.

### 4.3. Luminant Energy Mining Operations

Luminant is the largest power generation company in Texas. It operates eight natural gas driven plants (combustion turbines), five coal plants, and one nuclear power plant. Supporting its steam generation coal plants, it operates nine surface coal mines, Figure 12. While Luminant sports a state of the art M&D center in Dallas, Texas, many of its condition monitoring programs are rooted in its mining operations (Lawson, 2010).

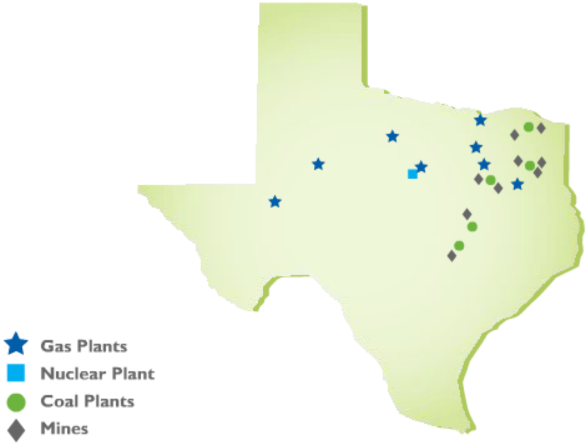

Figure 12: Luminant power generation map.

Luminant's Mine Maintenance Support Services (MMS) is the core group behind its condition monitoring program. Over the past several decades, the MMS group has utilized a range of technologies including vibration, oil, ultrasonic, infrared, and strain to monitor condition and degradation of mining equipment used in support of steam power generation plants. The MMS team is made of personnel with a broad range of skills including electrical, mechanical, maintenance, and computer systems, and project management.

In the four years leading up to the article, MMS efforts have produced an 18% savings in maintenance spend. These efforts produce a condition of maintenance (COM) report that feeds into allocation of maintenance funding, allowing Luminant to do the right maintenance at the right time.

The Luminant team produces a series of reports indicating the health or "maintenance need grade" of core equipment assets. These reports are both tabular in nature sharing multiple metrics as well as graphical, including equipment mimics and trends. Further, Luminant has collected a significant amount of sensory and condition indicating data that helps evolve the internal procedures and processes for condition monitoring. Luminant even shares its sensory data with OEMs to help evolve the design of equipment it uses.

Luminant's lessons are similar to those of Southern Company. One similar approach is getting the "buy-in" from management to support funding and growth of the program. Another similarity is the multi-disciplinary skills represented within the monitoring and maintenance team. Luminant adds both visual and numerical reporting to its elements of success.

Luminant finally leverages its IT infrastructure to house, manage, and mine the many years of sensory and condition indicating data it has collected. This accumulation of sensory and condition indicating data is a prime example of a Fleetwide application.

### 4.4. Duke Energy Fleetwide Implementation

Duke Energy has deployed DAANs, condition indicating analytics, as well as anomaly detection and visualization tools within several of their power generation plants in North America, Figure 13. Each of these plants has deployed 20 or more DAAN nodes per power generation block (Cook, 2013). Each plant has a computer server managing the DAANs, calculating condition indicators and reporting these condition indicators to the OSIsoft PI™ Historian. Instep Software's PRiSM™ software is at work building data driven models of normal behavior for anomaly detection.

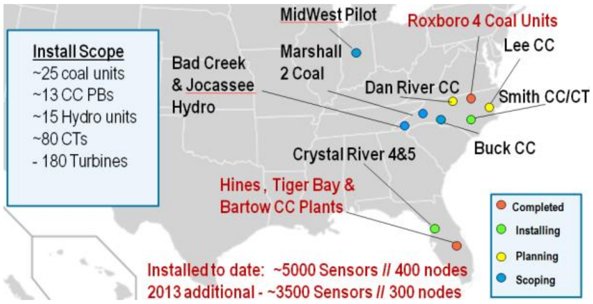

Figure 13: Duke Energy power generation M&D map.

There are a series of steps Duke Energy has followed to implement SmartGen (a monitoring and diagnostics program) at each of its plants, Figure 14. The core steps include Planning, Enclosure Drawings, Site Design, Site Install, Software Integration, and Plant Turnover. The components of each major step are shown here as a suggested guide.

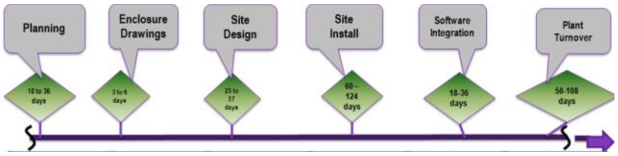

Figure 14: Steps to implementation of a fleetwide monitoring program.

There are several lessons learned from the work at Duke Energy's gas turbine power generation plants. Deployment of automated sensory data collection on the fleetwide scale requires significant resources for planning and implementation. Implementation managers are needed at each facility to manage the sequence, personnel resources, and equipment resources that come together to roll out the DAANs, server software, and enterprise connectivity.

Hardware installations can proceed ahead of software installation, especially identification of sensor types and locations and the subsequent installation. Server installations should be timed to coincide with DAAN installation. Once sensors and DAANs are installed, a validation process is needed to validate sensory measurements and calculated condition indicators match traditional manual based activities.

As the anomaly detection occurs on the OSIsoft PI™ Historian, validation on both condition indicators and PI representation of the condition indicators must occur prior to building data driven models. This is similar to any data science or predictive analytics application, data integrity is of high importance.

Personnel at all sites are excited and bought into the prospect of automated data collection, assisted/automated diagnostics and predictive techniques. Site persons continue to ask for more automation, more sensory types, and greater equipment coverage. Regular implementation process meetings focused on streamlining the implementation process, and on streamlining feedback are recommended.

The biggest lesson learned is that the system is working as expected. Already, visibility of equipment reliability has greatly improved, and plans are now being made to track maintenance savings and availability improvements. With a track record of plant installations, the roadmap for addressing additional plants is established, and can be built upon. Duke Energy is well on its way to complete its fleetwide monitoring and diagnostics center. Duke's efforts promise to result in maintenance savings and availability improvements, while increasing equipment health visibility and optimizing logistics of maintenance.

## 5. CONCLUSION

There are many factors which impact the success of an online fleetwide condition monitoring program. Starting small and leveraging common condition monitoring technologies simplifies initial FWM applications and reduces risk. With initial success, it is then possible to include the sophistication of the data acquisition and analysis node, the sophistication of automated diagnostics and prognostics (the analytics), and to articulated expected return on investment. Buy-in from senior management, along with multi-disciplinary M&D staffing, and thought out project plans are also important to the success of the FWM efforts. The case studies of Southern Company, Luminant, and Duke Energy each articulate these lessons. Given the continued evolution of monitoring technologies, including the embedded analytics of DAANs, and the in-line technology used for automated diagnostics and prognostics; there exists great promise for those organizations considering fleetwide asset monitoring.

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