Operations and Maintenance Recommended Practices

Chapter 5 Data Collection and Reporting

version 2017

ACKNOWLEDGEMENTS

The American Wind Energy Association (AWEA) Operations and Maintenance (O&M) Recommended Practices (RP) are developed through a consensus process of interested parties by AWEA O&M Committee. These RPs represent decades of experience from the members of the AWEA O&M Committee. This expertise, often gained from other industry sectors, helps inform, train and support wind energy technicians and managers in their efforts to improve reliability and project performance. These are, in general, the nuts and bolts of wind energy power plant maintenance and operations. As the industry matures, additional maintenance strategies and operations philosophies will certainly come to the fore, however, these basics will always be required knowledge for new technicians and asset managers expanding their areas of responsibility.

Development of the AWEA O&M RPs started in 2009, with the first edition publication in 2013. The current version is the result of hundreds of hours of volunteer time by many people and we, the AWEA O&M Committee Chairperson, Kevin Alewine, and Vice Chairperson, Krys Rootham, wish to thank all of the individuals who have participated in the AWEA O&M Committee to develop these documents and the companies that continue to allow those efforts, as well as, sharing their technical know-how.

AWEA Operations and Maintenance Committee:

- AWEA O&M Steering Committee
- Balance of Plant Subcommittee
- Blades Subcommittee
- Condition Monitoring Subcommittee
- Data Collection and Reporting Subcommittee
- End of Warranty Subcommittee
- Gearbox Subcommittee
- Generator Subcommittee
- Operations Subcommittee
- Tower Subcommittee
- Tower Auxillary Subcommittee

Again, thanks to everyone for their continued support for development of these recommended practices. Please contact any of us if you have questions or comments (OM@awea.org) regarding the Committee or these documents.

Thanks again for the efforts and accomplishments,

Kevin Alewine, Shermco
Chairperson, AWEA O&M Committee

FORWARD

The AWEA Operation and Maintenance Recommended Practices are intended to provide establish expectations and procedures to ensure all personnel performing service and maintenance on wind turbines have a minimum knowledge base.

The AWEA Operation and Maintenance Recommended Practices (O&M RPs) are not “best” practices nor the only procedures that should be followed. They represent suggestions from experts in the field who have refined their procedures over time. The preferred procedures in the future will no doubt change with improved communications, technology, materials and experience. These AWEA O&M RPs will be revised as needed.

The AWEA O&M RPs were initiated in 2009 and created by members of the AWEA O&M Committee to ensure that the future wind industry benefits from the experience gained from the past. Individual members donated their time and expertise to document these procedures.

The AWEA O&M RPs are organized into “chapters” to address the major functions of a wind turbine and its operation. Individual recommended practices address specific procedures used in each of those areas.

Many other organizations have developed consensus standards, recommended practices, best practices, etc. that also offer excellent supporting information for effective wind farm operations and maintenance. IEEE (Institute of Electrical and Electronic Engineers), NETA (International Electrical Testing Association), SMRP (Society for Maintenance and Reliability Professionals), AGMA (American Gear Manufacturer’s Association) just to name a few. These sources should be reviewed in developing sound maintenance strategies.

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The wind energy industry is covered by OSHA regulations for worker safety and health practices. §29 C.F.R 1910.269 is the OSHA standard that regulates employee safety in the operation and maintenance of electric power generation, transmission and distribution facilities and installations, which covers the wind energy industry and §29 C.F.R 1926, for construction activities.

Each employer shall choose to the appropriate regulation and standards to work in the wind energy industry and must be prepared to justify their determination, development, and implementation of their written program. Employers must also consider the regulatory requirements of state occupational safety and health plans. The OSH Act of 1970 encourages states to develop and operate their own job safety and health programs, which there are twenty-six (26) states and jurisdictions that operate OSHA-approved State Plans (SPS). Twenty-two (22) states operate complete state plans, while five states cover public employees only. SPS must set job safety and health standards that are "at least as effective as" comparable federal standards, including hazards not addressed by federal standards.

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Chapter Five: Data Collection and Reporting

*These RP's did not require updates from the original 2013 version.

RP 502 Smart Grid Data Reporting

The following recommended practice (RP) is subject to the disclaimer at the front of this manual. It is important that users read the disclaimer before considering adoption of any portion of this recommended practice.

This recommended practice was prepared by a committee of the AWEA Operations and Maintenance (O&M) Committee.
Committee Chair: Bruce Hamilton, Navigant
Principal Author: Benjamin Karlson, Sandia National Laboratories

Purpose and Scope

The scope of “Smart Grid Data Reporting” focuses on generating, collecting, and serving up wind farm data for smart grid operation. This data can also be useful for power purchaser and owner/operator reporting.

Introduction

It is important that readers understand what is meant by smart grid in this context. A smart grid is a modernized electric grid that uses information and communication technology to gather and act on information in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity.

Smart Grid Data Reporting

1. Data Requirements

The most important characteristic of a smart grid is the ubiquity of communication devices and the flow of information between all aspects of the grid, from the generation, transmission, distribution, and end use. Under the current grid operations scheme (non-smart grid) grid operators need to know certain operating information of all generation. This includes, but may not be limited to, real power, reactive power, and bus voltage at the point-of-interconnection. Additionally, grid operators need to communicate to generators operation commands such as how much power the grid can accept, what voltage schedule to follow, etc.

The following was taken from NERC's "Interconnection Requirements for Variable Generation" report:

> The following signals should be sampled at the normal SCADA (supervisory control and data acquisition) update rate:
>
> - Active power (MW)
> - Reactive power (Mvar)
> - Voltage at the point-of-interconnection
>
> The following wind plant status signals are also recommended but may be sampled at a slower rate:
>
> - Number of turbines available (or total MW rating of available turbines)
> - Number of turbines running and generating power (or total MW rating of turbines online and generating power)
> - Number of turbines not running due to low wind speed
> - Number of turbines not running due to high-speed cutout
> - Maximum and minimum reactive power capability of plant (for some plants in weak grid locations, it would also be prudent to know how much of the total range is dynamic, as opposed to switched capacitors or reactors)
> - Total available wind power (equal to production unless curtailed)
> - Average plant wind speed (when wind speeds are high and increasing, operators could anticipate high-speed cutout actions)
> - Plant main breaker (binary status)
> - Plant in voltage regulation mode (binary status)
> - Plant in curtailment (binary status)
> - Plant up ramp rate limiter on (binary status)
> - Plant down ramp rate limiter on (binary status)
> - Plant frequency control function on (binary status)
> - Plant auto-restart blocked (on/off)

A fully realized smart grid will incorporate a two-way flow of real-time information from generation to consumption.

Current data requirements needed from wind power plants to grid operators are clarified under the IEC 61400-25 communication standards. This standard provides a basis for the interoperability of SCADA systems and addresses the communication between SCADA systems installed on wind power plants and the grid operations centers that can benefit from the SCADA data.

1. Data Requirements
(continued)

The IEC 61400-25 Edition 1 (2008) standard has not been widely adopted yet, however, as smart grid initiatives move forward grid operators should adopt this standard as a means of facilitating communication and interoperability. Wind power plants interconnecting to the grid will have different data requirements as defined by the specific transmission owner with which the wind power plant is interconnected.

1.1. Phasor Measurement Units

Phasor Measurement Units (PMUs) are devices that measure the signals on the bulk electric grid using a synchronized common time source. If installed, they are installed on the grid side of a wind power plant point-of-interconnect (POI) and monitor in real-time the state of the electric grid. These units monitor voltage and current many times a second (typically 30 samples/second) allowing for fast response dynamic adjustments to be made on the grid providing for stability and reliability. This high frequency monitoring of wind power plants will enable better regulation and coordination of all interconnected generation.

Because PMUs are connected to the grid side of the POI of a wind power plant they are typically owned and maintained by transmission operators, though any wind power plant that opts to purchase and install a PMU should provide access to this data to grid operators.

1.2. Forecasting

Because the power output of a wind power plant is a direct function of the wind speed and the weather is an ever-changing system, the wind forecast and thus the wind power plant generation forecast play an important role in grid system operations. This forecast combined with the load forecast enables grid operators to commit generation resources on a day-ahead schedule allowing the system to be maintained economically and securely.

For detailed information regarding wind power plant forecasts see RP 504 on Wind Forecasting Data.

1.3. Active Wind Plant Control

As the smart grid initiative progresses it will become imperative that wind power plant's control systems are able to respond to signals sent from grid operators to actively control the operation of the wind plant. This might include reducing or increasing real power or reactive power, controlling the ramp-rate of the plant, or providing frequency regulation as requested by the grid. However, because today's wind power plants are typically operated to maximize power output they may face an economic penalty for operating in a different state.

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RP 503 Wind Turbine Reliability

The following recommended practice (RP) is subject to the disclaimer at the front of this manual. It is important that users read the disclaimer before considering adoption of any portion of this recommended practice.

This recommended practice was prepared by a committee of the AWEA Operations and Maintenance (O&M) Committee.

Committee Chair: David Zeglinski, OSIsoft, LLC
Principal Author: Roger R. Hill, Sandia National Laboratories
Contributing Author: Dave Ippolito, Versify

Purpose and Scope

The scope of “Wind Turbine Reliability” focuses data collection and the metrics for reporting and understanding overall plant reliability performance.

Introduction

The owner/operator bears the responsibility for collection of data and information for purposes of running the wind plant in a reliable and profitable manner. Reliability status reporting will be seen as failures, corrective and preventative maintenance, SCADA (time series) reporting, events, alarms, failures, MTBE, MTBF, downtime, maintenance costs, computerized maintenance management reporting (CMMS), condition monitoring functions.

The following discussion recommends practices for data collection and the metrics for reporting and understanding of the overall plant reliability performance. Reliability, Availability, and Maintainability (RAM) metrics will have a role in this. RAM metrics provide reliability and availability trends, causes, sources, reasons and impacts for plant downtime at the component level, and provide field performance.

A subset of the data from every turbine’s control system, as well as data collected at the metering, substation, and grid connection interface, is typically held in one or more of the plant-wide Supervisory Control and Data Acquisition (SCADA) systems.

Introduction
(continued)

The O&M function is focused on maintaining generation at high levels and conducting preventative and corrective maintenance of the turbines, their components and balance of plant. Production data by turbine should be maintained and analyzed for purposes of production engineering, an important to overall plant O&M function:

Table A

kWh	Daily, weekly, quarterly, annually
Stop Hours	Daily, weekly, quarterly, and annually
Capacity Factor	Daily, weekly, quarterly, or annually
kWh/kW	

Wind Turbine Reliability

1. Event Data

Event data needed to answer the basic questions of how often something fails, how long is it out of operation, and how much the down time costs. In other words, the symptoms, cause, and corrective actions for any failure or maintenance activity is a need that must be determined.

A record of each downtime event should be made:

Table B

Turbine ID	Distinguishes individual turbines
Event Code	Unique identifier for type of downtime event
Fault Code	Automated SCADA code that initiated the event
Event Name	Descriptive label for type of downtime event
Event	Start date and time
Event Type	Type of downtime (e.g., failure, preventative maintenance)
Event Duration	Hours of downtimes/return to service

It is important to track these metrics to individual components so that O&M planning, parts inventory and orders, manpower and equipment, and maintenance scheduling can be done as efficiently as possible.

2. Computerized Maintenance Management System (CMMS)

Work orders are often generated by plant managers to capture the need for repairs or other types of maintenance. A work order may have multiple purposes. It may be used for tracking of human resources, or for tracking the time the turbine spent offline. For purposes of reliability tracking, work orders should document the investigation into the cause of outage and which component failed and/or was replaced i.e. the root cause. In this way, work orders may provide insight into turbine performance and document operator actions which indicate the root cause of failure.

Ideally, work order systems will be computerized in an automated maintenance management system. Sandia has published a report entitled Wind Energy Computerized Maintenance Management System (CMMS): Data Collection Recommendations for Reliability Analysis (SAND2009-4184). Combined SCADA and CMMS capabilities will enable reporting of recommended individual turbine metrics of:

- Operational Availability
- Wind Utilization
- MTBE (operating hrs.)
- Mean Downtime (hrs.)
- Annual Cost (per Turbine)
- Intrinsic Availability
- MTBF (operating hrs.)
- Mean Failure Downtime (hrs.)
- Annual Failures
- Failures Cost (per Turbine)
- Mean Fault Downtime (hrs.)
- Annual Fault Cost (per Turbine)
- MTB Scheduled Maintenance (operating hrs.)
- Mean Scheduled Downtime (hrs.)
- Maintenance Schedule
- Annual Scheduled Cost (per Turbine)

An ability to reconcile and harmonize SCADA and CMMS data is suggested as a recommended feature and capability for O&M and RAM functions in operating a wind plant. Getting organized to do this will provide tools to improve reliability and profits.

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"Wind Turbine Reliability Database Update Appendix B: Report Template for individualized reports to partners." R.R. Hill, V.A. Peters, J.A. Stinebaugh, P.S. Veers, SAND2009-1171. windpower.sandia.gov/other/091171.pdf

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RP 504 Wind Forecasting Data

The following recommended practice (RP) is subject to the disclaimer at the front of this manual. It is important that users read the disclaimer before considering adoption of any portion of this recommended practice.

This recommended practice was prepared by a committee of the AWEA Operations and Maintenance (O&M) Committee.

Committee Chair: David Zeglinski, OSIsoft, LLC
Principal Author: Jeff Erickson, Versify

Purpose and Scope

The scope of "Wind Forecasting Data" describes best practices for the data required for accurate, actionable wind forecasting.

Introduction

By its nature wind generation is variable, intermittent, and uncertain. Employing sophisticated, data-driven methods to increase forecast accuracy enables more efficient and reliable power system operations. Short-term forecasts can be used for turbine active control and dispatch. Mid-term forecasts and day ahead forecasts can be used for power system management and energy trading, unit commitment and economic dispatch (optimizing plant schedules). Long-term forecasts are often used for longer term scheduling and maintenance planning at a wind farm.

Wind Forecasting Data

1. Procedures (Detailed Descriptions)

There is an ever growing volume of data points available to wind forecasters. While more data often means more accurate forecasts, one must weigh the cost and complexity of data-intensive methods against the results derived from simpler methods.

At its most basic level, there are two forms and sources of data necessary for any useable wind forecast: static data - latitude and longitude of the wind plant, and hub height, and dynamic data - the measurement of metered power output. Adding historical output increases the value of the forecast by allowing for an empirical relationship between forecasted wind speeds and power output.

1. Procedures (Detailed Descriptions)
(continued)

Moving down a level in granularity, additional data sources can help a forecaster increase accuracy. Tracking current availability (i.e. the number of wind turbines available now and the power generation characteristics of those turbines) allows for a power conversion analysis to calculate lost generation resulting from planned maintenance at the wind farm. Forecast availability (the number of wind turbines expected to be available in the future, and the power generation characteristics of those turbines) can help in planning for power de-rates associated with a future maintenance schedule.

Curtailments, whether from system operator instructions or transmission issues, impact forecasts and should be integrated into the forecast analysis data, both for real time and historical purposes.

Data about the wind itself, both wind speed and direction can be leveraged to increase forecast accuracy. Depending on the forecast providers' methods, varying degrees of wind data will be required and the forecast user should consult with the vendor to determine how much and what type of data to collect. Often if wind data is used, it is considered after power, availability and curtailment data. Wind data can be collected directly from on-site MET towers or can be based on averaging nacelle wind speeds across the plant. Again, it is recommended that the end user consult with the forecast provider to understand the methods used.

At the lowest level of granularity, turbine-level data can be integrated into the final analysis. Turbine level data is often used to predict ramp forecasts (large changes in output). Both on-site and off-site temperature, humidity, air pressure, wind speed, wind direction and power make up this category of data.

While data collection and integration techniques can differ among forecasters, the next and most immediate challenge is in turning this data into usable, action-based knowledge for the wind operator. Intelligent and timely operator response to wind forecast data can result in very significant monetary benefit to the generator operator. Everything from effective unit commit and generation balancing, to understanding the economic impact of a curtailment, to efficient, cost-effective maintenance scheduling, can be positively impacted by timely, appropriate operator action in response to wind forecasts.

2. Tools

Tools that provide a common and easy-to-use interface to forecast data and that can help direct an operator to an appropriate action are critical to the future integration of cost-effective wind integration.

Tools are available today that allow end users to integrate third party vendor wind forecasts so that meteorologists and planners may visualize third party data, create and shape their own internal ensemble forecast, and integrate those with trading and market systems.

Summary

In the near future, the ability to analyze wind forecasting models and provide insight into the best models under different weather conditions will provide end users insight into the forecast data they are buying. Inherently this will help produce more reliable wind forecasts and allow for scheduling and marketing of wind energy more aggressively to optimize revenue.

RP 505 Asset Identification and Data Reporting

The following recommended practice (RP) is subject to the disclaimer at the front of this manual. It is important that users read the disclaimer before considering adoption of any portion of this recommended practice.

This recommended practice was prepared by a committee of the AWEA Operations and Maintenance (O&M) Committee.

Committee Chair: Bruce Hamilton, Navigant
Principal Author: David Zeglinski, OSIsoft, LLC
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Purpose and Scope

The scope of “Asset Identification and Data Reporting” focuses on generating, collecting, and serving up wind farm data for asset management and maintenance and reliability improvements. There are two key components: the metadata system associated with the generating assets and the data collection system itself.

Data Reporting

1. Metadata System

1.1. Develop a Detailed Taxonomy

Developing a detailed equipment breakdown or taxonomy helps ensure that maintenance data is captured with enough detail to be useful. Using a breakdown of the equipment that provides a unique assessment opportunity for each component or part ensures greater insight in determining which assemblies, subassemblies, or components significantly affect reliability and availability performance (for example, “Drivetrain-Gearbox-Bearings-Planetary Bearing” provides much more information than just “Gearbox”). Fortunately, with metadata software, this needs to be done only once for each equipment type. The elemental framework can then be copied for each turbine where only the turbine name or number is globally replaced as it is copied/duplicated.

1.2. Attend to the Details

With any data collection system, one of the biggest challenges is ensuring that data is entered for every applicable data field. In addition to entering all the relevant information, ensuring that standard and correct information is entered is also essential. There is often a trade-off to be made when weighing the value of data collected against the cost of collecting it. With the right hardware and smart software, it is possible for technicians to record data quickly and accurately without adding an unnecessary burden. A well-designed system can greatly reduce the amount of follow-up data entry and provide the quality assurance required.

1.3. Ease of Use

To have an accurate, consistent, and usable system, it is important to limit the amount of time spent entering and updating records. This can be achieved by incorporating automated data collection and validation into maintenance processes. In addition to automated validation, use of handheld devices can decrease entry error and allow for automated capture of many data elements (e.g., date, time, asset, technician, etc.). Typically, the manner that maintenance data will be used is not known at the time the system is implemented. Modern software systems can provide an interface that makes data entry easy and accurate and can also store information in a way that facilitates later use by the various groups who need to access the data. These software systems must allow for modification of the metadata frames that then port to all similar assets so the system can be realistic, dynamic and “future-proof”.

1.4. Root Cause Analysis - Down to the Bolt

To truly understand the impact each part has on overall reliability and availability, it is important to distinguish between parts that caused a failure (primary failures), parts that failed as a result of the primary failure (secondary failures), and other parts that need to be repaired/replaced in the process of performing maintenance on parts with primary and secondary failures (ancillary failures). For example, if a power spike from a power supply causes the power supply to fail and also shorts out a circuit board under a console panel, then the power supply has a primary failure, the circuit board has a secondary failure, and the console panel has an ancillary failure. If multiple parts are worked on for the same maintenance action, a Failed Part field could be used to identify parts with primary failures and distinguish them from those with secondary or ancillary failures. Additionally, parts are sometimes opportunistically replaced when other maintenance events are underway, thus significantly reducing their replacement time and/or cost compared to their usual replacement time and/or cost. These opportunistic replacement activities should also be captured. In some cases, the part with a primary failure may not be obvious at the time of the maintenance event. In these cases, returning to the maintenance record after the root cause is discovered will be important, to create an accurate and complete assessment of the maintenance event.

1.5. Cost Tracking – Labor and Replacement Parts

While availability and reliability are key metrics in assessing equipment performance, understanding what is driving maintenance costs can be just as valuable. Typically, the parts and personnel costs are stored outside the maintenance system, and the relevant information from the maintenance system (including parts replaced and man-hours) is used to calculate the total cost for each maintenance event. This information needs to be holistically integrated with the real-time data via connectors to the Enterprise Resource Planning (ERP) system(s). Only then can visibility from normal operation to fault to repair and all of the costs associated be coordinated. When this information is integrated and available to all personnel responsible for asset operation, then root cause analysis and a complete understanding of asset operation costs can be obtained and kept for future use.

1.6. Parts' Source Identification

For relevant event types, the source of parts should be clearly captured. This includes parts cannibalized from other equipment, purchased outside the main supply system, and acquired by other means (including parts machined on site). Identifying the source of parts (including those exchanged between equipment) will allow for accurate cost calculations, in addition to setting the stage for advanced CMMS uses such as parts and inventory tracking; this can be accomplished through a "Parts Source" field. Integrating this information with real-time data (again) is critical to a complete asset management system for the wind plant.

2. Data Collection System

The first step to information-rich decision-making is accessible storage of the vast amounts of data generated by each turbine, substation, and ancillary equipment (Balance of Plant - BOP). As with any storage solution, the initial step in the design process is the most important: deciding the type and use of information that needs to be extracted, analyzed, and visualized. Designing a data collection infrastructure with the end use in mind allows for the eventual retrieval, analysis, reporting, and displaying of information in a far more efficient and effective manner.

2.1. Design, Install, Scale, and Keep Evergreen Data Collection Systems

Wind plant operators want tools to drive their decisions with solid data. After determining what systems are most appropriate and the general type of data that should be captured, implementation is the next step. Yet implementation is not a trivial task and requires committed and knowledgeable staff and executives both on the owner and vendor sides. Incomplete and ineffectual implementations result in high-cost systems with few benefits, often requiring replacement or upgrade before any return on investment can be achieved. Additionally, one of the most important aspects of data architecture is that it needs to evolve. Many good systems are eventually tossed aside or misused because they do not evolve and grow as the business changes. For companies that own or operate multiple turbine technologies, the initial design stage also needs to include an assessment of the data available from each technology and a way to map these data points so that equal comparisons can be made.

The design of the data collection and storage systems can be approached from two directions: internal resources and external vendor and system integrator services. Often the use of internal skills and systems facilitates a custom approach that best suits the company and its existing infrastructure. However, realistic assessment of the skills available versus the skills required is an important first step. A hybrid approach of using external contractors to fill any gaps in in-house knowledge is also an effective solution. Once it is established that the skills needed are available, a detailed cost assessment can then be performed.

Collecting data and collecting useful data are not the same, and this distinction is often the defining characteristic of a successful implementation versus an unsuccessful one. The vast amount of data available can paradoxically make collecting useful data more challenging. Wind plants produce staggering amounts of data – estimated annual storage of essential supervisory control and data acquisition (SCADA) data from a plant with 100 modern wind turbines can exceed 150 gigabytes of data annually and this figure increases dramatically if every SCADA tag is stored at the highest possible frequency. Collecting too many or too few pieces of data can both result in inefficient systems that do not produce the analysis results that are expected.

2.1. Design, Install, Scale, and Keep Evergreen Data Collection Systems

(continued)

Decisions need to be made in advance of data collection to establish the types of analysis needed, thereby ensuring the collection of the data needed to complete the analysis. Architecting the hardware properly at the sites to minimize data issues due to undersized hardware forcing future site upgrades (hardware and software) is key also. Management of the data system is also required during implementation to tune the data streams so that unnecessary data (instrument noise) is not collected. Proper tuning can dramatically reduce disk consumption and future storage requirements. Well-managed data streams also allow rapid retrieval via the real-time data search systems.

While data collection for wind turbines is important to fully understand plant reliability, data must be collected for turbines and other equipment in the Balance of Plant (BOP). Data from meteorological towers, the substation, and the electrical collection system are absolutely necessary to understand the reliability of the turbines and the whole plant. For example, turbine availability can be 100%, but if the substation is down the plant is not producing. Failing to capture such a situation will lead to large blind spots in any reliability analysis.

2.2. Data Collection and Storage

In any data storage scheme, the structure of the whole is as important as the structure of the individual parts. There are two common approaches to wind plant data storage; relational databases and data historians. Relational database (RDB) products offer storage of large data sets useful for non-real-time or instrument/equipment data. RDBs are very effective for storing asset information and other key textual data associated with the wind plant. This type of database is widely used in many implementations throughout many industries. Real-time data historian products are information technology systems that store time series data, allowing the storage of large data streams at high speed while using compression to manage the hard drive storage space needed for these millions of pieces of information. Data historians are commonly found in manufacturing, pharmaceutical, and utility industries including wind.

2.3. Supervisory Control and Data Acquisition (SCADA) - Time Series Data

One of two main types of information captured by SCADA is time series data on the turbine, BOP, and environmental conditions. For turbines, this time series data creates the "heartbeat" of the machine. It is collected almost continuously (typically once per second or more often) and is stored in regular intervals at the limit of the instrumentation and the data collection architecture. The various data streams that are captured are sometimes referred to as tags (for those familiar with traditional data bases, a tag is like a database field). These data points record the operating conditions of the turbine and its parts, as well as the environmental conditions in which the turbine is operating. Many plants choose to archive their SCADA data in a real-time historian.

A multitude of time series data is available from a wind turbine SCADA system, enabling a great variety of analysis. As an example, the set of tags necessary for basic reliability analysis for a turbine is:

2.3.1. Turbine Status or Operating State

Terminology can vary widely amongst owner operators or original equipment manufacturers (OEMs), but some basic examples include: up and running, available but idle, down for repair, curtailed, and manually stopped at the turbine.

This value can be stored as a text field (usually with abbreviated versions of the state descriptions) or as an integer (with a given number mapping to a specific description). Care should be taken that if this value is stored as an integer, that it is not translated to a real number in a historian or other database. If 1 means up and generating and 2 means down for maintenance, a value of 1.62 is not very useful.

For turbine status, high-resolution data (data captured very frequently versus less often) is necessary to determine turbine status over the full course of a day, week, month, or year. When turbines are coming online and offline frequently, data that does not show the state changes do not provide enough visibility into the turbine's true condition. This limitation can be overcome either by collecting this data at a higher frequency or by only capturing this data upon state change. Collecting upon change will yield the best data storage performance with respect to hard drive space consumption and retrieval speed.

2.3.2. Power Generated

Typically stored in MW, the power generated by the turbine is very useful for reporting on turbine production. It can also be a valuable “sanity check” when various data sources are in conflict regarding the turbine’s actual status.

Most SCADA systems offer more than one power metric (turbine, string, or park). It is important to be clear which is being reported. This is managed by careful metadata and taxonomy design.

2.3.3. Wind Speed

Typically, there will be at least two sources of wind speed data - the turbine’s anemometry and the meteorological tower. Both sources can be useful to understand what is really happening at a turbine.

All analyses of a wind plant’s operations need to consider wind speed. Ideally, the actual wind speed (usually measured in meters per second) should be captured. When this data is plotted in a turbine power curve, a highly effective tool for combining wind speed and power output and determining (by the shape of the curve) how a turbine is performing is available to owner/operator and OEM staff.

Beyond those listed above, many of the other turbine, BOP, and environmental tags in the SCADA time series data will be useful at some point for root cause reliability analysis. In particular, tags that are generally useful for root cause analysis include measures of temperature (including ambient air temperature and the temperature of components) and measures of other air conditions (including wind speed and direction, air pressure or density, and turbulence) as well as vibration modes from multiple contact points and rotational speeds of the components in the turbine. Transformer gas and condition monitors are also highly useful for preventing transformer failure as replacement lead times for these components are typically months to a year.

2.4. SCADA – Alarms

The second type of SCADA data relates to alarms at the turbine. Events, alarms, and faults are collected when they occur (not continuously, as with the time series data, but are typically stored as a time series to correlate with the instrument and asset data streams). With this kind of data, information is only stored when something interesting happens - namely, events are recorded when the operating or environmental conditions of the turbine and its parts fall outside of specific boundaries. Combined with work orders, alarm information can help provide a complete set of downtime events for each turbine, BOP equipment, and the plant. Ideally, any alarm that requires human intervention will also have a work order associated with it. As an example, turbine alarms should contain the following information as a minimum:

Turbine Identifier	Recording the turbine ID links each alarm with a specific turbine.
Event Identifier	Most SCADA systems have a list of a few hundred alarm types – capturing an identifier for each alarm, then cross-referencing the meaning from a complete list of alarms and their attributes, provides much information about what was going wrong. Attributes can include useful information, such as whether an alarm can be automatically or remotely reset, and whether the alarm was triggered automatically or by human intervention. Cross-referencing can be done automatically through the construction of look-up tables and maintaining continuity between alarms, alarm codes, metadata, real-time data and the overall plant and fleet taxonomy.
Alarm Start Date and Time	Date and time when the alarm begins.
Alarm End Date and Time	Date and time when the alarm ends.

2.5. Computerized Maintenance Management Systems – Work Orders

Beyond SCADA storage, many owner/operators have also implemented Computerized Maintenance Management Systems (CMMS) for their work orders. A CMMS enables access to work order data for trend analysis, detailed parts tracking, and root cause analysis. A CMMS is a crucial, but frequently overlooked, aspect of the data collection architecture. Paper work orders and technician tribal knowledge are ineffective sources of information about turbine, BOP, and plant performance, especially over the life of the equipment and wind plant. One of the largest analysis challenges facing the wind industry is the current dependence on manual maintenance and repair documentation processes. These are not scalable and deprive owner/operators of the crucial corrective action information that is necessary for root cause analysis. Well-written work orders can provide a goldmine of information for a company while poorly-written work orders can be a waste of valuable technician time.

One of the cardinal rules of a CMMS (or any other data entry system requiring human input) is that it needs to be as painless as possible to do data entry. Automating the data collection with handheld devices, bar coding, and passive identification systems (Radio Frequency Identification - RFID) can mean the difference between capturing data or missing critical pieces of the operations and maintenance (O&M) puzzle. The people involved in work order data entry can vary widely, but often include technicians, administrative staff at the plant, and employees in an Operations Command Center (OCC). Other important aspects to keep in mind in designing data entry systems are that optional fields tend to remain blank and "miscellaneous" is a popular choice. Avoiding inaccurate and incomplete tracking and recording can mean the difference between understanding turbine, plant, and fleet performance and multiple root cause unknowns. At a minimum, high-quality work orders for a turbine should contain:

2.5.1. Turbine Identifier

Recording a turbine ID links each maintenance event with a specific turbine. Events that do not tie to a specific turbine can still be captured, but this should be clearly specified. Ideally, there will be options to choose specific BOP equipment, in addition to specific turbines.

2.5.2 Event Type

Event type captures at a high level what kind of work is being performed (e.g., component failure, preventative maintenance, inspection, etc.)

All downtime and maintenance events should be recorded, including inspections and other scheduled maintenance events. Even inspections and scheduled maintenance that is relatively short in duration, relatively infrequent, and/or can occur while the system is running are crucial to understanding the availability, reliability, and financial performance of a system.

2.5.3. Affected Component

Ideally, the affected component would be chosen from a standard breakdown of the turbine (e.g., taxonomy, metadata framework or equipment breakdown workflow). This value may not be initially known with certainty, so a good CMMS needs to allow for updates, editing, and refinement as more knowledge is gained.

In order to conduct real root-cause analysis, it is also useful to capture a brief description of the failure mechanism and/or the external event that caused the downtime or maintenance (e.g., curtailment, chipped gear tooth, dirty oil).

For relevant event types, the source of parts is also a useful piece of information. This includes parts acquired through non-standard methods (e.g., swapped from another turbine, purchased outside the supply system, machined on site, etc.). Identifying the source of parts allows for more accurate cost calculations and will allow more advanced CMMS towards parts and inventory tracking.

2.5.4. Equipment Status

Not all maintenance events will stop a turbine from generating, for example, some inspections are allowed when the turbine is running.

Suggested choices for equipment status include Online, Offline/Fault, Planned Maintenance, Unplanned Maintenance, Degraded, etc. It is very important to establish categories for up and down time and for operations management to ensure accuracy and consistency amongst the engineering and technician teams.

2.5.5. Event Start Date and Time

Date and time when the status of the turbine changes. Or, if the turbine status does not change due to the start of the event, the date and time the maintenance event begins.

2.5.6. Event End Date and Time

Date and time when the status of the turbine changes. Or, if the turbine status does not change due to the end of the event, the date and time the maintenance event ends.

2.5.7. Downtime

There are many ways to measure downtime. From the event start and end times, the total duration of the downtime or event can be captured. Other useful measures include:

Active Maintenance Time	The total amount of time maintenance was being actively performed on the turbine.
Person-Hours	The total number of person-hours required to complete the maintenance action. Note that this may be very different (greater than or less than) total downtime, and may be greater than the active maintenance time if more than one technician was needed.
Waiting Time	Ideally, this can be broken into time spent waiting for a technician to become available, waiting for a part from supply, waiting for a piece of support equipment to become available, or waiting on other administrative or supply delays.

2.5.8. Description/Comments

Though free-text comments can be difficult to use in an automated way, allowing technicians to capture anything unexpected or unusual about a maintenance event can be quite useful when delving deeply into specific events or types of events. In addition, this field can be helpful to support the collection of additional data while the CMMS is being upgraded to capture it in a more appropriate field.

2.6. Other Systems

In addition to the data that is captured from SCADA and work orders, supplemental turbine and plant information is also needed. ERP systems containing cost and other financial and business information provide the supplemental information needed to support data-based decision making.

Ideally, cost information would include component-level repair costs, component-level replacement costs, consumables costs (e.g., the price of a liter of gearbox oil), costs associated with technician time, and costs associated with overhead (e.g., administrative time) if such overhead is linked to maintenance or downtime. Additionally, some plants also look at lost revenue from generation or penalties assessed for not generating.

Information on turbine and BOP configuration is another essential aspect of cross-fleet analysis when performing analysis at system, sub-system, component-group, and component levels, especially across multiple plants or turbine technologies. A hierarchical equipment breakdown flow or structure and the site taxonomy divide the turbines and BOP into their generalized parts in a parent-child relationship that allows sub-parts to be rolled up into sub-assemblies, sub-systems, and systems.

Once a general taxonomy is developed, then each of the turbine technologies or plants can be mapped to it, creating a standard that allows comparison. Also, a detailed description of the equipment (make, model, manufacturer of major components, presence/absence of optional systems such as de-icing equipment or condition monitoring, etc.) is important for comparisons. Lastly, documented system knowledge, such as turbine specifications or substation fault trees, can provide the basis for more advanced reliability analysis.

2.7. Data Processes

In the wind industry, many multi-site and OEM companies have implemented operations command centers (OCCs) with real-time operating data flowing from plants to a centralized monitoring and control center. The real-time data is then stored in a single large enterprise-level database covering multiple plants. This approach requires a robust and reliable connection from each turbine and plant to the OCC or reliable data storage at each site so when connection to the OCC is restored, the buffered data is passed to the OCC. An alternative, seen at smaller operators and plants, is where a storage system is implemented on-site and stores a finite time period of SCADA data. Some of these implementations allow for subsets of the data to be sent to a central office for storage and analysis periodically or after events.

Those companies that do store their SCADA data consider it highly proprietary and treat it as intellectual property. This adds a requirement for encryption and security during the transfer of data from the plant and access levels and controls that restrict who can view the stored data. If there is transfer of the data from a plant to an OCC, a hardened high-bandwidth connection is most desirable. This creates a dedicated connection between the wind plant and the OCC, making it a good choice for carrying large amounts of data as it is both reliable and secure. Once data is stored at the OCC, the use of integrated security protocols can fulfill the needs for controlling access to the data.

After data is stored and accessible to those with the rights to see and use it, data protection becomes a primary task of the data administration staff. Design, implementation, and maintenance of a backup and recovery plan are essential to preventing the loss of data through accident, data corruption, hardware failure, or natural disaster. The plan should include levels of criticality for the data, projected recovery timeframes, scheduling and monitoring of backups, on-going validation testing of the backups, and the media choices on which the backups will be stored.

In addition to backups, with the amount of data being stored for each turbine and plant, an archiving strategy is necessary to manage the size of the database and maintain a high-functioning retrieval system. One approach is to archive the raw data but to retain calculated values.

2.7. Data Processes
(continued)

Another approach is to store the data using special compression techniques that reduce the number of data pieces stored without losing the meaning of the data. Data historians are especially designed with this type of compression in mind. With the cost of storage coming down over the prior decades, archiving strategies should be periodically re-evaluated to ensure that the correct levels of data are available for analysis.

When setting up transfer and storage protocols, the data to be stored must be determined. This concern is especially relevant when looking at the need to summarize the voluminous SCADA time series data. For monthly or yearly performance metrics balanced against the detail needed for root cause analysis, real-time data compression algorithms become critical to balance data storage needs against data completeness. Compression means reducing the number of electronic bits that represent a piece of data, thus reducing the number of bits that need to be transferred from the plant or stored. For example, only storing values when they change can save a great deal of space if that data does not change often.

One of the other aspects of data integrity is addressing missing or illogical data, with data validation serving as an essential aspect of any data collection system. When there is only a single piece missing, it will likely have little to no impact on analysis, but when larger amounts of data are missing, perhaps covering hours, the loss may be important. The practice of data editing or filling in the data with realistic values can assist in creating a complete data set. For illogical data, values for a piece of data can be compared to previous values or sets/ranges of acceptable values, allowing an unrealistic value to be identified. Care must be taken with data editing, as it can reduce confidence in the data as a whole. Among other challenges, important signals can be missed if unexpected, but accurate, values are overwritten. Also, filling in unknown values can mask a data communications problem.

2.7. Data Processes
(continued)

For all of these data integrity concerns, their impact can be reduced by implementing good business processes and procedures, where all employees follow the same process when dealing with the data. Whether the employee is at the plant, in the corporate IT department, or in the engineering/analysis group, business processes allow for the same methodology to be implemented and for necessary improvements to be implemented systematically. Part of these remedies should be a standard approach to the use and interpretation of data. This creates an environment where comparisons between turbines and plants can easily be made because the analysis is based on the same assumptions about the data.

2.8. Integrate Data

One of the greatest challenges in using CMMS and SCADA data to perform reliability analysis is in matching work orders, SCADA time series, and SCADA alarm data. This linking of symptom (e.g., high SCADA temperature recordings followed by a gearbox over-temperature alarm) to corrective action (e.g., a work order to replace a lubrication oil pump) allows for the beginning stages of root cause analysis, parts tracking, and trending. An automated method for performing this linking will greatly improve the detail and accuracy of reliability analysis, but it is not an easy process. Challenges in linking data can include conflicts between CMMS and SCADA regarding turbine status, incomplete work orders, and missing SCADA data. Additionally, real situations that are difficult to interpret will appear, such as curtailment, overlapping work orders, and back-to-back alarms. While no systems emerge as the complete solution after a plant or fleet reaches Commercial Operation Date (COD), continuous investment and improvements to the operational and maintenance systems are crucial for assuring long asset life and the highest levels of production output.

3. Analysis
The culmination of the above two sections, is analysis. Analysis incorporates the data generated, collected, and made available to improve the understanding of the current reliability and performance of the wind plant and its turbines. A staged approach is required to impact an O&M strategy through improved availability, increased reliability, and reduced O&M costs: first establish baseline performance to understand what the current situation is, then identify performance drivers and determine their root causes, and finally create action plans for addressing those drivers with higher impact.

3.1. Understand Current Performance

Successfully answering questions such as “What is the current performance?” and “How good is it?” is the first step to making improvements. This will point toward problematic areas on which to focus. Examples of questions and analysis related to baseline performance include:

3.1.1. What is the Baseline Performance?

- Calculate basic operations and reliability metrics, such as Availability, MTBE (Mean Time Between Events), Mean Downtime, and Capacity Factor for the plant and then each turbine.

3.1.2. How Does the Plant Performance Compare to the OEM or Financial Expectations?

- Identify and graph how a typical turbine spends its time (what percent of the time is it running, idle and available, down for scheduled maintenance, curtailed, etc.).
- Be sure to identify when the turbine state cannot be determined (such as when SCADA communication is lost or the historian briefly stops recording).

3.1.3. Are the Data Aspects of the Operations and Maintenance Processes Well Understood?

- Make and document assumptions about the data being gathered and how it is gathered, stored, and used for analysis. Institutionalize these assumptions so that all departments have the same meaning for particular pieces of data.

3.2. Identify Performance Drivers

Once baseline performance is understood, then performance drivers can be found. Methods for identifying these drivers can include exploring trends, outliers, good performance, and surprising results. Examples of questions that can be answered at this point and their related analyses include:

3.2.1. What is Driving Poor Performance?

- Identify key contributors to low generation, unavailability (downtime), etc. Exploring top contributors is a simple, but very powerful method for identifying areas for improvement.

- Compare multiple metrics, such as event frequency versus event duration or generation versus turbine wind speed. The outliers are especially interesting in these types of graphs.

3.2.2. Where is Performance Roughly the Same? Where is There Great Variability?

- Explore turbine-to-turbine performance and variability in all the basic aspects including Availability, MTBE, Mean Downtime, and Capacity Factor.

- Explore trends (daily, weekly, monthly, and seasonal). Plot graphs of the metrics over time. Look at the whole plant and also look at individual turbines or individual event types, especially those with very high or very low performance.

3.2.3. Where Are the Business Data Processes Different?

- Address any inconsistencies in data processes and assumptions including determining if there is a valid reason for doing things differently.

- Understand limitations in the data systems, analysis/modeling, and reporting.

3.3. Determine Root Cause

After understanding baseline performance and identifying some of the key performance drivers, then root causes can be identified to solve problems. Examples of questions and analysis that can be addressed at this point include:

3.3.1. Why are Certain Aspects of Operations (e.g., Turbines or Groups of Turbines, Months or Days of the Week, Types of Scheduled Maintenance) Having Such a Negative Impact?

- Investigate de-rates and periods of unexplained performance.
- Interpret unexpected patterns.

3.3.2. What are the Root Causes of the Top Problems?

- After identifying the operational aspects that have the most impact, conduct root cause investigations. Follow through on this activity. Simply identifying potential root causes is not enough. Real fixes should be developed, tested, implemented, and assessed.

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RP 506 Wind Turbine Key Performance Indicator Data Reporting Procedures

The following recommended practice (RP) is subject to the disclaimer at the front of this manual. It is important that users read the disclaimer before considering adoption of any portion of this recommended practice.

This recommended practice was prepared by a committee of the AWEA Operations and Maintenance (O&M) Committee.

Committee Chair: David Zeglinski, OSIsoft, LLC
Principal Author: Dave Ippolito, Versify Solutions

Purpose and Scope

The scope of "Wind Turbine Key Performance Indicator Data Reporting Procedures" describes best practices in reporting Key Performance Indicators (KPI's) including recommended data granularity, frequency, methods for capturing and collecting data required to produce recommended KPI's.

Introduction

This document assumes the reader has working knowledge of SCADA, data capture, and data collection and historian technologies. While this document does not recommend specific technologies, it assumes that SCADA data may be captured and collected using some method of historian technology. Also, this document assumes that integrated values for any underlying data point that is captured may be extracted from the data historian at the described levels of frequency.

Presentation of Key Performance Metrics and any technologies associated with data reporting are also beyond the scope of this document, but is recommended that any reporting or presentation tool or application used allow for both high level "dashboard reporting" that may be tailored for senior management as well as the ability to drill down into granular details as needed by engineers, plant managers, and operators.

Procedures (Detailed Descriptions)

Data should be collected from the plant at various levels of granularity and frequencies based on how the data is to be applied in calculating key performance indicators described below. As a best practice, data is should be read from a plant's SCADA system and collected in the data historian utilizing industry standard protocols such as OPC or MODBUS. Depending on the KPI, calculations may be completed as the data is read from SCADA, or may occur after integrated data has been collected over a period of time.

The following table lists operational data that must be collected in order to produce key performance indicators described within this document. (See Table A)

Table A

MW	BOP / Turbine	Hour / Minute
Turbine Available	BOP / Turbine	Hour / Minute
Turbine Online	BOP / Turbine	Hour / Minute
Turbine Fault Code	Turbine	Minute
Wind Speed	Turbine	Minute
Wind Direction	BOP	Minute
Curtailment Events	Turbine	Start / Stop

Key performance metrics may be calculated as data is collected, or may be tabulated periodically as needed. The following describes KPIs that should be collected for turbines and the balance of the plant.

1. Total MWh

Integrated MWh values for the plant and for each turbine describe plant output and are used for other metrics.

2. Available MW

Hourly metric based on each turbine's nameplate capacity and the total amount of time that the turbine is available

= Sum(turbine available * turbine capacity)

3. Availability

Percentage of plant or turbine that is available for given hour

= Available MW / Nameplate Capacity

4. Potential Energy

Turbine capability based on design curve and meteorological conditions

= Design Curve(wind speed, RH, BP, etc.)

5. Capacity Factor

Percent of plant or turbine capacity that is producing power

= Total MWh/Nameplate Capacity

6. Curtailment Hours or Minutes

The total number or minutes or part of an hour during which there has been a curtailment event

= Total minutes between curtailment event start and stop

7. Curtailment MWh

Total MWh lost during curtailment events. Note that it may be desirable to track curtailment MWh for different types of curtailment events. Curtailment MWh is estimated using minute level integrated Potential Energy - Actual MW for each minute of a curtailment event. This is best computed on a minute level basis, and totaled for any given hour.

8. Turbine Faults

The number of distinct turbine fault events should be tracked for each turbine as well as the total number of faults for the balance of the wind farm. A turbine fault event begins when a turbine fault code is recorded, and ends when the turbine is reset and fault status indicates the turbine is back online.

9. Turbine Fault Lost Energy

Lost energy due to turbine faults may be estimated by subtracting actual energy from potential energy during a given fault event. It may be desirable to track lost energy by fault code, category, and plant levels.

RP 507 Wind Turbine Condition Based Maintenance System Open Architecture

The following recommended practice (RP) is subject to the disclaimer at the front of this manual. It is important that users read the disclaimer before considering adoption of any portion of this recommended practice.

This recommended practice was prepared by a committee of the AWEA Operations and Maintenance (O&M) Committee.

Committee Chair: David Zeglinski, OSIsoft, LLC
Principal Author: Kevin Line, Sentient Science

Purpose and Scope

The purpose of this document is to provide a recommended practice for condition based maintenance (CBM) system architecture for the wind plant, including wind turbine generator, balance of plant and other elements.

Condition based maintenance and condition monitoring has been shown in many industries to reduce the cost of ownership and increase the availability of assets for operations. Aviation and energy have multiple examples of implementing CBM with positive financial and operational results.

The goal of the best practice is to provide a common, scalable and open architecture to enable an interoperability and cooperation for CBM systems. The advantage to this approach is that the wind plant operator and owner will be able to leverage best in breed approaches for CBM through the implementation of an Open Architecture approach. Furthermore, future technology and capability will be easily integrated into the system, with little need for reconfiguration or modification.

Introduction

Implementation of a condition monitoring system can take many forms and processes and approaches. The general diagram of these systems is shown in Figure A. (*See Figure A*) The description of each component is as follows:

Wind Plant - The collection of wind turbine generators and balance of plant equipment needed to generate electricity.

Wind Turbine Generator (WTG) - The electrical and mechanical system for converting wind energy into electrical energy, including tower, foundation and balance of plant. The control center for the WTG is not included.

Introduction
(continued)

Balance of plant (BOP) - Remaining hardware in the plant, not including the WTG.

Control Sensors & Hardware - The hardware and software system, typically the SCADA system, on the WTG which supports the control and operation.

Condition Monitoring & Sensors - Data collection, processing and sensors for the purposes of assessing the health and remaining life. This equipment is in addition to SCADA hardware.

Data Storage - Standards-based storage of health and control data for the purpose of condition monitoring. Stored data can be local, centralized or both, depending on system architecture.

Data Processing - Local or remote health management system processes collected real-time or off-line data either in time- or frequency-domain. Health metrics and indicators are restored in the database.

Maintenance Interface - Alerts, health indicators and actions are communicated to appropriate stakeholders, ranging from local maintenance management to supply chain and engineering.

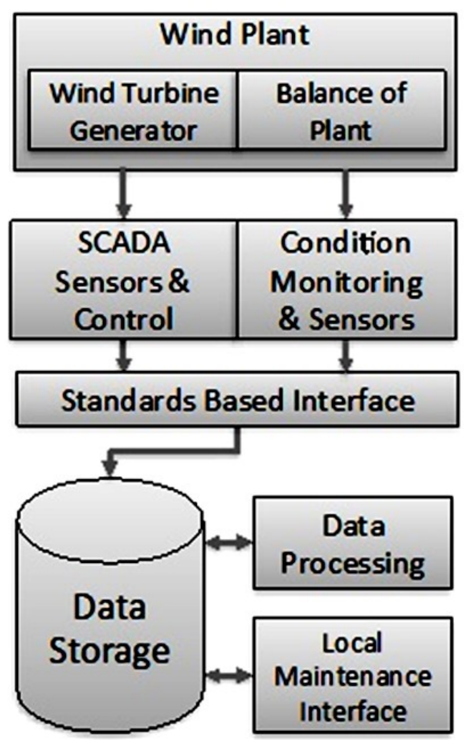


Figure A: Basic CBM System Architecture

CBM Open Architecture

1. CBM System Development

CBM system and data management strategy will be unique for each platform and plant, but follow a similar process. This process is outlined below:

1) Identify system failure modes, for both WTG and BOP through review of system supplier failure modes and effects (FMEA) analysis, industry data and interviews with Subject Matter Experts.

2) Determine CBM needs and strategy through analysis. Identify high priority components for CBM with careful consideration of failure rate, replacement cost, spare part lead-time and impact on operations.

3) For wind plant, determine required sensors, data collection, processing and storage equipment to meet strategy.

4) Leverage Open Architecture for CBM System and Data Management. Through application of Open Architecture, data collection, management and processing will have common interfaces to each development and integration. This architecture is created through apply Open Standards approached outlined in the sections below.

5) Implement CBM system, through procurement of hardware and software. Install systems and configure per manufacturer instructions.

2. Open Standards _ MIMOSA

Once CBM needs have been defined for the system, Open Standards should be applied. MIMOSA publishes a well-accepted open standard for developing and implementing condition based maintenance systems. Both the OSA-CBM and OSA-EAI are data and communication architectures that define the interfaces between hardware and software. These common interface definitions enable the application of 3rd party capabilities built to the same interface definition and enable data, software and hardware to remain compatible well into the future, as along as the standards are adhered. The complete definitions are found at *www.mimosa.org*. These open standards are the basis of this recommended practice.

The OSA-CBM architecture is defined by a set of components (physical or virtual components in the system) and workflows (transportation of data from source to user). To achieve this, the architecture is composed of segments and agents. Segments correspond to Measurement Locations (sensors), and Agents (people or systems that analyze data).

2. Open Standards _ MIMOSA
(continued)

The workflow for this system is conceptualized in Figure B, below. (*See Figure B*) From the point of view of the CBM framework, each sensor would be a Measurement Location. To populate the Ports in the Module with Data Acquisition (DA) Data Events, the sensor interface would be wrapped in an Algorithm. These Ports and any DA Data Events they contain would then be available for the rest of the Configuration to make use of. By using the Ports of one or more Algorithms as inputs for other Algorithms, the Configuration specifies a workflow that processes the data as it flows through. Additional preprocessing for the Measurement Locations is done at the Data Manipulation and State Determination levels, producing corresponding Data Events. The end products of this workflow are Health Assessment, Prognostics Assessment and Advisory Generation Data Events. These high-level Data Events are created by Agents, interfaced to by Algorithms in the workflow, that provide interpretations of the health and prognosis, as well as recommendations on how to deal with them. The CBM process makes Data Events available to external processes via the interface types in the OSA-CBM specification.

For example:

> Onboard the WTG, sensor data would be stored as Data Acquisition Events. During operation, the bandwidth usage would be minimized by limiting the Data Events sent to the ground station with Monitor Id Groups to pass on DA Events filtering out those with NumAlerts below a certain severity. Additional data may be requested by passing a Monitor Id Group to a CBM interface requesting a specific subset of data. They would be transferred in a serialized (XML, JSON, YAML, etc.) compressed format. Another possibility is to move some of the more critical or less processor intensive algorithms in the workflow onboard the WTG. Health and Prognostics Assessment Data Events produced by an onboard Digital Twin would take up much less bandwidth than the Data Acquisition Events consumed to produce them. This flexibility allows better balancing of the tradeoff between onboard processing and platform to ground station bandwidth. The network of Algorithms and Ports produce and consume the Data Manipulation, State Detection, Health Assessment, Prognostics Assessment, and Advisory Generation Data Events. External applications may then request the Data Events from specific Ports provided by the CBM interface by using Monitor Id Groups. HA Events are used to provide the health level of components, PA Events report their remaining useful lives, and AG Events give Recommendations and optionally Requests For Work.

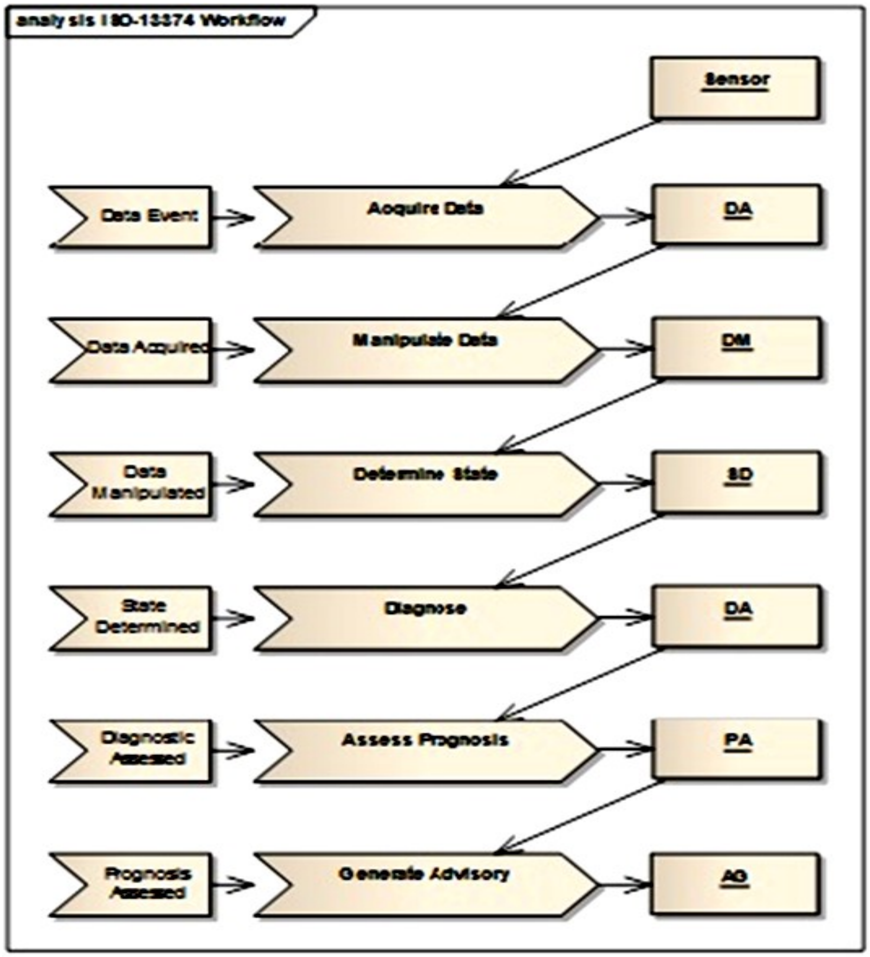


Figure B: OSA_CBM Workflow

3. Interface Definitions

Condition Based Maintenance System elements will be implemented in the above architecture using the OSA-CBM interface definitions. OSA-CBM interface definition simplifies integrating a wide variety of software and hardware components as well as developing a framework for these components by specifying a standard architecture and framework for implementing condition-based maintenance systems. It describes the functional blocks of CBM systems, as well as the interfaces between those blocks. The standard provides a means to integrate many disparate components, including interfaces with sensors, data acquisition devices, software algorithms and eases the process by specifying the inputs and outputs between the components. In short, it describes a standardized information delivery system for condition based monitoring. It describes the information that is moved around and how to move it. It also has built in meta-data to describe the processing that is occurring.

3. Interface Definitions
(continued)

OSA-CBM provides an interface standard and defines the interfaces between the functional blocks in a CBM system. Vendors can develop algorithms to fit inside of these blocks, separating the information processing from how it is presented. This separation allows proprietary code and algorithms to be kept hidden inside each of the functional blocks. It also creates a plug and play capability where vendors can easily insert updates or roll back to previous versions without affecting other modules or programs relying on the functional blocks. Figure C illustrates an example of proprietary algorithm in one OSA-CBM block. (*See Figure C*)

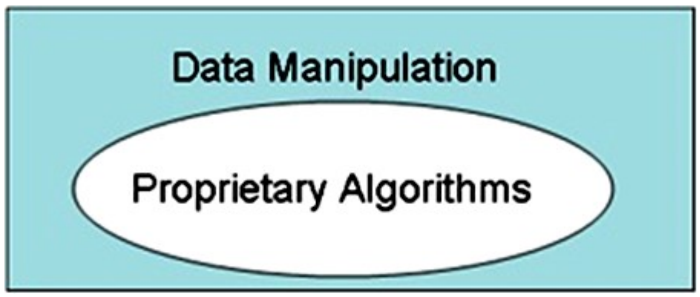


Figure C: Example of Proprietary Algorithm in One OSA-CBM Block

The Algorithm Configuration and the Interface Implementation. Figure D illustrates the main part of algorithm configuration in OSA-CBM UML specification 3.3.0. (*See Figure D*) Configuration provides information about Algorithm Input Data, descriptions of algorithms used for processing input data, a list of outputs, and various output specifics such as engineering units and thresholds for alerts.

Writers of Algorithms simply need to interact with this interface as it is provided to them in a CBM implementation. This can be accomplished simply in several ways, including inheritance from a base class in object oriented languages. The writer can then override a calling function that accepts an object providing method access to the outputs and any inputs. It is in this way that third-party code compiled into DLLs can be incorporated into the system transparently.

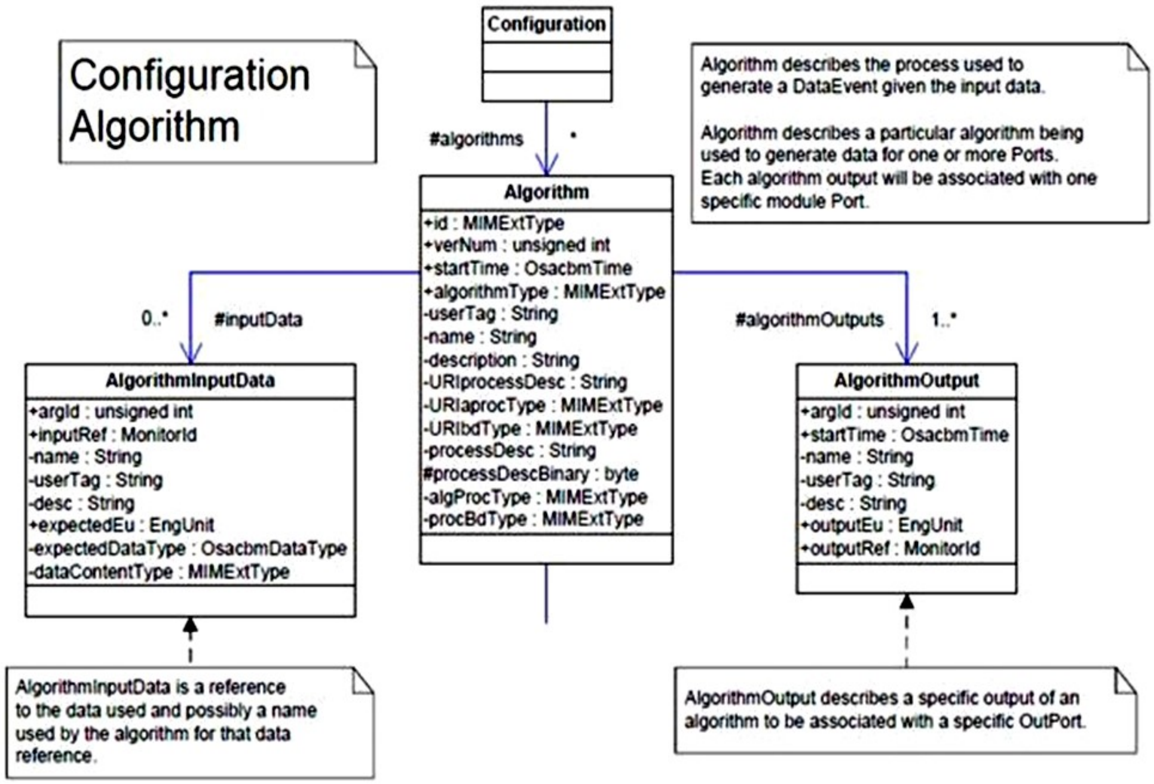


Figure D: Algorithm Configuration in OSA-CBM UML Specification 3.3.0

Summary

Implementation of the Open Architectures described herein is a recommended practice by AWEA. These architectures enable widespread and broad cooperation across the industry to enable improved capability and performance of wind turbine system.

References

Open System Alliance, OSA-CBM Specification 3.3.0, February 2010, www.MIMOSA.org

ISO-13374 Condition monitoring and diagnostics of machines -- Data processing, communication and presentation, 2007
www.iso.org/standard/36645.html

RP 508 Oil Analysis Data Collection and Reporting Procedures

The following recommended practice (RP) is subject to the disclaimer at the front of this manual. It is important that users read the disclaimer before considering adoption of any portion of this recommended practice.

This recommended practice was prepared by a committee of the AWEA Operations and Maintenance (O&M) Committee.

Committee Chair: Bruce Hamilton, Navigant
Principal Author: Allison Toms, Gastops

Purpose and Scope

The scope of “Oil Analysis Data Collection and Reporting Procedures” describes best practices in oil analysis data collection and reporting procedures for optimal information on the condition of the monitored component and proper maintenance actions.

Introduction

Experience has shown that premature gearbox failures are a leading maintenance cost driver of a wind turbine operation. Premature gearbox failures reduce turbine availability, result in lost production and downtime, and can add significantly to project lifecycle cost of operation. Oil debris and oil condition monitoring, used in conjunction with Prognostics and Health Management (PHM) monitoring to assess and monitor the health of a wind turbine gearbox, should be part of a comprehensive condition monitoring program.

Oil debris and oil condition analysis techniques offer the potential for detecting early component damage and lubricant degradation, trending the severity of such damage, estimating the time to reach pre-defined damage limits, and providing key information for proactive maintenance decisions and often prior to other monitoring techniques.

Oil debris RP 818 [1] “Wind Turbine On-line Gearbox Debris Condition Monitoring” and oil condition RP 819 “Online Oil Condition Monitoring” monitoring can be accomplished through continuous online sensors or traditional offline “point-in-time” oil and grease RP 815 “Wind Turbine Grease Analysis Test Methods” analysis sampling.

Data Collection

Data collection methods for offline periodic monitoring and online continuous monitoring are summarized below.

1. Offline Periodic Monitoring

Offline periodic “point-in-time” oil, grease, and filter samples, typically taken every six months for wind turbines, are sent to a laboratory for analysis. The laboratory analysis provides details on the oil’s physical properties and contaminants utilizing a wide variety of laboratory tests and instruments. The data generated from all these instruments should be automatically transferred to a laboratory information management system (LIMS) which also contains the sample collection and machinery component information. Manual transcription of data should be avoided.

2. On-line Continuous Monitoring

Online sensors provide continuous monitoring for each component being monitored at regular intervals, for example daily. This near real-time data is exported automatically by a variety of methods such as General Packet Radio Service (GPRS) cellular modem, supervisory control and data acquisition (SCADA), or Ethernet to a central monitoring location where the data is automatically processed to assess the health of the component.

Data Variability

Oil analysis data is impacted by a wide variety of factors which need to be taken into account for repeatable and reproducible oil analysis data interpretation. [2]

1. Operational and Maintenance Actions

Operational and maintenance actions impact data in predictable ways and these actions should be provided with each sample.

1.1. Operational intensity can impact how quickly a component wears and how rapidly a fault progresses. A relevant indicator of machine usage should be included in any limit and trend calculations.

1.2. Sampling, maintenance, filter, and oil changes are rarely performed at precise intervals. These irregular, opportunistic intervals have a profound effect on measurement data and interfere with trending techniques. Consequently, they need to be taken into account for accurate limit and trend calculations.

2. Sample Collection Techniques

Proper sample collection techniques play a large role in providing representative data. The recommended procedures in RP 102 "Wind Turbine Gearbox Oil Sampling Procedure" and RP 815 "Wind Turbine Grease Analysis Test Methods" should be followed.

3. Laboratories and Test Instruments

Laboratories and test instruments also impact data and the following should be adhered to for improved repeatability and reproducibility of data.

3.1. Variations in laboratory analytical instruments impact data reliability. Ideally, trending should only be performed on results obtained from the same make and model of test instrument.

3.2. If samples are analyzed at more than one laboratory, the laboratories should be in a quality assurance program demonstrating a correlation in results obtained from each laboratory and each instrument.

3.3. Laboratories utilized should be certified to ISO 17025 [3] to enhance confidence in the results.

The above examples are a few factors that impact oil analysis data interpretation. Online sensors have the benefit of overcoming some of these factors.

Data Analysis

A significant amount of data is generated by oil analysis monitoring. This data needs to be reduced to useful information regarding component health. Level limits are established to indicate different stages of a fault in progress. Finite limits are typically utilized for parameters such as allowable water contamination [4]. However, in addition to level limits, trending the rate of progression of a failure is also very important. A significant change in trend is indicative of the rate of damage progression towards level limits of defined failure stages [5]. Identifying a failure in the early stages is much more cost effective than allowing it to progress to later failure stages of the machine. Condition monitoring information should clearly and consistently indicate machinery condition from normal through various stages of failure.

Results Reports

Reports for offline periodic monitoring are obtained from oil sample analysis laboratories and reports for online continuous monitoring from automated data processing algorithms.

1. Laboratory Analysis Results

Laboratory analysis results of an oil, grease, or filter sample provide a detailed report of a lubricant's physical properties and quantitative analysis of key contaminants. Figure A is a typical report that provides:

a. Customer information
b. Component information
c. Sample information
d. Current sample data
e. Two or more prior samples of data for comparison
f. New oil data for comparison
g. Limit values, if available, for each applicable parameter measured
h. Trend values or trend charts, if available, for each applicable parameter measured
i. Laboratory comments
j. Laboratory recommendations

Limits utilized in the report should state whether they were derived based on customers' historical data specific to their components or whether they are generic to machine and oil type.

Note, not all parameters measured are applicable to the component. Thus, for non-relevant parameters, level limits and trends are not assigned. Numerous laboratory tests are available. Not all of them provide useful information on component health or can be linked to a failure mode.

Figure A: Laboratory Oil Analysis Report

Machine Condition	NORMAL
Lubricant Condition	MARGINAL

Machine Name: WT1 GEARBOX

Analysis Report

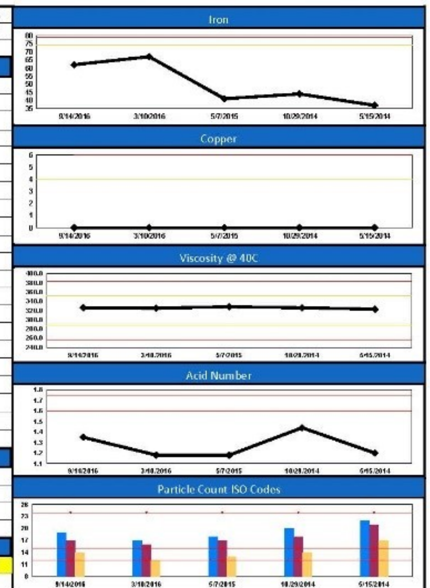
Component Information			Sample Information		Customer Information
Machine Type:	Industrial Gear	Sump Size: Unknown	Received:	09/15/2016	Wind Farm X
Lubricant:			Report:	09/15/2016	
Machine MFG:					
Machine MOD:					

PROBLEMS
Excessive Particle Count

COMMENTS The particulate contamination exceeds our limits for a gearbox (24/15/12). High particulate contamination will lead to abrasive wear and damage internal components. Reducing particle levels will significantly extend component life.

CUSTOMER NOTES

	Date Sampled	NEW OIL	9/14/2016	3/10/2016	5/7/2015	10/29/2014	5/15/2014
	Lab No	1708048	1776399	1653045	1512386	1372947	1317348
	Machine / Lube Cond.		N / M	M / M	N / M	N / M	N / M
ELEMENTAL SPECTROSCOPY (ppm) ASTM D5185 Mod (-) indicates below detection limit							
Wear Metals	Iron	-	62	67	41	44	37
Wear Metals	Copper	-	-	-	-	-	-
Wear Metals	Lead	-	-	-	-	-	-
Wear Metals	Aluminum	-	-	-	-	-	-
Wear Metals	Tin	-	-	-	-	-	-
Wear Metals	Nickel	-	-	-	-	-	-
Wear Metals	Chromium	-	-	-	-	-	-
Wear Metals	Titanium	-	-	-	-	-	-
Wear Metals	Vanadium	-	-	-	-	-	-
Wear Metals	Silver	-	-	-	-	-	-
Additives	Calcium	-	-	-	-	-	-
Additives	Magnesium	-	20	29	18	7	33
Additives	Phosphorus	489	411	540	335	412	494
Additives	Zinc	-	31	36	24	9	32
Additives	Barium	-	-	-	-	-	-
Additives	Molybdenum	-	37	45	34	20	95
Contaminants	Silicon	-	-	-	-	-	-
Contaminants	Boron	49	31	37	35	30	44
Contaminants	Lithium	-	-	-	-	-	-
Contaminants	Sodium	-	8	11	-	-	-
Contaminants	Potassium	-	-	-	-	-	-
FTIR SPECTROSCOPY (Indexing Numbers) ASTM E2412							
	Oxidation	60	59	54	56	59	54
	Nitration	1	2	1	2	1	1
	Anti Wear	15	15	15	15	16	14
	Other Fluid	52	52	52	54	54	51
PARTICLE COUNT (particles per ml) ISO 4406:99							
	ISO Code	18/16/13	19/17/14	17/16/12	18/17/13	20/18/14	22/21/17
	>4 Micron	1446	3264	1008	2178	5103	38670
	>6 Micron	561	1269	392	847	1984	15039
	>14 Micron	43	96	29	63	151	1147
	>50 Micron	1	4	1	2	6	50
	>100 Micron	0	0	0	0	0	2
VISCOSITY (centistokes) ASTM D445							
	Viscosity@40°C	327.8	326.2	325.4	328.2	326.4	323.3
ACID NUMBER (mg KOH/g) ASTM D974							
	Acid Number	0.88	1.35	1.18	1.18	1.44	1.20
WATER (PPM) a-ASTM D6304A b-IWI-133 c-ASTM D6304C d-IWI-134* e-IWI-135* f-IWI-136* g-Crackle h-IWI-370*							
	Water		100 (c)	134 (c)	140 (c)	40 (c)	100 (c)



Testing performed by Lab X, an ISO/IEC 17025:2005 accredited laboratory. L-A-B Accredited Certificate Number xxxx Testing. (*) - Not in scope of accreditation. Wind Farm X assumes sole responsibility for the application of and reliance upon results and recommendations reported by Lab X, whose obligation is limited to good faith performance.

Page 1 of 1

Lab No. 1776399

2. Online Sensor Data

Online sensor data processing provides automated analysis of near real-time results for the parameters they are measuring such as wear debris. Figure B is a typical daily sensor report for each sensor that indicates the status of each component by means of a trend plot identifying normal or alarm conditions with details on rate of damage progression for the failure mode. Figure C is a typical report that provides the status of all monitored components for the entire wind farm(s). Due to increased time reporting granularity, the real-time online sensor data provides earlier indication of a component's health status thus allowing operators to identify and take corrective action sooner to improve long-term reliability and reduce lifecycle cost.

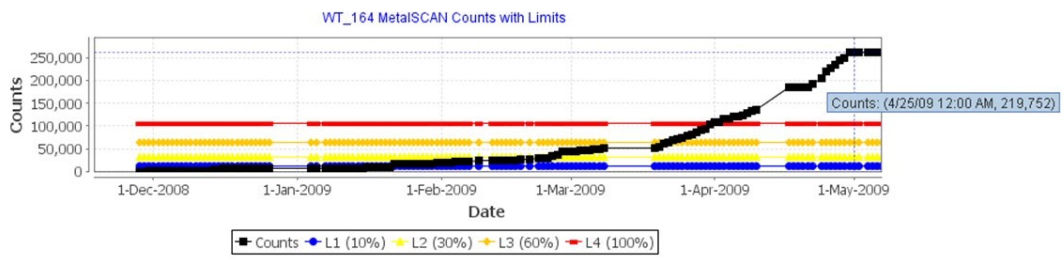
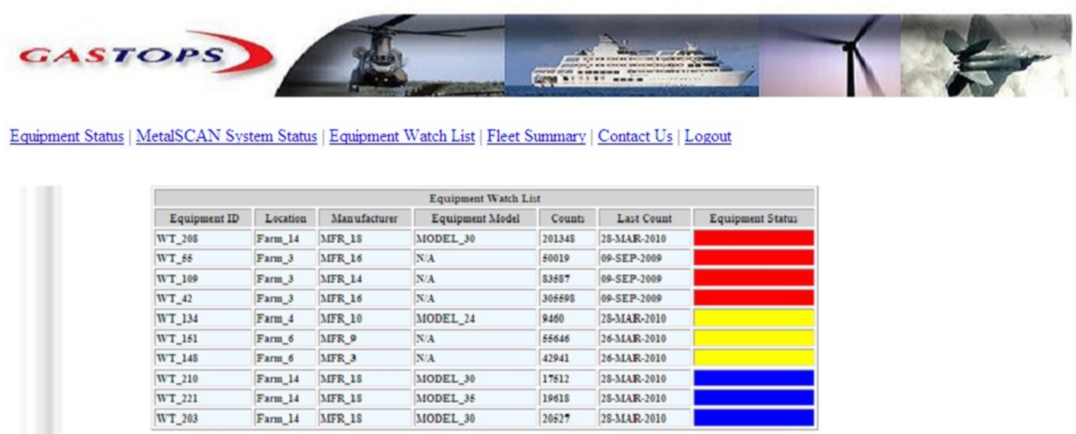


Figure B: Online Wear Debris Sensor Report - Trend Plot with Limits for One Gearbox



Equipment ID	Location	Manufacturer	Equipment Model	Counts	Last Count	Equipment Status
WT_208	Farm_14	MFR_18	MODEL_30	201348	28-MAR-2010	
WT_55	Farm_3	MFR_16	N/A	50019	09-SEP-2009	
WT_109	Farm_3	MFR_14	N/A	83587	09-SEP-2009	
WT_42	Farm_3	MFR_16	N/A	305598	09-SEP-2009	
WT_134	Farm_4	MFR_10	MODEL_24	9460	28-MAR-2010	
WT_151	Farm_6	MFR_9	N/A	55646	26-MAR-2010	
WT_148	Farm_6	MFR_3	N/A	42941	26-MAR-2010	
WT_210	Farm_14	MFR_18	MODEL_30	17812	28-MAR-2010	
WT_221	Farm_14	MFR_18	MODEL_35	19618	28-MAR-2010	
WT_203	Farm_14	MFR_18	MODEL_30	20527	28-MAR-2010	

Figure C: Online Wear Debris Sensor Report - Wind Farms by Over Limit Status

Results Integration

Oil and wear debris analysis results should be integrated with results from other sources of information that also include condition monitoring results whenever possible such as vibration and performance condition indicators. Systems can be configured to integrate various types of condition monitoring data, system configuration data, operational data, and maintenance data from different databases to provide enhanced diagnostics and prognostics information.

Summary

Maintaining proper lubrication and early detection of oil wetted component failures is critical to maximize component life and reduce lifecycle costs of a wind turbine. Oil debris and oil condition monitoring are effective techniques to support this goal. Analysis of the significant amount of data for useful information is provided through offline laboratory or online sensor data processing and reporting tools.

References

[1] ASTM D7917-14 Standard Practice for Inductive Wear Debris Sensors in Gearbox and Drivetrain Applications www.astm.org/Standards/D7917.htm

[2] Toms, L. A., and Toms, A. M., Machinery Oil Analysis—Methods, Automation and Benefits, Chap. 9, 3rd edition, STLE, Park Ridge, IL, ISBN: 978-0-9817512-0-7, 2008. store.noria.com/products/machinery-oil-analysis-methods-automation-benefits-3rd-edition

[3] ISO 17025 General Requirements for the Competence of Testing and Calibration Laboratories. www.iso.org/standard/39883.html

[4] ASTM D7720-11 Standard Guide for Statistically Evaluating Measurand Alarm Limits when Using Oil Analysis to Monitor Equipment and Oil for Fitness and Contamination www.astm.org/Standards/D7720.htm

[5] ASTM D7669-15 Standard Guide for Practical Lubricant Condition Data Trend Analysis www.astm.org/Standards/D7669.htm

RP 509 NERC GADS Reporting Practices

The following recommended practice (RP) is subject to the disclaimer at the front of this manual. It is important that users read the disclaimer before considering adoption of any portion of this recommended practice.

This recommended practice was prepared by a committee of the AWEA Operations and Maintenance (O&M) Committee.

Committee Chair: Bruce Hamilton, Navigant
Principal Author: Mike Curley, Navigant Consulting, Inc.

Purpose and Scope

The scope of "NERC GADS Reporting Practices" describes best practices in reporting data to North American Electric Reliability Corporation (NERC)'s Generating Availability Data System (GADS).

Introduction

Established in 1982, NERC GADS is the industry standard for reporting availability performance data. The system has been invaluable to NERC in helping to assess Bulk Electrical System (BES) reliability issues and trends.

In 2013, GADS became mandatory for conventional generating units 20 MW or larger in size. Before that time, approximately 73% of the conventional generators reported their performance data to GADS. Following mandatory requirements, the number of units reporting to GADS reached 95% of the installed capacity of North America. This did not include any wind or solar generating stations.

Benchmarking is the secondary use of GADS data. NERC and many consultants use GADS data to compare units' performance. For years, conventional generators have used GADS data to drive Continuous Improvement Programs by comparing their performance to industry performance. GADS allows an "apples to apples" comparison of data that is necessary to benchmarking programs.

For details on conventional generating unit data reporting requirements, please visit
www.nerc.com/pa/RAPA/gads/Pages/Data%20Reporting%20Instructions.aspx.

Mandatory Wind Turbine Reporting

For a number of years, GADS collected wind generation on a voluntary basis. The movement to make wind turbine generation mandatory was approved by the NERC committees and the Board of Trustees has approved the following schedule:

- January 1, 2017: The data collection period for voluntary reporting begins.
- January 1, 2018: Mandatory reporting begins for plants with a Total Installed Capacity of 200 MW or larger.
- January 1, 2019: Mandatory reporting begins for plants with a Total Installed Capacity between 100 MW and 199.99 MW.
- January 1, 2020: Mandatory reporting begins for plants with a Total Installed Capacity between 75 MW and 99.99 MW.

The current requirements for collecting data for the GADS wind turbines are listed in a template on the NERC Wind Turbine website at www.nerc.com/pa/RAPA/gads/Pages/GADS-Wind-DRI.aspx. The instructions for completing the template are in the GADS Wind Turbine Generation Data Reporting Instructions Effective January 1, 2017, on the same NERC website.

Many of the outage definitions in the conventional GADS reporting are used with wind. The main differences are conventional GADS uses hours and wind GADS uses wind turbine (WT) hours. “Turbine-Hours” is defined as the time (clock hours) for each WT subgroup is in a forced, maintenance, planned, operating, etc. mode.

Conventional GADS uses consistent definitions and equations developed by the industry (IEEE762) to calculate the key availability metrics. Wind GADS takes these same definitions and equations used by conventional GADS. This data will allow wind generators to compare their performance to others, knowing that when they see a term it has a standard definition and has been calculated in a consistent manner.

Status of Wind GADS as of April 2017

1. Wind Data Reporting Instructions (DRI) Changes approved by NERC's Planning Committee on September 13, 2016.

2. Revised Wind DRI was posted on NERC's website on October 7, 2016. The recent changes included:

- GADS Wind page
- Revision history within the document provides a summary of changes by section.
- Notice to GADS Working Group (GADSWG) – The industry body for monitoring and improving GADS works) and an announcement on the GADS page when available.

3. NERC is contracting with a vendor to create a software program to collect the required wind data as outlined in the recent GADS Wind Turbine Generation DRI. The new software has been reviewed by the GADSWG and is being rolled out.

- Roll out to include industry outreach, training, and registration to access the reporting application.
- Industry outreach by webinars and conference presentations to various wind industry groups.
- Additional outreach via NERC-issued announcements, NERC Regions, and GADSWG. NERC will be presenting three, free GADS Wind reporting training sessions at NERC-sponsored workshops in 2017 as follows:
    - Austin Texas May 4, 2017
    - Salt Lake City, Utah August 10, 2017
    - Atlanta, Georgia October 5, 2017

4. NERC has a new dedicated email for wind questions and comments: gadswind@nerc.net.

5. GADS Wind Reporting application is moving forward and will support data submission, views, and reports/exports.

Highlights of recent activities are as follows:

Purpose	Audience	Delivery method	Timeframe
Testing of Process Training Material	Regional contacts	In-person, instructor-led PowerPoint	Dec. 2016
Testing of Subject Matter Training Material	GADSWG	Webinar-based, instructor-led PowerPoint	Dec./Jan. 2017
Revised Process and Subject Matter Training	Potential GADS Wind users and Regions	In-person and webinar-based instructor-led PowerPoint, including recorded webinar	Feb. and Mar. 2017, plus Oct. and Nov. 2017
Testing of Application Tool Training Material	Regional contacts and GADSWG	Announcement with link to draft training videos on NERC's website with request for feedback	Jan. 2017
Application Tool Training videos	Potential GADS Wind users and Regions	Videos available on NERC's website	Feb. 2017
Train-the-Trainer	Interested organizations	In-person, instructor-led PowerPoint	Q2 or Q3 2017

6. IEEE 762 "Definitions for Use in Reporting Electric Generating Unit Reliability, Availability and Productivity" working group is reviewing the definitions and equations for GADS Wind. NERC requested the IEEE committee reform to look at the definitions and equations for the new wind DRI.

7. If you are interested in speaking with the Chair of the NERC GADS Wind Turbine Generation DRI, please contact:

Mr. Fred "Doc" Beasom
Principal PGD Engineer
NextEra Energy Operating Services, LLC
661-821-3490
Fred.Beasom@NextEraEnergy.com

8. If you are interested in speaking with the Chair of the IEEE 762 regarding WT definitions and equations, please contact:

Mr. Alex Schneider
630-613-3395
ASchneider@Quanta-Technology.com

RP 510 HV Substation Data Collection

The following recommended practice (RP) is subject to the disclaimer at the front of this manual. It is important that users read the disclaimer before considering adoption of any portion of this recommended practice.

This recommended practice was prepared by a committee of the AWEA Operations and Maintenance (O&M) Committee.

Committee Chair: Bruce Hamilton, Navigant
Principal Author: Bill Young, Electrical Consultants Inc.

Purpose and Scope

This scope of “HV Substation Data Collection” focuses on wind farm data collection recommendations specific to the high voltage (HV) substation.

Substation Data Reporting Recommendations

1. Identity Data Offtakers

The first step in setting up telemetry for any new site is to identify all of the internal and external data offtakers telemetry requirements. This includes what data points are needed, what protocols and circuits are required, and when the data is needed. Often the interconnecting transmission owner and/or the Independent System Operator (ISO) will have strict data requirements which require certain live supervisory control and data acquisition (SCADA) telemetry to be flowing to their SCADA system before substation energization and plant synchronization. Once this step is completed, the particular telemetry requirements of each identified data offtaker can be examined to determine the required SCADA tags.

2. Common Substation Components and Recommended Data Tags

2.1. Substation Network/IED Connections

Typically all of the substation relays, control building equipment, and alarms are tied into an remote terminal unit (RTU)/SCADA Gateway/Data Concentrator. Devices can be connected various ways including using serial cables, Ethernet cables, or fiber cables. Some RTUs include dedicated programmable logic controllers (PLC)’s, Windows or Linux computers with SCADA software, or other proprietary devices.

2.1. Substation Network/IED Connections
(continued)

Some RTUs are very simple and can pull all the various SCADA tags together and serve them up to a master device while some RTUs can do all kinds of extra things like math operations, custom logic functions, send emails, etc.

2.2 Transformer(s)

Tag	Description
LOR TRIP	Trip status of the lockout relay associated with this transformer
LOR Coil Fail	Coil failure monitoring of the lockout relay associated with this transformer
Winding Temp	Depending on transformer, there may be multiple temperature alarms available
Oil Level	Low oil level alarm
Sudden Pressure	
Sudden Oil Flow Trip	
87 TRIP	Transformer Differential Relay TRIP indication
Loss of AC Power	Loss of AC power for fans, etc.
Loss of DC Power	Loss of DC control power

Table 1: Typical Transformer Tags

2.3. Breaker(s)

The table below is a set of recommended SCADA tags associated with each high voltage breaker. Other switching devices such as circuit switchers, MODs, etc. will have a smaller subset of these points, potentially only a status feedback.

Tag	Description
VA	A phase voltage of associated BUS
VB	B phase voltage of associated BUS
VC	C phase voltage of associated BUS
IA	A phase current through breaker
IB	B phase current through breaker
IC	C phase current through breaker
P	Real power through breaker
Q	Reactive power through breaker
Breaker\Circuit Switcher\MOD Status	52a Status of breaker\Circuit Switcher\MOD
Loss of close or trip voltage Alarm	
Loss of heater voltage alarm	
Spring Charge Alarm	
Trip Coil 1 Fail	Indication that trip coil 1 has failed
Trip Coil 2 Fail	Indication that trip coil 2 has failed
Trip Indication	Trip indication from associated breaker protective relay
Local/Remote Status	Any local/remote switch status

Table 2: Typical Breaker Tags

2.4. Meter(s)

The tags needed from the substation meters can vary depending on site specific PPA, GIA, ISO, and other requirements. Below is an example typical tag list for a substation check meter. Other tags such as detailed harmonic measurements, line and transformer compensation, etc. may and are often included as well depending on the site requirements.

Tag	Description
VA	A phase to neutral voltage
VB	B phase to neutral voltage
VC	C phase to neutral voltage
VAB	A phase to B phase line to line voltage
VBC	B phase to C phase line to line voltage
VCA	C phase to A phase line to line voltage
Vll AVG	Average line to line voltage
IA	A phase current
IB	B phase current
IC	C phase current
MW	Megawatts. Typically with the convention that the wind farm producing power is shown as positive.
MVAR	Megavars. Typically with the convention that the wind farm producing VARS is shown as positive.
PF	Power Factor
F	System Frequency
kWH Delivered	A counter of kilowatt hours delivered. Typically with the convention that the wind farm producing power is delivering to the GRID. This convention can change site to site depending on other requirements.
kWH Received	A counter of kilowatt hours received. Typically with the convention that the wind farm consuming power from the GRID is received. This convention can change site to site depending on other requirements.
kVh Delivered	A counter of kilovar hours delivered. Typically with the convention that the wind farm exporting VARS to the GRID is delivered. This convention can change site to site depending on other requirements.
kVH Received	A counter of kilovar hours received. Typically with the convention that the wind farm c is received. This convention can change site to site depending on other requirements.

Table 3: Typical Meter Tags

2.5. Control House/Enclosure

Data from the control enclosure provides some critical alarms such as indication of loss of AC power or a fire, etc. It is important to properly monitor these alarms so that site operations can respond in a timely manner before larger problems happen.

Tag	Description
Panel or Summary Alarm	Any panel summary or other summary alarms or protective relay alarms that may be available in the control enclosure. Alarms may be brought in individually or grouped.
Building Smoke Alarm	
Building Hydrogen 1 Percent Alarm	The Hydrogen concentration near the batteries has reached 1%.
Building Hydrogen 2 Percent Alarm	The Hydrogen concentration near the batteries has reached 2%.
Building Door Alarm	The door to the control enclosure has been opened.
Building Battery Charger Summary Alarm	An alarm associated with the battery charger.
Building Battery Charger AC Fail	The AC source to the battery charger has failed.
ATS Normal Source Indication	The automatic transfer switch for the control enclosure is using the normal AC source.
ATS Emergency Source Indication	The automatic transfer switch for the control enclosure is using the emergency AC source.
HVAC Lockout Or Loss of Power	
HVAC Low Or High-Temperature Alarm	

Table 4: Typical Control Enclosure Tags

3. Typical Wind Farm SCADA Components That Tie Into the Substation

3.1. Turbine Network

The various sensors in each turbine connect to a PLC or some type of computer. These devices are typically connected to network switches that all connect back to a central switch. This allows all of the individual turbines to communicate with the Wind Farm Management System/Wind Farm Power Plant Controller (WFMS/PPC). The wind turbine network is typically a fiber optic connected Ethernet network running between all of the turbines and the turbine manufacturer's overall power plant control system, which may be located in the substation control building/ enclosure, its own enclosure, or in a separate operations building. This network is often isolated from the substation network. Often data from the turbine network is not directly pulled from the Substation SCADA System, but often turbine data is exposed via an OLE (Object Linking and Embedding) for Process Control (OPC) server that can be read into the plant historian.

3.2. Wind Farm Power Plant Controller

The wind farm power plant controller is typically a server or combination of servers that control the wind park. Often these are provided by the turbine manufacturer, but there are also setups with third party controllers as well. The PPC is the eyes into the wind farm system. It allows the operations group to see the status of the park or individual turbines, see the various sensor readings on the turbines, control the turbines, and it also keeps the wind park producing in an acceptable range in terms of both MW and MVAR output as defined by any interconnection agreements, ISO curtailments, etc.

Table 5 below shows typical data that the WFMS/PPC may receive from the Substation SCADA System.

Tag	Description
MW Curtailment Set Point	Plant MW Curtailment Signals from the ISO, Market Participant, Plant Owner or other may come through the substation RTU or be directly entered into the plant turbine SCADA system.
Voltage Set Point	If the plant is operating on a voltage schedule this set point may or may come through the substation RTU or be directly entered into the plant turbine SCADA system.
VAR Set Point	This set point may or may come through the substation RTU or be directly entered into the plant turbine SCADA system.
Substation Analog and Digital Values (Power, Energy, Breaker Status, Alarm Status, etc.)	If the plant SCADA system is acting to aggregate all of the alarms and provide a single interface there may be many points coming from the substation RTU.

Table 5: Tags to PPC

Table 6 below shows typical data and commands that the PPC may send to the Substation RTU.

Tag	Description
Number of turbines online	Number of turbines producing power
Number of turbines offline	Number of turbines not producing power
Number of turbines state unknown	Number of turbines with loss of communication
Number of turbines available	Number of turbines that may or may not be running but are available if there is sufficient wind
Gross MW	
Gross MVAR	
Wind Speed	
Temperature	
Pressure	
Wind Direction	
Open/Close Capacitor or Reactor	If there are one or several static reactive devices such as fixed capacitor(s) and reactor(s) there may be one or more tags related to the status and control of these devices.

Table 6: Tags from PPC

3.3. Substation HMI

A Human Machine Interface (HMI) is typically just a computer with software the reads SCADA Tags from a data concentrator or RTU and displays the data in a meaningful way on a screen. HMI's can also allow an operator to have remote control of breakers and other devices. HMI's can replace annunciator functionality by including "Virtual" annunciators and alarms. HMIs can be used to view historical data. Many modern HMI systems allow both local viewing on a dedicated monitor as well as remote viewing through a web page or other mechanism. An HMI is not a required device and many substations do not have them, but if included they can provide quick visibility of what the site is doing as well as summarize any alarms.

3.4. Interface to POI Utility

The interconnecting utility will often require various SCADA tags from the wind farm and often the wind farm owner will want data from the utility such as revenue meter data. This connection may be done in various ways such as over optical ground wire (OPGW) as a direct fiber connect between the utility RTU and the wind farm RTU, a dedicated private phone line, point to point Virtual Private Network (VPN) between customer and utility, etc. THIS CONNECTION IS OFTEN REQUIRED TO BE FULLY OPERATIONAL BEFORE PERMISSION TO BACK FEED IS GRANTED!

Questions to ask about point of interconnection (POI) utility's data requirements:

- What SCADA tags do they require?
- What SCADA tags will the site want from them?
- Will they require any control?
- When do they require SCADA to be fully functional?
- What type of SCADA testing do they require?
- What protocol do they wish to use to communicate?
- How do they want to communicate physically? (e.g. direct fiber, microwave, leased line, etc.)
- Do they require any equipment, rack space, or floor space in the control building?

3.5. Interface to ISO

Depending on the location of the wind farm there may be additional Independent System Operator (ISO) requirements related to SCADA. For example, wind farms in California will be in CAISO territory and wind farms in Texas in ERCOT territory. CAISO, ERCOT, PJM, SPP, MISO, etc. all have varying telemetry requirements, some much stricter than others and some requiring information to be finalized many months ahead of when a new plant will energize. It is very important to understand what ISO requirements may be applicable on any given project early on. ISOs have various SCADA connection requirements as it pertains to the method, protocol, required security and segregation, etc. ISOs take their data VERY seriously. For example, a wind farm can be shut down if all of the required meteorological data is not being properly transmitted to the ISO in some cases.

Questions to ask about Independent System Operator (ISO)'s data requirements:

- What SCADA tags do they require?
- What SCADA tags will we want from them?
- Will they be issuing any curtailment signals?
- When do they require SCADA to be fully functional?
- What type of SCADA testing do they require?
- What protocol do they wish to use to communicate?
- How do they want to communicate physically? (e.g. direct fiber, microwave, leased line, etc.)
- Do they require any equipment, rack space, or floor space in the control building?

3.6. Interface to Owner

Typically the owner will have some type of external data connection to the plant. Commonly a dedicated T1/MPLS or other circuits. There will often be a router and a firewall device between the Substation Network and the outside world. The firewall helps secure the Substation Network and meet NERC requirements.

3.6. Interface to Owner
(continued)

Questions to ask about Owner SCADA data requirements for the Substation:

- What SCADA tags do you require?
- Do you require remote breaker control?
- What type of SCADA testing do you require?
- What protocol do you wish to use?
- How do they want to communicate physically (e.g. direct fiber, microwave, leased line, etc.)
- What additional floor space will you need for IT or telecom equipment?
- How often is this data needed?
- How will this data be used?
- How will critical alarms be separated from non-critical alarms?

Conclusion

The SCADA tags listed throughout this recommended practice give a good overview of the tags needed to effectively monitor a high voltage substation as well as some of the common tags needed for the various data offtakers that typically connect to the substation. It is important to review the particular requirements on a site-by-site basis as there are many factors that can play into the different data requirements. What makes sense for one site does not always fit for another.

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