Maintaining Substation Reliability Using an Asset Management Strategy

*From **Electricity Today**, October/November 2000*

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As a result of economic pressures caused by deregulation, utilities are looking at new ways to approach the business of operating and maintaining their assets. In particular, one utility has taken a look at managing their substation assets as if they were stocks in a portfolio. Like financial managers who try to maximize return-on-investment for each asset in a client's portfolio, substation maintenance managers try to maximize the value of each task. This is done through careful consideration of the condition of each asset and its ability to produce revenue. Such an approach requires a deep understanding of both the criticality and the reliability of each asset.

The asset management strategy also requires a deep understanding of the impact of failures on the overall business picture. Currently, this utility depends heavily on predictive maintenance assessments conducted periodically on the equipment. This approach adds value to the maintenance work that is actually conducted on each asset by ensuring that the asset actually needs the service. This approach has the effect of limiting the overall work scope accomplished on each asset and ensures that only necessary work is accomplished.

This utility has reviewed business practices in other competitive industries to understand how these companies manage the assets associated with their business. Companies in competitive industries, such as those found in petrochemical and chemical process, have employed this concept of asset management for many years. One characteristic that separates the top performers in these competitive industries is the use of data and analysis to drive decisions.

Types of RCM

Two major schools of thought exist for RCM Analyses. One school (and probably the most popular) is promoted by John Moubray in his book entitled: 'Reliability Centered Maintenance II'. The book takes the 'component-based' position where all decisions about the maintenance strategy for a piece of equipment are based on the component taken 'within its operating context'. To fulfill this requirement, a component-based approach needs to account for differences in environment and process. (Same component, different conditions.)

The other school of thought suggests that the production unit is broken down into systems and that only RCM tasks that mitigate system failures be considered. This approach has several advantages over the component-based approach, but has some disadvantages as well.

Streamlined RCM

A natural solution to this dilemma is to shorten or streamline the process. One streamlined approach requires the use of pre-defined templates, where the user selects from a list of tasks based on equipment type. The Electric Power Research Institute (EPRI) has experimented with this approach at some utilities with varying levels of success. This template approach is different from principles in RCM II (Moubray) in that analysis is done on the equipment 'within its operating context'. The templates that are available only address asset types, and do not take location into account.

RCM Procedures

RCM has the reputation of being tedious, complex and time consuming. This depends upon the level of sub-component upon which the failure mode analysis is done. A complete analysis would look at actual and potential failures for each sub-component (down to the nuts and bolts!). Some people think that this is extreme and most practitioners would limit the analysis to the first sub-component level. Below is the general four step procedure used to carry out RCM Analysis.

Step 1 System Definition:
Critical Asset Identification

System Based Approach

The system-based approach to RCM requires practitioners to identify critical processes or units. A critical system is one where a failure of that system causes a failure of the production unit or process. To conduct a system analysis, the analyst needs to identify system boundaries that dictate which components belong to which system. In some cases, the system definition is simple and is limited by the physical boundaries.

In order to determine criticality of the system, the analyst must understand what happens when system failure occurs:

- Does unit fail if the system fails?
- Define system function: What function does the system perform?
- Define system criticality: Is the system critical for operation, or can we operate the plant or circuit without this system? Does the system contain redundancies or backups?
- Define each functional failure: For each functional failure, describe ways in which it affects the overall system or other components.
- Does system fail if a component in the system fails?

Component Based Approach

The component-based approach, specified in reference 2, looks at each asset within its operating context and attempts to answer the following questions:

- Is failure hidden or evident?
- Does failure cause safety problem or potential loss of life?
- Does failure cause environmental problems?
- Does failure cause loss of production?
- Determine component criticality
- Does production unit fail if the component fails?

Step 2 Failure Modes and Effects Analysis

The next step in Reliability-Centered Maintenance is to conduct a Failure Modes and Effects Analysis (FMEA). The Failure Modes and Effects Analysis is a powerful tool that helps analysts to understand what causes failure and, more importantly, what happens when certain types of failures occur. Many advanced maintenance strategies employ this methodology for thinking through potential problems. In some cases, the identification of critical failure modes can be addressed by changes in design. In other cases, a regular material replacement strategy is most cost effective at preventing failures.

To conduct the FMEA For each component contained within the system, the analyst needs to answer the following questions:

- What are the functions and associated performance standards of the asset within its present operating context?
- In what ways does it fail to fulfill its functions?
- What causes the functional failure?
- What happens when each functional failure occurs?
- In what way does each functional failure matter?
- What can be done to prevent each failure?
- What if a suitable preventive task cannot be found?

Step 3 RCM Task Development

Once the FMEA has been completed, the analyst has two analysis options for selecting RCM Failure Mitigating Tasks: System-Based Analysis or Component-Based Analysis. For system based analysis, the analyst needs to develop tasks that only preserve system function. This approach assumes that redundant equipment, contained within a system, is not critical with a 'run to failure'strategy applied. For component-based analysis, the analyst needs to develop tasks that will mitigate or diminish the effect of the failure mode identified with FMEA.

Both approaches result in the specification of a task type. The task types for this analysis are as follows:

- Scheduled On-Condition Task
- Scheduled Restoration Task
- Scheduled Discard Task

RCM Task Definition

For each failure mode identified, a task needs to be developed that conforms to the following criteria:

- Will the task effectively mitigate the failure?
- How often does it need to be performed?
- Is it worth doing?
- What is the cost?
- What is the benefit?

Each RCM task is subjected to the above reasoning to ensure that improved reliability goals and reduced costs are met.

Step 4 Task Comparison
At this point, the analyst needs to compare existing tasks with PM Tasks that already exist for the equipment under study. In some cases, existing tasks may be part of the maintenance of the equipment. The RCM analysts recommend adding new tasks or modifying existing tasks. Analysts may delete existing tasks, provided that they have proven to be ineffective. To know if a particular task has been effective, an analyst need only review past work order data.

To facilitate RCM Analysis, work order data, asset data, functional location data, condition analysis (predictive) data and FMEA and RCM task development need to be brought together into a single computing environment. All of these steps can be configured in Meridium to individual company specifications. The following discussion describes how the work order analysis is conducted.

Using Work Order Data to Estimate Reliability

Data Requirements
Table 1 gives a general guide for the type of information needed to conduct reliability analysis using work order data from a computerized maintenance management system.

Analysis Methods:
Linear Estimations
Measurements of mean time between failures (MTBF) and other reliability measures can be calculated directly from the failure records. A number of calculations are used, but the most common is simply to specify a particular period of time (typically one year) and divide by the number of failures in the period. Some calculations will take the number of pieces of equipment in the population into account while others allow the interval to be defined by the first failure and the last failure. This approach suffers from a lack of consistency in the data and methods used, therefore, comparisons to standard values, as a basis for decision-making is difficult.

Statistical Estimations
Distribution and Growth Analyses are generally considered more advanced and behave more consistently than linear estimations. Distribution Analyses in-clude Weibull, Normal, Lognormal, Exponential, and many others. Each distribution type has a particular application, but the most flexible and most frequently used is the Weibull analysis.

Weibull analysis not only gives the failure rate but also the failure pattern, either infant mortality, random failures, wear-out failures or rapid wear out.

Another popular approach to reliability analysis is Reliability Growth Analysis. Growth is used to detect changes in the failure rate. This is particularly useful for RCM. Growth models can be used to measure improvements in the reliability of assets that have been subjected to RCM. Examples of Weibull and Growth analysis of substation equipment are provided later in the paper.

Corrective actions
Reliability Analysis can be a guide to most common problems experienced with substation equipment. Among these types of problems are:

Equipment design problems can be identified with queries of failure modes by equipment type. This process can identify commonly failed components among a population of similar equipment.

Equipment material problems: In some cases, the reliability analysis can point to a deficiency in materials or in material selection. These problems often behave as 'early wear-out'failure mode, which is easily identified with a Weibull analysis.

System design problems are identified using reliability analysis where the wrong piece of equip ment was used in the design of substation and frequent failure of this equipment occurs as a result. Failures of similar systems can be subjected to the same analysis procedures that are conducted at the asset level. Problem systems can be identified by low values for MTBF and compared with other similar systems.

Construction problems often show up during a start-up, after a repair period, turnaround or outage has been accomplished. These problems are often the result of inadequate or improper construction techniques and material failures.

Identification of unsatisfactory maintenance procedures, like construction problems, inadequate or unsatisfactory maintenance procedures can be identified and separated by comparing similar components between systems maintained by different crews. The level of training, adherence to standard procedure and attention to detail all play a role in the quality of repairs provided by the operating and maintenance crew.

Identification of improper operating procedures: Wide temp erature swings and inadequate level control can lead to poor product quality and reduced equipment life. Failures caused by inadequate operating procedures manifest themselves as premature 'wear-out' modes and are easily identified through Weibull Analysis. Since operations problems usually involve critical equipment, cost of resulting failures will typically run higher than normal maintenance problems.

Inadequate preventive maintenance activities: Maintenance-preventable failures can be identified through work order backlogs and an analysis of spare parts usage. While usage of spare parts does not ensure their correct installation, inadequate PM activities can show up in a reliability analysis as uncharacteristically low values for MTBF for equipment of this type, as compared with manufacturer's or industry standards.

Key Performance Indicators

Software programs, such as Meridum's Enterprise Reliability Management System, offer users an opportunity to develop and track key performance indicators. Key performance indicators allow companies to compare performance with other companies or internal departments within the same company. This kind of analysis can point to specific reliability problems with certain areas or show that generic problems persist across an entire company.

Some of the key performance indicators available in Meridium are:

- Mean Time Between Failures (MTBF) by Equipment type
- Mean Time Between Failures (MTBF) by Manufacturer
- Average Repair Cost by Equipment Type
- Average Repair Cost by Manufacturer
- Average Number of Failures and Repairs by Equipment type and Manufacturer
- Average Downtime by Equipment Type and Manufacturer
- Cost of Unreliability by Unit, Equipment Type and Manufacturer
- Monthly MTBF (rolling 3 or 12 month averages) by Asset Type and Manufacturer
- Monthly Total Number of Failures Equipment Type and Manufacturer
- Monthly Average Total Cost Equipment Type and Manufacturer

Case Histories

The following examples show the analysis of CMMS data using Meridium Reliability Analysis tools. These examples are based on real data extracted from work order information. The first example gives a Weibull distribution of transformer failures.

Without getting into the details about how a Weibull Analysis is constructed, suffice to say that good Weibull analysis results depend on clean and complete data that can be organized by failure cause. Reference (5) gives the Weibull parameters for comparison to industry data. This kind of analysis can be conducted on different kinds of equip ment, groups of equipment or even systems or circuits.

Growth also gives a good estimate of the current MTBF (failure rate) and can tell the user if reliability is improving or declining. Unlike Weibull, Growth models can include data from various failure modes and is a good alternative when the failure causes are unknown. Growth models parameters can be used in forecasting failures.

Predictive Maintenance Assessments

Another powerful method that is used as an overall asset management strategy is to periodically inspect substation equipment for signs of deterioration. Tasks designated as 'Scheduled On-condition' tasks need a condition inspection in order to trigger the on-condition task. Many have employed the application of predictive maintenance methods for substation equipment. Among the Inspection methods used are:

Infrared imaging requires the use of an infrared camera to detect areas of abnormally high temperatures. These images provide a two dimensional view of the temperature distribution of substation equipment. This technology is particularly effective for substation equipment because a key failure mode for high voltage equipment is the corrosion of contacts and deterioration of high voltage connections. Prior to failure, elevated temperatures are experienced at or near the connections.

Partial discharge detection requires the use of an acoustic emission sensor coupled to a suitable electronics-measuring device such as a high-speed oscilloscope. Ultrasonic activity in the 100 to 200 kilohertz band is often indicative of partial discharge conditions existing within a transformer. The short duration pulses due to electrical arcing generate this high frequency acoustic activity.

Portable Hydran units measure the hydrogen concentration in a sample of a transformer or circuit breaker's insulating oil. The Hydran unit detects the presence of gaseous hydrogen in the sample that is indicative of partial discharge arcing. The portable unit provides the results of the analysis, right in the field, to inspection personnel.

Acoustics and Vibration detection equipment can be used to detect transformer core looseness and core misalignment. High levels of acoustical energy at 2 times line frequency (120 Hz) and harmonics is indicative of transformer core misalignment. Sub-harmonic (below 60 Hz) random vibrations can be measured with a vibration transducer mounted on the casing of the transformer.

This kind of testing can reveal core looseness, though this approach is still experimental.

Dissolved Gas Analysis is usually conducted on samples taken from oil filled transformers and breakers. Laboratory analysis of insulating oil samples is accomplished using a gas chromatograph (GC), which can measure the chemical composition of the sample. While different labs perform different tests, among the gasses usually checked are CO, CO2, Hydrogen and Acetylene. Results of the presence of abnormal gas concentrations are given in part per million (ppm) or percent (%).

The advantage of this method is that these values can be measured and trended over time, while the disadvantage is that the analyst must wait, sometimes as long as several days to get the results of the analysis. Two detection methods are employed to detecting transformer gassing:

- Simple: comparison of gas concentrations to a set limit, and;
- Complex: calculated values based on multiple gases or changes over time

Cost Benefits

Method

Reference 7 provides a guide for calculating the benefit associated with a work order that prevented a failure, similar to the one shown below. The example below shows the estimated benefit from an Infrared Thermography scan of a transformer.

Calculations

The calculation is based on assumptions about what could have happened if the fault goes undetected. Worst case, probable and possible scenarios are estimated and assigned appropriate probabilities.

Estimated costs are discounted by the probability of occurrence and actual costs are subtracted out to get the 'Total Cost Benefit'. These benefits are then linked back to individual work orders where aggregates across equipment types, areas and business units can be calculated.

Conclusions

By minimizing unexpected breakdowns, we maximize return on capital investment. Asset criticality, reliability, and condition assessment plan key roles in helping to manage risk.

By conducting reliability centered maintenance as an overall strategy for critical asset management, a powerful enterprise system, like Meridium, is necessary to bring together the information from across the enterprise to make effective decisions.

Effective informed decisions are the key to minimizing risk of failure and effectively managing the reliability of substation equipment.

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*Reprinted from **Electricity Today** magazine.*