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Risk Based Power Transformer Fleet Management Expert System Condition Assessment Tools

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SUMMARY

Risk assessment and management are key elements in any well developed asset management plan and an increasing number of utilities are devoting resources to the tasks of improving their understanding of and capability to make risk-based decisions. Consequently there is growing interest in the tools and methodologies required to better assess equipment performance and risk and provide quantitative information to drive the asset management decision processes. In addition, risk and performance assessment tools can be integrated into smart grid implementations, turning smart grid generated equipment status data into information and providing timely equipment and system condition and risk exposure metrics to improve operating reliability and efficiency.

A suite of integrated risk and performance assessment tools for substation equipment has been developed and successfully demonstrated with the application of algorithms to power transformers and high voltage circuit breakers. This analytics based approach to transformer intelligent fleet management has two components. One considers a failure rate, derived from life analysis utilizing EPRI's Transformer Industry-wide Database, appropriate for the unit in question. The other provides a condition assessment of the particular unit. This condition index quantifies how this unit is both performing and aging relative to others in its class. Together they provide a risk assessment for individual transformers and an integrated fleet view. The approach supports effective equipment planning, maintenance, refurbishment and replacement decisions by providing the require knowledge about asset performance and the ability to predict future performance. These risk based analytics can be applied to a variety of equipment decisions to minimize equipment lifecycle costs of replacement and maintenance including failure costs.

Ultimately, these risk and performance assessment tools could be integrated into smart grid implementations. As the smart grid moves from a conceptual stage to a functioning system, there will be more equipment and operational data available that could be utilized by risk assessment processes to generate information to make performance and risk assessment processes more dynamic. In addition to supplying up-to-date assessment information to asset management, such an implementation could provide information about current equipment and system risk exposures useful for making system operations decisions that could improve operations and reduce risk.

KEYWORDS

Risk Assessment
Asset Management
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The Challenge

In today's business environment, utilities are faced with numerous asset management challenges including aging infrastructure, budget constraints, uncertain future investment levels, internal competition for capital dollars, greater regulatory scrutiny and diminishing expertise. In general a utility's success is based on its financial performance, relationship with regulators and customer satisfaction level. In turn these measures of success are gauged by key performance metrics such as safety, capital expenditures, operations and maintenance expenses, system and equipment reliability and availability. Equipment performance is the fundamental underlying factor affecting the utility's ability to achieve and maintain expected levels in all of these key performance metrics. Analytical tools for improving equipment performance are essential for successful asset management.

Asset managers are faced with a host of conflicting performance objectives. In the case of substation equipment, the major conflict is between the desires for high reliability and availability and low maintenance and capital costs. Traditionally, utilities managed equipment performance by preserving equipment functions. However, an asset management approach and the challenges of maintaining performance with limited resources require utilities to manage by assessing and mitigating risk. Mathematically, risk can be described as a function of the probability or the likelihood of an event occurring and the resulting consequences of the event. Practically, risk can be quantified as a function of equipment condition, its application and criticality. Algorithms and methodologies that can assess and project operational risk allow utility managers to make better informed decisions. Key to the methodologies described below is a set of algorithms that provide information based on actual equipment condition. These algorithms have been designed to maximize the value of data most utilities already collect and can be implement in a variety of utility specific applications.

The primary applications of substation equipment performance assessment methodologies and tools are to support decisions both for the fleet as a whole and for individual units. Best-practice maintenance and asset management decisions are based upon the ability to understand risks associated with actual equipment condition and performance. There are four key steps are necessary to understand these risks.

- Assessing existing performance
- Specifying required performance
- Projecting future performance
- Understanding how to bridge gaps

Therefore, effective equipment planning, maintenance, refurbishment and replacement decisions require knowledge about asset performance and the ability to predict future performance. To be well informed about equipment's expected performance; one must analyze both the asset's individual historical performance data and that of other assets of similar characteristics or type. Similarly, fleet management decisions are best made with an understanding of expected performance of the group. Analytics for Substations Asset Performance (ASAP) addresses both requirements.

ASAP for Transformers

Perhaps the substation components of most interest for performance and risk assessment are power transformers. These are obviously critical operating components in the power system, are often the most expensive, and require long and disruptive repair and replacement procedures. Consequently, the initial ASAP focus was the development of risk based analytics aimed at assessing a transformer's condition and ultimately the risks associated with its operation. ASAP's intelligent fleet management for transformers addresses several aspects of the fleet risk management challenge: emergent issues, maintenance strategy, monitoring strategy and long term replacement (Figure 1). EPRI's Intelligent Fleet Management approach provides decision support for all while integrating the failure risk and loss of life.

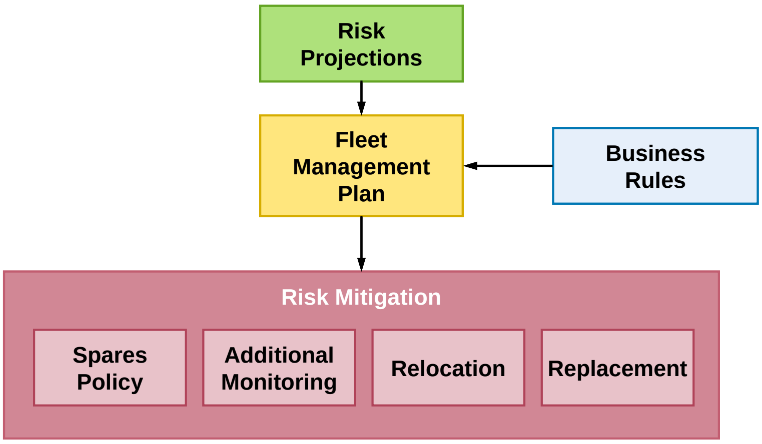

Figure 1. *ASAP informs a complete fleet management plan.*

The primary focus for both maintenance and asset managers is the risk assessment for transformer failure. Intelligent fleet management has two components. One considers a failure rate, life analysis utilizing EPRI's Transformer Industry-wide Database, appropriate for the unit in question. The other provides a condition assessment of the particular unit. This condition index quantifies how this unit is both performing and aging relative to others in its class. Together they provide a risk assessment for the transformer (Figure 2).

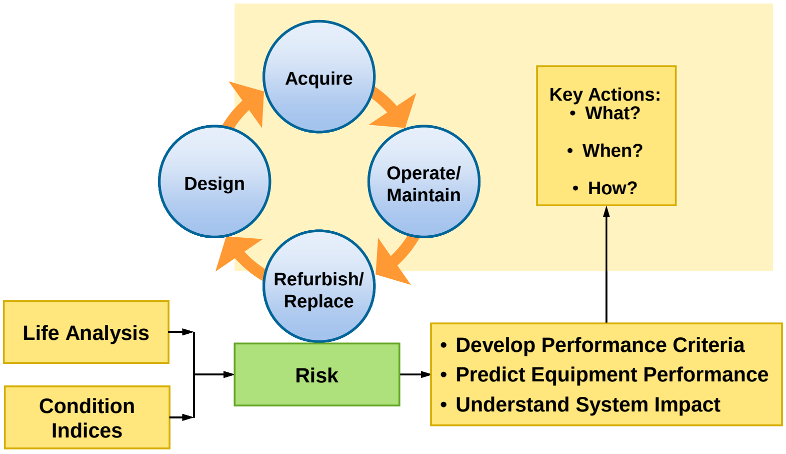

Figure 2. *Transformer assessment considers both life analysis and current condition.*

The discussion in this paper focuses on the condition index algorithms. The methodology ranks transformers and enables identification of high-risk units for more detailed testing and analysis. Focusing critical resources on high-risk units is far more cost-effective than providing the same level of review for an entire transformer fleet, in which most units are in good operating condition. This approach uses readily available data from utility historical records, computerized maintenance management systems, and test results.

Transformer Condition Assessment

The past two decades have seen a tremendous growth in the amount and types of data that can be collected and made available for the monitoring and assessment of transformer condition. However, periodic Dissolved Gas Analysis (DGA) is routine practice for power transformers and most utilities have years of DGA data readily available. The assessment methodology follows a Pareto principle and identifies the small number of units that require detailed review by using this data as the initial screen for transformer condition assessment. Less readily available data and more expensive tests are directed only at units identified as potentially at risk (Figure 3).

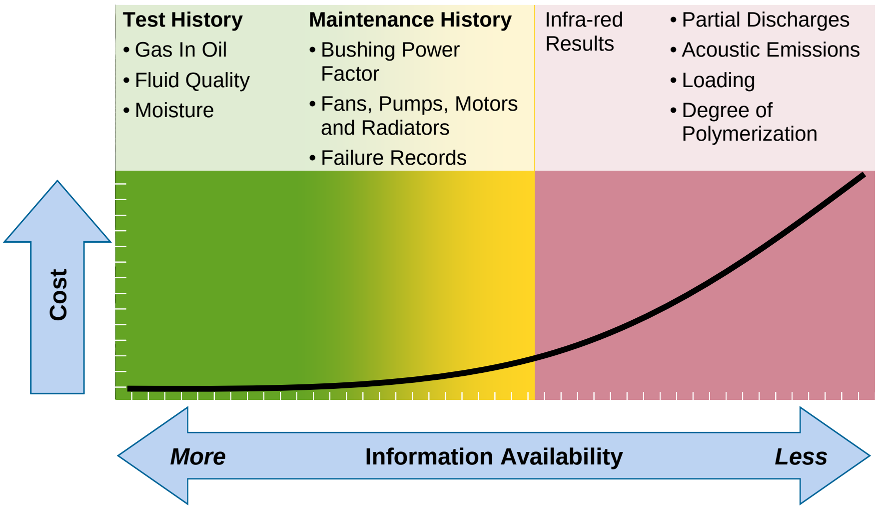

Figure 3. *ASAP extracts maximum data from more readily available data.*

The transformer analytics developed start with a set of rules based on gas levels, gas trends, combinations of gasses (patterns) and their trends along with additional rules to determine whether or not a particular failure mechanism in the transformer exists. The approach utilizes expert knowledge of power transformer failure mechanisms and dissolved gas analysis, collected over decades of field experiences captured in a rule-base expert system.

There can be any number of failure mechanisms, arranged in any fashion that conforms to the physical state of a transformer. New failure mechanisms can be added to the rule base at any time, without the need to adjust prior rules. Failure mechanisms can be as broad as "thermal" or as fine-grained as "winding insulation deterioration – thermal degradation." Fine-grained classifications provide more information to the user, but require more rules to differentiate between the individual failure mechanisms.

The expert system algorithms assess both normal aging degradation and abnormal conditions and the tool provides two corresponding classes of main body condition indices. One, the abnormal index, corresponds to shorter term risk, potentially pre-fault, conditions. Abnormal Degradation identifies units that may be experiencing unexpected problems due to manufacturing defects or operating issues. This index has three components corresponding to the belief in the suspected failure mechanism classification: thermal, electrical and core. The other condition index, Normal Degradation, gauges the longer term, wear-out risks. This index identifies units that may be approaching end of service life through expected degradation of paper from normal operation over an extended time. Both sets are combined to assess the overall condition of the transformer main body. A separate set of rules and index is used to assess any load tap changer condition.

Diagnostic algorithms and expert system software transform the data into useful information for making decisions. The condition index algorithms maximize the value of data most utilities are already collecting. Results for individual units and the fleet can be viewed and analyzed. Individual assessments can be aggregated to provide a methodology for managing the entire fleet. Figure 4 shows the four indices for a portion of a utility transformer fleet sorted by normal degradation.

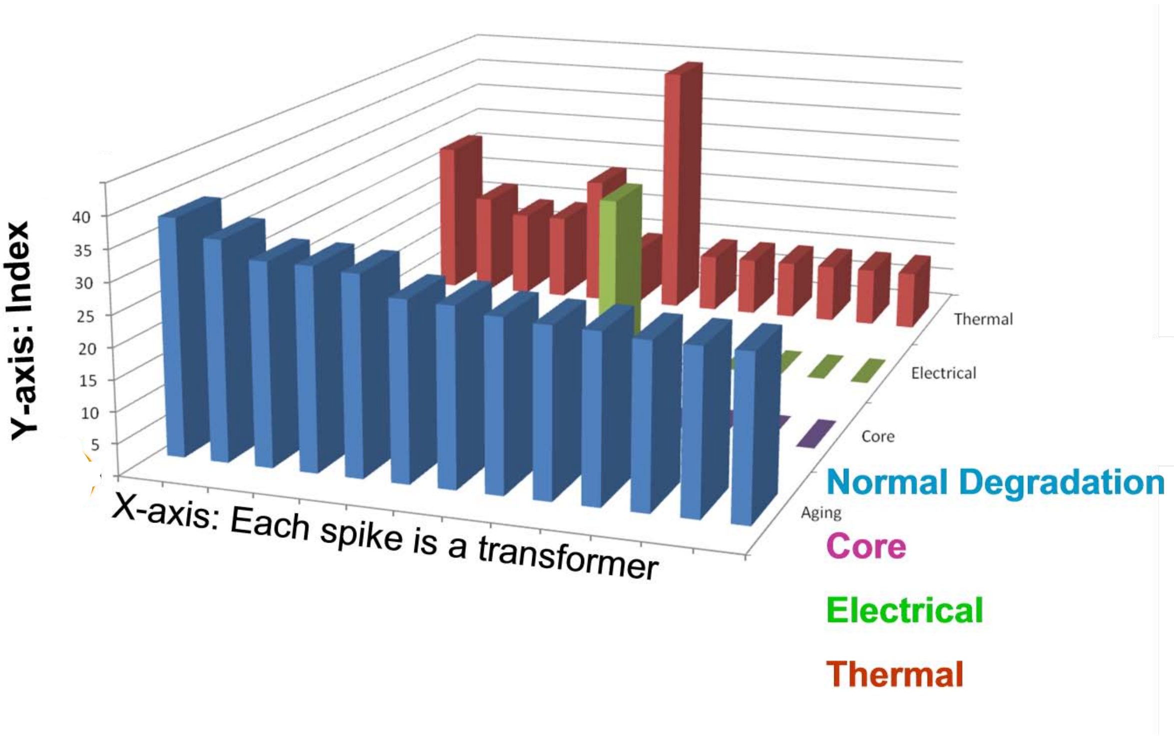

Figure 4. *Normal and abnormal indices for units selected for further review.*

Condition Index Validation

The normal degradation index is of particular interest to asset managers. Transformer insulation systems are largely made up of paper and a dielectric fluid. The condition of the paper insulation system generally defines the economic service life of a transformer, as it is not replaceable. The condition of the insulating paper is determined primarily by its remaining mechanical strength, which tends to decrease more rapidly than electrical strength. A good measure of the mechanical strength is a measurement of the Degree of Polymerization (DP) of paper samples taken throughout the insulation system. This is a destructive test and can generally only be done when a transformer is retired.

Consequently, assessing the amount of degradation of an in-service power transformer paper insulation system is difficult. There is no direct test that can be performed on an operating transformer to give a precise, definitive measure. The newly developed algorithms use a combination of evidence to arrive at a likelihood of degradation. And, as a development step, these algorithms require some method to validate and verify performance of the algorithms. This would be needed for any test or methodology to assess the condition of power transformer insulating systems.

To substantiate the algorithm calculations and recognizing the industry need for the ability to gauge the effectiveness of condition assessment methods, EPRI began aggressively pursuing opportunities to gather paper samples from transformers that have failed or are being retired. EPRI has had fifteen such opportunities over the past three years, while additional opportunities continue to be identified.

Once the paper samples are analyzed to determine the DP of the transformer's insulation system, these measurements are recorded in a database, along with the transformer's nameplate information and any available condition data. This database can then be utilized to verify any condition assessment methodologies that utilize this data. The agreement between the physical measurement of DP and any calculated condition assessment provides a measure of the accuracy, and therefore the usefulness, of the calculation algorithms.

EPRI's ASAP intelligent fleet management algorithms were applied to the transformer DGA results corresponding to the paper samples collected. The EPRI algorithms produce a Normal Degradation Index, which is a number between 0 and 1.0 that indicate the likelihood that a given transformer's insulation system is in a degraded state. The Normal Degradation Index was calculated for each transformer included in the Degradation Database. There is excellent correlation between the measured DP and the Normal Degradation Index for the 15 data points, as shown in Figure 5.

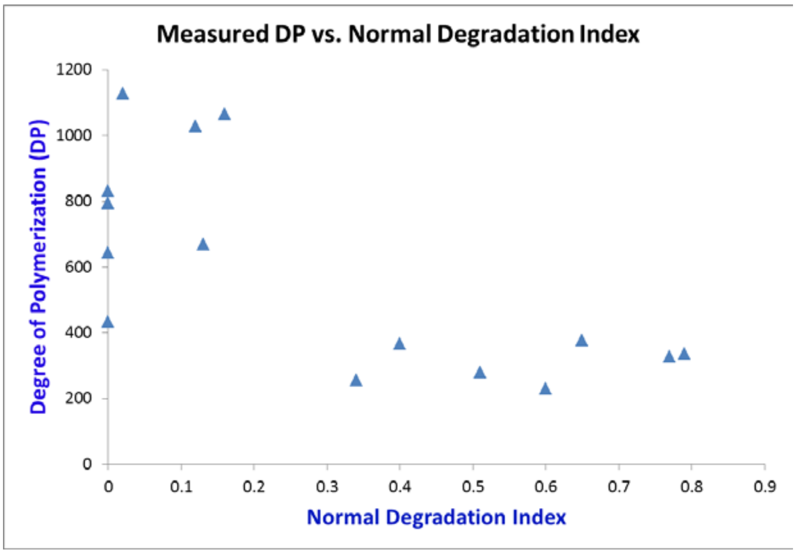

Figure 5. *Measured degree of polymerization versus normal degradation index*

The excellent results demonstrated with the Transformer Degradation Database indicate that the new methodology may provide a dependable assessment of current insulation system condition and insights to a transformer's remaining useful service life. Such information about in-service transformers, derived from readily available information, will be valuable for assessing fleet condition, selecting units for retirement and planning capital investments.

While fifteen data points is a significant step forward, EPRI continues to pursue new opportunities to develop more cases to add to the Degradation Database. EPRI members are encouraged to consider working with EPRI to gather the relevant samples and information as their transformers are retired. In addition to paper samples, an oil sample should be taken prior to removing the transformer from service, so that it may be analyzed both for quality and for chemical markers of degradation.

The risk-based analytical methodology provides a smart approach to substation asset management that can help utilities avoid equipment failures, reduce maintenance costs, enhance O&M decision-making, improve power system reliability, and increase asset utilization.

Conclusions

The initial ASAP focus was the development of risk based analytics aimed at assessing a transformer's condition and ultimately the risks associated with its operation. ASAP's intelligent fleet management for transformers addresses several aspects of the fleet risk management challenge: emergent issues, maintenance strategy, monitoring strategy and long term replacement. ASAP transformer intelligent fleet management has two components. One considers a failure rate, derived from life analysis utilizing EPRI's Transformer Industry-wide Database, appropriate for the unit in question. The other provides a condition assessment of the particular unit. This condition index quantifies how this unit is both performing and aging relative to others in its class. Together they provide a risk assessment for individual transformers and an integrated fleet view.

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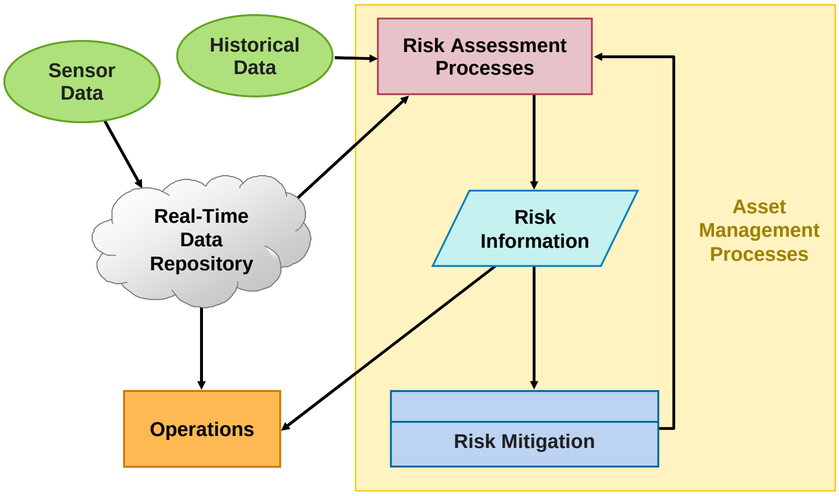

Figure 6. *ASAP smart grid integration*

Risk assessment and management are key elements in any well developed asset management plan, but the information provided by ASAP's risk-based algorithms can be utilized across many function within the utility as shown in Figure 7.

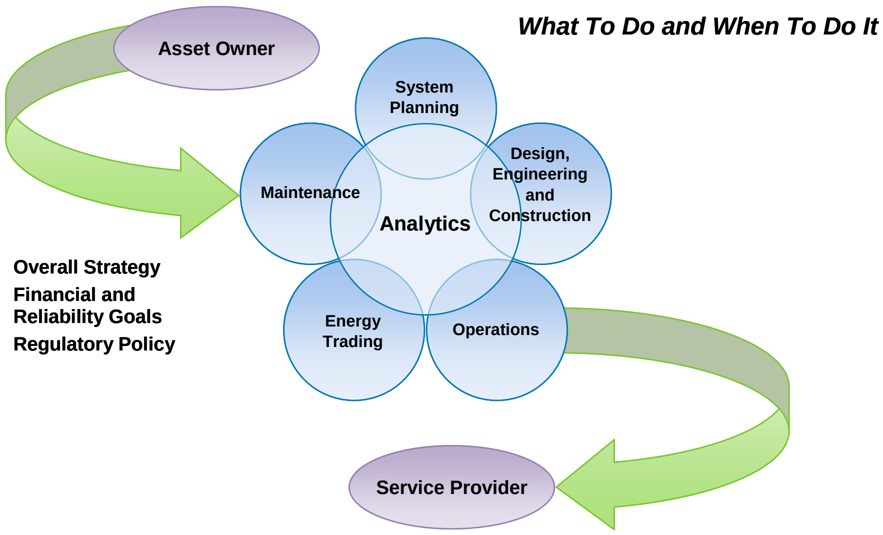

Figure 7. *Applying analytics to utility functions*

The approach supports effective equipment planning, maintenance, refurbishment and replacement decisions by providing the required knowledge about asset performance and the ability to predict future performance. These risk based analytics can be applied to a variety of equipment decisions to minimize equipment lifecycle costs of replacement and maintenance including failure costs. Numerous utilities have used this approach to focus limited resources on the right equipment, thus reducing risk and maintaining power system reliability in a cost-effective manner.

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