TRANSMISSION AND SUBSTATIONS

CONDITION BASED REPLACEMENT FOR T&D ASSETS

Introduction

Utility transmission and substation (T&S) asset managers striving to maintain defined service levels within resource constraints face numerous challenges. A principal challenge is deciding if, or when, to replace assets. In the past, individual equipment replacement decisions were often based on age, excessive maintenance, or poor reliability or availability. More recently, there has been a trend towards a condition-based replacement (CBR) approach. In such an approach, the equipment condition drives the replacement decision. Potential benefits of CBR are avoiding the capital expenses of replacing equipment with significant remaining service life based on arbitrary criteria such as age, while avoiding the costs associated with unreliable operation of equipment in a significantly degraded state.

Implementing condition-based replacement requires:

- Selection of equipment performance and condition metrics
- Determination of effective and economic measurement and collection of the metrics
- Setting a threshold for action based on the assessed metrics

Asset condition assessment can help ascertain whether assets have degraded below acceptable performance levels. The decision on what metric level below which some action is required is a function of the utility's risk tolerance. An asset's condition can be assessed through continuous monitoring, routine inspection and assessment or using analytics to infer condition based on readily available data (design, historical maintenance, operations and test results (material and diagnostic). Given the scarcity of defensible transmission equipment reliability data, often asset condition metrics are used instead of failure probabilities for risk measurements. Hence, asset condition may also serve as an important input in risk-based asset management decisions.

Contents

Introduction 1
Industry Challenge 2
Industry Trends in Asset Condition Replacement 2
Circuit Breakers 2
Power Transformers 3
Wood Poles 4
Overhead Transmission Line Conductors 4
What is EPRI Doing? 5
Conclusion 6
References 6

Industry Challenge

The following challenges motivate Transmission companies to consider condition-based replacement strategies:

- Need for sound technical basis for decision making
- Improved forecasts of capital and operations and maintenance (O&M) cash flow
- Reduced unplanned expenses and increased benefits and value of planned work
- Effective dissemination of information to multiple stakeholders in a systematic and repeatable manner
- Improved reliability and availability through reduced reliance on reactive approaches

Industry Trends in Asset Condition Replacement

The following will provide a better understanding of how several utilities make condition-based replacement decisions for circuit breakers, power transformers, T&D wood poles and transmission line conductors. Challenges to CBR implementations and what EPRI is doing to overcome the challenges will be discussed.

Circuit Breakers

Results of a recent EPRI survey of over 30 transmission companies shows that utilities identify circuit breaker replacement candidates based on the following criteria – safety, condition, reliability/availability, ownership costs (maintenance, unavailability of skills, spares availability etc.), age, environmental impact and asset health index trigger. Of these criteria, circuit breaker condition had the second highest importance. 50% of respondents have a condition assessment methodology in place to help identify circuit breaker replacements. Some supplied description of the process and factors. For example:

- Utility 1 relies on the following steps to identify circuit breaker replacement candidates based on condition:
  - Operational Tests with every scheduled maintenance.
  - Contact Resistance and Insulation Resistance done every or every other scheduled maintenance.
  - Timing Test done every or every other scheduled maintenance.
  - For gas breakers, moisture tests are done on an "as indicated" basis. Purity tests can be performed on an as needed basis.
  - For OCBs, Dielectric and Oil Color tests are done on an "as indicated" basis.
- Utility 2 relies on the following inputs to better understand breaker condition and identify replacement candidates:
  - Number and severity of fault operations based on the manufacturer overhaul recommendations
  - Age of breaker
  - Availability of spare parts
  - History of non-scheduled maintenance
  - Technical Service Bulletins (TSBs)
- Utility 3 uses three complementary approaches to determine the need for maintenance or replacement of a particular circuit breaker or class of circuit breaker:
  - The first approach uses in-service monitoring and out of service diagnostic tools and tests to determine various circuit breaker condition related parameters.
  - The second approach uses a circuit breaker maintenance ranking software program developed by EPRI to assist in determining the inferred condition of the circuit breaker. This software collects data from various sources and utilizes algorithms to determine which circuit breakers are most in need of maintenance.
  - The third approach utilizes data collected during the teardown, overhaul or inspection of circuit breakers to predict the condition of other circuit breakers of the same type.

Each approach gives insight into a particular circuit breaker's need for maintenance or a class of circuit breakers need for maintenance. A circuit breaker peer group, consisting of subject matter experts from engineering, maintenance and asset management then directs the circuit breaker maintenance program and replacement program in accordance with pre-defined Engineering guidelines using the information from the three different approaches.

The peer team is responsible to issue a yearly maintenance and replacement plan and general status of the asset management plan for circuit breakers.

The life of circuit breakers can be extended by maintenance on components and subsystems, e.g., fixing bearings in the mechanism, changing the compressor oil; refurbishing interrupter contacts. There are also options to replace subsystems—a compressor or control mechanism—which would allow use of the same breaker for a longer period. The principal challenge with breaker replacement decisions is economics: how many maintenance dollars and labor hours should be invested compared to purchasing a new breaker? When is it better to replace, or not? For example, an SF6 circuit breaker leak, depending on location and leak rate, could be addressed by sealing and repairing the leak, or replacing the breaker.

Power Transformers

For transformers, the key element in deciding when to replace a functioning unit is the condition of the bulk insulation—the paper on the windings in the main tank. Paper degradation is irreversible and at some point, increases the likelihood of failure of the transformer to an unacceptable level. The options to address degraded paper insulation are to rewind (refurbish) phases or replace the transformer.

Some transformer sub-systems can be replaced. For example, a degraded bushing can be replaced relatively inexpensively compared to the cost of a new transformer. However, if there are bushing and cooling system problems, the asset manager may decide to replace the transformer after considering other factors such as age, overall condition, future maintenance costs, environmental risks, outage availability, system position, criticality and availability of spares. Another factor that also may play a role in transformer replacement decisions is lead time. The results of a EPRI survey of utility approaches to making transformer replacement decisions are presented below.

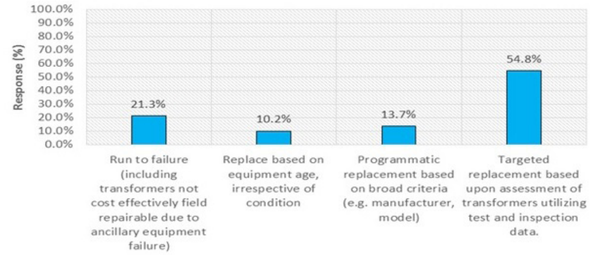

Figure 1: Utility Approaches for Making Transformer Replacement Decisions

43% of respondents indicated that their companies replace transformers as part of an obsolescence program. The reported rate of replacement (historical or planned) ranged from 0.7% to 4%/year. The responses given when asked what factors were used to determine when replacement was necessary are shown in the figure below.

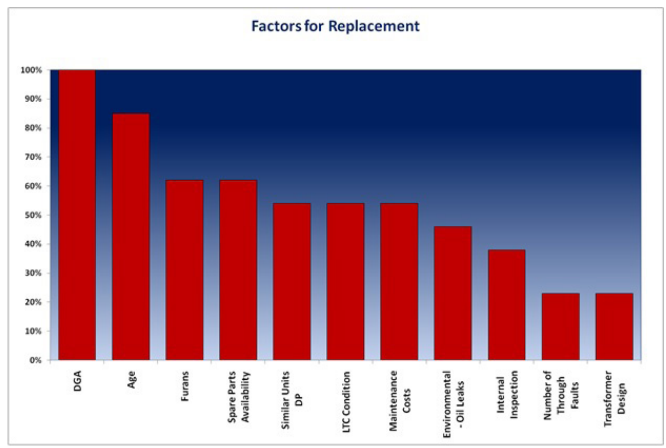

Figure 2: Utility Factors for Transformer Replacements

Other responses include: Insulation Power Factor, Industry Data, Special Operating Circumstances, Loading, Criticality of Customers, Regulatory Issues and/or Politically Sensitive.

59% of respondents have an established condition assessment methodology for assessing the condition of each individual transformer. 31% indicated that the development of such a methodology was in progress. 10% indicated that their company had no established condition assessment methodology. Of those with condition assessment methodologies, 88% performed the work in-house, while the remainder chose to use an outside contractor to do the assessment. Responses giving input to condition assessment methodologies are shown in the figure below:

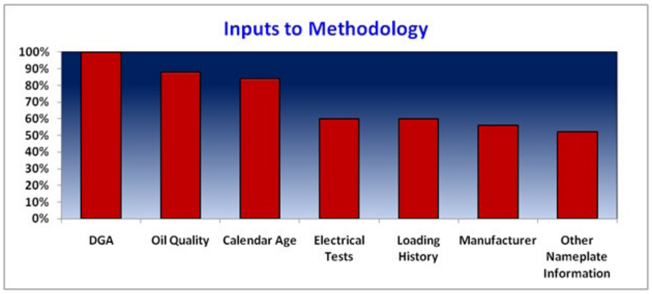

Figure 3: Utility Condition Assessment Methodologies

Wood Poles

Wood poles are used extensively in the electric utility industry to support both transmission and distribution class overhead lines. Wood poles provide a generally reliable and economic structure but, as for all utility devices, they have a finite service life. Poles can fail due to sudden and catastrophic damage, such as from accidents or storms, but most gradually degrade because of natural stressors. In addition to the normal mechanical load, stressors include insects, birds, bacteria and fungi.

One would expect degradation to increase over time, and therefore be closely linked to pole age. However, age alone is not a reliable indicator of pole condition. Many old poles perform well, and some younger poles show significant loss of strength. In fact, there are many variables that may affect the rate of pole degradation.

Utilities periodically perform inspections to assess the current remaining strength of the pole and provide a related metric that can be used as a trigger for removal or maintenance, either immediately for severely degraded poles or within the next maintenance cycle.

From typical wood pole inspection data, models can be developed that relate pole age to the likelihood of the pole being in a state warranting rejection at some future time. This rejection rate model can then be applied to the installed pole fleet and, using a Monte Carlo simulation, a series of yearly expected number of poles that would be rejected if assessed can be calculated. The model and modeling results can be used to inform fleet management decisions, guide scheduling of the assessment inspections and estimate replacement needs.

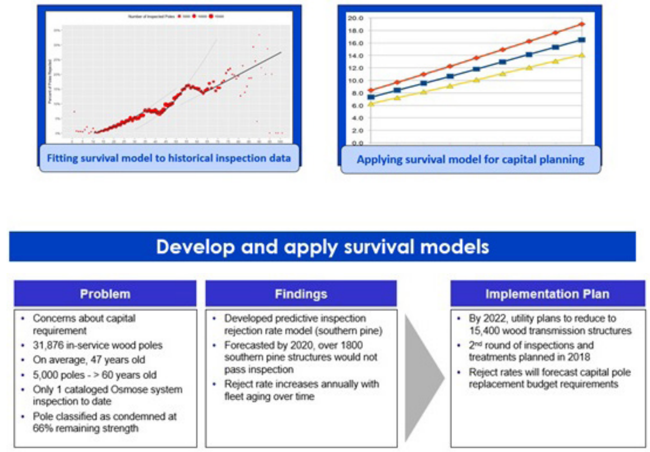

FIgure 4: Modeling of Wood Pole Inspection Data for Fleet Management Decision Making

Overhead Transmission Line Conductors

There are utilities around the globe that have in-place conductor condition assessment programs. As shown in the figure below, a typical condition assessment program uses a laboratory methodology to assess removed-from-service samples past a certain age with assessment factors that may include visual inspections of rust and corrosion, as well as ASTM compliant tests on samples' mechanical integrity (e.g., torsional ductility, remaining tensile strength). These condition parameter measurements are usually derived through third-party laboratory testing on samples typically a few meters in length taken from the field. Based on the test results, a condition score can be assigned for each individual factor tested. An overall condition for the sampled conductor is then expressed as a weighted average of scores associated with the assessment factors. The worst condition score is typically defined as the condition warranting removal or replacement (i.e., final degradation state). One example methodology is shown below.

Figure 5: Example Methodology Using Assessment Factors to Derive Conductor Overall Condition Score

If there are enough tested conductor samples, the overall condition scores may be used in statistical analysis to better understand the probability of a randomly drawn conductor sample being in a specific state (e.g., an overall condition score of 5 or end of life). The models can then be applied to in-service conductor population to develop a replacement forecast.

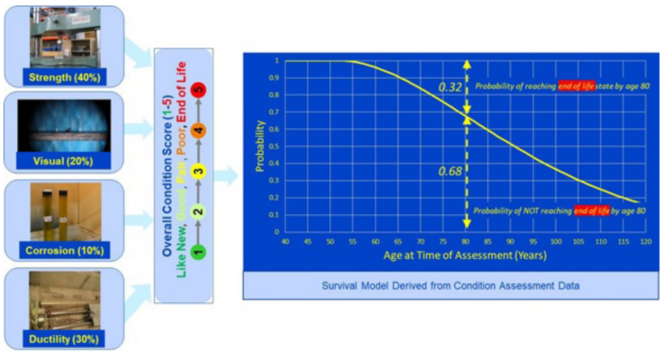

Figure 6: Development of Conductor Survival Model Using Condition Assessment Data

What is EPRI Doing?

Some of the challenges in developing and implementing condition-based asset replacement approaches are:

- Gaining quantitative understanding of the relationship between equipment condition and expected remaining service life
- Access to rich equipment performance data that can enable statistically valid metrics (e.g., failure rates) by family, make, model, application, age and condition
- Guidance on reliability and diagnostic efficacy of non-invasive inspection techniques
- Guidance on reliability and diagnostic efficacy of online monitoring techniques

To overcome these challenges a number of efforts are currently underway. As part of EPRI's transmission research, there are investigations to assess technology and develop tools, methodologies and metrics to assist utilities in transmission condition-based asset replacement.

- Development and utility demonstrations of a methodology to assist condition-based circuit breaker replacement. Circuit breaker replacement ranking (CBRR) is a risk-based approach designed to meet the needs described above and help utilities identify replacement candidates. It provides an analytical basis that is: consistent and repeatable, objective and documented, risk based and addresses regulatory concerns. Using existing data, the methodology infers the relative costs and risks of keeping a breaker in service. The input parameters for applying this method are selected based on understanding how circuit breakers are built, operate and wear. The method employs a relative ranking concept. The worst performer is assigned a maximum value of 100 and all remaining breakers are scaled proportionally. The CBRR is a function combining three major indices:
  - Functionality Index: How likely will the breaker be fit to continue operation?
  - O&M Index: What is the anticipated O&M cost that the breaker might incur?
  - Consequences Index: What are the consequences if the breaker fails to perform its function?
- Development and utility demonstration of rule based expert system approach to assess transformer condition, also known as Power Transformer Condition Assessment software
- Populating an industry wide repository with equipment performance data – idb.epri.com
- Analytics to better understand wood pole performance as a function of various variables such as species, original treatment type, age, pole class, length, diameter, inspection type etc.
- Development of sampling protocol and database structure for recording results from laboratory testing of field aged conductor samples. Analytical models to better understand end of life, influence of various test parameter, sample location and efficacy of inspection approaches
- Technology assessment of commercially available and emerging wood pole and conductor inspection techniques

- Technology assessment of commercially available and emerging online monitors (including circuit breaker, load tap changer and transformer monitors). The evaluation includes not only the technical performance of the on-line monitors but also the total cost of ownership. The results guide the industry on specification and interpretation

Conclusion

Asset condition assessment can help ascertain whether assets have degraded below performance levels requiring action. An asset's condition can be assessed through continuous monitoring, routine inspection and assessment or using analytics to infer condition based on readily available data (design, historical maintenance, operations and test results).

Implementing condition-based replacement requires:

- Selection of equipment performance and condition metrics
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EPRI has a range of initiatives to provide utilities with the knowledge necessary to utilize CBR methodologies for several equipment types.

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