CONDITION ASSESSMENT AND ASSET MANAGEMENT IN ELECTRIC POWER T&D NETWORKS

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ABSTRACT

This paper presents a methodology to assess the technical condition of electric power transmission and distribution (T&D) networks and to define related asset management strategies (AMS). The analysis is based on a methodology named Reliability Centered Asset Management (RCAM™) that considers the condition and the importance of the assets in the network as the drivers for their management. The paper also provides details about the implementation of the approach in terms of the attributes considered, and present the results of the application of the proposed methodology in one European country.

INTRODUCTION

Pressures are increasing upon utilities world-wide to provide a high level of service quality at minimum cost, which requires a well founded AMS to ensure network assets remain in a satisfactory condition [1]. Central to a comprehensive AMS is the ability to evaluate and know the condition and performance characteristics of all inventoried assets in the T&D network. A revision of business processes would also require an evaluation on the relative importance of such assets.

The combination of both factors (i.e., condition and its importance) would now help significantly in improving all asset-related business processes while defining adequate asset management programs, for example. One of the main focuses of the AMS that would result from the methodology included in this paper is to allow the development of an asset management program focused on minimizing the total cost of managing and operating the assets throughout its entire life cycle for a given level of performance and risk.

A methodology for a condition assessment of a selected group of assets of a Transmission and two Distribution Companies in Europe is summarized in this paper. The condition assessment was part of an Independent Technical Audit requested by the owners of the T&D networks.

METHODOLOGY

Network operators are often faced with the need to improve economical efficiency while maintaining or even increasing power quality levels at the same time. The methodology approach included in this paper provides some detailed and quantitative information on the relevant correlations and aspects that are critical to decision making [2].

The results provided by our methodology should be useful for decision makers with the aim of [3]:

- Gaining insight into the correlation between decisions and their effects on network cost and quality,
- Building a sound scheme for evaluating relevant aspects in asset management with objective and documented decisions, and
- Increasing the efficiency of resource usage while safeguarding required quality levels also in the long-term.

The analysis was developed using a methodology known as Reliability Centered Asset Management (RCAM™). RCAM combines the results of the Condition Assessment (CA) with the importance of each asset in the system in order to help define AMS.

Figure 1 shows a typical RCAM diagram in which the relation between condition and importance is analyzed in order to select asset management strategies. Each color area represents a different AM strategy (i.e., white area would be corrective maintenance while blue area would be time-based maintenance).

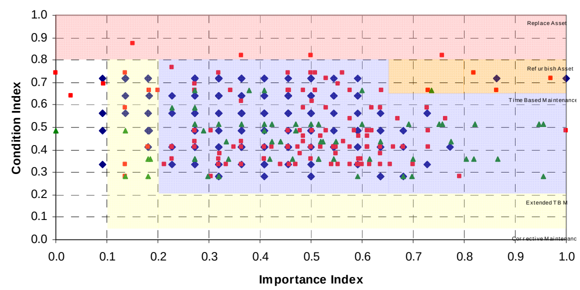

Figure 1 RCAM Diagram

The condition index is calculated in a scale between 0 and 1 (where "0" means the best condition and "1" means the worst condition). The importance index is also calculated in a scale between 0 and 1 (where "0" means least importance and "1" means maximum importance).

The following asset management strategies are considered in the methodology:

a. **Corrective maintenance:** asset maintenance is done when a defect or problem is reported. Typically this kind of strategy is adequate for very low risk assets, which have a very good condition or a very low importance for the system.
b. **Extended Time Based Maintenance:** in this strategy the standard TBM can be postponed or delayed. Adequate for assets with low risk.
c. **Time Base Maintenance (TBM):** standard maintenance program is recommended. Adequate for intermediate risk assets.
d. **Asset Refurbishment:** recommended for high risk

assets. Continuous conditioning monitoring could also be used as an alternative.

e. **Asset Replacement:** recommended for very high risk assets. Portable spares could be an alternative to mitigate the risks.

Replacement and refurbishment strategies are related with Capital Expenditures (CAPEX). The other three strategies are related to Operational Expenditures (OPEX).

EVALUATION CRITERIA

Condition Assessment Model

The Transmission and Distribution condition model developed for transformers, substations, and lines includes the attributes included in Table 1 below:

	Condition Attribute	Power Transformers	Substations	Lines	Distribution Transformer
1	Age	x	x	x	x
2	Maintenance Records	x	x	x	
3	Operational Experience	x	x	x	
4	Ambient Condition	x	x	x	x
5	Physical condition	x	x	x	x
6	Peak Load	x		x	
7	Oil Condition	x			
8	Transformer Voltage Ratio				x
9	Transformer Size				x
10	Circuit Breaker Technology		x		
11	Support Type			x	
12	Conductor Type			x	

Table 1 Condition Attributes for T&D Networks

A brief definition of the criteria is described next:

1. **Age:** disaggregated in six groups where the older assets get higher points in the age scale.
2. **Maintenance Records:** refers to the number of inspections reported in an established period of time.
3. **Operational Experience:** refers to the average number of defects reported in an established year.
4. **Ambient Condition:** refers to the impact of the environment that surrounds the asset.
5. **Physical Condition:** refers to the results of site visits performed to a selected sample. This data is then extrapolated to the remaining of the assets.
6. **Peak Load:** refers to the historical peak load. This is an important factor as the condition worsens exponentially when the asset is overloaded.
7. **Oil Condition:** refers to the recommended procedures of the IEC 60599 standard. The standard consists in checking whether the gas concentration levels are within a certain range, if measurements are available. This procedure identifies potential insulation damages, internal discharges, and/or high temperature impacts.
8. **Transformer Voltage Ratio**: includes the most popular ratios as per in the case study. For same size transformers those with the highest voltages tend to be in better condition (less current for a given power delivery).
9. **Transformer Size:** transformers of bigger sizes are usually built with higher standards in order to reduce their related costs.
10. **Circuit Breaker Technology:** refers to the technology installed and the voltage level of the asset.
11. **Support Type:** refers to the characteristics of the overhead lines supports.
12. **Conductor Type:** refers to the characteristics of the overhead lines conductors.

The condition index is the result of the numerical grade of the previously mentioned factors. Weight factors are considered in the calculation based on the impact that each attribute could have on the Asset Condition.

Importance Index

The calculation of the importance index (II) is usually done with a detailed evaluation of the system reliability considering individual and multiple simultaneous outages of elements, based on the individual failure rates and repair times. The model should incorporate the consideration of: i) load transferring to adjacent feeders for faster restoration of supply, and; ii) the fact that the actual loading affects the reliability indices by the use of load duration curves that can be customized by load point.

Figure 2 below shows a typical process diagram for the recommended reliability assessment.

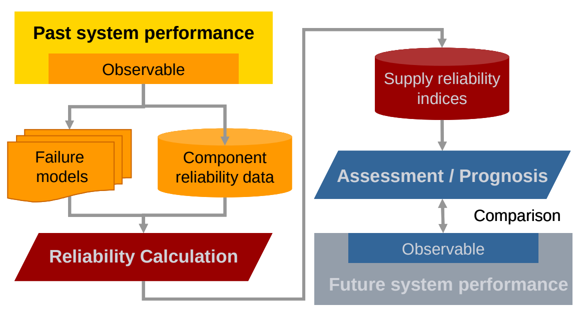

Figure 2 Network Reliability Assessment

During the Technical audit phase, a simplified approach may be implemented if there are time constraints. This simplified approach, based on data like load, rates, and number of assets (among others), only provides an initial estimation of the assets importance, useful for the purpose of a short term technical due diligence.

In the simplified approach, the Transmission and Distribution importance indexes can be calculated as a function of the attributes shown in Table 2 below.

	Importance Attribute	Power Transformer	Substations	T OHL	D OHL	Distribution Transformer
1	Peak Load	x	x		x	
2	Transformers per Substation	x				
3	Transformer size					x
4	Number of Feeders	x	x			
5	Line Load			x		
6	Feeder Length				x	

Table 2 Importance Attributes for T&D Networks

1. **Power Transformers:** considers substations' loading and the quantity of feeders or lines connected to the substation. In those substations with more than one transformer the II is adjusted by a factor of 50%.
2. **Substations:** considers the substations' installed transformer capacity and the numbers of feeders connected to the substations.
3. **Overhead Lines (OHL):** considers the lines' load and substation's importance index as estimated previously at both ends of the lines.
4. **Distribution Feeders:** considers the feeder's load and the feeder's length. A higher weight (66%) is assigned to the feeders load.
5. **Distribution Transformers:** considers the transformer size in kVA.

A complete reliability assessment including systems simulations is recommended for the final definition of the company AMS.

STUDY CASE

The methodology described above was applied as part of the technical audit conducted to one Transmission Company and two distribution companies in one European country. The condition assessment focussed on integrated assets and not in individual pieces of equipment (with the exception of the power and distribution transformers). The scope of work included around 5,000 assets in the three companies plus the distribution transformers (over 40,000).

For every single asset the available historical data was processed in order to estimate the condition and importance indexes. Physical inspection was limited to a selected sample of the assets and the results extrapolated to the remaining assets. The total condition assessment was executed in a three months period.

Figures 3, 4 and 5 summarize the results for one of the utilities under study. Figure 3 shows the condition index results indicating the number of assets per range. Figure 4 shows a similar information but for the importance index. Figure 5 shows the distribution of the recommended asset management strategies obtained from the RCAM diagrams with the input of the condition index and the importance index calculated for every asset.

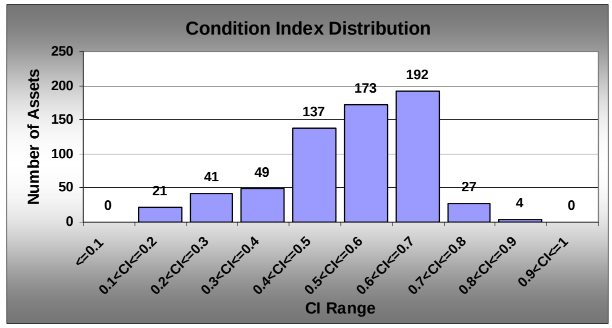

Figure 3 Condition Index Results

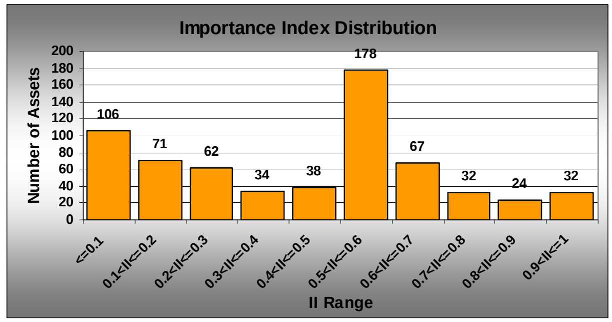

Figure 4 Importance Index Results

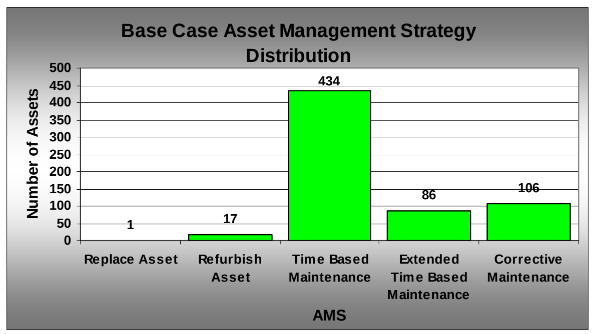

Figure 5 Recommended Asset Management Strategies

A sensitivity analysis was conducted in order to estimate the evolution of the condition assessment under different scenarios that include factors like: age increase, loading increase, maintenance practices and equipment technology. The results were also used to develop and implement a methodology for the estimation of the average service life of the assets groups.

The methodology was based on a correlation between the condition index and the assets' age. Results were extrapolated in order to define the most typical age in which each asset would reach a condition level that would justify its replacement. Figure 6 below shows an example of the service life estimation results:

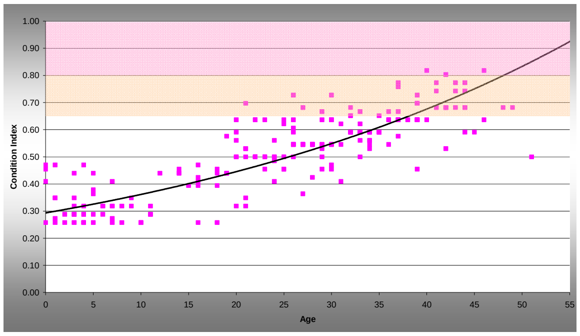

Figure 6 Average Service Life Estimation

The age structure of the current transmission and distribution networks was also analyzed and a set of renewal rates or level of reinvestment, relative to the installed asset base was calculated and compared with the age structure to determine the currently applied renewal rate.

The scope of the technical audit may also include the evaluation of the companies' performance using a "Top Down" approach. The analysis' objective may be to determine whether the value of a number of representative performance indicators for the particular network is comparable to those of other utility companies. This is often referred to as benchmarking analysis.

The top down evaluation and the condition assessment is a powerful tool for the diagnostic and due diligence of T&D networks.

CONCLUSION AND RECOMMENDATIONS

Changes on the electricity market and regulation during the last few decades have induced additional cost pressures targeting system operations, asset management strategies oriented to optimize the use of the assets through different approaches including reliability centered maintenance are cost effective and should be thoroughly evaluated to reach such goals while maintaining or even improving reliability levels and the quality of service in general.

A basic strategy for T&D networks could be following methods for the simulation of equipment inventory in terms of cost, reliability and importance. This paper showed a practical methodology to establish AMS. Other concluding remarks include:

1. The discussed methodology allows a quick assessment for the condition of the assets of transmission and distribution networks.
2. The results of the study case proved to be aligned with the real situation of the utilities under evaluation.
3. The estimated assets average service life using the results of the condition assessment was comparable with standard utility practices.
4. The simplified methodology developed for the calculation of the importance index is acceptable for a short term technical audit of the networks.
5. For developing of and/or updating an Asset Management Strategy a full reliability assessment of the network is always recommended.
6. The condition assessment model can be implemented at single equipment levels and then the results integrated up to the network levels.
7. The condition assessment results should be complemented which a benchmarking evaluation of key performance indicators.

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BIOGRAPHIES

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