# NETWORK ASSET CONDITION ASSESSMENT AND REFURBISHMENT PLANNING

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**Abstract.** Ageing infrastructure is a major problem in the Electricity Supply Industry due to demand growth and performance requirements. It is further exacerbated by higher equipment loading and reluctance in replacement program, and can most probably be regarded as one of the major crippling factors within electrical utilities. Utilities acted as if equipment would last forever. This is changing, largely because it is becoming obvious that equipment eventually fails. By following a systematic approach, supported by a computerised system, utility engineers can make informed decisions regarding future strategies to extend the life of equipment through altered maintenance policies or de-rating, or to refurbish or replace equipment.

**Keyword Index** – Equipment age, condition assessment, reliability

## 1 Introduction

Many electric distribution networks around the world are experiencing difficulty in meeting their customer service quality targets and stakeholder profit margins [6]. These problems are due to the fact that large portions of their systems consist of ageing infrastructure. A power system composing mostly old equipment near the end of its useful lifetime, configured in a layout that is itself quite old and not completely compatible with modern needs, produces reliability, maintenance and budgeting challenges. If these challenges are not anticipated and brought under control, they will eventually overwhelm even the most effective organization.

Many traditional utilities seem incapable of proactively addressing this ubiquitous and looming problem. More than any other issue, ageing infrastructure illustrates the potential of asset managers to address critical transmission and distribution problems. First, it forces asset owners (executive management) to articulate clear goals in terms of budget, system performance and acceptable risk. It also requires an asset registry that tracks, at a minimum, the age of each piece of equipment in the field. Engineers can then perform detail technical analysis such as inspect, repair, extend life, replace and make system modifications. This analysis must take a multiyear approach, since ageing infrastructure cannot be addressed in a single budget cycle. If performance and risk targets cannot be met within budget constraints, asset owners must decide which target to relax [6].

## 2 Asset Management

Along with network performance improvement strategies, network refurbishment strategies form a major focus of Asset Management. Asset Management is the art of balancing cost, performance, and risk.

### *2.1 Asset Management Goals*

In its most general sense, asset management is a business approach designed to align the management of asset-related spending to corporate goals. The objective is to make all infrastructure-related decisions according to a set of stakeholder driven criteria. The payoff will be spending decisions capable of delivering the greatest stakeholder value from the investment.

Asset management is thus a corporate strategy that seeks to balance performance, cost and risk. Achieving this balance requires the alignment of corporate goals, management decisions and technical decisions. The typical goals of asset management are to [4]:

- Balance cost, performance and risk,
- Align corporate objectives with spending decisions, and
- Create a multiyear asset plan based on a rigorous and data driven process.

Along with the above goals utilities face the challenge of reducing cost and increasing levels of reliability. To manage this, financial instruments that link reliability to profits are becoming increasingly more common. Examples include performance-based rates and performance guarantees, more loosely referred to in this paper as performance or reliability target.

### 2.2 *Performance Targets*

In their most general form, performance-based targets are regulatory statutes, referred to as performance based rates (PBR's), that rewards utilities for good reliability and penalize poor performance. Regulators use PBR's under rate cap situations to counteract the tendency of utilities to cut cost and allow reliability to suffer. Performance is usually based on average customer interruptions measures such as System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI).

Reliability guarantees on the other hand are the simplest method of giving customers choice. Each customer chooses a performance contract. Expensive contracts guarantee high levels of performance while basic contracts guarantees modest levels of performance and the cheapest contracts do not provide guarantees. Customers experiencing reliability below guaranteed levels receive rebate checks or credits on their energy bill.

Both these instruments relate directly to the topology of the system supplying customers, as well as the performance of individual component within the system. Network reliability assessment is well understood by asset investment planners and forms a key part of network planning.

## 3 Equipment Reliability & Ageing

Good distribution planning ensures that money spent today has lasting value in future. Along with service-level voltage, reliability is a critical performance measure for distribution systems due to its high impact on cost and customer satisfaction. In addition, as mentioned above, Regulators are moving towards adopting reliability targets that utilities are expected to achieve. The primary performance measure of distribution asset planning is thus reliability, and the primary risk measure is the probability of not meeting reliability targets [3].

Reliability, in the context of this paper, refers to the frequency and duration of power outages, and the ability / capacity of the system to transmit energy while in service. Both these network attributes (outages / capacity) are influenced by the age and condition of network components.

System reliability models typically use average equipment failure rates and nominal equipment ratings in prediction models. Although generally acceptable for capital planning, the use of average values has two drawbacks. First, average values cannot reflect the impact of relatively unreliable equipment and may overestimate the reliability of worst performing networks. Secondly, average values cannot reflect the impact of equipment condition. Component age and condition thus needs to be considered when predicting system performance.

### 3.1 *Equipment Reliability as a Function of Age*

Component reliability parameters, such as failure rate (λ), Mean Time to Repair (MTTR), and Probability of Failure (P), are used to measure component behaviour in order to predict system performance.

The reliability of a component in terms of component ageing is defined through the hazard rate curve which characterizes the operating life for a component. Figure 3-1 shows the increase in expected component failure as a function of age for a switch and distribution transformer.

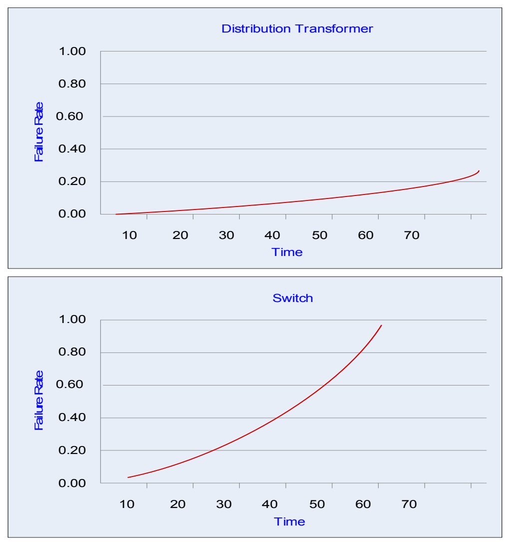


*Figure 3-1: Equipment Hazard Rates*

Table 3-1: [5] further shows component failure rates for various power system components as a function of age.

*Table 3-1: Component Failure Rates*

| Component | $\lambda_{new}$ | $\lambda_{real}$ | $\lambda_{old}$ |
|---|---|---|---|
| Substation Transformer | .003 | .02 | .15 |
| Distribution Transformer | .0007 | .005 | .037 |
| Overhead Line | .042 | .2 | .96 |
| Underground Cable | .005 | .02 | .082 |
| Circuit Breaker | .0009 | .0066 | .049 |
| Switch | .007 | .05 | .37 |

### 3.2 Equipment Rating as a Function of Age

Apart from reliability, the ageing of equipment further results in a reduced capacity or rating. Since the major nodes of deterioration and failure are often heat-related or other service-stress created causes, such as failures, one option available to an operator is to reduce the loading or to change the maintenance strategy in order to increase the expected lifetime of the equipment. Figure 3-2 shows a de-rating curve for a power transformer that has an expected 40-year lifetime and has already seen 30 years of service at designed load levels.

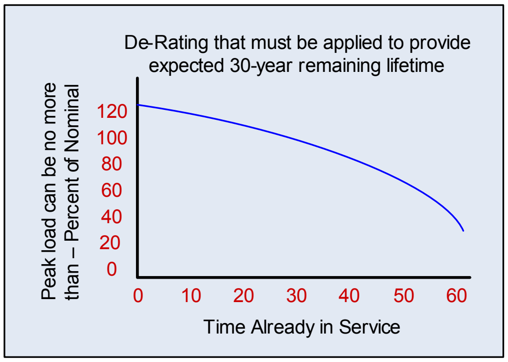


*Figure 3-2: Transformer De-rating Curve*

Figure 3-3 shows the same power transformer under different maintenance policies [2].

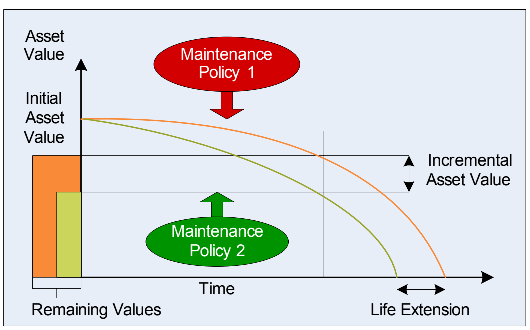


*Figure 3-3: Transformer under different maintenance policies*

## 4 Equipment Condition Assessment

Traditionally utility managers, engineers and operators managed equipment lifetime and failure as if it were out beyond the planning horizon. Those failures that did occur were treated as anomalies, due to flaws, mistakes or just plain bad luck. This is changing, largely because it is becoming obvious that equipment does eventually fail.

*Figure 4-1: Equipment Condition*

A simple and practical approach to ensure that electrical infrastructure life expectancy is planned to meet future needs, is achieved by adopting a thorough asset condition assessment and refurbishment planning process.

The main objectives of such a process include:

- The development of a systematic replacement or refurbishment program, driven by asset condition and age, and
- The assessment of the perceived performance (reliability) and thermal capability of assets.

Both the above attributes impacts directly on Asset Management of Regulatory targets.

### 4.1 Condition Assessment Methodology

A life extension or refurbishment program that will permit continued economical operation of electrical infrastructure must address both:

- Individual facilities as they approach design life, and
- Individual equipment on a system wide basis.

Site specific assessment is conducted that provides a systematic across the board estimate of the remaining life of electrical facilities. The process is based on a number of tasks of which the main tasks include:

- The definition of the condition assessment methodology,
- Definition of utility standards, targets and criteria,
- Identification of equipment to be included in the investigation,
- Review and interpretation of historical information and reports related to the equipment under investigation,

- Development of attributes, criteria and weighting factors for each equipment type,
- A physical visual inspection,
- The identification of critical equipment, earmarked for further investigation or replacement,
- The development of a multiyear refurbishment plan, and
- The development of predictive performance and capability measures.

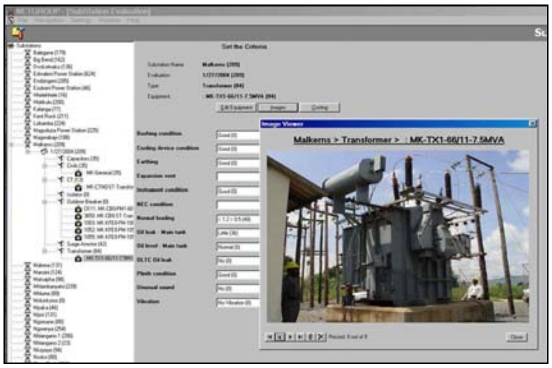


*Figure 4-2: Condition Assessment System*

### *4.2 Condition Assessment System*

A technical condition assessment system has been developed by NETGroup that allows for the set-up of refurbishment projects in a structured manner. The system allows for the capturing of equipment condition information through mobile technology, followed by systematic evaluation and prioritisation of refurbishment projects and actions. The system is dynamic in nature in that it allows for projects to be set-up individually without the reconfiguration of database structures to specific utility needs. The following equipment structure is used:

Equipment Type: (Power Transformer)

- Attribute: (Condition of Tank)
  - Criterion: (Damaged / Good)
    - Weight: (0 to Max weight)

#### *4.2.1 Equipment Definition*

Depending on the goals and objectives, different equipment types could be included in the assessment exercise. Equipment could be only substation related or may also include lines and cables. Substation equipment may further include only critical equipment and ignore less important equipment. The establishment of the criticality of equipment can be achieved through prior sensitivity analysis assessing the outcome of equipment scores related to the corporate objectives or goals or may be specified by the utility.

#### *4.2.2 Equipment Assessment Attributes and Weight*

Once the equipment to be included in the condition asset condition assessment exercise has been selected, the basic attributes, criteria and associated weights are developed for each piece of equipment.

Table 4-1 shows typical attributes and the associated maximum weight for each attribute of a power transformer. A scoring guideline is shown in Table 4-2. The totalling of weight result in a score which prioritises individual equipment related to the entire system.

*Table 4-1: Power Transformer Inspection Form*

| Attributes | Weight | Score |
|---|---|---|
| Age (year of operation) | 8 | |
| Oil type | 1 | |
| Condition of tank | 1 | |
| Condition of tap changer | 2 | |
| Condition of Cooling | 1 | |
| Condition of bushings | 2 | |
| Condition of insulation | 2 | |
| Transformer loading | 3 | |
| Mechanical stress | 3 | |
| Dielectric stress | 2 | |
| Noise level | 1 | |
| Gas in oil analysis | 5 | |
| Oil analysis | 6 | |
| Experience with unit | 4 | |

*Table 4-2: Score Guideline*

| Age (years of operation) | Score |
|---|---|
| Less than 1 | 0.00 |
| 1 – 10 | 0.05 |
| 11 – 25 | 0.20 |
| 26 – 29 | 0.40 |
| 30 – 35 | 0.60 |
| 36 – 40 | 0.80 |
| Greater than 40 | 1.00 |

### 4.2.3 Data Collection and Technical Audit

The information used for the study is usually obtained from the utility for review purposes, followed by discussion with key personnel. The technical audit comprises of an exercise where basic information about the installations are obtained and evaluated on site. A further phase allows for a design engineer to evaluate this basic information and to provide a technical perspective of the state, suitability of the design and maintainability of the equipment.

Data collection and infrastructure visual inspections allows for:

- A systematic review of infrastructure that may have reached or exceeded their original design life,
- Identify systems, structures and equipment approaching wear-out or becoming obsolete,
- Prioritise replacement, refurbishment, and follow-up tasks, and
- Support the development of a capital program that will ensure economic network refurbishment.

It must be noted that a preparation exercise to exhaust readily available information prior to the site visit is essential.

## 4.3 Condition Assessment Outcome

The outcome of the asset condition assessment is primarily:

- The development of a systematic replacement or refurbishment program, driven by asset condition and age, and
- The assessment of the perceived performance (reliability) and thermal capability of involved assets.

A key output from the assessment is a prioritised list of equipment condition and age profiles. As an example, a standard output from the condition assessment systems is a prioritised view of substation scores within a distribution network, such as shown in Figure 4-3. Substations with the highest score are predicted to have the oldest and worst performing equipment.

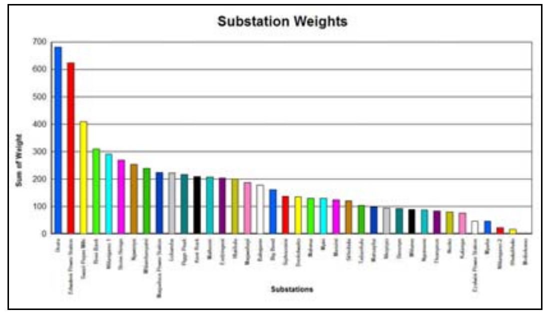


*Figure 4-3: Weighted Substation Scores*

### 4.3.1 Prioritised Equipment Condition

Through the evaluation of the prioritised list, engineers obtain actual information regarding specific equipment condition such as failed equipment components or conditions that might cause failures. This information is manipulated to identify strategic actions to rectify or mitigate possible violations [2]. These actions include:

- Maintain existing maintenance policy or change maintenance policy to ensure effective operation. This action is usually applicable to equipment regarded as being in normal condition, or
- Follow a strategy whereby equipment should be refurbished, or replaced. Normally this decision is based on age or further diagnostic tests.

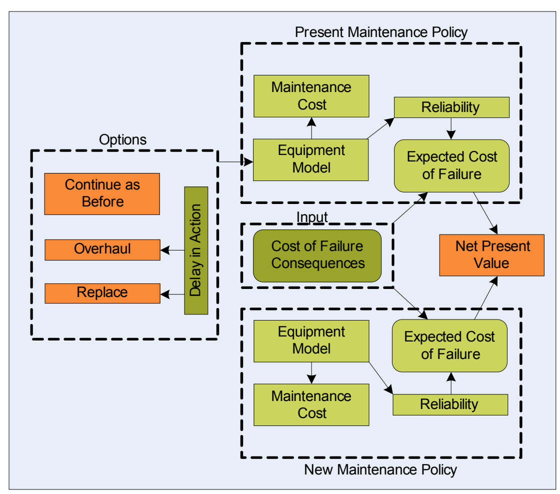


*Figure 4-4: Strategic Option Selection*

### 4.3.2 Equipment Age Profiles

Age can be used for the longer-term planning or the strategic planning phase of the exercise and gives guidance to the number and location of equipment approaching or exceeding its expected useful life.

Although age in itself does not provide any conclusive information on the state of equipment or the need to refurbish or to replace, it does provide a good overview of the extent of the task at hand. Age profiles are used to highlight the following aspects:

- It provides insight into the state of the network,
- Identify replacement cost of assets older than a certain age,
- List and phase equipment to be refurbished or replaced in order to maintain an age of less than a specified value, and
- At what rate equipment age will increase if the current replacement or refurbishment rates are adhered to for the next 20 years.

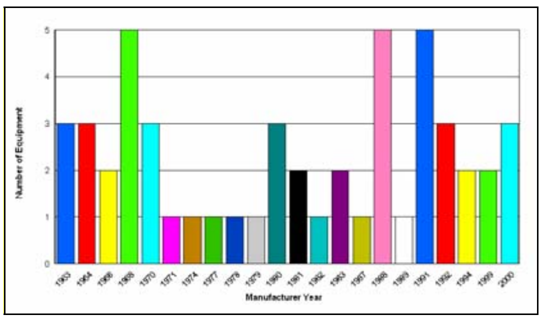


*Figure 4-5: Transformer Age Profiles*

### 4.3.3 Failure Rate Model

As previously indicated, there exist a relation between equipment age / condition and its failure rate. The basis for predicting equipment failure rate lies in sufficient historical data. This allows for the use of regression-based equations to interpolate failure rates corresponding to the worst and best condition scores. An exponential model normally best describes the relationship between the normalized equipment condition and equipment failure rates [1]. A typical formula is shown in equation 4-1:

$$\lambda(x) = Ae^{Bx} + C \qquad (4\text{-}1)$$

Where:

λ = failure rate,

x = condition score,

Three data pairs are further required to solve for parameters A, B and C. This can be achieved by defining best, average and worst condition scores of 0, 0.5 and 1, corresponding to λ(0), λ(0.5) and λ(1). These equipment failure models are used as basis for network reliability assessment to predict network performance in relation to performance targets.

### 4.3.4 Capacity Model

A further output from the condition assessment exercise involves the development of capacity models for critical equipment such as transformers and cables. These are only done for the equipment, probably less than 10%, which could not be classified as normal. The basic failure model for a transformer, shown in Figure 4-6 [7], assumes that there are a number of key parameters (such as dielectric, thermal or mechanical strength), that when exceeded, will lead to failure. The withstand strength of transformer will naturally decrease over its life due to various ageing processes, but may deteriorate faster than normal under the influence of agents of deterioration, e.g. moisture, or if some abnormal destructive deterioration process occurs.

For the identified units, on-line diagnoses are carried out which might include magnetizing current, frequency response analysis, partial discharge and dielectric response measurements.

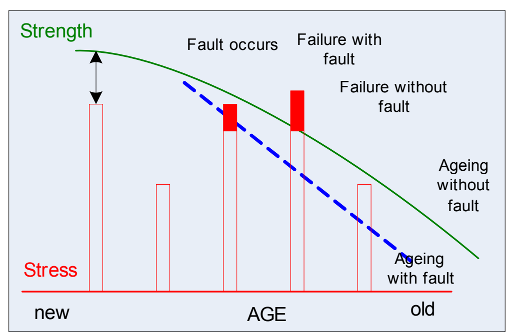


*Figure 4-6: Transformer Failure Model*

Once analysed, similar strategies as shown in Figure 4-4 can be followed to extend the units life or recommend replacement. As an example, the unit might be de-rated to ensure that the expected useful life be reached.

## 5 Consolidated Refurbishment Plan

The key success to the refurbishment plan lies in the integration of equipment refurbishment or replacement with the strategic network development or strengthening plan. The development plan forms part of an organisation's Asset Management strategy and should comply with the objectives and goals of the Asset Management strategy. The refurbishment plan is thus a key ingredient to the effectiveness of the Asset Management strategy, due to the fact that it directly influences network performance and capacity.

Through the analysis of the results obtained from the equipment condition exercise, the planning engineer can develop a strategic refurbishment plan. The plan consists of equipment renewal and life extension programs and provides the following input to the network development plan:

- An equipment replacement schedule and associated cost estimates for both primary and auxiliary equipment,
- Recommendations with regard to equipment life extension strategies in terms of component refurbishment or changes in maintenance strategy, and
- Recommendations for equipment performance and capacity parameter adjustment for the use in load flow and reliability simulations.

## 6 CONCLUSION

Reliability is a critical performance measure for distribution systems due to its high impact on cost and customer satisfaction. Substantial portions of electrical networks throughout the world consist of infrastructure approaching or exceeding their expected useful life. Equipment age and condition has a direct influence on network reliability. This paper has shown that through a systematic approach, supported by a computerised system, the condition and age of equipment can be assessed. Once filtered and prioritised, specific actions can be developed to extend the life of equipment through altered maintenance policies or de-rating, or refurbishment or replacement based on age or recommendations supported by diagnostic test. The paper has further shown that through the development of equipment failure and rating models, network performance prediction can be enhanced. These models provide improved insight to the actual network performance in relation to performance target, which in turn allows for more accurate identification of equipment responsible for target deviances.

## 7 REFERENCES


1. Brown R.E, Frimpong G, Willis H.L., Failure Rate Modeling Using Equipment Inspection Data, IEEE Transactions on Power Systems, VOL. 19, NO. 2, May 2004,
2. Anders G.J, Endrenyi J., Yung C., Risk-based Planner for Asset Management, IEEE Computer Applications in Power, October 2004,
3. Brown R.E., Hanson A.P., Willis H.L., Luedtke F.A., Born M.F., Assessing the Reliability of Distribution Systems, IEEE Computer Applications in Power, January 2001,
4. Brown R.E, Spare J.H., Asset Management, Risk and Distribution System Planning, IEEE Transactions on Power Systems, 2004,
5. Ross D.P., Welch G.V., Willis H.L., Sensitivity of System Reliability to Component Aging in Metropolitan, Urban and Rural Areas, IEEE Transactions on Power Systems, 2001,
6. Willis H.L., Welch G.V., Schrieber R.R., Aging Power Delivery Infrastructure, ISBN:0-8247-0539-4, 2001,
7. Guuinic P., Aubin J., CIGRE's Work on Power Transformers, Paper presented at the EPRI "Substation Equipment Diagnostics Conference IX", February 18-21, 2001, New Orleans, Louisiana, USA.