Condition-Based Strategies for Transformer Age Assessment

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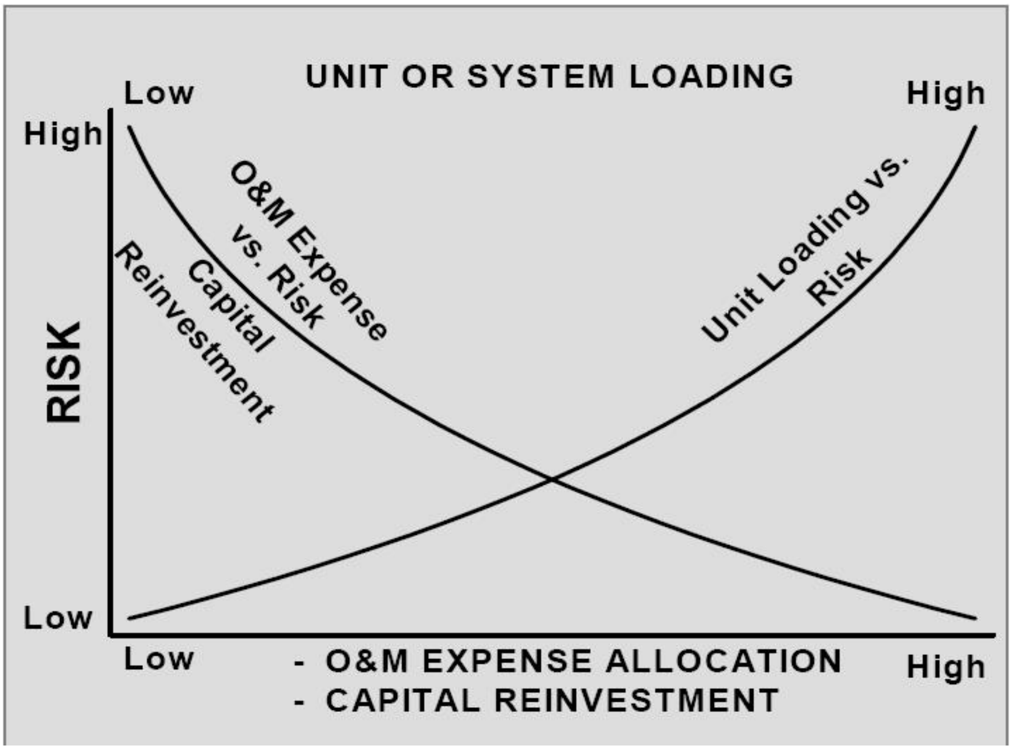
ABSTRACT

Electric utility companies have a low tolerance for failure and hence risk-cost has become a very real cost of doing business. Power transformers are, therefore a major concern. Each unit can supply numerous customers, but a failure of a single unit can result in loss of service with considerable amount of expense associated with lost revenue, replacement and other collateral costs. Although this situation has been clearer to Southern Africa Utility Manager s, expenses for maintenance are tight and available capital to reinvest in this aged infrastructure is almost universally unavailable. “Condition based” Strategies are being applied in managing these somewhat aged and important substation assets.

The challenge facing the industry today is in leveraging the most out of existing assets without reducing customer service, while increasing the value of shareholder investment. This requires operations and maintenance managers to fully understand the probable condition of old and often highly loaded units.
This also requires ranking of equipment for purpose of priortising maintenance expenses or capital investment. In many cases, re-rating the transformer planned loading capacity for normal contingent operation is needed and may be dependent on the condition of the unit.
Refurbishment or options for enhancing transformer performance to reduce temperature increase life and /or increase loading are often considered as options to defer capital spending on new equipment.

The following chart indicates that optimization of risk, based on limited capital and operations and maintenance (O&M) spending and increased loading limits, is the ultimate management challenge that affects customer satisfaction and bottom-line performance in today’s electric utility environment.



Utility engineers and managers are using condition-based tools today. This forms the starting-points for developing better engineering and financial methods for priotising maintenance expenses or capital reinvestment for groups of transformers or making decisions about replacement of individual problem units on the system.
By developing a rigorous method of determining probable condition and by pinpointing they’re least healthy and most critical “Red” Transformers on their system and, in using such knowledge, to best financially manage these important assets.

Establishing the Condition State for Operating Power Transformers

Statistical methods, based on historical failure models, are often used to establish the probable condition of all units or groups of transformers on the system. However, this method cannot identify the condition state or vulnerability of individual operating units. Unfortunately, there is no single scientific method available and condition evaluation is often subjective. Evaluation methods are often modified or limited by the availability of information from the manufacturer or from the system's operations and maintenance records. Added to this, the skill level and experience of the people involved in the process are a key variable in making decisions related to the quality of the available information and, subsequently, the probable condition of the unit. A complete appraisal method for an individual unit often involves field inspections and testing. This decision often depends on the feasibility of taking units out of service and expenditure, balanced against the importance or criticality of the unit on the system.

The process for benchmarking the probable condition of an individual unit, compared to the other units on the system, is often controlled by moving through three gates or levels:

Level 1 - Data and Design Analysis
Level 2 - Energized and De-Energized Testing
Level 3 - External and Internal Inspection

Condition evaluation methods are subjective and are generally based on the quality of information, requiring the results to be weighed depending on each of the factors that have been selected. Typical factors used for evaluation are related to the equipment design, environment, usage and historical maintenance or testing data and are listed in the following table.

Typical Factors for Calculating Weighted Condition Factor (WCF)

Design		**Operating Environment**	Usage	**Historical Tests & Diagnostics**
Main unit Manufacture Vintage Winding Configuration Materials Short Circuit BIL	Ancillary Equipments Oil Preservation LTC DETC Cooling Equipment Bushings	Source Impedance Protection Scheme Lighting Level Ambient Temperatures Load Power Factor LTC Regulation Range	Historical Loading Pattern Prior Overload Conditions Prior Through Faults Fault Levels Maintenance Practices	DGA-Dissolved Gas analysis Oil Quality Power Factor Insulation Resistance Maintenance Records Furan (Predicted DP)

Level 1 evaluation factors can be used as a preliminary process (and as the only method) for evaluating groups of units and, when used with transformer priority (discussed in the following section), can provide an overall ranking and the basis for deciding if subsequent level 2 and 3 inspection and testing will be required for evaluating individual units.

As we have seen from the criteria given in the above Table, many factors must be considered and weighted against each other to result in a realistic condition evaluation. However, the probable condition of the internal insulation is usually a key consideration due to the fact that the condition is, for the most part, "irreversible". Spontaneous and non- spontaneous events will have combined to lead to this irreversible condition. Years of use or high loading, frequent and/or close-in faults, high moisture or oxygen in oil over time, high measured furan levels and/or low measured degree of polymerisation (DP) are all key indicators of this condition.

Establishing Group ranking and Priority

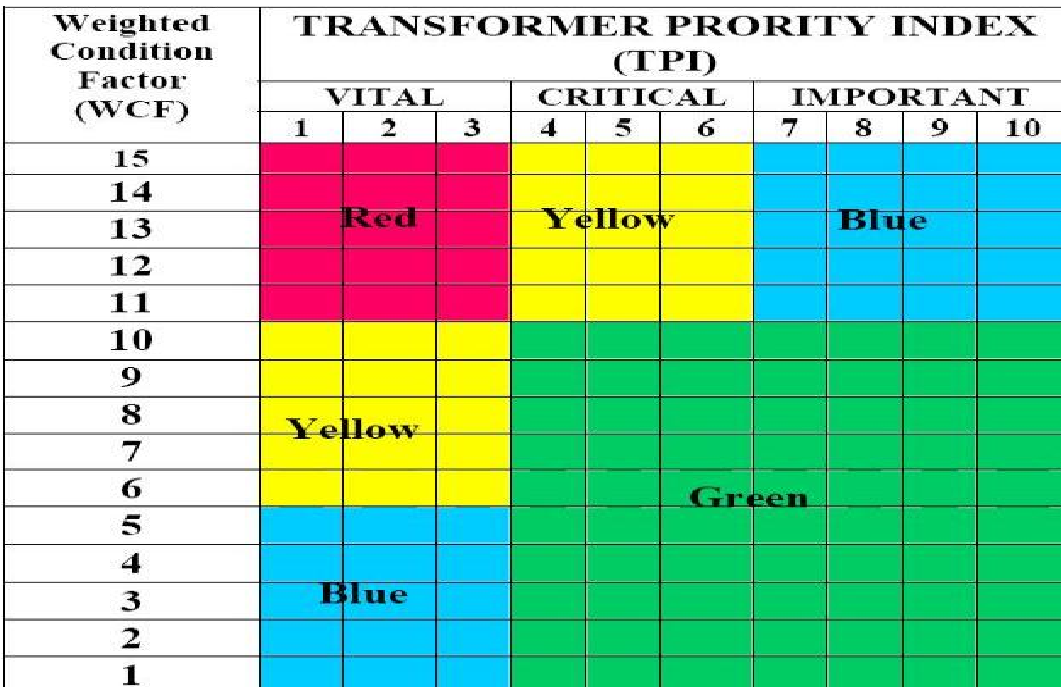
In most cases, knowledge about the probable condition of an individual unit does not in itself provide the basis for making good maintenance, loading or capital spending decisions. As an example, two units of equally poor condition may results in one being placed on a high level of care and attention while the other is placed on a "run-to-failure" status. It is important to compare the unit's probable condition or Weighted Condition Factor (WCF) versus the level of its importance or criticality for future use on the system (TPI). For the utility to determine this importance, the criteria must be selected by a cross-section of appropriate asset managers, maintenance staff, operations managers and engineers. These criteria can be determined by canvassing a list of the above selected people and by voting based on the most/least important factors for future use. Typical utility company factors are shown in the Table below. The individual unit's Transformer Priority Index (TPI) can be calculated by scoring the available data for the unit being evaluated against a qualitative subset for each of the selected factors.

Transformer Priority Index (TPI)- Factors Crucial for Future Use

Maintenance	Planning	Operations
Application (use)	Growth Areas	Load Served
Voltage Class	System Location	Contingency
Size of Units	Capital Budget	Customer Contracts
Type/Band	Available Spares/ Risk	System Impact
Age/ Vintage	Load Limits	Risk Level
Historical Problems	-High	
No Problems	-Low	
Fault Levels	Population Density	
Ancillary Equipment State		
-Bushings		
-Tap Changers		
-Oil System		
-Cooling System		

The combination of the individual unit's Weighted Condition Factor and Transformer Priority Index can be used to make decisions about the extent to which the unit can be operated and maintained. For instance, a unit rated in poor condition, and in a position vital to the system's operation would warrant a high level of attention; whereas a unit rated in similarly poor condition but not crucial to future system operation, may be operated with a minimum of attention.

An example of the Condition Ranking method is shown in the following Table. The units are ranked into four groups: Red, Yellow, Blue and Green, indicating the level of risk associated with operating older units, and can be used as "Decision Matrix" for all areas of Asset Management.



Condition Appraisal Program

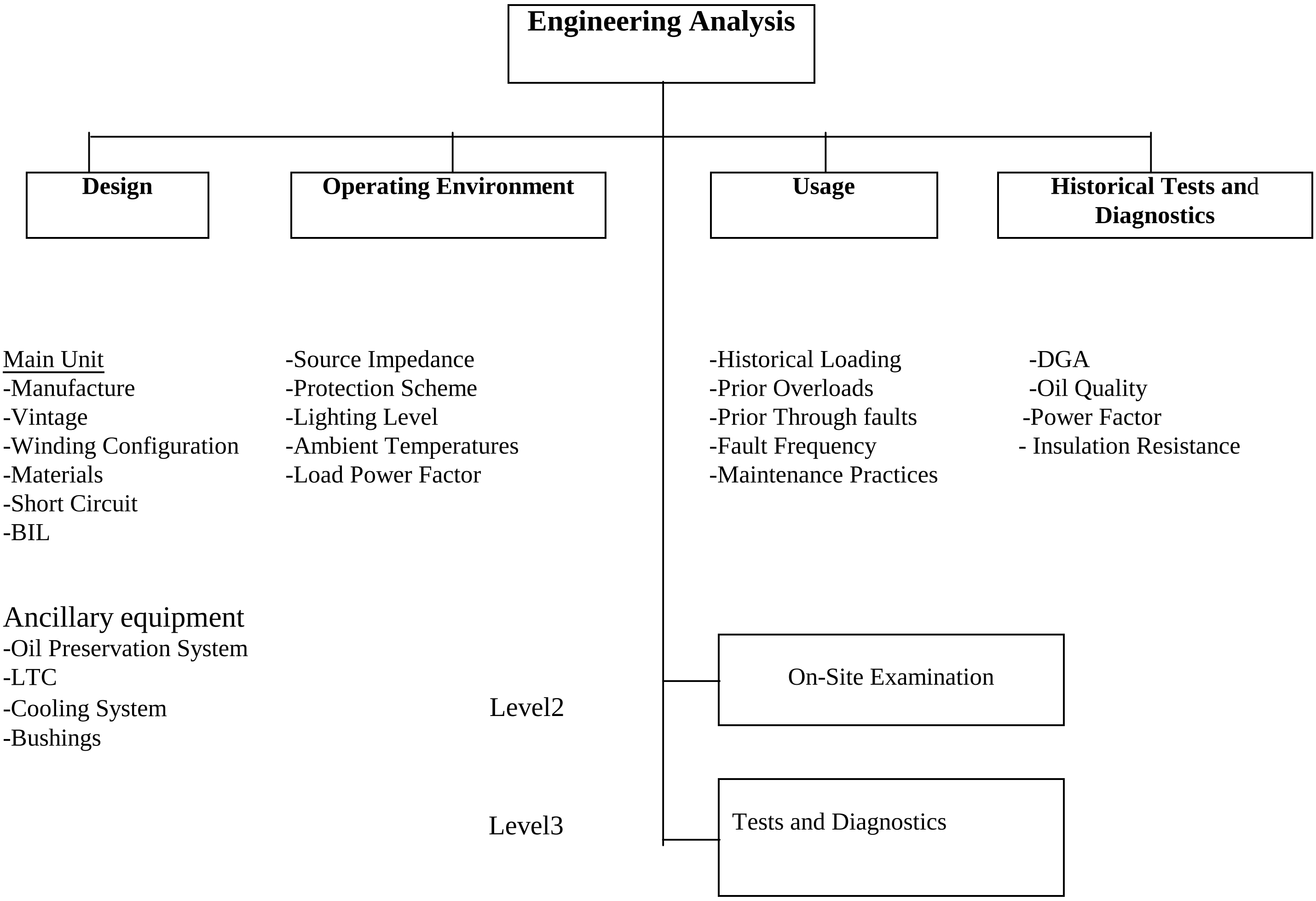
A condition appraisal program should include the following levels.

Level 1- Transformer Engineering Analysis
Level 2- Internal and External Field Inspections
Level 3- Testing and Diagnostics

Each of these steps has several elements, which facilitate the benchmarking process. These elements can also identify defects or deficiencies, some of which may be reversible and possible lead to transformer life extension or improved load capacity.

It is important to understand that some assumptions will need to be made about design elements, sizes, materials and condition of components in the Level 1 analysis. The purpose of level 2 and 3 is not only to perform the required inspection and tests, but verification of the prior assumptions must be made at that time.

Conditional Appraisal- Level 1



Condition Appraisal-Level 2

Level 1

Engineering Analysis

Level 2

On-Site Examination

External Inspection

-Cooling System
-Bushings
-Lightning Arresters
-LTC switch
-Tank

Internal

-Coils and clamp
-LTC and NLTC Switches
-Oil Level and Gas Space
-Leads and Paper

Level 3

Tests and Diagnostics

Condition Appraisal-Level 3

Tests and Diagnostics

-Dissolved Gas Analysis(DGA)
-Moisture in Oil
-Power factor (Dissipation Factor)
-Magnetising Current
-Winding resistance
-Frequency response Analysis (FRA)
-Discharge detection and Location
-Furan (Predicted DP)
*|Particle Count

-Leakage reactance/impedance
-Turns Ratio
-Insulation resistance
-Moisture level in paper insulation
* Degree of polymerisation
-Vibration,location of sensor
-Infrared scan
-Return Voltage Method (RVM)

Conclusion

Determination of the probable condition of today's operating, and somewhat aged, power transformers is a complex and arduous exercise. This requires a rigorous methodology in order to benchmark and rank the units on any given system.

All transformers are not created equal. Historically there has been little standardization, even within and given manufacturer, over the past 50 years.

Most units are custom designed to meet individual utility specification involving significant difference in design methodology, features, safety factors and use of materials. Economic and environmental requirements, such as no-load and load loss evaluation factors and noise levels, can have a significant impact on design of any tow units with" identical nameplate ratings"

Transformers are consumable assets and can be loaded in a variety of ways. Due to deterioration of the insulation system resulting from temperature, moisture level and the possibility of oxygen ingress, two units of the same design and chronological age can have a totally different "service age" or residual life expectancy.

No two operating environments are the same. The leading cause of failure of power transformers is listed as "external". The frequency and magnitude of short circuit faults can shorten the life or catastrophically fail even the "best" transformer.

There is no single scientific method available to determine the condition or end-of-life of an operating power transformer. Experienced engineers, chemists and technician are required to conduct analysis, test, inspections and review historical data to help form the decision

The combination of analytical, inspection and testing methods, when used together help form a complete picture of the condition of a specific unit or groups of units in service. The results of the proposed condition appraisal benchmarking program will help significantly in directing future condition-based maintenance and possible dynamic loading of these Transmission and Distribution assets.

Transformer Chemistry Services [TCS] prefers ranking transformer using at least two data points of the various Insulating oil tests that we provide

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