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Condition Appraisal of Power Transformers

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I. INTRODUCTION:

The new deregulated electric utility environment is driving Transmission and Distribution companies to find ways to improve their competitive position. Maximizing return on investment (ROI) is often a key financial driver when formulating a profitable T & D operation and maintenance strategy.

Increased equipment utilization, deferred capital expenditure and reduced maintenance expense are all a part of the guidelines for today's T & D asset strategists and managers. Although tighter operating budgets and reduced spending are nothing new to utility engineers and planners, today's increased need to leverage more out of existing equipment must be achieved with the majority of T&D assets nearing the end of their life cycle.

At many Transmission and Distribution companies, the majority of substation assets are 20 to 40 years old. Power Transformer capacity additions have reduced from 185 GVA (giga Volt Amperes) to 50 GVA per year over the past twenty-five years (Figure 1).[1]

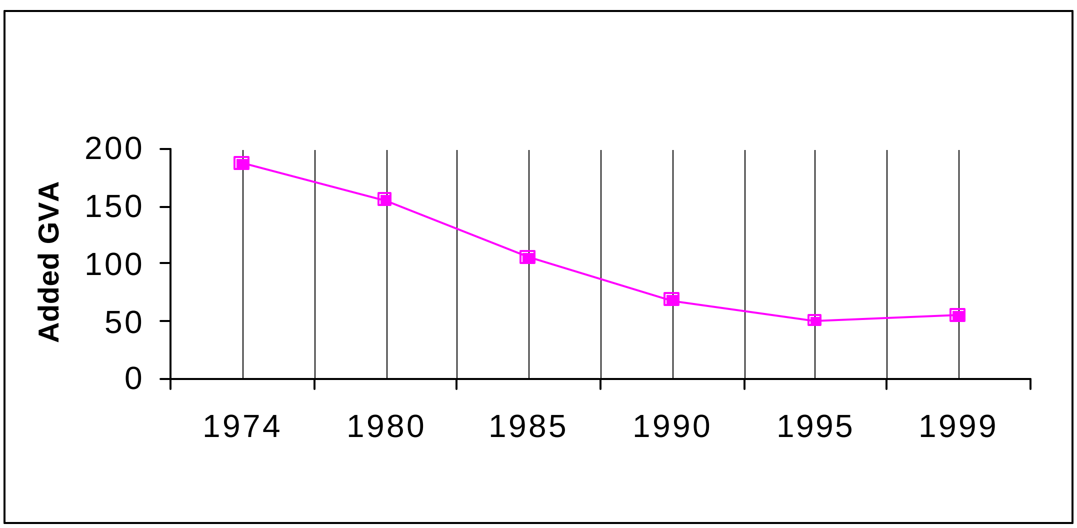


FIGURE 1
Power Transformer Additions Per Year

These annual transformer additions are primarily required to replace failed units. Approximately 40 per cent of these additions are for load growth. However, the net effect of the twenty-five years of declining capital spending is a significant accumulated increase in utilization, or transformer load factor, over this period. For this reason, and due to the insulation aging factor, a 25 year old transformer today, is not the same as a 25 year old transformer was fifteen or more years ago.

Power transformers are the single largest capital item in substations, comprising almost 60 percent of the total investment. The utility expenditures associated with this investment in acquisition, installation, operation and maintenance typically do not reflect the magnitude of this investment. The cost of premature and unexpected failure of one of these assets can be several times the initial cost of the transformer. There is not only the refurbishment or replacement cost but also possible costs associated with clean-up, loss of revenue, and deterioration in the quality of power delivery.(2)

As competitive pressures within the utility industry mount, and the transmission and distribution infrastructure continues to age, these critical assets will become very visible to management, stockholders and customers, alike. Future demands will include reductions in forced outages and failure rates which can only be achieved with significant changes in the way utilities manage, operate and care for transformers. These changes will include acquisition of new transformers along with strategic “Life Cycle Management Programs” for existing units.

Within this framework, scheduled maintenance is being replaced by condition-based (CRM) or predictive maintenance where equipment testing and diagnostics play an increasingly important role. In addition, real time monitoring of equipment and it’s operating environment will enable load planners to dynamically load transformers to optimum limits without compromising reliability. This paper discusses a rigorous methodology for determining the probable condition of power transformers in use today.

II. The Condition of Units Today

Determining the probable condition of power transformers which have reached the majority of their service life is a complex matter involving many variables:

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

- Most units are custom-designed to meet individual utility specifications 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 the design of any two units with “identical” nameplate ratings.

- Transformer insulation systems, particularly for EHV units, are complex structures which require thorough analysis to determine electrical, dielectric and thermal stress levels. Without the detailed design skills and tools, this can result in a significant difference in design integrity for units in the same voltage class.

- Utility purchasing and local P.U.C. practices have over the years resulted in major differences in loading practice with some being ultra conservative and others very aggressive.

- Transformers are consumable assets and can be loaded in a variety of ways.(3)(4) Due to deterioration of the insulation system resulting from temperature, moisture level and the possibility of oxygen ingress in the oil, 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 position of the unit on the system (and protection system), the service load and power factor, physical location to sunshine and airflow, system impedance and probability of over-voltage from switching and lightning strikes, corrosive elements. The leading cause of failure for power transformers is listed as "external". The frequency and magnitude of short circuit faults can shorten the life or catastrophically fail even the "best" transformers on a T & D system.

- Maintenance is arbitrary. Historically, maintenance practices and frequency were dictated by individual transformer manufacturers. As previously discussed, maintenance expenditure is low compared to the asset cost. This is in part due to the fact that power transformers are (have been) very reliable with the typical system failure rate being 0.5 to 0.8 percent. We are now entering a maintenance regime where "less is more". Condition based or predictive maintenance relies heavily on testing, diagnostics, monitoring and the management of data resulting in action plans. A major part of this maintenance approach is to understand the demographics and probable condition of units on the system as the key to managing risk and reliability.

There is no single scientific method available to determine the condition or end-of-life of an operating power transformer.(5) Experienced engineers, chemists and technicians are required to conduct analysis, tests, inspections and review historical data to help form the decision.

- A graphic representation in the loss of insulation life and mechanical integrity from normal and fault conditions is provided in Figure II.

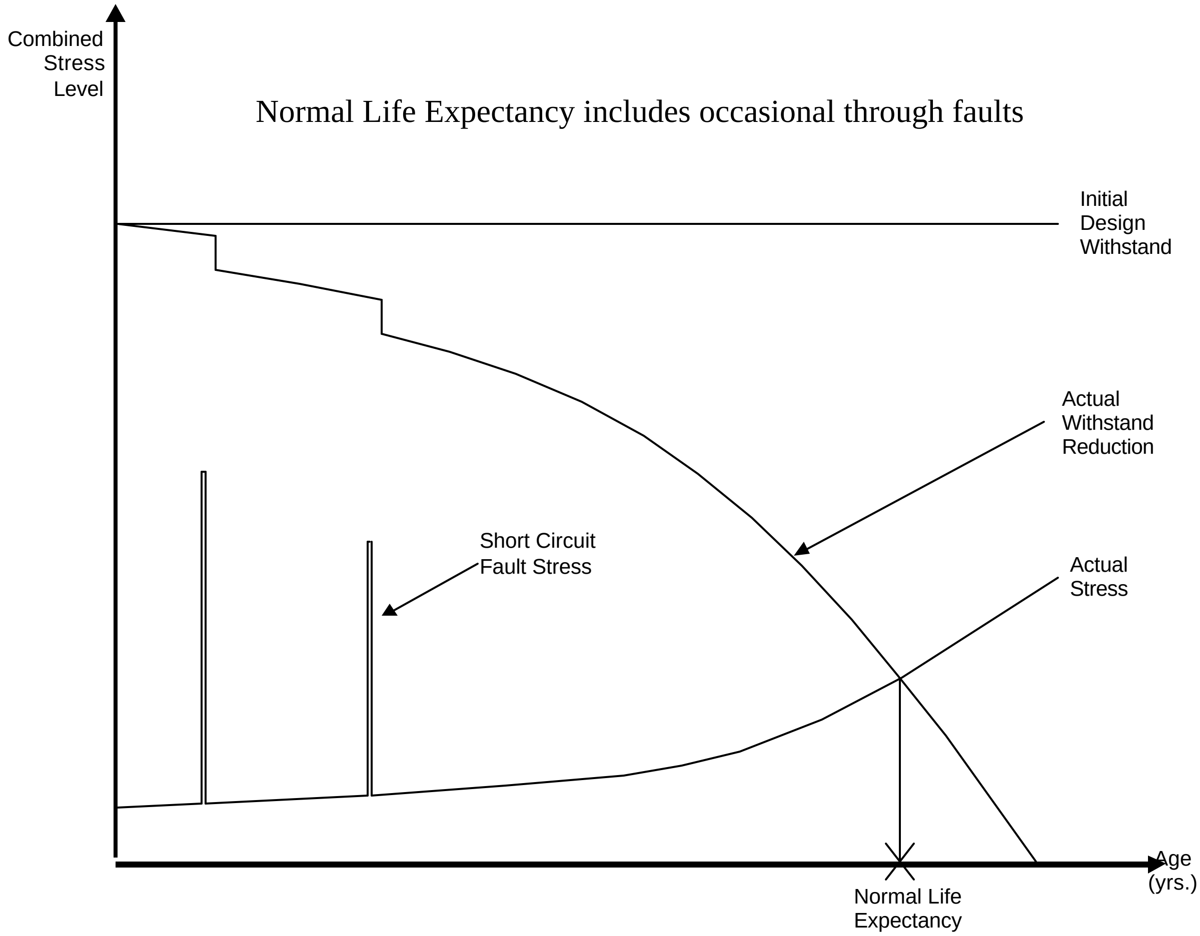


Figure II
Transformer Life Cycle

III. <u>Condition Appraisal - Overview</u>

Condition appraisal is a benchmarking project for ranking units as a part of a CRM program, risk management or for decisions related to optimum or practical load limits for specific transformers. A complete condition appraisal for a selected key group of transformers is a vital element in any life cycle management and/or dynamic loading program. The key transformers are typically chosen based on a criticality index. This index is often established by the utility based on age, critical loads, load growth, size, etc., and may be a variation of the criticality index selection used for a RCM program. A complete condition appraisal is a project that ranks the selected transformers according to its present condition as compared to the other transformers being evaluated. After this ranking is complete, a condition assessment (which is an on-going process of diagnostics and monitoring) can be established to determine aging, fault or incipient failure.

The decision about where to set priority to initiate a condition or risk evaluation program, and where to place emphasis on maintenance resources, often depends on management focus. Chart I shows the typical mix of criteria depending on the management area of responsibility.

Maintenance	**Planning**	**Operations**
• Application (GSU, etc.)	• Growth Areas	• Load Served
• Voltage Class	• System Location	• Contingency Needs
• Size of Units	• Capital Budget	• Contract Severity
• Type / Brand	• Spares / Risk	• System Impact
• Age / Vintage	• Load Limits	• Risk Level
• Historical Problems	- High	
• Fault Levels	- Low	
• Current Problems		
• Ancillary Equipment		

Chart I
Criticality / Priority Index Criteria

The condition appraisal is a fundamental part of any transformer life cycle management program and the benchmarking of these units facilitates the following:

- Prioritizing maintenance resources for transformers.
- Development of load planning database which includes transformer optimum load, temperature rise and loss of insulation life.
- Provides direction to future diagnostics or on-line monitoring spending, as part of a condition based or predictive marketing strategy.
- Enables decisions on field re-engineering to extend transformer life, such as uprated cooling, filtration, and oil preservation system.

IV. Complete Condition Appraisal Program

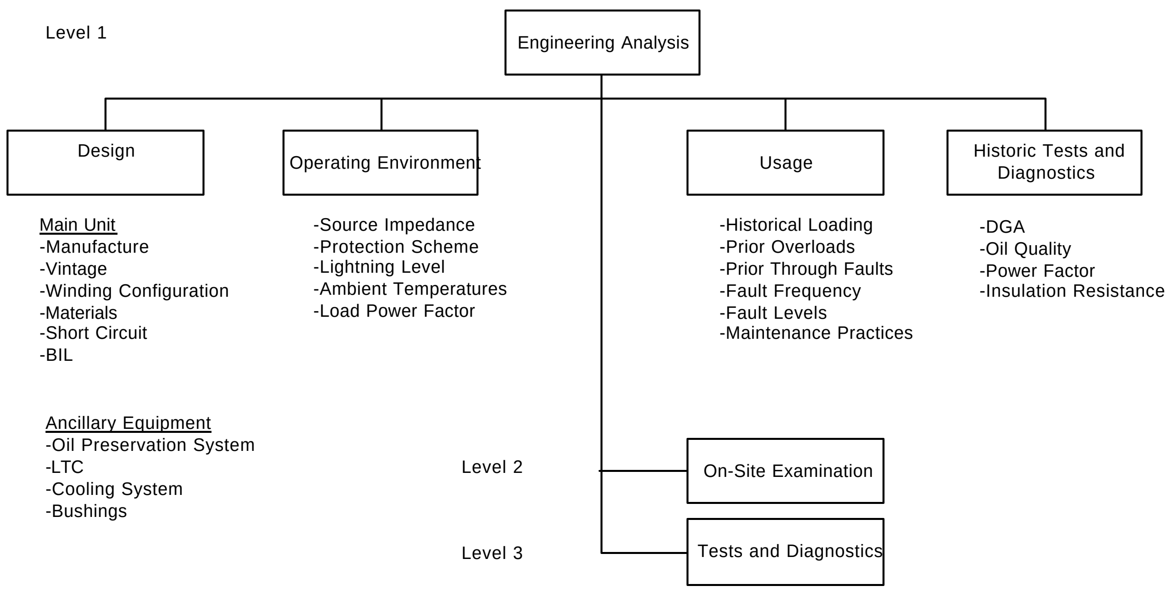
A complete condition appraisal program should include the following levels:

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

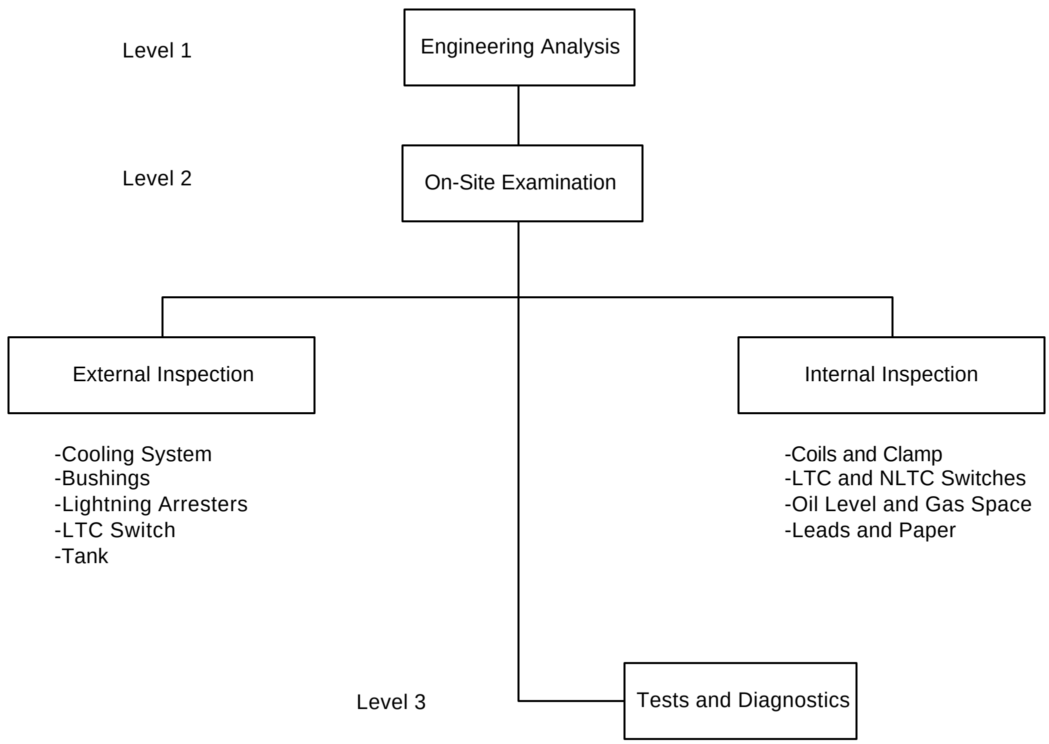
Each one of these steps is represented by the following Figures III, IV and V, and has several elements which facilitate the benchmarking process. These elements can also identify defects or deficiencies, some of which may be reversible and possible lead to transformer life extension or improved load 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.

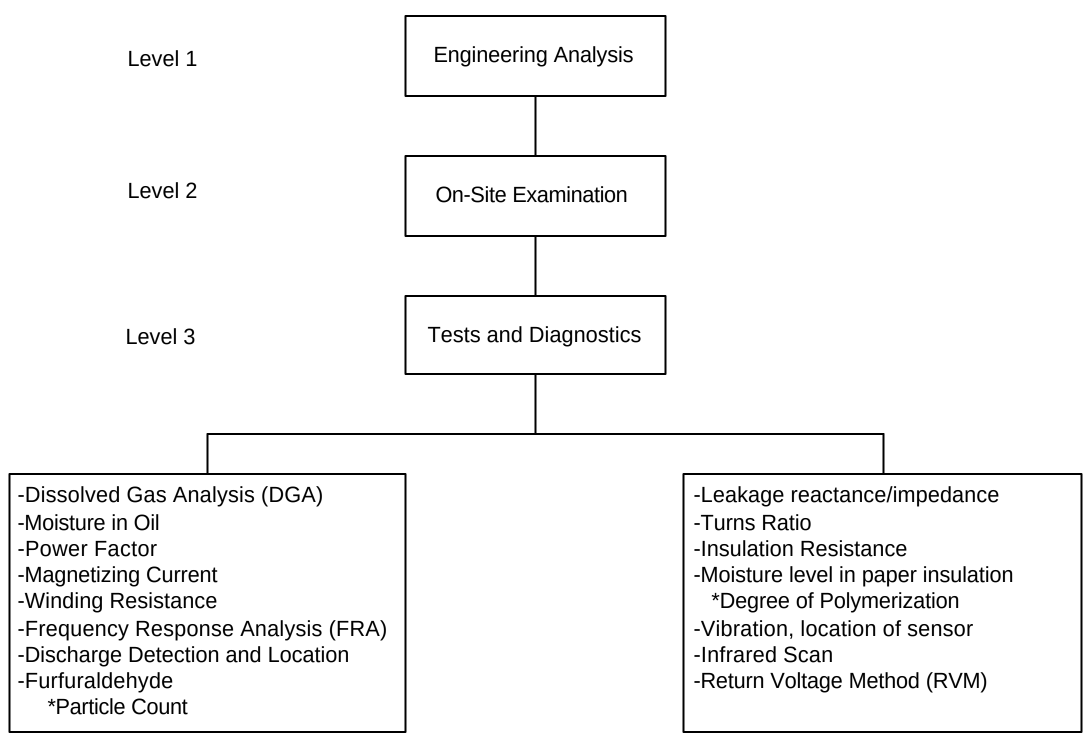
Condition Appraisal - Level 1



Condition Appraisal - Level 2



Condition Appraisal - Level 3



At the conclusion of all levels of the condition appraisal process, the transformers are assigned a numerical index according to the weighted results. This index number will provide the utility with better tools to manage the life cycle costs of the transformer including:

- Providing a starting point condition to increase the effectiveness of predictive or Reliability Centered Maintenance.
- Identifying problem units and taking action to correct known defects or to re-deploy units. These units can then be used more effectively.
- The field tests performed as a part of condition appraisal can be used to refine the thermal model used to predict internal transformer temperature which are used to determine optimum load and/or end-point of life criteria.
- The condition appraisal project can also identify units that can be uprated via cooling modifications in the field or units that should be retired.
- Managing the end of life of endangered transformers, the utility can save a significant amount of money versus a catastrophic failure and associated clean-up costs.

V. Loading Units Based on Monitoring and Condition

In future load planning scenarios, the thermal model characteristics for each transformer would be programmed and be available real time against which actual performance would be monitored. Transformer performance characteristics, in addition to information on both ambient temperature and loading cycle are critical in determining the transformer load available for normal operation and emergency events. In dynamic loading, these inputs are evaluated in real-time to allow the operator flexibility in deciding how much the unit can be loaded at any given point in time. This mathematical thermal model is then used to predict the individual transformer's internal temperatures and insulation loss of life. A computer program is utilized to calculate temperatures of the winding, hottest-spot and top oil with various loading and ambient scenarios. These what-if cases allow the user to determine the effects of load condition have on the life and health of the transformer.

VI. 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.

This paper discusses a combination of analytical, inspection and testing methods, when used together help form a complete picture of the condition of a specific unit or group 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 valuable T & D assets.

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